Potential Zinc Uptake of Different Wheat Cultivars Grown Under Calcareous Soil Conditions of Dera Ismail Khan Pakistan

Irfan Ahmad [1], Nasr Ullah Khan [2*], Jamal Abdul Nasir [3], Wasif Rasool [4], Naimat Ullah [5], Muzammil Mahboob Ur Rehman [5], Hanzla Qasim [6], Hira Abbas [7], Muqadas Shahzain [8], Naina Haider [9], Sidra-Tul-Muntaha [10]

[1] Faculty of Agriculture, Department of Soil Science, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan

[2, 3, 4, 6, 7] Faculty of Agriculture, Department of Plant Breeding & Genetics, Gomal University, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan

[5, 8, 9, 10] Institue of Biological Sciences, Gomal University, Dera Ismail Khan Khyber Pakhtunkhwa, Pakistan

* Corresponding Author: **Nasr Ullah Khan**

Article Info

ISSN (online): 3049-0588
Volume: 02
Issue: 03
May - June 2025
Received: 08-03-2025
Accepted: 07-04-2025
Page No: 21-33

Abstract

Zinc deficiency caused by inadequate dietary intake is a pervasive nutritional problem across the globe. Therefore, increasing zinc levels in wheat and other cereal crops through biofortification has become a serious concern and a top priority research. A field experiment was conducted in Department of Soil Science, Gomal University, Dera Ismail Khan Pakistan. The objectives were to evaluate the effect of zinc (Zn) on the growth, yield and yield contributing traits of wheat and to find out the best variety of wheat for yield maximization. Five wheat varieties, V1: AZRC, V2: Gulzar, V3: PS-15, V4: Fakhr e Bhakkar and V5: Wadan-17 were tested at 7.5 kg ha-1 zinc application. The treatments were arranged in randomized complete block design with three replications. The basal dose of NPK at the rate of 120: 60: 40 kg ha-1 respectively, was applied to all varieties. The result of study showed that Gulzar and AZRC variety resulted maximum plant height (81.67 and 79.67cm), number of tillers (407.67 and 383), spike length (12.02 and 11.36 cm), number of spikelets per spike (24.66 and 22.66), number of grains per spike (59.67 and 58.11), 1000 grain weight (51.31 and 48.01 g), biological yield (16.73 and 15.67 t ha-1), Straw yield (9.73 and 9.52 t ha-1) and harvest index (41.78 and 39.23 %), respectively. Similarly, chlorophyll content, protein content and zinc uptake by plant was recorded maximum in Gulzar and AZRC as 2.82 and 2.68, 11.91 and 11.72 %, 30.49 and 29.13 5 mg ka-1, respectively. All traits of wheat recorded lowest in PS-15. Thus, agronomic biofortification is the best way to enrich wheat grains with zinc for human consumption. In conclusion, Gulzar and AZRC were found to be most suitable for both optimum grain yield and grain biofortification of wheat.

DOI: https://doi.org/10.54660/GARJ.2025.2.3.21-33

Keywords: Zinc, Biofortification, Wheat (*Triticum aestivum* L.), Human Nutrition, Yield, Yield Contributing Traits

Introduction

Wheat (*Triticum aestivum* L.) is regarded as the world's most important cereal crop (Ahmad *et al.*, 2018) [4]. The area under cultivation in Pakistan for the 2020-21 wheat cropping season was reported to be 9168.2 thousand hectares, with an output of 27464.1 thousand tones and an average yield of 2974 kg ha^{-1} (Pakistan Economic Survey, 2020-21). In Khyber Pakhtunkhwa province of Pakistan in 2018-19, the total area under wheat was 739570 hectares, with a total production of 1327580 tons and an average yield of 1795 kg ha^{-1} (Crop statistics Khyber Pakhtunkhwa, 2018- 19) [21].

Wheat cultivation faces challenges such as low yields and micronutrient deficiencies, particularly zinc (Verma *et al.*, 2022) [65]. Enhancing yield per hectare is essential to meet the rising global demand (Kheir *et al.*, 2022) [39].

Although high-yielding cultivars exist, further improvements are needed. Yield is affected by pests, soil quality, and climate change (Prasad *et al.*, 2021; Chapman *et al.*, 2012) [51, 18]. Sustainable strategies are increasingly important as the global population grows.

Over two billion people, primarily in developing countries, suffer from zinc deficiency due to inadequate dietary intake, leading to stunted growth, weakened immunity, and higher infection risks (Chasapis *et al.*, 2020; Kiran *et al.*, 2022) [19, 40]. Zinc requirements vary by age, gender, and physiological conditions. Adult women need 10 mg/day, men require 12 mg/day, and women need up to 14 mg/day during pregnancy and lactation. These levels are often unmet in underdeveloped nations due to reliance on zinc-deficient cereal grains (Bouis *et al.*, 2011) [15]. Populations in countries such as Turkey, Iran, China, Pakistan, and India consume cereals low in zinc, exacerbating the deficiency (Alloway, 2009) [8]. Zinc biofortification of wheat offers a sustainable solution to improve dietary zinc intake. The COVID-19 pandemic highlighted the essential role of micronutrients in maintaining immune health (WHO, 2020) [66]. While approaches like supplementation, fortification, and dietary diversification exist, developing micronutrient-rich staple crop cultivars holds promise for reducing global deficiencies (Singh, 2017) [60].

Pakistan's alkaline calcareous soils are highly deficient in zinc, boron, and iron, affecting cereal crops like wheat and rice, especially in dry to semi-arid regions (Alloway, 2008) [7]. Zinc is vital for plant growth, influencing metabolic responses under salinity (Tahir *et al.*, 2009) [63], and is involved in enzyme function, membrane integrity, protein synthesis, and chlorophyll and pollen formation (Cakmak, 2009; Pandey *et al.*, 2006) [17, 49]. However, zinc bioavailability is low in salt-affected soils, leading to frequent deficiencies. Zinc fertilization improves both crop yields and grain zinc content (Liu *et al.*, 2019) [43]. It also enhances grain nutritional quality (Vanitha *et al.*, 2022; Liu *et al.*, 2019; Mazhar *et al.*, 2021) [64, 43, 46]. Fertilization is a crucial strategy to address human zinc deficiencies in underdeveloped regions where soil zinc is lacking (Chapman *et al.*, 2012) [18]. Environmental factors like climate and soil quality can affect the performance of different wheat genotypes in terms of fortification (Kumar *et al.*, 2018; Karayigit, 2022) [48, 32]. The research focuses on enhancing zinc (Zn) content in wheat grains to support biofortification efforts and to examine genotype diversity, heritability, yield, and Zn concentration and bioavailability in wheat. It also explores the role of zinc fertilization in the relationship between yield and biofortification traits. Ultimately, the study seeks to address breeding and agronomic strategies to improve wheat grain zinc content evaluating the impact of soil conditions on zinc uptake in diverse wheat cultivars and assessing variability in zinc uptake among different wheat varieties along with comparison of environmental sustainability of different wheat varieties in zinc uptake.

Materials and Methods

Cultural practices

Wheat varieties were sown in the first week of December 2022 at 100 kg ha^{-1} using a drill method with 33 cm row spacing. Fertilizers were applied at 150:100:60 kg ha^{-1} (N: P: K) using urea, DAP, and potassium sulfate, with nitrogen split into two doses (half at sowing and half with the first irrigation), while P and K were applied as a basal dose before sowing. Soil samples (0-30 cm depth) were collected and analyzed for nutrient content. Five irrigations of canal water throughout the crop cycle were given and TRI-STAR herbicide (containing mesosulfuron-methyl, florasulam, and MCPA isooctyl) was applied to control annual grass and broadleaf weeds.

Methods

A field experiment was conducted during the 2022-23 Rabi season at Gomal University, D.I. Khan, Pakistan to study the impact of zinc fertilizer (applied @ 7.5 kg ha^{-1} as zinc sulphate) on five wheat varieties (Table 1). The study followed a Randomized Complete Block Design (RCBD) with three replications, using plot sizes of 2×3 m².

Table 1

S. No	Name
1	AZRC
2	Gulzar
3	PS-15
4	Fakhr-e-Bhakkar
5	Wadan-17

Parameters

Data was recorded for parameters (Table 2). All measurements were taken from representative samples across replications to ensure data reliability.

Table 2

S. No	Parameter
1	Plant Height (cm)
2	Number of Tillers (m^{-2})
3	Spike Length (cm)
4	Number of Spikelets spike^{-1}
5	Number of Grain Spike^{-1}
6	1000 Grain Weight (g)
7	Grain Yield (t ha^{-1})
8	Straw yield (kg ha^{-1})
9	Biological yield (kg ha^{-1})
10	Harvest Index (%)
11	Chlorophyll Content (µg cm^{-2})
12	Protein Content (%)
13	, Zinc uptake by plant (mg kg^{-1})

Statistical Analysis

Statistical analysis was conducted using Statistix8.1 software, with treatment effects evaluated through ANOVA and mean separation by LSD test (p≤0.05) following Steel *et al.*, (1997).

Results and Discussion

Plant Height (cm)

Plant height of wheat varied significantly among different cultivars of wheat under zinc application. The results showed that the maximum plant height of wheat recorded in Gulzar as 81.67 which was at par with AZRC (79.67). Wadan-17, Fakhr e Bhakkar and PS-15 showed plant heights of 78.33, 78.00 and 76.33 respectively, which was lower than Gulzar and AZRC cultivars (Figure 1). Plant height of Gulzar and AZRC cultivar may have increased due to zinc because of improved photosynthetic activities that produced more assimilates in Gulzar and AZRC cultivar which were responsible for taller plant height compared to other cultivars.

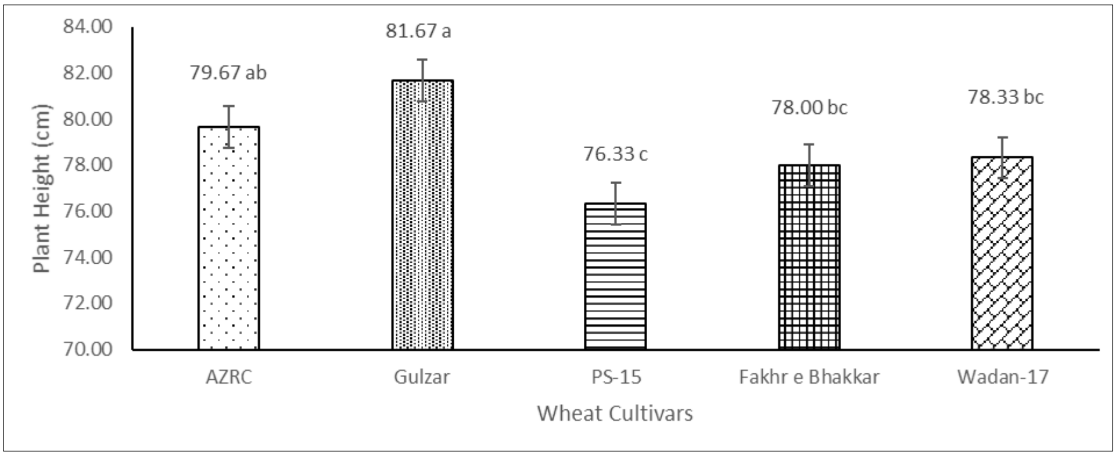

Fig 1: Plant Height Variation Among Wheat Cultivars in Response to Zinc application

According to the research findings of (Al-Otayk, 2010; Rashid *et al.*, 2004; Hussain *et al.*, 2001) [9, 56, 28], the primary reason for variation in plant height is genetic variability. A statistically similar value for plant height (99 cm) was computed for zinc level at the rate of 7.00 kg ha^{-1}, followed by plant height (97 cm) for 3.50 Zn kg ha^{-1}. Shorter plant height (93 cm) was calculated for the control plot. Taller plants (101 cm) were produced among different levels of zinc at the rate of 10.50 kg ha^{-1}. When zinc was applied at a rate of 10 kg ha^{-1}, the plants height of wheat increased than the control group (Khan *et al.*, 2009; Ranjbar & Babmaniar, 2007) [36, 55]. Solely zinc fertilizer application had a beneficial impact on plant height. According to the finding of Zain *et al.*, (2015) [67], applying micronutrients (Zn) significantly increased wheat plant height. According to Abbas *et al.*, (2010) [1], when the recommended quantities of NPK are applied, plant height increases considerably along with an increase in Zn rate as compared to control. Plant height in the Fakher-e-Bhakkar cultivar was recorded as the highest in pots and in the field at 91.5 cm and 81.2 cm respectively, when compared to Zincol and Faislabad 2008 (Sher *et al.*, 2022) [59].

Number of Tillers (m^{-2})

Significant differences ($p < 0.05$) were observed in case of number of tillers of wheat. Maximum number of tillers was found in Gulzar (407.67) followed by AZRC (383). Fakhr-e-Bhakkar and Wadan-17 showed an average result compared to Gulzar and AZRC. PS-15 exhibited the lowest number of tillers of 291.67 (Figure 2). Zinc plays an important role in plant hormones such as auxins and cytokinin’s are synthesized and regulated by zinc. The promotion of cell division and elongation, which are essential for tiller development, is facilitated by these hormones and these functions possibly stimulate more in Gulzar compared to other varieties.

Zn deficiency lowers enzymatic activities and auxin metabolism, which lowers the number of tillers. In contrast, application of Zn significantly increased the number of productive tillers due to an increase in enzymatic activation, improvement in auxin metabolism and photosynthate translocation (Khan *et al.*, 2006; Maqsood *et al.*, 1999) [35, 45]. The plant may have a higher chance of bearing more fruitful tillers per unit area if essential nutrients had been applied, because it might have improved the production of metabolites synthesized (Elayan, 2008; Abdallah and Hanaa, 2013) [23, 2]. Ilyas *et al.*, (2020) [29] found that the application of zinc had a substantial impact on the yield attributes of several wheat varieties. The most productive tillers (302.33) were seen when 40 kg of $ZnSO_4$. H_2O ha^{-1} was applied to the soil plus 0.4% zinc solution was used for seed priming plus foliar spray at 0.5% Zn solution, which was at par with 40 kg $ZnSO_4$. H_2O ha^{-1} to the soil as 289 tillers. In the control treatment, however, the least productive tillers (261.89) were noted. In comparison to the lowest productive tillers plant-1 of (3.29) from Fakhri Sarhad, the maximum productive tillers plant-1 of (3.68) was recorded for Pirsabak-2013 variety of wheat. Atta Habib ranked third with (3.37) productive tillers plant-1 (Rahman *et al.*, 2019) [54].

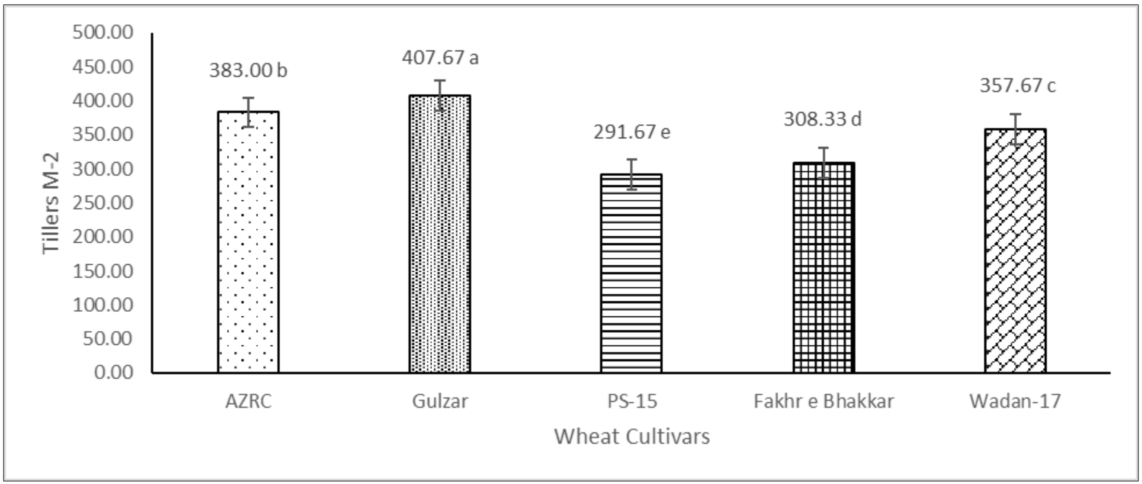

Fig 2: Number of tillers (m^2) Variation Among Wheat Cultivars in Response to Zinc application

Spike Length (cm)

The results pertaining to spike length of different wheat varieties showed significant ($p < 0.05$) variations as depicted in Figure 3. The longest spike length was recorded in Gulzar with an average length of 12.02 which was at par with AZRC with spike length of 11.36. The lowest spike length in comparison to Gulzar and AZRC was recorded in PS-15 as 10.08 cm. The maximum spike length in Gulzar variety compared to other varieties may be attributed to the effective application of Zn because micronutrients applied to booting stage, the length of the spikes increases significantly. Increasing availability of micronutrients aided in appropriate nutrition, which therefore resulted in longer ears and more grains in each of the ears. This might be the result of proper uptake and mobility of zinc in Gulzar during the reproductive stage.

Hamid *et al.*, (2024) [26] spike length of wheat was significantly affected by the application of zinc treatment. The mean spike lengths for Zn @ 5 kg ha^{-1} (12.244) and Zn @ 10 kg ha^{-1} (13.533) were higher than those of the control group (11.133). According to Arif *et al.*, (2017) [11], the zinc and potassium fertilizer had a significant ($P < 0.05$) impact on spike length. A combination of potassium and zinc applications, at 375 and 15 kg ha^{-1} respectively, resulted in maximum spike length, measuring 14.01 cm. On control plots, however, the minimum spike length (8.16 cm) was noted. Plants treated with Zn @ 10 kg ha^{-1} showed higher spike lengths, which is identical to Zn application at a rate of 15 kg ha^{-1}. Spike length was reduced in the plot receiving no zinc (Arshad *et al.*, 2016) [12]. Sher *et al.*, (2022) [59] determined that the spike length of the Fakher-e-Bhakkar cultivar of wheat was the greatest in pots (12) and in the field (10.7), when compared to Zincol and Faislabad-2008.

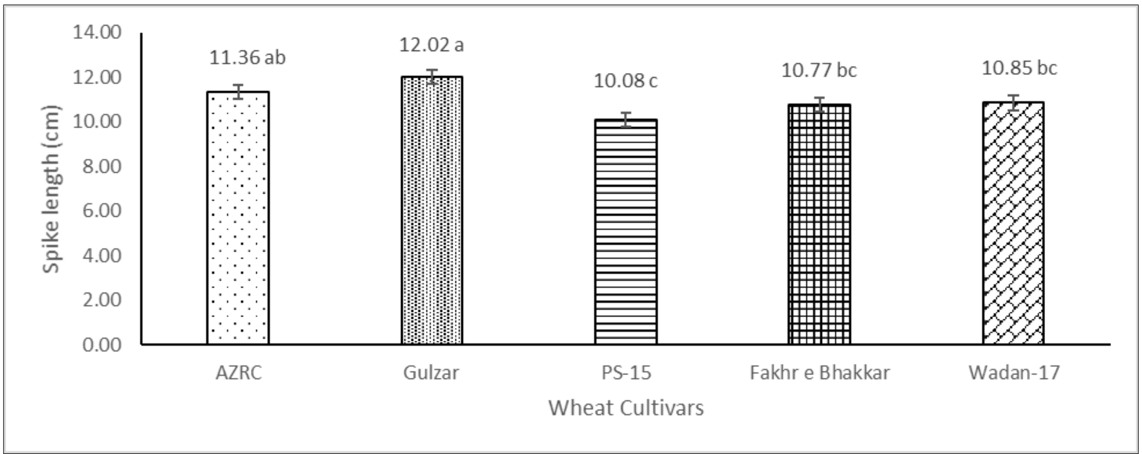

Fig 3: Spike length (cm) Variation Among Wheat Cultivars in Response to Zinc application

Number of Spikelets spike^{-1}

The spikelets spike^{-1} of wheat recorded amongst the wheat varieties showed significant difference at 5% level of significance. Maximum spikelets spike^{-1} showed 24.66 in Gulzar cultivar followed by AZZRC (22.66) (Figure 4). While the lowest was recorded 17.66 in PS-15. Better interaction between zinc and Gulzar cultivar might be the cause of greater number of spiklets per spike in Gulzar compared to other varieties. Sufficient availability of zinc supports cell division and elongation inside the spike meristem of Gulzar cultivar, resulting in the production of additional spikelets and ultimately increasing the total number of spikelets per spike.

Hamid *et al.*, (2024) [26] revealed that spikelets per spike for Zn @ 5 kg ha^{-1} (16.556) and Zn @ 10 kg ha^{-1} (17.889) was higher compared to the control group (14.689). The increase in the number of spikes and spikelets per unit area was caused by a higher number of fertile tillers per plant. An increase in the number of spikelets per spike may have resulted from a high level of micronutrients increasing the availability and uptake of other essential nutrients (Rahimi *et al.*, 2012) [53]. Additionally, Ahmadi and David (2016) [5] observed that nitrogen and zinc had major effects on the number of sparklets pe spike in wheat. According to Bashir *et al.*, (2023) [14], the number of spikelets per wheat spike is greatly influenced by zinc fertilizer application. Zinc application @ 2 kg ha^{-1} yield maximum number of spikelets per wheat spike (Gismy *et al.*, 2020) [25]. Sher *et al.*, (2022) [59] demonstrated that number of spikelets per spike in Fakher-e-Bhakkar cultivar of wheat was recorded maximum in pots and field as 53 and 18 respectively as compared to Zincol and Faislabad-2008. Fakhri Sarhad came in third with a spikelet spike-1 of 25.32. Our findings concur with those of (Saleem *et al.*, 2007; Rahman *et al.*, 2019) [57, 54].

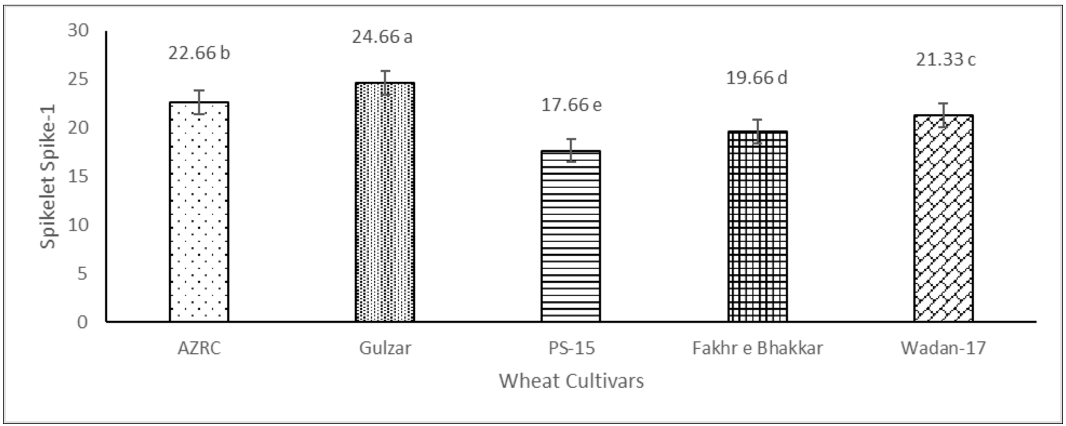

Fig 4: Number of Spikelets spike^{-1} Variation Among Wheat Cultivars in Response to Zinc application

Number of Grain Spike^{-1}

The use of Zn fertilizer significantly improved number of grain spike^{-1} in AZRC, Gulzar, PS-15, Fakhr e Bhakkar and Wadan-17. Maximum grain spike-1 was found 59.67 in Gulzar, which was statistically similar to AZRC, Wadan-17 and Fakhr e Bhakkar as 58.11, 55.0 and 54.22 respectively (Figure 5). Minimum grain spike^{-1} was found 59.67 in PS-15. Zinc plays a crucial role in the formation of pollen grain formation and function which are influenced by zinc. Enough zinc promotes effective pollination and fertilization, which increases the overall number of fertilized ovules and, as a result, increases the number of grains per spike and these functions may be more pronounced in the Gulzar, AZRC, Wadan-17 and Fakhr e Bhakkar.

Hamid *et al.*, (2024) [26] indicated that number of grains per spike for Zn @ 5 kg ha^{-1} (46.267) and Zn @ 10 kg ha^{-1} (53.044) was higher compared to the control group (39.489). The are consistent with Arif *et al.*, (2006) [10], The grains spike^{-1} were considerably better with a 25 kg soil application of zinc and in line with a soil + foliar spray of zinc, according to Paramesh *et al.*, (2020) [50]. Wheat cv. BARI gom30 had the largest number of grains per spike (47.70) after receiving a zinc application of 2 kg ha^{-1}, suggesting that zinc had a beneficial impact on this yield component (Gismy *et al.*, 2020) [25]. Sher *et al.*, (2022) [59] stated that at 6% concentration usage of exogenous zinc increases the number of grains per spike in wheat (Fakher-e-Bhakkar) variety exhibiting the greatest improvement. Pirsabak-2013 had the highest number of grains spike-1 (70.38), followed by Atta Habib with a spike-1 of (66.11), while Pakhtunkhwa-2015 saw the lowest amount of grains spike-1 (56.80). (Kashif *et al.*, 2008) [33] also reported the same results. They examined the important effects of various kinds on wheat's grain spike-1 (Rahman *et al.*, 2019) [54].

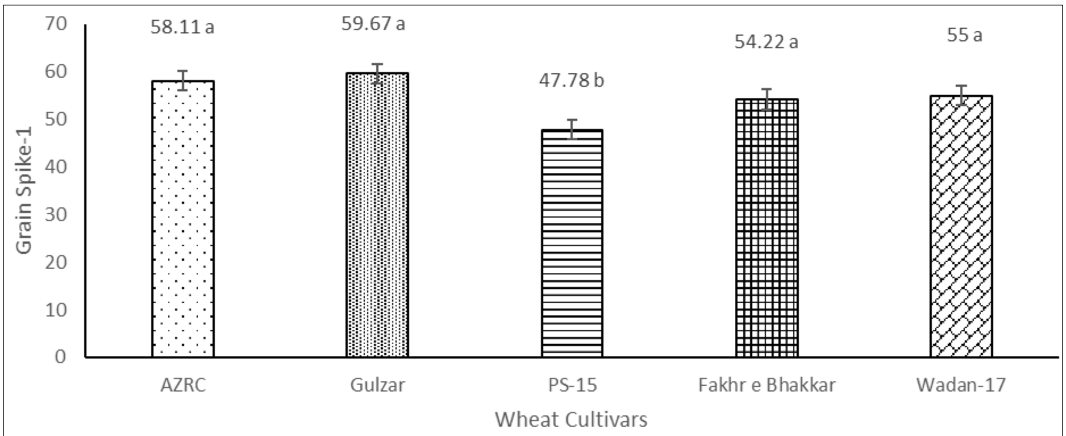

Fig 5: Number of Grains Spike^{-1} Variation Among Wheat Cultivars in Response to Zinc application

1000 Grain Weight (g)

The present findings showed a significant difference ($p < 0.05$) between various wheat varieties. Thousand grain weight values ranged from 42.58 to 51.31 g for all wheat cultivars. The collected data indicated that 1000 grain weight obtained from Gulzar wheat cultivars as 51.31 g, remained maximum compared to others (Figure 6). While minimum 1000 grain weight was noticed 42.58 g in PS- 15 cultivar. Among the 5 cultivars, Gulzar cultivars resulted maximum 1000 grain weight as compared to other wheat cultivars, this might be due to better response of Gulzar under zinc. The application of zinc raised the 1000 grain weight because it enhanced physiological processes, which in turn increased photosynthate translocation, which in effect altered the grain weight.

Grain yield and its components were improved by the application of zinc fertilizer alone (Zain *et al.*, 2015) [67]. The application of micronutrients, especially zinc significantly increased wheat 1000-grain weight, various forms and quantities of Zn exhibiting different effects (Khattak *et al.*, 2015) [37]. The direct application of zinc fertilizer in soil such as @ 15 kg of $ZnSO_4$ and 0.5% ZnSO4 solution as foliar spray had the higher weight of 1000 grain (50.6 g). According to Khattak *et al.*, (2006) [38], applying zinc to maize at a rate of 5 kg ha^{-1} $ZnSO_4$ increased grain yields in both wheat and maize. Rahman *et al.*, (2019) [54] concluded that when compared with Fakri Sarhad, who had the lowest weight of 1000 grains (36.20g), Atta Habib had the heaviest weight (46.10g), followed by Pirsabak-2013 (43.84g).

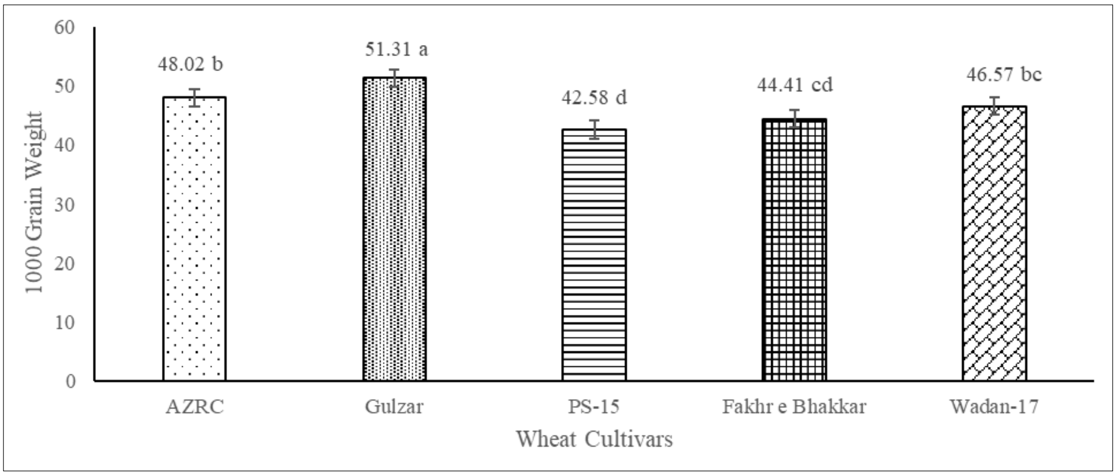

Fig 6: 1000-Grain Weight Variation Among Wheat Cultivars in Response to Zinc application

Grain Yield (t ha^{-1})

According to Figure (), there were significant ($p < 0.05$) differences in the grain yield (t ha^{-1}) data for the (AZRC, Gulzar, PS-15, Fakhr-e-Bhakkar and Wadan-17) wheat cultivars. Maximum grain yield was recorded in Gulzar followed by AZRC as 6.99 and 6.15 respectively. While lowest grain yield was observed 5.04 in PS-15 (Figure 7). The reason behind this outcome could be the use of Zn proved to be successful in elevating the yield and yield components of Gulzar through several activities and surpassing other varieties in its effectiveness. For instance, zinc enhances the amount of chlorophyll in the crop which stimulates photosynthetic activity. Similarly, zinc improves carbohydrate metabolism, nitrogen assimilation, and starch synthesis. All these factors contribute to the crop's improved growth and development, which results in increases yield and yield components.

Chattha *et al.*, (2017) [20] determined that the rate of 50 kg ZnSO4 per ha^{-1} was increased wheat crop yield (5.5 t ha^{-1}). Zinc synchronizes stand establishment and promotes increasing the temperature range during germination, both of which eventually increase wheat grain output and improve grain yield (Farooq *et al.*, 2008) [24]. However, Khan *et al.*, (2009) [36] also determined that zinc application in soil increases nutrient transfer from soil to plant significantly, which improves grain yield. Variations in wheat cultivars were responsible for zinc uptake and genetic composition which may account for differences in grain yield, zinc content, and phytic acid content. Fakhar-E-Bhakkar resulted in a maximum grain production of 4990 kg ha^{-1} of wheat under inorganic fertilization. To achieve the highest grain yield, an NPK dose of 150-120-60 kg/ha is recommended (Irshad *et al.*, 2018) [30]. Rahman *et al.*, (2019) [54] stated that the highest grain yield of 5611.5 kg ha^{-1} was recorded for the Pirsabak-2013 followed by Atta Habib. While Fakhri Sarhad had the lowest grain yield (4348.5 kg ha^{-1}). These results are consistent with Shahzad *et al.*, (2013) [58].

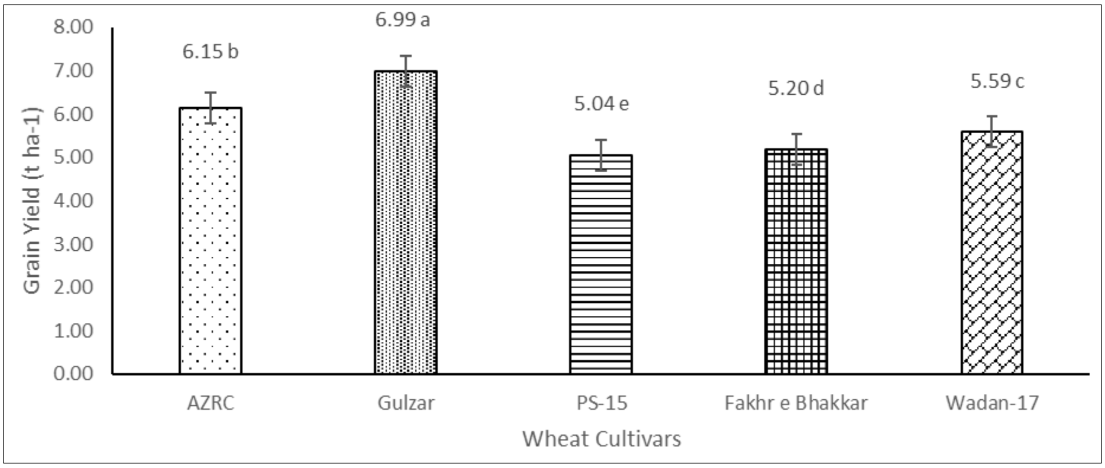

Fig 7: Grain Yield (t ha^{-1}) Variation Among Wheat Cultivars in Response to Zinc application

Straw yield (kg ha^{-1})

Interactions between zinc application and wheat cultivars were found to be significant for straw yield. Maximum Straw yield (9.73 t ha^{-1}) was recorded in Gulzar which was statistically similar to AZRC (9.52 t ha^{-1}) and Wadan-17 (8.85 t ha^{-1}) (Figure 8). While the lowest straw yield among cultivars was found in Fakhr e Bhakkar and PS-15 with recorded values of 8.53 and 8.18 t ha^{-1}, respectively. The observed outcome may be attributed to the effectiveness of the application of Zn in augmenting the straw yield of Gulzar, AZRC and Wadan-17 as compared to others. The synthesis and activation of the enzymes involved in the production of lignin depend on zinc. Plant tissues, especially the stems, are structurally supported by the complex polymer lignin, which increases wheat stem strength and stiffness. Sufficient zinc availability in Gulzar, AZRC and Wadan-17 cultivars may be promoted adequate lignin deposition. More biomasses can be nourished by stronger stems, which increases the output of straw in Gulzar cultivar.

The increase in harvest index could be the result of both the biological yield of the wheat crop and an increase in parameters associated to yield (Tabatabai *et al.*, 2015) [62]. According to Ilyas *et al.*, (2020) [29], the control treatment had the lowest harvest index (41.23%) and the highest harvest index (44.83%) in the seed priming at a rate of 0.4% Zinc solution + soil application at a rate of 40 kg $ZnSO_4.H_2O$ ha^{-1} at first irrigation + foliar spray at a rate of 0.5% Zn solution. Applying 25 kg of zinc to the soil resulted in the highest wheat straw yields. Crops treated with soil plus zinc foliar spray produced the second-highest yields. In comparison to plots without zinc, the 25 kg-soil application of zinc increased yield by 16.7% (Paramesh *et al.*, 2020) [50]. According to Arshad *et al.*, (2016) [12], plots with a zinc application rate of 5 kg ha^{-1} showed a higher straw production, but plots without a zinc treatment showed a lower straw yield. More zinc in the soil may have contributed to the higher straw output, which in turn may have raised wheat straw yield. These results are in line with those of Curtin *et al.*, (2008) [22], who found that the amount of zinc applied enhanced the amount of straw yield.

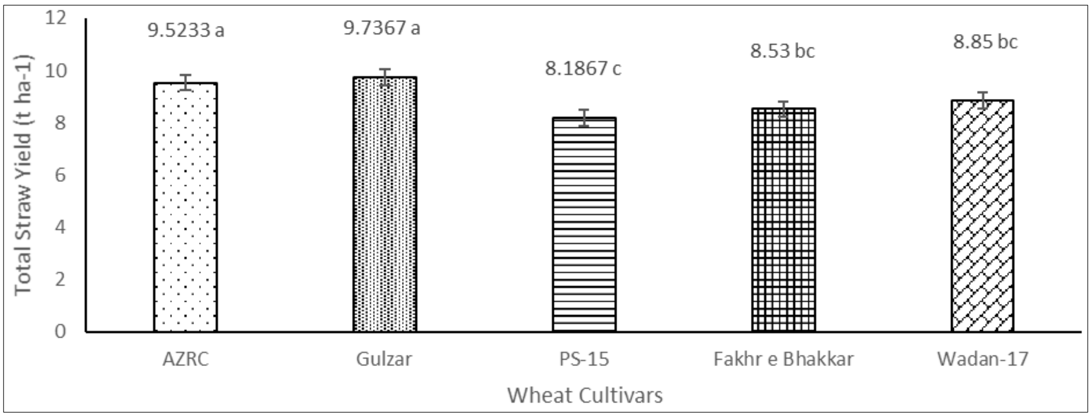

Fig 8: Straw yield (kg ha^{-1}) Variation Among Wheat Cultivars in Response to Zinc Application

Biological yield (kg ha^{-1})

The biological yield of wheat recorded amongst the wheat varieties showed significant difference at 5% level of significance. The highest biological yield of Gulzar variety was recorded 16.73 t ha^{-1} followed by AZRC and Wadan-17 having yield of 15.67 and 14.43 t ha^{-1} respectively. The variety Fakhar e Bhakkar resulted the yield of 13.72 t ha^{-1} and the least was recorded 12.70 t ha^{-1} in the PS-15 (Figure 9).

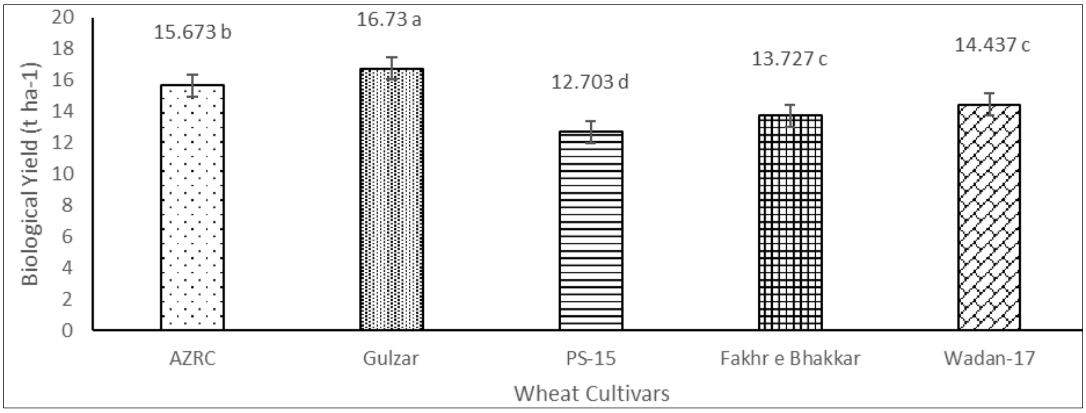

Fig 9: Biological Yield (kg ha^{-1}) Variation Among Wheat Cultivars in Response to Zinc application

The maximum biological yield of Gulzar cultivar might be the result of better response of Gulzar cultivar under Zn, compared to other cultivars. Zinc functions in the metabolism of RNA, carbohydrates, indole acetic acid and ribosome. Plant growth and biological yield are enhanced by continuous zinc uptake during later stages, or grain filling stages, and by its continuous loading of endosperm from xylem. These functions may be performed better in Gulzar cultivar that cause improvement in biological production.

According to Arif *et al.*, (2017) [11], the biological yield of wheat showed a linear rise in response to increasing potassium and zinc levels. Compared to other levels of potassium and zinc, the largest biological yield of 10190 kg ha^{-1} was produced by potassium at 375 kg ha^{-1} and zinc at 15 kg ha^{-1}. This might be because the treatment of zinc and potassium @375 kg ha^{-1} and 15 kg ha^{-1} produced taller plants which eventually improved crop biological yield. Comparatively, the control plots produced the lowest biological yield (7205 kg ha^{-1}).

Harvest Index (%)

Figure () exhibit the significant ($p < 0.05$) variances in the harvest index data for various wheat cultivars. Gulzr cultivar had maximum harvest index of 41.78 followed by AZRC, Wadan-17 and Fakhr-e-Bhakkar. While the lowest harvest index was recorded 35.53 in PS-15. This result could be better interaction between zinc and Gulzar cultivar (Figure 10). Application of zinc facilitates the absorption and application of additional nutrients, which are essential for grain development and yield. An improved harvest index is a result of improved nutrient translocation and absorption.

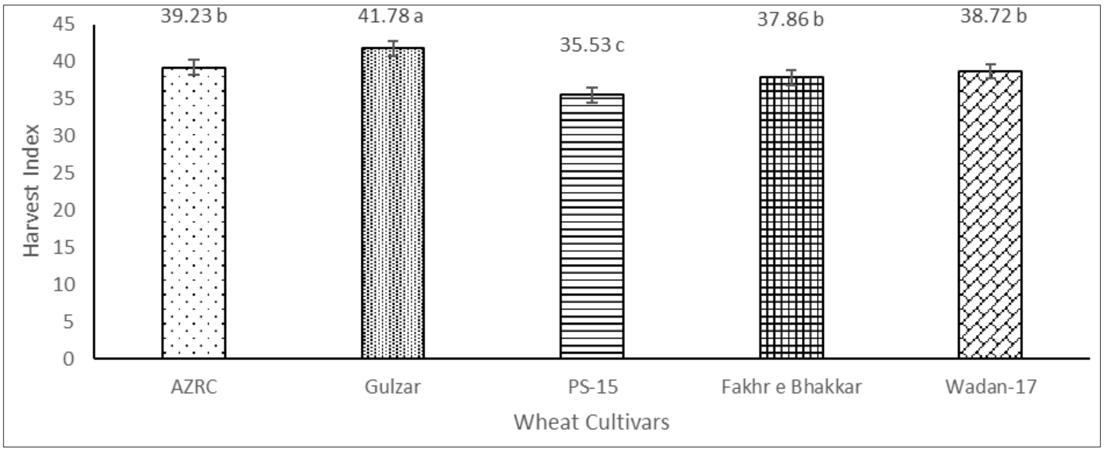

Fig 10: Harvest Index (%) Variation Among Wheat Cultivars in Response to Zinc application

The harvest index was significantly affected by the Zn application methods. According to Hassan *et al.*, (2019) [27], the highest harvest index (40.41%) resulted with soil applied zinc followed by seed priming, whereas the lowest harvest index (36.24%) was noted for no Zn treatment. On the other hand, Arif *et al.*, (2017) [11] found that the plots fertilized with 375 kg ha^{-1} potassium and 5 kg ha^{-1} zinc had the highest harvest index (46.09%). Control plots showed a minimum harvest index of 39.91 percent. Zinc fertilizer treatment enhanced the harvest index of wheat cultivar SST806 under drought stress circumstances, improving nutrient balance and production characteristics (Abdi *et al.*, 2023) [3]. In comparison to NPK fertilization alone, the use of increasing amounts of zinc fertilizer specifically 10 kg ha^{-1} significantly raised the wheat harvest index (Keram *et al.*, 2014) [34]. Zinc fertilizer application, especially at 5 kg Zn ha^{-1}, greatly enhanced wheat yield components, suggesting a beneficial impact on the harvest index (Ali *et al.*, 2013) [6].

Chlorophyll Content (µg cm^{-2})

Chlorophyll content was found significant in all cultivars under Zn application. The Gulzar and AZRC cultivar reflected the highest contribution towards chlorophyll content. Maximum chlorophyll content 2.82 was showed in Gulzar which was statistically similar to AZRC (2.62). While the lowest chlorophyll content of 2.23 was recorded in PS-15 (Figure 11). This result possibly suggests a more efficient synergy between zinc and the wheat cultivars Gulzar and AZRC. This enhancement in Gulzar and AZRC by Zinc macronutrient demonstrates the importance of zinc to plants. Zinc is involved in many enzymatic activities and hence promotes growth and development, the formation of auxin, a substance that controls growth (indole acetic acid), all requires zinc. Zinc deficiency in plants causes stunted growth and small leaves due to disturbances in auxin metabolism. Low zinc levels can lead to a 50-70% reduction in photosynthesis, protein production, membrane integrity, and yield. Chlorosis, leaf burn, stunted development, leaf deformity, and dwarf leaves are some of the visible indicators of zinc deficiency. Chlorosis is a change in leaf colour from bright green to pale green, yellow, or white. It is caused by an absence of chlorophyll in plants.

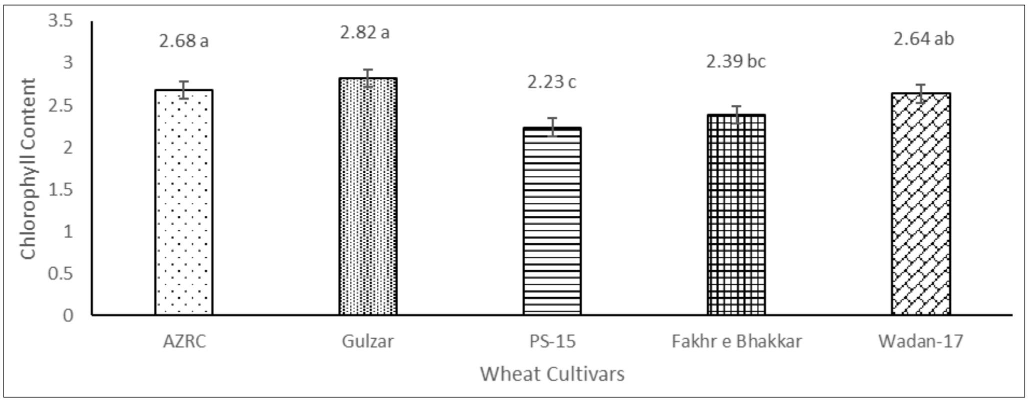

Fig 11: Chlorophyll Content (μg cm^{-2}) Variation Among Wheat Cultivars in Response to Zinc application

According to Aslam *et al.*, (2014) [13], zinc application had a positive effect on chlorophyll contents in wheat line L-5066, and this increase in chlorophyll pigments is consistent with previous studies (Quary *et al.*, 2006; Broadly *et al.*, 2007) [52, 52]. These studies found that increasing Zn concentrations in wheat had an increasing effect on chlorophyll content. The treatment RDF + Spraying of Chelated Fe @ 2.0% yielded the highest overall chlorophyll content (4.378 mg/g). It also remained statistically equivalent to the treatment RDF + Soil application of ZnSO4 @ 10 kg ha-1 + FeSO4 @ 20 kg ha-1). The treatment (N-P-K: 120-60-60 kg ha-1) yielded the lowest total chlorophyll content (2.074 mg/g) of wheat (Kandoliya *et al.*, 2018) [31].

Protein Content (%)

Analysis of variance regarding protein content inferred that the protein content percentage was significantly influenced by zinc and cultivars of wheat. Highest protein content was recorded 11.91 in Gulzar which was statistically similar to AZRC and Wadan- 17. While the lowest protein content of 10.35 and 9.79 were observed in Fakhr e Bhakkar and PS-15 respectively (Figure 12). Gulzar, AZRC and Wadan-17 responded better under zinc application, and this could be due to Zn activating the glutamic dehydrogenase enzyme, promoting the production of RNA and DNA, and increasing the concentration of gliadin and glutenin, the primary protein components is gluten that accumulate in the later stages of grain filling. The quality of wheat protein content is determined by its inherent chemical composition, which has a response function in various enzymatic activities in grain.

A comparison of the means revealed that the Falat cultivar had the highest percentage of protein by 13.23 and consumed 00.5 of zinc per hectare, whereas the Star cultivar had the lowest percentage of protein by 9.98% and did not consume any zinc fertilizer (Majd *et al.*, 2015). The treatment RDF + Soil application of ZnSO4 @ 10 kg ha-1 + FeSO4 @ 20 kg ha-1 produced the greatest protein content of wheat crop (13.14%), which was 12.3% higher than the control treatment (Kandoliya *et al*. 2018) [31].

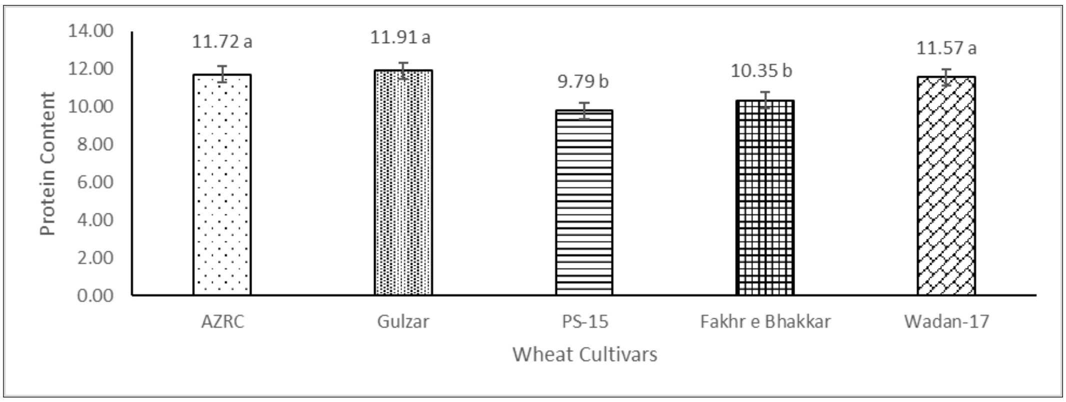

Fig 12: Protein Content (%) Variation among Wheat Cultivars in Response to Zinc application

Zinc uptake by plant (mg kg^{-1})

The data related Zinc uptake by plant of wheat showed that significant differences are present between cultivars. Maximum zinc uptake by plant was recorded 30.49 in Gulzar which was at par with 29.12 in AZRC. While the lowest uptake of zinc was noticed 23.84 in plot where PS-15 cultivar was cultivated. In soils, zinc has a unique role (Figure 13). Zinc is the building blocks of several metabolites, including hormones, enzymes, and chlorophyll, nutrients have an impact on a range of physiological processes that affect plant development and productivity as well as provide protection against biotic and abiotic challenges. Similarly, all growth parameters had better response in Gulzar and this response is due to the more uptake of Zn in Gulzar cultivar as compared to others.

Singh *et al.*, (2019) [61] reported that low Zn wheat genotypes ranged from 39.6 mg kg^{-1} to 47.9 mg kg^{-1}. Application of high zinc levels zinc concentrations ranged from 36.7 to 71.7 mg kg^{-1}, with an average of 49.7 mg kg^{-1}. The Zn concentration in the grain varied greatly between genotypes and under Zn treatment. PBW-175 had the largest increase in Zn intake (from 161 to 264 g ha^{-1}), while JW-3211 had the lowest increase (from 143 to 162 g ha^{-1}). Punjab-11 had the highest Zn concentration in grain (48.67 mg kg^{-1}), followed by Lasani-2008 (45.67 mg kg^{-1}), Saher-2006 (42.63 mg kg^{-1}), and Faisalabad-2008 (40.5 mg kg^{-1}) with foliar spray treatment. Soil Zn application resulted in grain Zn concentrations of 28-38 mg kg^{-1}, while control treatment results in 18-30 mg kg^{-1} (Kiran *et al.*, 2021) [41].

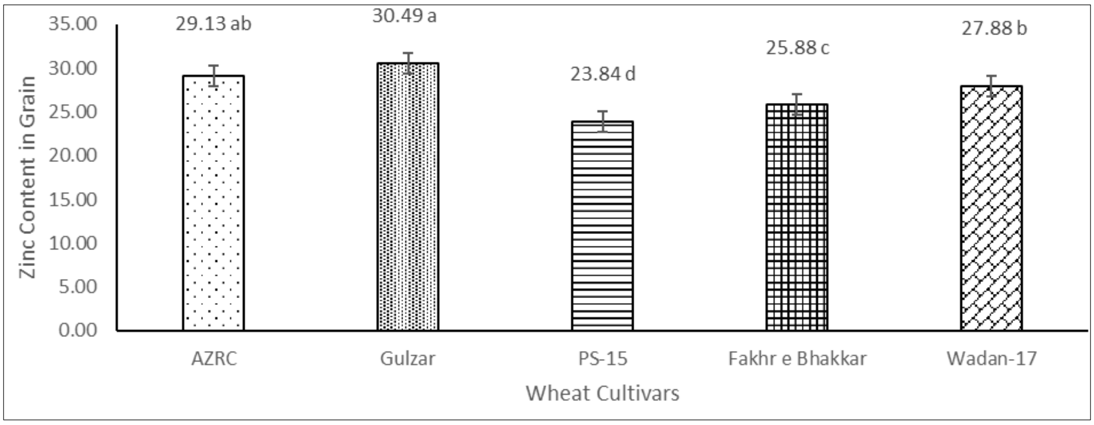

Fig 13: Zinc uptake by plant (mg kg^{-1}) Variation Among Wheat Cultivars in Response to Zinc application

According to Keram *et al.*, (2012) [34], wheat uptakes more zinc in recommended dose of NPK along with higher zinc application. The application of 20 kg Zn ha^{-1} along with the recommended amount of NPK resulted in the maximum and considerable uptake of Zn (327.74 g ha^{-1}) and was significantly greater than the control. While the increase in Zn uptake could be attributed to the positive interaction between K and Zn (Morshedi and Farahbakhsh, 2010) [47] and the synergistic effect between N and Zn (Ashoka *et al.*, 2008), the treatment comprising the application of 5 and 10 kg Zn ha^{-1} was on par with 20 kg Zn ha^{-1} on Zn uptake.

Conclusion

Our investigation confirmed that Gulzar and AZRC wheat cultivar was more responsive to zinc application. In terms of various traits of wheat crops, the statistical analysis depicted that Gulzar and AZRC cultivar were showed maximum plant height, number of tillers, spike length, number of spikelets per spike, number of grains per spike, 1000 grain weight, biological yield, grain yield, Straw yield and harvest index. Other important parameters such as chlorophyll content, protein content and zinc uptake by plant were also recorded maximum in Gulzar and AZRC. While Wadan-17 and Fakhr-e-Bhakkar showed average result compared to Gulzar and AZRC. All traits of wheat recorded lowest in PS-15. The analysis of five advanced wheat cultivars for growth and yield at uniform dose of zinc revealed the best performance by AZRC and Wadan-17 while Gulzar performed exceptionally well under zinc application. AZRC and Gulzar wheat cultivars were considered the best choice for maximum productivity under 7.5 kg ha^{-1} zinc application to meet the demands of a growing population while mitigating the threat of food insecurity through resilience to climate change.

Authors Contribution

Nasr Ullah Khan and Irfan Ahmad conceived the idea and designed the project. Jamal Abdul Nasir, Wasif Rasool, Muzammil Mahboob Ur Rehman and Hanzla Qasim conducted the experiment and collected the data. Hira Abbas, Muqadas shahzain, Naina Haider and Sidra-Tul-Muntaha analyzed the data. Nasr Ullah Khan, Irfan Ahmad and Naimat Ullah drafted the manuscript. All authors read the manuscript before submission.

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