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Research Article

Evaluating Advance Wheat Lines for Enhanced Zinc Efficiency and Climate Resilience

Shafiq-ur-Rahman Memon[1,2†*], Zia-ul-hassan[2†], Khalid Hussain Talpur[2], Inzamam Ali Jamali[3], Saima Parveen Memon[4] and Nizamuddin Depar[5]

[1]University School for Advanced Studies IUSS Pavia & University Campus Bio-Medico di Roma, Italy, [2]Department of Soil Science, Sindh Agriculture University Tandojam, Pakistan, [3]Sindh Water & Agriculture Transformation Project, Tandojam, Pakistan, [4]College of Environmental Science and Engineering, Yangzhou University, Yangzhou, China, [5]Soil & Environmental Sciences Division, Nuclear Institute of Agriculture, Pakistan.

[†]*Contributed equally as co-first authors* (**Corresponding author*: shafiq.memon@iusspavia.it)

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ABSTRACT

Zinc (Zn) has long been considered as an indispensable micronutrient for crop production and its deficiency is now well established in Pakistani soils. We conducted a field study to evaluate the Zn use relations of five advanced wheat lines, viz. IV-1, IV-2, NARC-2, PAK-13, and V-119 under Zn-deficient soil conditions as affected by the application of 5.0 kg Zn ha^{-1}. The study involved three complete blocks with properly randomized treatments. Application of 5.0 kg Zn ha^{-1} significantly improved traits such as shoot and root fresh weight (61% and 68%), dry weight (50% and 39%), shoot and root length (77% and 74%), shoot and root Zn concentration (72% and 75%), Zn accumulation (35% and 27%), and Zn-use efficiency (69%). Among the wheat lines, NARC-2 and V-119 demonstrated efficient-responsive characteristics under both Zn-deficient and sufficient conditions. NARC-2 was highly responsive for the biomass production (both shoot and root) and Zn-use efficiency, while V-119 excelled in shoot and root length, Zn concentration, and Zn-use efficiency. IV-3 was the most efficient line under Zn-deficient conditions, showing superior tolerance and a high Zn-efficiency ratio, but was less responsive under sufficient Zn. PAK-13 was highly responsive under sufficient Zn, particularly for Zn-use efficiency, but less effective under deficiency stress. Our findings conclude that zinc nutrition significantly affected biomass production and zinc dynamics of wheat lines at the early growth stage. The NARC-2 and V-119 were found to be the most promising wheat lines for both Zn-deficient and sufficient conditions, with NARC-2 emerging as the most efficient-responsive wheat line. Further research is recommended to validate these findings.

Keywords: Wheat lines, Biomass production, Zinc efficiency, Zinc response, Climate-smart agriculture

Introduction

Wheat (*Triticum aestivum* L.) is a globally grown staple food crop, ensuring human food security, with a global production of ~800 million tons (FAO, 2024). In Pakistan, it covers an area of ~9.0 million hectares and produces ~28 million tons annually with an average yield of around 3.1 Mg ha^{-1} (GoP, 2024). However, when compared to other wheat-growing nations, the average wheat output of Pakistan is much less. Several factors contribute to low wheat yield, but limited fertilizer-use-efficiency has been identified as the primary cause (Vishandas et al., 2006). The deficiency of essential plant nutrients results in significant losses in crop productivity. Zinc (Zn) is an important micronutrient, deficient in over 50% of soils worldwide (Singh et al., 2023). Accordingly, over a billion individuals worldwide suffer from deficiency of Zn (Khan et al., 2022).

Zinc deficiency is associated with numerous soil and environmental factors, such as high soil pH, low soil organic matter, waterlogged condition, dry climate, and calcareousness (Recena et al., 2021). Cereal crops produced on Zn-deficient soils have been shown to exhibit Zn deficiencies in their grains (Biesalski, 2013). Plants under Zn deficiency are particularly vulnerable to environmental stressors, such as drought stress and pathogenic diseases. Additionally, Zn-deficient plants have slowed development and leaf necrosis. Plant growth, yield, and overall crop output all significantly decrease as a result of Zn insufficiency (Marschner, 1995).

In addition to its involvement in enhancing the concentration of iron (Fe) in leaves, Zn is thought to be involved in gene expression, membrane integrity, and enzyme activation (Cakmak et al., 2023). Rashid et al. (2022) reported that 70% of Pakistan's soils and nearly the whole rice tract have inadequate Zn availability. Globally, Zn-efficient rice, barley, and wheat cultivars that can be cultivated on soils deficient in Zn have been developed to address this issue (McDonald, 2008).

Genetically modified Zn-efficient genotypes have the capacity to efficiently uptake, translocate and accumulate Zn in their reproductive parts. They make the insoluble fraction of Zn available to their roots (Velu et al., 2018). Zn efficiency and shoot Zn absorption were substantially improved in field conditions in Zn-deficient calcareous soils (Cakmak et al., 1997). Zn-efficient genotypes may not always have greater Zn concentrations in their leaves, shoots, or grains, despite having a high capacity for Zn absorption. This could also apply to wheat genotypes that are deficient in Zn (Velu et al., 2018). Increased Zn absorption by effective genotypes under a Zn deficit condition increases the production of dry matter, which can lower Zn concentrations. This phenomenon is known as dilution due to growth (Marschner, 1995). According to Cakmak et al. (2010), genotypes that are Zn-efficient are thought to increase yields of food crops in soils with poor Zn bioavailability, which may help alleviate human malnutrition caused by insufficient supply of Zn.

Compared to cereals produced on Zn-adequate soils, those cultivated on Zn-deficient soils have an 80% lower grain Zn concentration (Bhatt et al., 2020). Finding wheat genotypes that are effective in efficiently absorbing Zn at different phases of growth is therefore crucial (Hussain & Kausar, 2002). This strategy might provide a workable way to produce wheat sustainably in soils having low Zn availability.

Keeping the above facts in mind, we conducted this field study was conducted to assess the efficiency and response of selected advance lines of wheat developed in Pakistan.

Materials and Methods

Experimental design and treatment details: A field study was executed using a two-factor randomized design involving three complete blocks Factor A involved application of 0 and 5.0 kg Zn ha^{-1}. Factor B comprised of five recently developed advance lines of wheat, viz. IV-1, IV-2, NARC-2, PAK-13 and V-119. Main plots were sown with wheat lines while sub-plots received Zn doses. The size of the experimental plot was 15 m^2 (5 .0 m × 3.0 m).

Sowing of advance wheat lines: Wheat was planted at 130 kg ha^{-1} seed rate. The rows and plants within rows were kept 30 and 10 cm apart, respectively. The crop was monitored throughout the cropping season. All the standard cultural and protective measures were adopted upon requirement.

Fertilizer application: Zinc fertilizer treatments were applied at sowing through zinc sulphate ($ZnSO_4. 7H_2O$), containing 23% of elemental Zn. A blanket dose of nitrogen (N) and phosphorus (P) fertilizers was applied at 150-75 kg N-P ha^{-1} through urea and diammonium phosphate, respectively. At sowing, total amount of P was applied to wheat with half of the total N fertilizer through broadcasting. The leftover N was applied in two splits at first and second irrigation through top dressing.

Analysis of experimental soil: Soil samples were obtained from the experimental area prior to sowing following protocols outlined by (Ryan et al., 2001). The soil of experiment area was a sandy clay loam, with alkaline reaction (pH: 8.1), non-saline (EC 0.94 dS m^{-1}), deficient organic matter (0.68%), medium calcareous (14.1%), and deficient in ABDTPA-Zn (0.87 mg kg^{-1}).

Collection of data: Harvesting was done 42 days after sowing to record important plant traits, i.e. fresh and dry biomass (shoot and root length of shoot and root, ratio of root to shoot. Moreover, Zn concentration of shoot and root was determined as suggested by Ryan et al. (2001).

Statistical analysis: The recorded data were analyzed using Statistix ver. 8.1. The differences among treatment means were analyzed using the Honestly Significant Difference Test of Tukey at alpha 0.05.

Results

Shoot Fresh Weight (g plant^{-1}): As shown in Table 1, shoot fresh weight was significantly improved by the two main factors, wheat lines and zinc levels as well as by their interaction. Shoot fresh weight of advance wheat lines increased by 61% at the higher rate of Zn. Shoot fresh weight was shown to be strongly impacted by Zn nutrition across two zinc levels. The NARC-2 produced maximum shoot biomass followed by PAK-13 and IV-2, which was minimum in case of V-119 and IV-3.

The wheat lines IV-3 were the most susceptible to Zn deficiency stress. The NARC-2, IV-2, and V-119 were the most Zn-efficient lines. Similarly, wheat lines NARC-2 and PAK-13 produced maximum biomass when supplied with adequate amount of Zn (Table 1).

Root fresh weight (g plant^{-1}): The results revealed that root fresh weight was considerably increased by the two main factors, wheat lines and Zn levels as well as by their interaction. The fresh weight of the roots increased by

68% as the rate of Zn increased to 5.0 kg ha^{-1} (Table 1). Root fresh weight was shown to be strongly impacted by Zn across two zinc levels. It was maximum for NARC-2 followed by PAK-13 and IV-2 and minimum for IV-3. Compared to IV-3, NARC-2 produced nearly twice as much fresh weight of roots (1.89 times). It was also observed that IV-3 was the most non-efficient wheat deficiency under Zn deficiency stress. In contrast, it was noticed that the wheat lines NARC-2, IV-2, and V-119 were effective under Zn deficiency stress. The most responding advance wheat line at sufficient Zn level were NARC-2 and PAK-13, whereas IV-3 was the least sensitive. Root fresh weight was maximum for NARC-2 and PAK-13, while minimum for IV-3 (Table 1).

Table 1. Shoot and root fresh weight (g plant^{-1}) of advance wheat lines as affected by zinc nutrition

Advance Lines	Shoot fresh weight (g plant^{-1})			Root fresh weight (g plant^{-1})		
	Zn (kg ha^{-1})		Lines mean	Zn (kg ha^{-1})		Lines mean
	0	5		0	5	
NARC-2	0.915bcd	1.790a	1.353A	0.461bcd	0.805a	0.633A
PAK-13	0.765cd	1.650a	1.208AB	0.384cde	0.747a	0.565AB
IV-2	0.800bcd	1.198b	0.999BC	0.406bcde	0.540b	0.473B
IV-3	0.625d	0.785cd	0.705D	0.314e	0.354de	0.334C
V-119	0.833bcd	1.045bc	0.939CD	0.419bcde	0.472bc	0.446BC
Zn mean	0.788B	1.294A		0.397B	0.584A	

Means followed by the same letters are alike at alpha 0.05.
P-values from analysis of variance: *Shoot fresh weight:* Zinc 0.0139, Lines 0.0001, Zinc x Lines: 0.0013, *Root fresh weight:* Zinc 0.0442, Lines 0.0002, Zinc x Lines: 0.0033, Honestly significant difference (HSD0.05): *Shoot fresh weight:* Zinc 0.0140, Lines 0.2372, Zinc x Lines: 0.0407, *Root fresh weight:* Zinc 0.1659, Lines 0.1198, Zinc x Lines: 0.2055

Shoot dry weight (g plant^{-1}): It was noticed that shoot dry weight was significantly enhanced by the two main factors, i.e. wheat lines and Zn levels as well as by their interaction (Table 2). Adequate Zn nutrition enhanced shoot biomass up to 50%. The order of shoot dry weight of advance wheat lines was NARC-2 > PAK-13 > IV-2 > V-119 = IV-3. In comparison to IV-3, NARC-2 produced nearly twice as much shoot dry weight (1.89-fold). The wheat line IV-3 was the most Zn-deficiency susceptible wheat line. In contrast, NARC-2, IV-2, and PAK-13 were efficient to deal with the Zn deficiency.

Table 2. Shoot and root dry weight (g plant^{-1}) of advance wheat lines as affected by zinc nutrition

Advance Lines	Shoot dry weight (g plant^{-1})			Root dry weight (g plant^{-1})		
	Zn (kg ha^{-1})		Lines mean	Zn (kg ha^{-1})		Lines mean
	0	5		0	5	
NARC-2	0.410cd	1.020a	0.715A	0.181cd	0.665a	0.423A
PAK-13	0.378cd	0.941a	0.659AB	0.166d	0.456ab	0.311AB
IV-2	0.393cd	0.683b	0.538BC	0.173d	0.424bc	0.299AB
IV-3	0.309cd	0.447bcd	0.378D	0.136d	0.255bcd	0.195B
V-119	0.350d	0.596bc	0.473CD	0.154d	0.288bcd	0.221B
Zn mean	0.368B	0.737A		0.162B	0.418A	

Means followed by the same letters are alike at alpha 0.05.
P-values from analysis of variance: *Shoot dry weight:* Zinc 0.0465, Lines 0.0001, Zinc x Lines: 0.0007, *Root dry weight:* Zinc 0.0199, Lines 0.0030 Zinc x Lines: 0.0098, Honestly significant difference (HSD0.05): *Shoot dry weight:* Zinc 0.3446, Lines 0.1249, Zinc x Lines: 0.2143, *Root dry weight* Zinc 0.1021, Lines 0.1351, Zinc x Lines: 0.2319

Similarly, maximum response of adequate Zn nutrition to produce shoot dry biomass was recorded for PAK-13 and NARC-2 while minimum was noted for IV-3. Due to the interaction of two main effects, PAK-13 and NARC-2 produced maximum shoot dry biomass while the reverse was true for IV-3 (Table 2).

Root dry weight (g plant^{-1}): Root dry weight was significantly altered by the two main factors, i.e. wheat lines and Zn levels as well as by their interaction. The root dry weight of advance wheat lines increased by 39% with the increasing Zn level (Table 2). Root dry weight was shown to be strongly impacted by the Zn treatment (5.0 kg ha^{-1}). Root dry weight was maximum for NARC-2 followed by PAK-13 and IV-2 and minimum for IV-3 and V-119. Compared to IV-3, NARC-2 produced nearly twice as much root dry weight (2.16-fold).

The most inefficient wheat line under Zn deficiency stress was IV-3. Contrarily, NARC-2, PAK-13, and IV-2 were found to be most efficient. Similarly, PAK-13 and NARC-2 proved to be the most responsive while IV-3 was the least responsive to adequate Zn nutrition. Maximum dry biomass of root was obtained for PAK-13 and NARC-2 and minimum for IV-3, based up on the interactive effect (Table 2).

Shoot length (cm plant^{-1}): Shoot length increased by 77% where Zn treatment was administered. Maximum shoot length was recorded for V-119 followed by IV-2 and NARC-2, while minimum was noted for PAK-13 andIV-3. Under Zn deficiency stress, V-119, IV-2, and IV-3 were found to be efficient. Similarly, NARC-2 and V-119 responded more to adequate Zn nutrition when compared to IV-3. Maximum shoot length was achieved by V-119 and NARC-2, while IV-3 produced minimum (Table 3).

Table 3. Shoot and root length (cm plant^{-1}) of advance wheat lines as affected by zinc nutrition

Advance Lines	Shoot length (cm plant^{-1})			Root length (cm plant^{-1})		
	Zn (kg ha^{-1})		Lines mean	Zn (kg ha^{-1})		Lines mean
	0	5		0	5	
NARC-2	16.2fg	25.4a	20.8BC	8.6c	14.0ab	11.3AB
PAK-13	16.0g	22.6bc	19.3CD	8.5c	15.2a	11.8AB
IV-2	19.5de	23.9ab	21.7AB	9.5bc	12.0abc	10.8B
IV-3	17.7ef	20.3de	19.0D	10.1bc	10.5abc	10.3B
V-119	20.9cd	25.1a	23.0A	12.5abc	15.0a	13.8A
Zn mean	18.0B	23.5A		9.8B	13.3A	

Means followed by the same letters are alike at alpha 0.05.

P-values from analysis of variance: *Shoot length:* Zinc 0.0325, Lines 0.0002, Zinc x Lines: 0.0014, *Root length:* Zinc 0.0049, Lines 0.0273, Zinc x Lines: 0.0429, Honestly significant difference (HSD0.05): *Shoot length:* Zinc 3.5350, Lines 1.7279, Zinc x Lines: 2.9650, *Root length:* Zinc 0.3446, Lines 2.9953, Zinc x Lines: 4.6187

Root length (cm plant^{-1}): Root length was substantially improved by both the main factors, i.e. wheat lines and Zn levels as well as by their interaction. Root length increased by 74% at sufficient Zn level (Table 3). The root length of wheat lines was shown to be strongly impacted by Zn. Root length was maximum for V-119 followed by PAK-13 and NARC-2, while minimum for IV-2 and IV-3. Under Zn deficiency stress, V-119, IV-3, and NARC-2 were the most efficient wheat lines. Similarly, V-119 and NARC-2 were the most responsive wheat lines at adequate Zn level while IV-3 was the least responsive. Maximum root length of the was noticed for NARC-2 and V-119and minimum for IV-3.

Shoot Zn concentration (mg g^{-1}): The concentration of Zn in the shoots of advance wheat lines was substantially enhanced by the two factors (Zn treatments and wheat lines) as well the interaction between them (Table 4). Zinc nutrition was found to be highly influential in terms of contributing to Zn content of shoots. The order of wheat line's Zn content was, NARC-2 > V-119 > IV-3 > IV-2 = PAK-13. Zinc content in shoots of NARC-2 was observed 1.28 times higher than that of PAK-13. Additionally, where no Zn was applied, PAK-13 was the most negatively impacted line. Moreover, under Zn deficiency stress, IV-3, V-119, and NARC-2 were noted to be effective. Similarly, NARC-2 and V-119 outyielded all other wheat lines at sufficient Zn dose, but PAK-13 was the least responsive. Due to the interaction between the wheat lines and Zn rates, the data showed that the highest shoot Zn content was observed in the cases of NARC-2 and V-119, and lowest Zn content of shoots was observed in PAK-13 (Table 4).

Root Zn concentration (mg g^{-1}): The results showed that both the main factors (wheat lines and Zn treatments) as well as their interactions significantly enhanced the root Zn content of advance wheat lines (Table 4). Root Zn content increased by 75% at the higher dose of Zn treatment. The order of the root Zn content was NARC-2 > V-119 > IV-3 > PAK-13 = IV-2. When compared to IV-2, Zn content of NARC-2 was nearly doubled. Furthermore, it was noticed that NARC-2 was the most negatively impacted advance line as it was the least responsive under Zn deficiency stress (no Zn applied). However, V-119, IV-3, and IV-2 performed effectively

Table 4. Shoot and root Zn concentration (mg g^{-1}) of advance wheat lines as affected by zinc nutrition

Advance Lines	Shoot Zn concentration (mg g^{-1})			Root Zn concentration (mg g^{-1})		
	Zn (kg ha^{-1})		Lines mean	Zn (kg ha^{-1})		Lines mean
	0	5		0	5	
NARC-2	18.3def	30.4a	24.3A	13.5f	29.1a	21.3A
PAK-13	16.1f	21.8cd	19.0C	16.5e	22.9b	19.7BC
IV-2	17.9ef	25.1b	21.5B	17.4e	20.0cd	18.7C
IV-3	20.2cde	23.0bc	21.7B	18.9d	20.7c	19.8BC
V-119	18.1def	25.2b	21.6B	19.2cd	22.0b	20.6AB
Zn mean	18.1B	25.1A		17.1B	22.9A	

Means followed by the same letters are alike at alpha 0.05.

P-values from analysis of variance: *Shoot Zn concentration:* Zinc 0.0149, Lines 0.0000, Zinc x Lines: 0.0001, *Root Zn concentration:* Zinc 0.0180, Lines 0.0012, Zinc x Lines: 0.0000, Honestly significant difference (HSD0.05): *Shoot Zn concentration:* Zinc 2.0929, Lines 1.4363, Zinc x Lines: 2.4646, *Root Zn concentration:* Zinc 2.1057, Lines 1.2941, Zinc x Lines: 2.2206 under the treatment receiving no Zn application. Similarly, at adequate Zn dose, NARC-2 and PAK-13 outyielded all other lines, whereas IV-2 responded the least to the same treatment. It was also noticed that the wheat lines and Zn interaction resulted in the highest root Zn content observed in NARC-2 and PAK-13, and the lowest was determined in IV-2 (Table 4).

Shoot Zn accumulation (mg plant^{-1}): The ANOVA showed that shoot Zn accumulation was significantly increased by the two main factors (wheat lines and Zn treatment doses) as well as by their interaction (Table 5). The shoot Zn increased by 35% with the increasing rate of Zn application. In comparison to IV-3, NARC-2 accumulated Zn in the shoots more than twice as much (2.32-fold). Furthermore, it was observed that PAK-13 was the most negatively impacted under the treatment of no Zn application. However, under no Zn application, NARC-2, IV-2, and V-119 performed effectively. While at adequate Zn supply, NARC-2 and PAK-13 efficiently accumulated Zn in their shoots, whereas IV-3 performed the least under the same Zn level. It was also noticed that, as a result of the interaction between Zn doses and the advance wheat lines, NARC-2 and PAK-13, and IV-3 accumulated the highest and lowest Zn content, respectively (Table 5).

Table 5. Shoot and root Zn accumulation (mg g^{-1}) of advance wheat lines as affected by zinc nutrition

Advance Lines	Shoot Zn accumulation (mg plant^{-1})			Root Zn accumulation (mg plant^{-1})		
	Zn (kg ha^{-1})		Lines mean	Zn (kg ha^{-1})		Lines mean
	0	5		0	5	
NARC-2	7.505d	31.031a	19.268A	2.447b	19.345a	10.896 A
PAK-13	6.103d	20.601b	13.352B	2.743b	10.489b	6.616 B
IV-2	7.037d	17.138bc	12.087BC	3.034b	8.484b	5.759 B
IV-3	6.246d	10.307d	8.276C	2.567b	5.274b	3.920 B
V-119	6.323d	15.000c	10.661BC	2.965b	6.338b	4.651 B
Zn mean	6.643B	18.815A		2.751B	9.986A	

Means followed by the same letters are alike at alpha 0.05.

P-values from analysis of variance: *Shoot Zn accumulation:* Zinc 0.0339, Lines 0.0001, Zinc x Lines: 0.0002, *Root Zn accumulation:* Zinc 0.333, Lines 0.0004, Zinc x Lines: 0.0003, Honestly significant difference (HSD0.05): *Shoot Zn accumulation:* Zinc 8.2696, Lines 3.8826, Zinc x Lines: 6.6626, *Root Zn accumulation:* Zinc 4.8367, Lines 3.0593, Zinc x Lines: 5.2497

Root Zn accumulation (mg g^{-1}): The two factors (wheat lines and Zn application doses) as well as their interaction significantly improved root Zn accumulation (Table 5). Comparing NARC-2 to IV-3, the amount of Zn accumulated in the roots was nearly doubled (2.7-fold). Moreover, under no Zn supply, NARC-2 was observed to be the most negatively impacted wheat line. Under inadequate Zn supply, IV-2, V-119, and PAK-13 performed the best of all. At adequate Zn supply, NARC-2 and PAK-13 outyielded all other lines. (Table 5).

Zinc-efficiency ratio: The Zn-efficiency ratios of three of the five advance lines were greater than the average of the five lines, with IV-3 > V-119 = IV-2 (Figure 1). Compared to the average of the five advance wheat lines, the Zn-efficiency ratios of the two other advance wheat lines were almost similar. Thus, it is evident from these findings that IV-3 was the most effective to withstand Zn deficit stress.

Discussion

In the current field experiment, five advance wheat lines were developed in Pakistan were cultivated under two Zn application rates, i.e. adequate and inadequate Zn supply, in order to determine their Zn-relations at the early stages of growth. The findings (Tables 1–5 and Figure 1) supported the idea that the biomass production of wheat negatively impacted by inadequate supply of Zn.

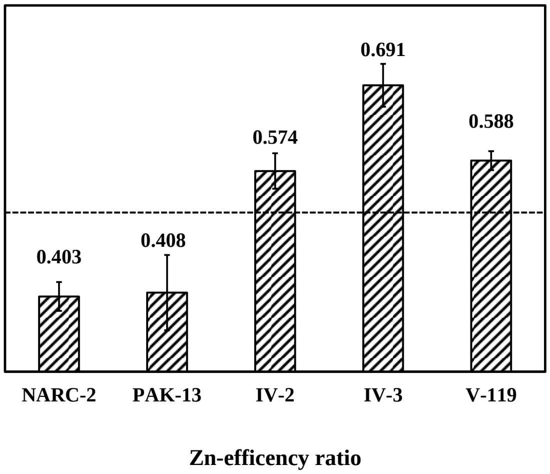

Figure 1. Zinc-efficiency ratio of five advance wheat lines as affected by zinc nutrition at early growth stage (the dotted line denotes average Zn-efficiency ratio of all five wheat lines, i.e. 0.533).

The results showed that sufficient Zn nutrition had a substantial impact on nearly all of the growth parameters, and that stress from Zn deficiency negatively impacted all of these traits. The findings confirm widespread Zn in Pakistani soils and the sensitivity of advance wheat lines to Zn deficiency.

Zinc is a micronutrient that is necessary for human nutrition and crop growth (Cakmak, 2010; Montalvo et al., 2016). In plants, it plays several crucial roles, such as protein synthesis, maintenance of the integrity of cell membranes, defense against reactive oxygen species etc. It is also an integral part of several enzyme systems in plants (Cakmak et al., 2023; Ozturk et al., 2023). Due to its involvement in the above-mentioned critical plant processes, Zn shortage severely impacts plant development, productivity and agricultural output. However, these effects vary by geography and crop genotype (Rashid et al., 2022).

Several plant physiological processes dependent on Zn is restricted in the conditions of inadequate Zn nutrition (Cakmak et al., 2023). It causes a decrease in shoot development, the emergence of whitish-brown necrotic patches on leaves, a decrease in net photosynthetic rate and chlorophyll content, and a decrease in Zn-containing enzymes (Xing et al., 2015).

Significant primary and interaction effects of varieties and Zn treatment on wheat productivity and Zn content have been linked to widespread Zn deficiencies in Pakistani soils (Maqsood et al., 2009). Furthermore, Cakmak et al. (2001) found that after 32 days of development, the shoot dry matter of genotypes was significantly reduced due to Zn deficiency. They discovered that the shoot dry weight of most genotypes was comparable when there was an adequate supply of Zn.

In current study, 5.0 kg of Zn ha^{-1} significantly improved different growth parameters (Table 1–5). Crop performed the best under the higher dose of Zn, which seems as an ideal dosage for achieving an economically viable productivity as well and plant Zn content, according to Khan et al. (2022). Akca and Taban (2024) looked at how applying Zn to an alkaline-calcareous soil enhanced wheat production and yield attributes. The most cost-effective method was to apply 5 kg Zn ha^{-1}. The effect of Zn application was evaluated in a field experiment by Cakmak et al. (2010) and reported the positive impacts on Zn on yield and quality to wheat grains. They discovered that foliar Zn treatment significantly raised the concentration of Zn in wheat grain and its fractions.

Currently, five advance wheat lines that might be used to develop Zn-use-efficient wheat genotypes showed significant genotypic heterogeneity (Table 1 to 5 and Figure 1). Zn-use-efficient crop genotypes have been shown in the literature to be able to grow well and yield enough grains even in low-Zn soils, which reduces the need for chemical fertilizers (Rashid et al., 2022). The best and most economical way to deal with the problem of Zn deficiency is to develop crop genotypes for high concentrations of Zn grains. Additionally, Zn fertilization helps to biofortify cereal grains with Zn (Cakmak, 2010).

Conclusion

Our findings conclude that zinc nutrition significantly affected biomass production and zinc dynamics of wheat lines at the early growth stage. The NARC-2 and V-119 were found to be the most promising wheat lines for both Zn-deficient and sufficient conditions, with NARC-2 emerging as the most efficient-responsive wheat line. Further research is recommended to validate these findings.

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Conflict of Interest

No competing interests are disclosed by the authors.

Author Contribution

SRM: Conduct of field study, data collection, chemical analyses, writing initial draft of MS; ZH: Idea conceiving, execution of field trial, data analysis, editing all drafts of MS; KHT: Literature review and writing initial draft; IAJ: Data presentation, format and style; SPM: Assistance in field experiment and writing initial draft of MS; ND: Technical assistance in chemical analyses, revision of initial draft of MS. All authors approve and assume the responsibility of the content of MS.

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