

Available on <https://www.joarps.org>
Journal of Applied Research in Plant Sciences
(JOARPS)
ISSN: 2708-3004 (Online), 2708-2997 (Print)



Assessing Zinc Requirement of Newly Developed Wheat Variety NWB-50

Ghulam Fareed Aghani¹, Saima Kalsoom Babar^{1*}, Muhammad Awais², Suhaira Noor³, Hassan Ali Shujrah¹

¹Department of Soil Science, Sindh Agriculture University Tandojam, 70060, Pakistan

²Institute of Plant Sciences, Faculty of Natural Sciences, University of Sindh, Jamshoro, Sindh, Pakistan

³Department of Energy and Environment, Sindh Agriculture University, Tandojam 70060, Sindh, Pakistan

*Corresponding author: E-mail: skbabar@sau.edu.pk

Article Received 07-06-2026, Article Revised 26-06-2026, Article Accepted 05-07-2026

ABSTRACT

Pakistan is facing Zinc (Zn) scarcity at its' peak, that restrict wheat production and nutritional value of grains. Improving the available Zn in wheat grains is essential for crop performance as well as for human health. Wheat is a principal food and a major alimental Zn source of the population. Understanding wheat responses to soil-applied Zn is therefore critical. Hence, the present study was led to evaluate the growth, yield, and Zn availability of newly developed wheat variety (NWB-50) with various Zn doses. The experiment followed a Randomized Complete Block Design (RCBD) consisting of five Zn treatments Control (0 kg Zn ha⁻¹), T1 (1.25, T2 (2.5, T3 (5.0, and T4 (7.5 kg Zn ha⁻¹)) each replicated three times. All agronomic traits were significantly ($p \leq 0.05$) affected by Zn application. The maximum plant height (99.7 ± 2.1 cm), number of tillers ($372.3 \text{ m}^{-2} \pm 6.74$), number of spikelets (21.7 ± 0.88), spike length (12.2 ± 0.15 cm), grains per spike (68.2 ± 0.70), 1000-grain weight ($40.7 \text{ g} \pm 0.85$ g), grain yield ($4387.3 \text{ kg ha}^{-1} \pm 16.34$), biological yield ($8526.7 \text{ kg ha}^{-1} \pm 64.71$), harvest index ($51.4 \pm 1.3\%$), grain Zn concentration ($41.7 \text{ mg kg}^{-1} \pm 0.49$) and straw Zn content ($24.1 \text{ mg kg}^{-1} \pm 0.69$) were recorded in treatment four. The minimum values were observed in the control. It is concluded that treatment four was the prime dose among other tested doses in this experiment to improve growth, yield, and Zn biofortification of wheat cultivar NWB-50 grown in a calcareous soil.

KEYWORDS: malnutrition; micronutrient; cereal grains; calcareous soil; climate change

INTRODUCTION

Zinc (Zn) persists its unique position in plant growth due to various physiological and biochemical reactions. Its involvement in the activation of enzymes, protein synthesis, nucleic acid metabolism, photosynthesis and resistance to adverse environment make it more distinctive (Çakmak & Rengel, 2024). Zinc also contributes to membrane stability (Shao *et al.*, 2023) and influences hydrogenase activity, carbonic anhydrase function, ribosomal stability, and cytochrome synthesis. Therefore, Zn deficiency can lead to plant disorders, reduce crop yield, inhibit plant growth, and poor grain quality (Yadav *et al.*, 2023). Zinc deficiency is extensively present in arid and semi-arid regions like Pakistan, mainly due to high soil Zn fixation and low solubility (Rashid *et al.*, 2022). This deficiency significantly reduces crop productivity and grain nutritional quality (Sukhwai *et al.*, 2022). From human nutrition perspective, wheat grain should contain approximately 45mg Zn kg⁻¹. However, most wheat grains contain only 20-35 mg Zn kg⁻¹ (Yadav *et al.*, 2023). Therefore, the application of Zn fertilizer is essential to overcome this deficiency and enhance grain Zn concentration (Rashid *et al.*, 2022).

Globally, so many studies are performed on Zn' importance, yet the Zn deficiency is prevalent significant public health concern. Almost forty percent of the world's population currently living in developing countries with cereal-based diets, which are naturally low in bioavailable Zn (Çakmak & Kutman, 2018). Agronomic biofortification, which refers to using mineral fertilizers to enhance micronutrient content in plants, has proven to be an affordable and sustainable approach to tackling this problem (Bouis & Saltzman, 2017). Many scientists previously addresses that zinc fertilization increases grain Zn concentration, crop growth, and yield parameters. (Gupta *et al.*, 2021; Szerement *et al.*, 2022). Moreover, adequate Zn nutrition is associated with increased physiological efficiency, grain filling and stress tolerance in plants (Ramzan *et al.*, 2020).

Recent breakthroughs in nutrient management techniques, such as coated fertilizers and integrated fertilization, have also led to better nutrient use efficiency and crop productivity. For example, Zn applied with coated urea fertilizers has been reported to improve growth, nutrient uptake and grain yield in cereals (Babar *et al.*, 2024). Likewise, new fertilization strategies, such as nano-nutrient enhanced fertilizers, have been shown to have profound effects on crop yield

and nutrient cycling (Babar *et al.*, 2025). These results point to the need to develop fertilizer approaches that enhance both agronomic and nutritional productivity. Wheat production and grain quality both are affected by Zn deficiency. It is still a great challenge to feed the ever-increasing world population with adequate and nutritious food. Now, one in nine individuals are food insecure, and a significant number of them are malnourished (Khan & Ali, 2023). Ten billion people are predicted around 2050 (UN, 2024). Thus, staple cereal production is critical to improve as well as its nutritional quality in order to achieve food security for upcoming generations (Albahri *et al.*, 2023).

However, zinc fertilization is strongly influenced by genetically-based differences, soil properties and management strategies. Recent studies have highlighted the need to use appropriate Zn fertilizer levels for different crop varieties to achieve optimal yield and nutritional quality. But there is a lack of data on the Zn requirement of new wheat varieties. The wheat variety NWB-50 has demonstrated good agronomic performance under local growing conditions, but has not been tested for its response to different levels of Zn (Talpur *et al.*, 2024). Therefore, present research was directed to determine Zn requirement for “NWB-50” and to assess the effect of zinc fertilization on plant growth, yield and Zn availability in the calcareous soils after recommended sowing time.

MATERIALS AND METHODS

The existent research was carried out at the well-established experimental fields of the Nuclear Institute of Agriculture (NIA) in Tandojam. The specific experimental site is located at the coordinates of 25°42'19.1"N latitude, and longitude of 68°51'63.6"E. The field trial was arranged under randomized complete block design (RCBD) having five treatments with three replications. Treatments were; Control (0 kg), T1 (1.25 kg), T2 (2.5 kg), T3 (5.0 kg), and T4 (7.5 kg Zn ha⁻¹ respectively) in the form of zinc sulphate heptahydrate. The seeds of advanced line of wheat, NWB-50 was supplied by NIA Tandojam.

Field execution: The total experimental area was 432 m² (16 m × 27 m), divided into 15 equal plots of 16 m² (4 m × 4 m) each. Soil preparation was done according to the recommended agronomic practices. Certified seeds of NWB-50 were sown in November 2024 (Rabi season) in rows 20 cm apart using a seed drill at the commonly suggested seed rate of 125 kg ha⁻¹. The basal fertilizers sources were urea, diammonium phosphate (DAP) and sulfate of potash (SOP). A complete dose of phosphorous and potash along with one-third of urea for nitrogen were applied at sowing and the rest of the N was applied in to two equal splits at the time of first and second irrigations. Zinc fertilizers were applied with the first irrigation to avoid the antagonism between P-Zn. A total of four irrigations were applied. Weed, pest and disease

control were done using standard practices as per prescription of NIA until the crop was harvested.

Prior to sowing of the crop or any fertilizer amendment, at 0-20 cm depth soil samples were taken to taste the basic properties of soil, a stainless-steel auger was used for the process. The samples were labeled, dried in the air, ground and sieved (2mm) to eliminate stones, pebbles and transferred in polyethylene bags. Samples were shifted to the laboratory regarding soil analysis. Soil EC, pH, soil texture and organic matter were determined as recommended procedures (Estefan *et al.*, 2013). Soil-available P, K, and Zn were also analyzed following the procedure outlined in laboratory manual of Estefan *et al.* (2013).

Agronomic constraints and analysis: Five plants were randomly selected at the time of harvesting from each unit for prescribed observations. Agronomic parameters which were collected are; plant height (cm), number of spikelets per spike, spike length (cm), , number of grains per spike, 1000-grain weight (g), grain yield (kg ha⁻¹), and biological yield (kg ha⁻¹). Plants were washed with tap water and distilled water, dried at room temperature for 48 hours and oven dried at 70°C for 48 hours. Once completely dried, the samples were cut into small pieces using stainless steel scissors, ground into powder form with a grinder mill and stored in plastic vials plant analysis. The Zn content in wheat straw and grains was determined using the di-acid wet digestion method with per-chloric acid -nitric acid in (HClO₄-HNO₃) a 1:2 ratio. After digestion, Zn content in the plants was analyzed (Estefan *et al.*, 2013).

Statistical analysis: The collected data were thoroughly analyzed by analysis of variance (ANOVA) in Statistix ver. 8.1. Means were separated using the least significant difference (LSD) test ($p \leq 0.05$). To create bar graphs, R software version 4.3.2 and the ggplot2 package were used. Means were represented by vertical bars with $\pm$ standard errors (SE) as error bars. The mean values and LSD significance letters were shown on top of each bar. Bar colours were set to a colour-blind-safe palette (Set2 from ColorBrewer). The x-axis represented treatments as Control, T1, T2, T3, and T4, and the y-axis depicted the respective parameters with units. We used theme bw to create a black and white theme for publication.

RESULTS AND DISCUSSION

Soil physico-chemical properties: The soil was analyzed according to (Ryan *et al.*, 2001). The soil had 17.5% sand, 57.5% silt and 25% clay, categorizing it as silty loam. The soil was non-saline (EC = 0.95 dS m⁻¹), medium alkaline (pH = 7.81), low in organic matter (0.67%), very low in available phosphorus (6.0 mg kg⁻¹) and exchangeable potassium (90 mg kg⁻¹), and deficient in available zinc (0.48 mg kg⁻¹) (Table 1). Such conditions are common in dry and semi-dry regions, such as Pakistan (Rashid *et al.*, 2022). Wheat is a staple food contributing almost 40% of the world's

energy needs (Singh *et al.*, 2023), but it has naturally low Zn content that fails to meet the human needs (Çakmak & Kutman, 2018). This makes Zn deficiency

detrimental to plant growth and yield (Rehman *et al.*, 2018)

Table 1. Physico-chemical properties of soil before execution of field study

Parameter			Results
Texture	Sand (%)	17.5	Silty loam
	Silt (%)	57.5	
	Clay (%)	25	
EC1:2.5 (dS m ⁻¹)			0.95
pH (1:2.5)			7.81
Organic matter (%)			0.67
AB-DTPA Extractable Phosphorus (mg kg ⁻¹)			6.0
AB-DTPA Potassium (mg kg ⁻¹)			90
AB-DTPA Zinc (mg kg ⁻¹)			0.48

Growth and Yield constraints: All agronomic parameters were significantly ($p \leq 0.05$) increased with increased Zn application. Height was directly proportional to Zn levels, maximising with 7.5 kg of Zn ha⁻¹ (99.7 cm) compared to 77.9 cm in the control (Figure 1A). This growth is due to Zn's impact on auxin synthesis, which controls cell division and elongation (Cakmak & Rengel, 2024), and is in agreement with (Nawaz *et al.*, 2015). Similarly, tiller number (Figure 1B) was highest (372.3 m⁻²) with 7.5 kg Zn ha⁻¹, followed by 263.7 m⁻² under control, while 1.25 and 2.5 kg Zn ha⁻¹ had no statistical difference. Zinc

increases branching and boosts photosynthesis (Shao *et al.*, 2023). The number of spikelets per spike (Figure 1C) was highest at 7.5 kg zinc per hectare (21.7) paralleled to 16.4 with zero zinc application, however, treatments 1, 2, and 3 had no significant difference. This enhancement is due to Zn's impact on protein synthesis and ribosomal stability (Yadav *et al.*, 2023). Spike length (Figure 1D) increased to 12.2 cm with increased Zn application, as contrast under no Zn application (7.1 cm), improvement in reproductive growth of plants is associated with available zinc (Alloway, 2015).

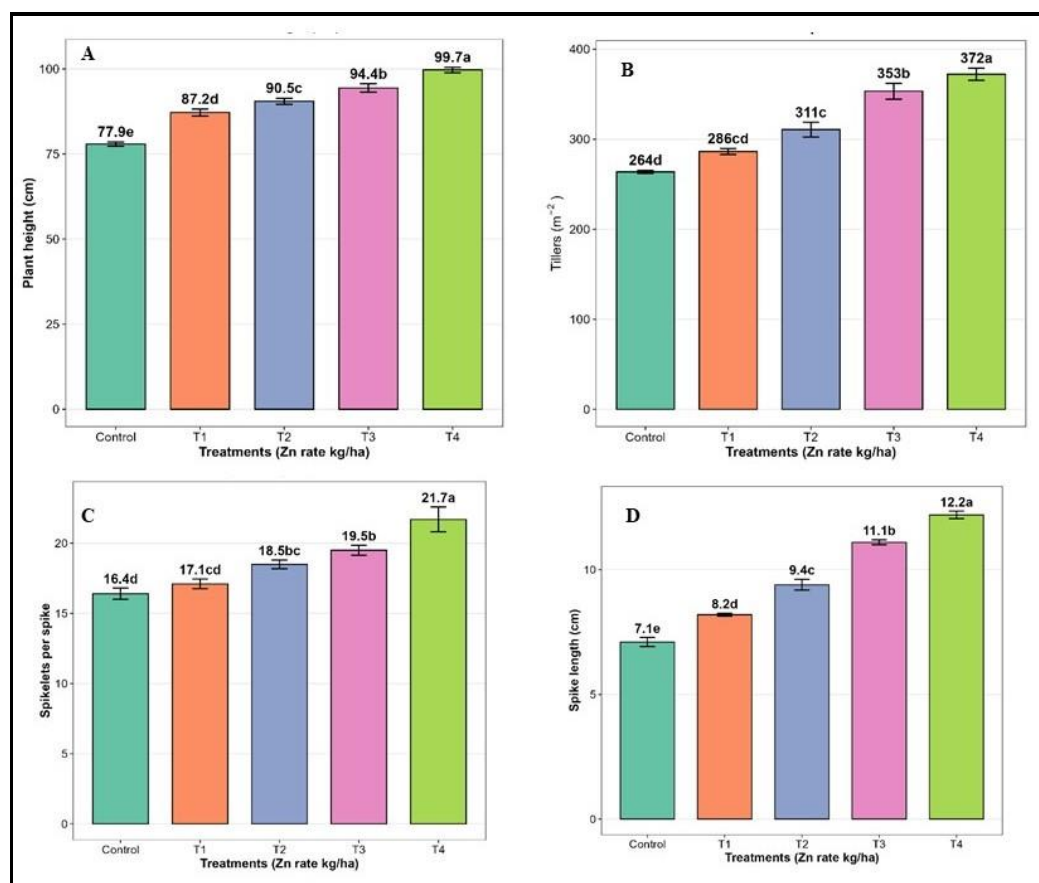


Figure 1. Response of NWB-50 wheat growth parameters to Zinc application: (A) Plant height (cm), (B) Number of tillers (m⁻²), (C) Spikelets per spike, (D) Spike length (cm)

There was a substantial rise in grains per spike up to 68.2 under treatment 4, in contrast to 47.3 grains were recorded without zinc application (Figure 2A). Increased grain set is due to increased pollen viability and decreased spikelet sterility (Sukhwal *et al.*, 2022), in agreement with (Jan *et al.*, 2015). The 1000-grain weight (Figure 2B) was highest at 40.7 g at 7.5 kg Zn ha⁻¹ compared to 26.0 g in control because Zn plays a critical role in carbohydrate metabolism and starch formation during grain development (Shahid *et al.*, 2023). Grain yield (Figure 2C) showed a 56% increase at 7.5 kg Zn ha⁻¹ (4387.3 kg ha⁻¹) compared to control (2809.5 kg ha⁻¹). The average national yield of wheat in Pakistan is 3.0 Mg ha⁻¹ (GoP, 2024), while yield at

7.5 kg Zn ha⁻¹ (4.39 Mg ha⁻¹) is much higher than this level. This is in line with (Firdous *et al.*, 2018) and (Zulfiqar *et al.*, 2020). Zinc enhances yield and grain quality (Yokokawa *et al.*, 2024) and applying ZnSO₄·7H₂O boosts grain yield especially in low-Zn soils (Akram *et al.*, 2020; Akca & Taban, 2024). Biological yield (Figure 2D) was 8526.7 kg ha⁻¹ at 7.5 kg Zn ha⁻¹ compared to 6500.3 kg ha⁻¹ in the control, due to improved photosynthetic efficiency and carbon dioxide metabolism (Beltayef *et al.*, 2023). Micronutrient fertilization is becoming crucial as soil fertility has declined due to imbalanced fertilizations (Nongbet *et al.*, 2022).

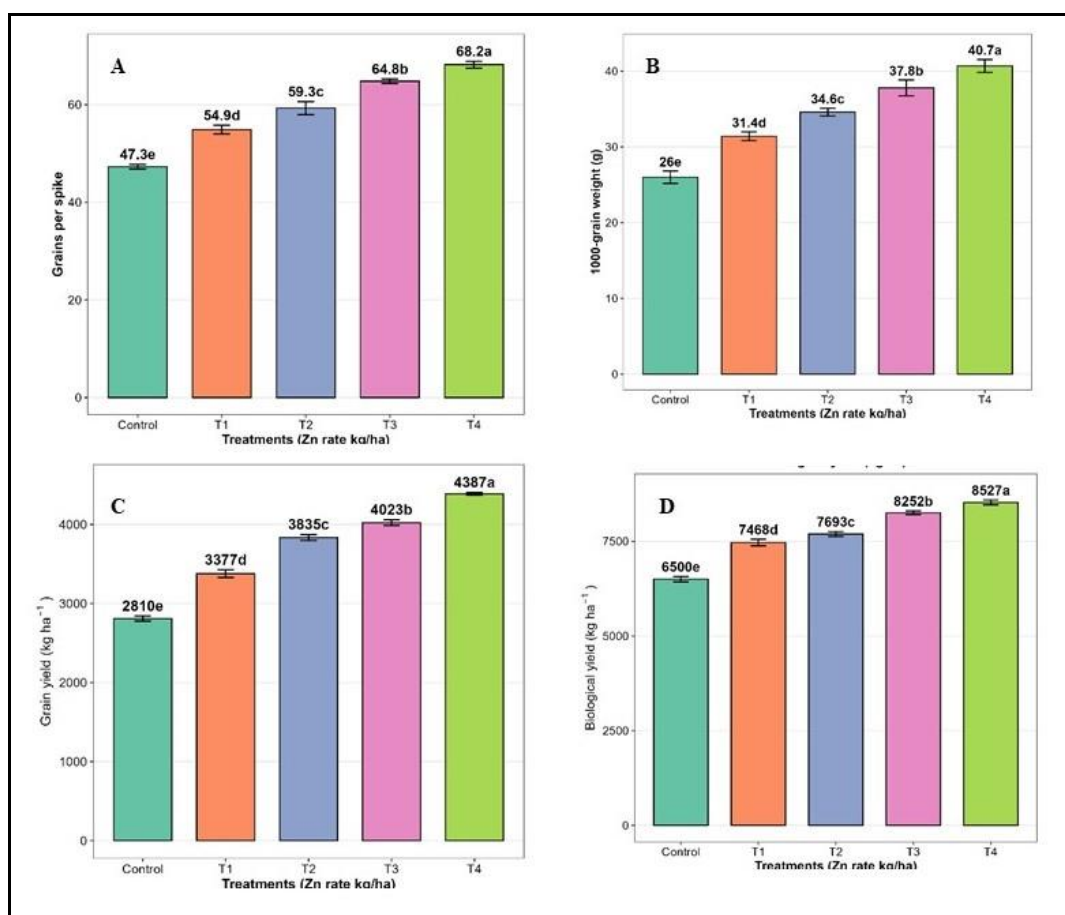


Figure. 2. Zinc application effects on yield components of wheat variety NWB-50: (A) Grains per spike, (B) 1000-grain weight (g), (C) Grain yield (kg ha⁻¹), (D) Biological yield (kg ha⁻¹)

Harvest index: Figure 3 showing the harvest index as affected by Zn application. The maximum harvest index (51.4%) was recorded at 7.5 kg Zn ha⁻¹, while minimum (43.2%) was obtained from the control, with 2.5 and 5.0 kg Zn ha⁻¹ levels being similar. This increase suggests that Zn increases assimilate

partitioning into the grain (Mazhar *et al.*, 2023), which is essential for food production as the globally, inhabitants are predicted to reach ten billion around 2050 (UN, 2024), requiring significant increases in cereal production and quality (Albahri *et al.*, 2023).

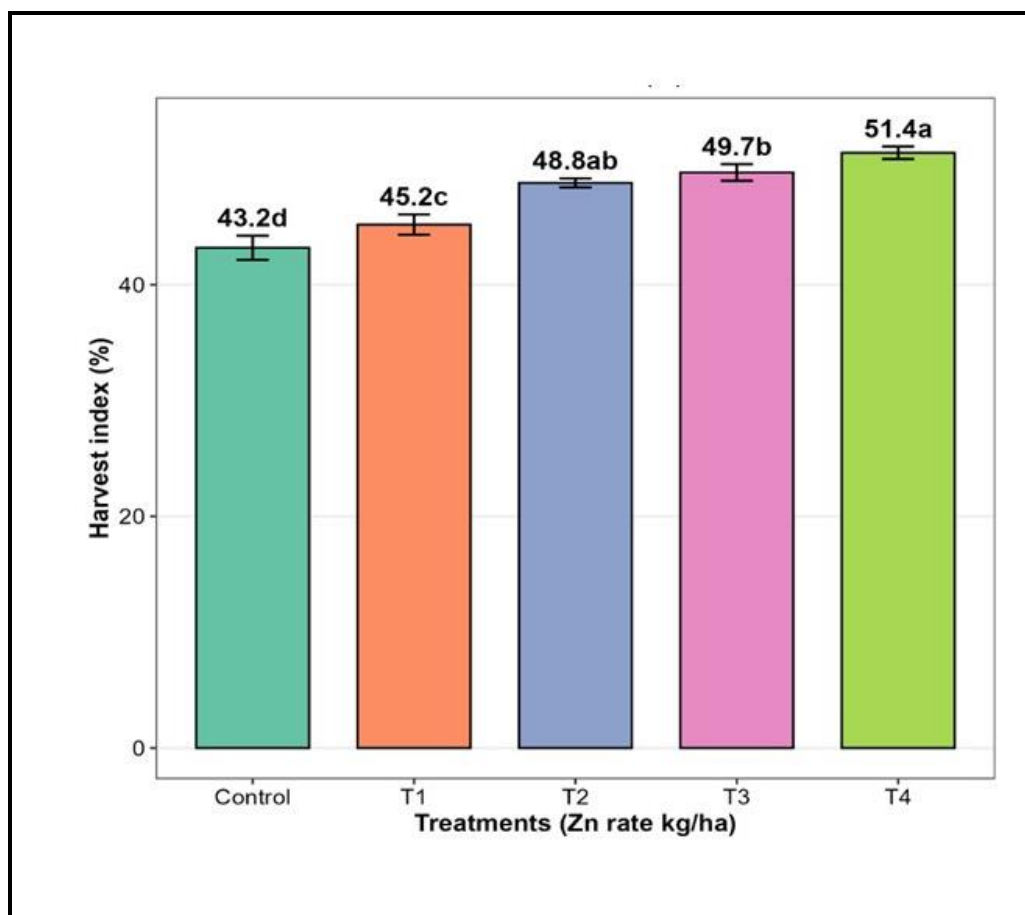


Figure 3. Harvest index (%) of wheat variety NWB-50 as influenced by Zinc application

Zinc content in wheat: Zinc content in wheat grains and straw increased significantly ($p \leq 0.01$) with zinc application. The Zn concentration in grains (Figure 4A) was 41.7 mg kg^{-1} in treatment 4, compared to 23.3 mg kg^{-1} in the control. Zinc content in grains was observed as 28.1 mg kg^{-1} under treatment 1, which was significantly different from treatment 2, and 3. The desired concentration of Zn for human consumption is about 45 mg kg^{-1} (Yadav *et al.*, 2023) and we recorded the concentration 41.7 mg kg^{-1} is closer to this claim under treatment 4. Zinc fertilization is a successful biofortification approach because one-third of the world population suffer from Zn deficiency, and in developing countries 50-70% of calories come from low-Zn cereals (Çakmak & Kutman, 2018). The Zn concentration in straw (Figure 4B) showed a similar trend as shown in grains, Zn content 24.1 mg kg^{-1} was recorded in treatment 4, compared to 12.5 mg kg^{-1} with no Zn application. Zinc accumulation in vegetative parts suggests that some of the fertilized Zn may re-enter the soil pool, enhancing the soil Zn pool (Hacisalihoglu, 2020).

Optimal zinc rate: The new wheat variety (NWB-50) responded positively to zinc application, with $7.5 \text{ kg Zn ha}^{-1}$ proving to be an optimum rate for improving grain yield Zn concentration in both wheat grains and straw. No sign of Zn toxicity or yield reduction were observed at this application rate. These findings are in accordance with Talpur *et al.*, (2024), who reported that advanced wheat lines grown on calcareous soils responded well to soil applied zinc with 5 to $7.5 \text{ kg Zn per hectare}$ being the optimum rate. Similarly, Singh and Sandhu (2020), observed that zinc application improved both wheat yield and grain quality. Since no zinc toxicity and yield decline were recorded in current research at $7.5 \text{ kg Zn per hectare}$, evaluating higher zinc application rates in future studies may help to determine more increased zinc rate in safer modes. As Zn plays a pivotal role in enzymes activation, synthesizing proteins and enhancing plant tolerance to environmental stress (Çakmak & Kutman, 2018), it's efficient management is essential for achieving maximum wheat production under local conditions.

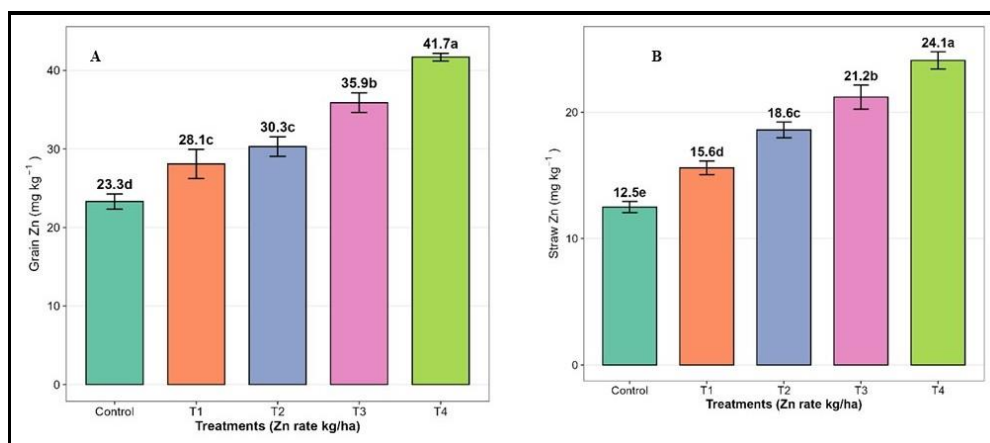


Figure 4. Zinc content in grains and straw of NWB-50 wheat variety as affected by zinc application: (A) Grain Zn content (mg kg⁻¹), (B) Straw Zn content (mg kg⁻¹)

CONCLUSION

The present study clearly demonstrates that soil-applied zinc plays a vital role in improving wheat growth, yield performance, and grain zinc enrichment under Zn-deficient soils of Pakistan. Application of Zn significantly enhanced physiological, yield-related, and nutritional parameters of wheat at 7.5 kg Zn ha⁻¹; this rate was the most effective for improving growth, yield, and zinc uptake under the conditions of the present study. This Zn level not only maximized grain and biological yield but also substantially increased grain and straw Zn concentrations. The variety “NWB-50” performed exceptionally well. Although phytic acid concentration and zinc bioavailability were not determined, the increased transfer of zinc into grains suggests improved grain zinc nutritional quality.

RECOMMENDATIONS

Our findings may not be directly applicable to all agro-ecological regions. We recommend that future research should include multi-location and multi-season trials across diverse soil types and climatic conditions to validate and refine the zinc fertilizer recommendation for the newly developed wheat variety NWB-50. There is also a need to investigate the residual effect of zinc on the next crop, critical soil Zn value for NWB-50, and cost-benefit analysis for different levels of Zn application under different environmental conditions. Testing of zinc coated urea or Zn⁺ nitrogen fertilization may also improve nutrient use efficiency and lesser production expenses.

AUTHORS' CONTRIBUTION

Ghulam Fareed Aghani contributed to the conceptualization of the study, data collection, and preparation of the original manuscript draft. Saima Kalsoom Babar designed the methodology, supervised the research, performed formal analysis, and revised the manuscript. Muhammad Awais assisted with the literature review, graph generation and data interpretation. Suhaira Noor contributed to data analysis and manuscript review. Hassan Ali Shujrah

participated in data collection and validation of the results.

CONFLICT OF INTEREST

The All authors declare that there is no conflict of interest.

REFERENCES

- Akca, H., & Taban, S. (2024). Optimizing grain zinc biofortification in bread wheat: Innovative fertilization strategies for field conditions. *Journal of Soil Science and Plant Nutrition*, **24**(3), 4714-4726.
- Akram, M. A., Depar, N., & Irfan, M. (2020). Agronomic zinc biofortification of wheat to improve accumulation, bioavailability, productivity and use efficiency. *Eurasian Journal of Soil Science*, **9**(1), 75-84.
- Albahri, G., Alyamani, A. A., Badran, A., Hijazi, A., Nasser, M., Maresca, M., & Baydoun, E. (2023). Enhancing essential grains yield for sustainable food security and bio-safe agriculture through latest innovative approaches. *Agronomy*, **13**(7), 1709.
- Alloway, B. J. (2015). Soil factors associated with zinc deficiency in crops and humans. *Environmental Geochemistry and Health*, **31**(5), 537-548.
- Babar, S. K., Abbasi, Z., Rajper, I., Babar, H., & Shujrah, H. A. (2025). Efficiency of nano-silicon coated urea with various fertilizing techniques on maize (*Zea mays* L.) performance and nitrogen content. *Journal of Applied Research in Plant Sciences*, **6**(1), 01-07.
- Babar, S. K., Akca, H., Taban, S., & Shujrah, H. A. (2024). Effect of Zn applied with or without palm stearin coated urea on the growth and mineral element concentration of maize (*Zea mays* L.). *Journal of Applied Research in Plant Sciences*, **5**(01), 119-125.
- Beltayef, H., Mechri, M., Saidi, W., Raza, T., Hajri, R., Othmani, A., & Melki, M. (2023). Synergistic interaction of *Rhizobium tropici*, *Rhizopagus irregularis* and *Serendipita indica* in promoting snap bean growth. *Agronomy*, **13**(10), 2619.
- Bouis, H. E., & Saltzman, A. (2017). Improving nutrition through biofortification: A review of evidence from HarvestPlus, 2003 through 2016. *Global Food Security*, **12**, 49-58.
- Çakmak, İ., & Kutman, U. B. (2018). Agronomic biofortification of cereals with zinc: A review. *European Journal of Soil Science*, **69**(1), 172-180.
- Cakmak, I., & Rengel, Z. (2024). Humboldt Review: Potassium may mitigate drought stress by increasing stem carbohydrates and their mobilization into grains. *Journal of Plant Physiology*, **303**, 154325.
- Firdous, S., Agarwal, B. K., & Chhabra, V. (2018). Zinc-fertilization effects on wheat yield and yield components. *Journal of Pharmacognosy and Phytochemistry*, **7**(2), 3497-3499.

- GoP. (2024). Agricultural Statistics of Pakistan, 2022-23. Government of Pakistan, Ministry of National Food Security & Research (Economic Wing), Islamabad.
- Gupta, P. K., Balyan, H. S., Sharma, S., & Kumar, R. (2021). Biofortification and bioavailability of Zn, Fe and Se in wheat: Present status and future prospects. *Theoretical and Applied Genetics*, **134**(1), 1–35.
- Hacisalihoglu, G. (2020). Zinc (Zn): The last nutrient in the alphabet and shedding light on Zn efficiency for the future of crop production under suboptimal Zn. *Plants*, **9**(11), 1471.
- Jan, M., Anwar-ul-Haq, M., Akhtar, J., & Waraich, E. A. (2015). Zinc application to rice genotypes under saline conditions. In *Sustainable Agriculture Reviews: Volume 18* (pp. 253-272). Springer International Publishing.
- Khan, Z., & Ali, A. (2023). Global food insecurity and its association with malnutrition. *Emerging Challenges in Agriculture and Food Science*, **2**.
- Mazhar, Z., Akhtar, J., Alhodaib, A., Naz, T., Zafar, M. I., Iqbal, M. M., ... & Naz, I. (2023). Efficacy of ZnO nanoparticles in Zn fortification and partitioning of wheat and rice grains under salt stress. *Scientific Reports*, **13**(1), 2022.
- Nawaz, H., Hussain, N., Yasmeen, A., Arif, M., Hussain, M., Rehmani, M. I. A., ... & Ahmad, A. (2015). Soil applied zinc ensures high production and net returns of divergent wheat cultivars. *Journal of Environmental and Agricultural Sciences*, **2**(1), 1-7.
- Nongbet, A., Mishra, A. K., Mohanta, Y. K., Mahanta, S., Ray, M. K., Khan, M., ... & Chakrabarty, I. (2022). Nanofertilizers: A smart and sustainable attribute to modern agriculture. *Plants*, **11**(19), 2587.
- Ramzan, Y., Hafeez, M. B., Khan, S., Nadeem, M., Batool, S., & Ahmad, J. (2020). Biofortification with zinc and iron improves the grain quality and yield of wheat crop. *International Journal of Plant Production*, **14**(3), 501–510.
- Rashid, A., Zia, M., & Ahmad, W. (2022). *Micronutrient fertilizer use in Pakistan: Historical perspective and 4R nutrient stewardship*. CRC Press.
- Rehman, A., Farooq, M., Ozturk, L., Asif, M., & Siddique, K. H. (2018). Zinc nutrition in wheat-based cropping systems. *Plant and Soil*, **422**, 283-315.
- Ryan, J., Estefan, G., & Rashid, A. (2001). *Soil and plant analysis laboratory manual*. ICARDA.
- Shahid, S., Hina, A., Abbasi, A., Maqsood, S., Ansari, M., Haq, I. U., & uz Zaman, Q. (2023). Organic approaches toward iron and zinc biofortification in legume crops. In *Legumes Biofortification* (pp. 347-369). Springer International Publishing.
- Shao, J., Tang, W., Huang, K., Ding, C., Wang, H., Zhang, W., ... & Qari, S. H. (2023). How does zinc improve salinity tolerance? Mechanisms and future prospects. *Plants*, **12**(18), 3207.
- Shiferaw, B., Smale, M., Braun, H. J., Duveiller, E., Reynolds, M., & Muricho, G. (2013). Crops that feed the world 10. Past successes and future challenges to the role played by wheat in global food security. *Food Security*, **5**, 291-317.
- Singh, N., & Sandhu, K. S. (2020). Effect of zinc fertilization on wheat yield and nutrient uptake. *Journal of Plant Nutrition and Soil Science*, **183**(6), 741-749.
- Singh, S., Kaur, J., Ram, H., Singh, J., & Kaur, S. (2023). Agronomic bio-fortification of wheat (*Triticum aestivum* L.) to alleviate zinc deficiency in human being. *Reviews in Environmental Science and Bio/Technology*, **1**-22.
- Sukhwil, A., Meena, R., Jain, D., Meena, R. H., & Jat, G. (2022). Molecular characterization of zinc solubilising bacteria isolated from different rhizospheric soil and assessment of their physiological attributes. *The Pharma Innovation Journal*, **11**(3), 332-340.
- Szerement, J., Szatanik-Kloc, A., Mokrzycki, J., & Mierzwa-Hersztek, M. (2022). Agronomic biofortification with Se, Zn, and Fe: An effective strategy to enhance crop nutritional quality and stress defense A review. *Journal of Soil Science and Plant Nutrition*, **22**(1), 1129–1159.
- Talpur, K. H., Jamali, I. A., Memon, S. P., & Depar, N. (2024). Evaluating advance wheat lines for enhanced zinc efficiency and climate resilience. *Pakistan Journal of Agriculture*, **1**(1), 1-7.
- UN. (2024). *World Population Prospects 2024: Summary of Results* (UN DESA/POP/2024/TR/NO.3). United Nations Department of Economic and Social Affairs, Population Division.
- Wang, S., Zhang, X., Liu, K., Fei, P., Chen, J., Li, X., ... & Tian, X. (2019). Improving zinc concentration and bioavailability of wheat grain through combined foliar applications of zinc and pesticides. *Agronomy Journal*, **111**(3), 1478-1487.
- Yadav, A. K., Seth, A., Kumar, V., & Datta, A. (2023). Agronomic biofortification of wheat through proper fertilizer management to alleviate zinc malnutrition: A review. *Communications in Soil Science and Plant Analysis*, **54**(2), 154-177.
- Yokokawa, H., Morita, Y., Hamada, I., Ohta, Y., Fukui, N., Makino, N., ... & Naito, T. (2024). Demographic and clinical characteristics of patients with zinc deficiency: Analysis of a nationwide Japanese medical claims database. *Scientific Reports*, **14**(1), 2791.
- Zulfiqar, U., Hussain, S., Ishfaq, M., Matloob, A., Ali, N., Ahmad, M., Alyemeni, M. N., & Ahmad, P. (2020). Zinc-induced effects on productivity, zinc use efficiency, and grain biofortification of bread wheat under different tillage permutations. *Agronomy*, **10**(10), 1566.

Publisher's note: JOARPS remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.



This is an open access article distributed under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited. To

view a copy of this license, visit [Creative Commons Attribution 4.0 International License \(CC BY 4.0\)](https://creativecommons.org/licenses/by/4.0/)