Enhancing wheat production and quality in alkaline soil: A study on the effectiveness of foliar and soil applied zinc

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Cultivation of high-yield varieties and unbalanced fertilization have induced micronutrient deficiency in soils worldwide. Zinc (Zn) is an essential nutrient for plant growth and its deficiency is most common in alkaline and calcareous soils. Therefore, this study aimed to evaluate the effect of Zn applied either alone or in combination with foliar spray on the quality and production of wheat grown in alkaline soil. Zn was applied in the form of zinc sulfate ($ZnSo_4$) to the soil and as a foliar spray during the sowing and tillering stages, respectively. Results showed that Zn fertilization of wheat, irrespective of modes of application, significantly increased grain and biological yield, grain per spike, and 1000 grain weight over control; however, its effect was more noticeable when applied as 7.50 kg ha^{-1} of soil Zn combined with foliar Zn at 2.5 kg ha^{-1}. Zn application significantly increased the grain protein content from 9.40% in the control to a maximum of 11.83% at an application rate of soil Zn of 10 kg ha^{-1}. Similarly, Zn addition promoted wheat Zn, ~~phosphorous~~ (P), and potassium (K) concentrations in wheat grains. Moreover, correlation analysis showed that the grain Zn concentration was positively correlated with the grain P concentration. The correlation between P concentration in wheat grains and grain weight was not significant. Grain weight was positively correlated with tillers per plant, grain yield, and biological yield. There were positive correlations between protein content, biological yield, grain yield, and tillers per plant, except for protein content and tillers per plant. Therefore, Zn supplementation is crucial for improving wheat yield and grain quality.

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Abstract: Cultivation of high-yield varieties and unbalanced fertilization have induced micronutrient deficiency in soils worldwide. Zinc (Zn) is an essential nutrient for plant growth and its deficiency is most common in alkaline and calcareous soils. Therefore, this study aimed to evaluate the effect of Zn applied either alone or in combination with foliar spray on the quality and production of wheat grown in alkaline soil. Zn was applied in the form of zinc sulfate ($ZnSo_4$) to the soil and as a foliar spray during the sowing and tillering stages, respectively. Results showed that Zn fertilization of wheat, irrespective of modes of application, significantly increased grain and biological yield, grain per spike, and 1000 grain weight over control; however, its effect was more noticeable when applied as 7.50 kg ha^{-1} of soil Zn combined with foliar Zn at 2.5 kg ha^{-1}. Zn application significantly increased the grain protein content from 9.40% in the control to a maximum of 11.83% at an application rate of soil Zn of 10 kg ha^{-1}. Similarly, Zn addition promoted wheat Zn, ~~phosphorous~~ (P), and potassium (K) concentrations in wheat grains. Moreover, correlation analysis showed that the grain Zn concentration was positively correlated with the grain P concentration. The correlation between P concentration in wheat grains and grain weight was not significant. Grain weight was positively correlated with tillers per plant, grain yield, and biological yield. There were positive correlations between protein

content, biological yield, grain yield, and tillers per plant, except for protein content and tillers per plant. Therefore, Zn supplementation is crucial for improving wheat yield and grain quality.

Keywords: Zinc, foliar spray, wheat yield, grain quality, alkaline soil

1. Introduction

Wheat belongs to the family Poaceae and is a key cereal crop for the vast majority of people worldwide. For almost 36% of the global population (2 billion people), wheat is the most favored staple food. Wheat accounts for nearly 55% of all carbohydrates and 20% of all calories consumed worldwide (Azeem et al. 2019; Jat et al. 2018). Pakistan is one of the top wheat-producing countries in the world, ranking 8th and accounting for approximately 3.17% of the total global wheat production (Sher et al. 2022). The substantial production contribution of wheat makes it a crucial food grain crop for the country's economy. The grain yield of wheat is affected by several biotic and abiotic factors. Among abiotic factors, one of the primary causes of low yield is nutritional imbalance and lack of essential macro-and micronutrients (Azeem et al. 2019). To some extent, wheat yield has improved owing to the application of mineral nitrogen (N) and ~~phosphorous~~ (P), but the potential yield has not been achieved in Pakistan (Khan et al. 2017). By 2050, the world's population is expected to reach 9.8 billion, presenting a major challenge for scientists to not only increase food production, but also improve the nutritional quality of the food produced, especially in developing regions (Ahmad et al. 2023).

Alkaline calcareous soils in developing countries, owing to poor management, have resulted in reduced crop productivity and quality (Bhatt et al. 2020). Zinc deficiency is most common in alkaline and calcareous soils. Most soils in Pakistan are calcareous, which can cause nutrients to become unavailable owing to factors such as high pH, low organic matter, salt stress, and imbalanced application of mineral fertilizers (Hafeez et al. 2013). These factors collectively contribute to Zn deficiency in soils. It is now an established fact that Pakistan's soil is deficient in zinc, which can cause a reduction in the yield of certain cereal crops, such as wheat. ~~Therefore,~~ those who consume a diet high in cereals may experience health issues linked to micronutrient deficiencies (zinc) such as impaired brain and immune function, stunted growth in children, harm to physical development, weakened resistance to disease, unfavorable pregnancy outcomes in women, and increased morbidity and mortality (Cakmak 2008). In Pakistan, approximately 12 million children suffer from stunted growth, whereas zinc deficiency affects 22.1% of women and 18.6% of children under the age of five (Sher et al. 2022).

In Pakistan, the first recognized zinc problem in soils was confirmed, and later studies confirmed the widespread zinc deficit in all rice-growing regions (Yoshida & Tanaka 1969). ~~A~~ study conducted in the alkaline soils of Pakistan, Khattak et al. observed that Zn applied at 5 kg ha^{-1} and 15 kg ha^{-1} increased wheat yield by 18% and 41% over control, respectively (Khattak et al. 2015). They also observed that soil Zn application combined with foliar spraying increased the wheat grain protein content by 29.5%. Reducing Zn deficiency in plants can be achieved through a variety of practices, such as the supplementation of mineral Zn fertilizer through soil and foliar spray (Peter et al. 2017). Zinc foliar application is a technique used to enhance the zinc status of plants by externally applying solid or liquid zinc fertilizers to crop leaves at the appropriate growth stage. Wang et al. demonstrated that in alkaline soil of loess plateau of China, combined application of soil Zn and foliar spray did not significantly affect grain yield and biomass of wheat crop; however, Zn foliar spray significantly increased Zn grain concentration by 28% and 89% during first and second season of wheat (Wang et al. 2012). Conventionally, mineral Zn fertilizers are the most commonly used because of their low cost and high solubility (Roohani et al. 2013). However, fixation reactions can reduce the bioavailability of zinc in soils with low organic matter, high carbonate content, and high pH. This can lead to the adsorption of calcite or the precipitation of Zn $(OH)_2$ or $ZnCO_3$, making conventional fertilizers ineffective for crop zinc uptake (Recena et al. 2021; Rehman et al. 2020). In another study, Walaszek et al. reported that Zn has a strong affinity for clay adsorption and also tends to accumulate unusable Zn hydroxide at alkaline pH (Walaszek et al. 2018).

The size of the accessible Zn pools in the soil had a significant impact on the Zn concentration and yield of the plants. The Majority of cereal-growing regions face chemical and physical obstacles that considerably decrease the access of Zn to plant roots. Thus, strategies are required to enhance Zn availability in soils and to improve cereal grain quality and production. Many researchers have studied the effect of Zn fertilizer on crop yield; however, limited information is available on soil Zn fertilizer application combined with foliar spraying in alkaline soils in Pakistan. Considering the above facts, the current study aimed to address the limited availability of Zn in alkaline soils. This was achieved by evaluating the following set of objectives: (i) to evaluate the effect of Zn application either alone or in combination with foliar spraying, on the quality and production of wheat grown in alkaline soil; (ii) to determine the optimal rate of Zn application for maximum wheat yield and quality in alkaline soil; and (iii) to investigate the effect of Zn application on the protein content of wheat grains in alkaline soils.

2. MATERIALS AND METHODS

2.1 Experimental Site

In the alkaline soil of the Kohat region (33°30'22.4"N 71°26'06.0"E), a field experiment was carried out to assess the impact of soil and foliar applied zinc on the growth, yield, and quality of wheat crop during Rabi 2020–2021. The study site has a semi-arid and subtropical climate, with an average annual rainfall of 500-600 mm. Meteorological data were obtained fromthe Pakistan Meteorological Department website (https://www.pmd.gov.pk/en/). During the summer months from May to September, the mean maximum and minimum temperatures were 39 and 25 °C, respectively. According to the International Union of Soil Sciences (IUSS) Working Group WRB, the physiochemical properties of the experimental site were measured, such as pH (8.1) and EC (0.32 dSm^{-1}), which showed that the soil was alkaline and non-saline. The Soil texture was clay loam with 22, 38, and 40% silt, sand and clay, respectively. Furthermore, soil organic matter was 0.69% and AB-DTPA extractable P, K, and Zn were 1.5 mg kg^{-1}, 55.0 $mgkg^{-1}$ and 0.58 $mgkg^{-1}$, respectively. The soil was low in organic matter content and AB-DTPA extractable Zn.

2.2 Experimental Procedure

A Randomized Complete Block Design (RCBD) was used in the current study, with three replications. The area of each plot was 9 m2 (3 m × 3 m), and there were a total of 33 plots. Wheat was sown at 120 kg ha-1 on November 22, 2020, and harvested on May 5, 2021. There were 11treatments including; control (T1), soil Zn 5 kg ha^{-1} + 0 kg ha^{-1} foliar Zn (T2), soil Zn 3.75 + 1.25 foliar Zn (T3), soil Zn 2.5 + foliar Zn 2.5 (T4), soil Zn 1.25 + foliar Zn3.75 (T5), soil Zn 0 + foliar Zn 5 (T6), soil Zn 10 + foliar Zn 0 (T7), soil Zn 7.25 + foliar Zn2.50 (T8), soil Zn 5 + foliar Zn 5 (T9), soil Zn 2.50 + foliar Zn 7.50 (T10) and soil Zn 0 + foliar Zn 10 (T 11). Soil Zn was applied at the time of sowing, and foliar spray was applied at the tillering stage. Each treatment received a base dose of N P K at 120:90:60, which was applied as urea, diammonium phosphate (DAP), and sulfate of potash (SOP), respectively, at the time of sowing.

2.3 Agronomic observation

For data concerning tillers per plant, five plants were randomly selected from each treatment and counted after averaging. One thousand grains were randomly collected from each treatment using a grain counter machine and weighed using a weight balance. Grain yield was obtained by harvesting the four central rows of each plot, threshed using a mini wheat thresher, dried, and then weighed. Biological yield obtained by harvesting mature wheat from four central rows of each treatment, then dried and weighted. Grain and biological yields were converted into kg ha-1 using the following formulas:

$$\text{Biological yield} = \frac{\text{yield in selected rows} \times 10000}{\text{R to R distance} \times \text{row length} \times \text{no of rows selected}}$$

$$\text{Grain yield} = \frac{\text{yield in selected rows} \times 10000}{\text{R to R distance} \times \text{row length} \times \text{no of rows selected}}$$

2.4 Soil and plant samples analysis and calculations

Soil samples were collected from 0-20 cm depth with the help of Augar randomly from three locations in each plot before crop sowing to determine the initial physicochemical properties of the experimental site. Visible plant residues and roots were removed by hand and stored in labeled plastic bags for laboratory analysis. Soil samples were air-dried and passed through a 2-mm sieve. Similarly, plant samples were collected randomly from each plot at harvest. The plant samples were cut into small pieces, air-dried, and stored for analysis. Appropriate techniques were used to determine the soil pH (McLean 1982) and electrical conductivity (EC) (Rhoades 1996). The methods of (Bouyoucos 1962) and (Nelson & Sommers 1996) were used to determine the texture and organic matter content, respectively. The method suggested by (Soltanpour & Schwab 1977) was used to measure AB-DTPA extractable P, K, and Zn content in the soil (before wheat sowing). Briefly, AB-DTPA extractable Zn was determined by adding 10 g air-dried soil and 20 ml AB-DPTA solution. The solution was shaken for 15 min and filtered through a 42-wattman filter paper. The extract obtained was used to measure P, K, and Zn contents is soil samples using an 880 nm spectrophotometer, flame photometer, and atomic absorption spectrophotometer, respectively. The contents were calculated in soil samples by the following formula

$$\text{P, K and Zn (mg kg}^{-1}\text{)} = \frac{\text{Instrumental reading} \times \text{volume of AB-DTPA}}{\text{Weight of soil (g)}}$$

In plant samples, the Zn concentration was determined using the procedure of (Soltanpour & Schwab 1977). 1 gm plant sample was taken in crucible and was ash at 550 °C. After converting the plant sample to ash, it was cooled to room temperature. 10 ml of 0.5 N HCL was then added and filtered through 42-wattman filter paper. AN atomic absorption spectrophotometer was used to measure the Zn concentration in the samples. Zn was calculated in plant samples by the given formula

$$\text{Zinc (mg kg}^{-1}\text{)} = \frac{\text{Instrumental reading} \times \text{volume of extract}}{\text{Weight of plant sample (g)}}$$

AB-DTPA extractable P and K in plant samples were determined using the method described by ().plant sample (0.5 g) was placed in a conical flask, and 10 ml concentrated HNO_3 was added. After 24 h, 4 ml perchloric acid was added and heated on a hot plate until white fumes appeared. After cooling, the sample was diluted by adding 100 ml distilled water and filter through 42-wattman filtered paper in a 100 ml volumetric flask. For P determination, 1 ml filtrate in a 25 ml volumetric flask was taken and 5 ml ascorbic acid mix reagent was added. The volume was adjusted to 25 ml and the sample was kept in the dark to develop a dark color. An 880 nm spectrophotometer was used to measure the P in the plant samples. For extractable AB-DTPA K, a flame photometer was used to measure the K in the plant samples. AB-DTPA extractable P and K in plant samples were determined by the following formulas

$$\text{P (mg kg}^{-1}\text{)} = \frac{\text{Instrumental reading} \times \text{volume made}}{\text{Weight of plant sample (g)} \times \text{volume taken}}$$

$$\text{K (mg kg}^{-1}\text{)} = \frac{\text{Instrumental reading} \times \text{volume made}}{\text{Weight of plant sample (g)}}$$

The Zn protein content in the wheat grains was measured according to (Khattak et al. 2015). Sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) was used to study the effect of zinc on the wheat protein content. Grain flour samples (0.5 g) were obtained in triplicate to determine the grain protein content. After adding 0.25 mL of protein buffer, centrifuging the mixture was centrifuged for 15 min at 13 K rpm after combining it with a vortex mixer. Using an ultraviolet spectrophotometer for spectroscopic analysis, the supernatant was removed at E-280 nm in mg/mL, or nearly 1 optical density (OD). % protein was estimated as follows by multiplying the absorbance by the dilution factor.

$$\% \text{ protein} = \text{absorbance reading} \times \text{dilution} \times 100/1000$$

2.5 Statistical Analysis

Using SPSS version 20.0 software, the data were statistically examined by variance analysis (ANOVA) and compared using the Duncan test ($P < 0.05$).

3. RESULT

3.1 Agronomic attributes

The results indicate that certain rates of zinc fertilizer application, whether applied soil or foliar, had a positive impact on both the biological and grain yield of wheat (Table 1). Regardless of the method used, Zn application had a considerable positive impact on grain yield. The plots with the maximum grain yield (3639 kg ha^{-1}) received soil + foliar Zn at rates of 7.50 kg ha^{-1} and 2.50 kg ha^{-1}, respectively, followed by plots that received soil Zn at 5 kg ha^{-1} + 5 kg ha^{-1} foliar Zn with an average yield (3608 kg ha^{-1}). The lowest grain yield (2712 kg ha^{-1}) was observed in the control. The yield was higher in plots that received zinc, both as a soil and foliar spray. Similarly, the highest dry matter in wheat was found in the plots where Zn was given as soil and foliar at 7.50 $kgha^{-1}$ and 2.50 kg ha^{-1}, respectively, which produced 8802 kg ha^{-1} biological yield, followed by plots that received 5 kg ha^{-1} of Zn fertilizers in both the soil and foliar, which had an average dry matter of 7994 kg ha^{-1}. The lowest biological yield was observed in control plots.

The outcome of our experiment predicted that the number of tillers per plant in T_{11} (foliar Zn at 10 kg ha^{-1}) was statistically significant compared to the control ($P < 0.05$) (Table 1). The maximum number of tillers per plant (n = 7.56) was found in T_{11}, followed by the plots that were administered zinc through soil and foliar (5:5 kg ha^{-1} and 2.5:7.5 kg ha^{-1}), producing (n = 7.50) and (n = 7.45) tillers per plant. Most treatments were significantly different from the control treatments. The number of tillers per plant was higher in plots where the foliar ratio of Zn was higher than that of the soil.

The results showed that Zn addition to wheat crop increased 1000 grain weight but not significantly, except for T_1 (control) and T_8 (soil Zn 7.5 kg ha^{-1} + foliar 2.5 kg ha^{-1}). Data on 1000 grain weight ranged from 40.36 to 48.37 g. The maximum 1000 grain weight was recorded in T_8 (48.37 g) and T_7 (47.47 g), followed by T_6 (47.38 g), whereas the minimum (40.35 g) was recorded in T_1.

3.2 Grain Zn, P and K nutrition

The findings regarding grain Zn, K, and P affected by Zn addition at various levels through the soil and foliar layers are presented in (Table 2). The maximum Zn concentration (0.51%) was recorded in the control plot, followed by (0.49%) in the soil application Zn at 5 kg ha^{-1}. The minimum Zn concentration in wheat grains was recorded in plots that received Zn through soil and foliar application. The effect of Zn supplementation either through soil or foliar application was non-significant on P grain concentration; however, treatments that received Zn supplementation had the highest P concentration compared to the control (0.12%). Zn level had a considerable impact on the potassium concentration of wheat grains. The potassium concentration in the grain increased by 6.24% compared to that of the control with foliar Zn spray at 5 kg ha^{-1} (T_6). The plot that received Zn only through the soil at a rate of 10 kg ha^{-1} had the lowest wheat grain K concentration.

3.3 Grain protein content

Zinc fertilization, whether applied through foliar spray or soil, significantly increased the protein content of wheat grains (Table 3). There were significant differences among the means of some treatments, whereas others showed a simple increase over the control. T_7 (soil Zn 10 kg ha^{-1}) treatment showed a 25.88% increase over the control, followed by T8 (soil 7.50 $kgha^{-1}$ + foliar 2.50 kg ha^{-1}), which increased grain protein content by 21.99%. T2-T10 showed an increase in protein content from 2.48% to 25.88% compared with the control. The data showed that increasing soil Zn with decreasing foliar levels gradually enhanced the protein content in the grain.

3.4 Correlation analysis

Correlation analysis showed that grain Zn concentration was positively correlated with P concentration in the wheat grains (Table 4). The correlation between Zn concentration in wheat grains and K was not significant. The wheat grain K concentration was negatively correlated with the grain P concentration. The correlation between P concentration in wheat grains and grain weight was not significant. The correlation between the grain K concentration and wheat grain yield was not significant. Grain weight was positively correlated with tiller number per plant, grain yield, and biological yield. There were positive correlations between protein content, biological yield, grain yield, and tillers per plant, except for protein content and tillers per plant.

4. Discussion

4.1 Wheat yield and yield components

Zn was applied through soil and foliar at 7.50 kg ha^{-1} and 2.50 kg ha^{-1}, respectively, which greatly improved wheat grain production. These results highlight the significance of zinc availability in increasing wheat yield. Khattak et al. reported that in alkaline soils of Pakistan, adding Zn at a rate of 5 kg ha^{-1} or twice as a foliar spray increased maize grain yield by 29 % and 14%, respectively (Khattak et al. 2006). The results of the current study are similar to those of other studies, which showed that the combined application of Zn through soil + foliar application was more effective in increasing grain production and plant growth than Zn soil application alone (Imran & Rehim 2017). With soil + foliar treated plots, better photosynthetic activity and biomass accumulation resulted in better yields, which could be explained by a sufficient Zn supply up until harvesting and an increase in several enzymatic activities, which in turn led to greater yields (Hussain & Yasin 2004; Paramesh et al. 2014). According to Alloway 2008, the Zn concentration in plants increases photosynthesis, carbohydrate transformation, and seed development (Alloway 2008). Other authors have also shown the benefits of using Zn fertilization in wheat yield and yield components (Cakmak et al. 2010; Nawaz et al. 2015).

A significantly greater biological yield was observed when foliar Zn fertilizer was supplemented with soil. This might be because of the successful response of the wheat crop to foliar Zn spraying. The fact that zinc is known to be crucial for different enzymes as a metal component or as a functional, structural, or regulatory co-factor may support the increase in biological output caused by zinc nutrition (Singh et al. 2018), which is an essential ingredient in the production and breakdown of proteins, nucleic acids, and carbohydrates (Cakmak 2008). Therefore, Zn plays a crucial role in biomass synthesis as a co-factor of auxins and lipids (Chattha et al. 2017; Hassan et al. 2019). Furthermore, soil Zn with foliar treatment had greater pigment content and biological outcome production in maize crop (75 and 54 %, respectively) (Mosanna & Behrozyar 2015). According to a previous study, maintaining protein synthesis in wheat meristems necessitates a high Zn concentration (Mat Hassan et al. 2012). Our results are supported by those of

Paramesh et al. who recorded highest wheat straw yield (6.92 t ha^{-1}) with both soil Zn + foliar spray (Paramesh et al. 2020).

The number of tillers plant were more in plots where the foliar ratio of Zn was kept higher than that of the soil. Our findings are in accordance with the results of Soleimani 2006, who reported that foliar zinc spray improved the number of plant tillers (Soleimani 2006). Zn is thought to influence carbohydrate metabolism through photosynthesis and sugar conversion, and Zn deficiency can cause net photosynthesis to drop by 50-70%, causing drastic changes in yield components (Alloway 2004). Zn fertilizer application increased the proportion of productive tillers, which could be due to the availability of additional nutrients to the growing tillers (Gul et al. 2011; Ramzan et al. 2020). Our results showed that Zn addition to wheat crop increased 1000 grain weight but not significantly, with the exception of the treatment (Soil Zn7.50+Foliar Zn2.50). Zinc is required for growth hormone synthesis, starch production, and maturation, all of which contribute to seed weight gain (Sarkar et al. 2007). External zinc fertilization increased 1000-grain weight, possibly because of the strong mobility of zinc within the plant from leaves to stems, roots, and maturing grains (Rengel 2001). Another study found that when zinc was applied to wheat, the weight of 1000 grains increased substantially (Torun et al. 2001).

4.2 Plant nutrient concentration in wheat grain

Data regarding grain Zn, K, and P as affected by Zinc addition at various levels through soil and foliar are shown in (Table 2). The results demonstrated that grain P concentration increased with Zn fertilizer either through soil or foliar application compared to the control. It is also evident from (Table 2) when grain Zn concentration increased, the P concentration decreased in the grain and vice versa. This might be caused by the negative interaction between Zn and P. These results indicate that zinc is friendly with P up to the boot stage and translocate parallel to each other, but after depletion in plants, they hinder each other translocation to the given part if one increases and the other decreases, and vice versa. Rayan et al. mentioned that because of the dilution effect, increasing P fertilizer application causes Zn deficiency in plants (Ryan et al. 2008). A study conducted in alkaline soils by Khattak et al. reported that P retention in leaves and grains increased with increasing zinc levels, yet it behaved differently in parts of the plant (Khattak et al. 2006). After attaining the maximum value of P with soil Zn 10 kg ha^{-1} + one foliar spray presented a higher concentration of P in leaves, while two foliar sprays showed a decrease in P concentration (-13.5%). Our results are consistent with those of (Paramesh et al. 2014), who observed that the soil + foliar Zn spraying treatment had the highest P concentration in wheat grains. Plants absorb more P from the soil after receiving zinc as a foliar spray (Bukvić et al. 2003). T_6 in the current study had a significant effect on the K concentration of wheat grains compared to the other treatments, except T_2. The increase in K content of wheat grains with soil Zn + foliar spray might be due to the zinc synergistic relationship with potassium (Razzaq et al. 2013). Zn application through foliar spraying has been shown to improve the macronutrient components of plants (Sayed et al. 2004). Results of another study reported that Zn application increased maize grain Mg and K contration (Szakal 1989).

4.3 Grain protein content

Wheat grain protein content has increased as a result of the soil and foliar applications of zinc fertilizer. According to current research findings, Zn is one of the main nutrients for improving the protein and amino acid content of grains.

Zinc is a stimulating component that enhances indoleacetic acid synthesis by increasing protein and amino acid content of grains. Another study conducted in alkaline soils by Khattak et al. 2015 found that Zn treatment increased grain protein content, with the most effective treatment being Zn at 5 kg ha^{-1} applied to the soil with one foliar spray (Khattak et al. 2015). The findings of the current study were consistent with those of Paramesh et al. who showed that application of Zn 25 kg ha^{-1} into the soil resulted in an 11.8 % increase in grain protein compared to the control (Paramesh et al. 2014). Zn helps increase wheat β-Carotene content, which improves protein and other quality characteristics (Kharub & Gupta 2003). Another researcher documented that during the seed formation, maximum zinc uptake and protein synthesis happen at the same time (Ozturk et al. 2006). According to Barunawati et al. soil Zn application with foliar spray increased dry matter building and N uptake in wheat crop, which in turn raised the protein content of grains (Barunawati et al. 2013). Zn shortage is linked to N metabolism; when Zn absorption in plants is reduced, the amount of protein in the plant reduces dramatically (Gupta et al. 2016). Thus, protein synthesis necessitates appropriate Zn supplementation (Patel et al. 2007). Zinc nutrition can change the protein composition of wheat grains (Peck et al. 2008).

CONCLUSIONS.

The application of Zn, whether through foliar spray or soil application, was found to benefit both the yield and quality of wheat grown in alkaline soil. The highest grain and biological yields and 1000 grain weights were recorded when Zn was applied at 7.50 kg ha^{-1} in soil with a combination of foliar Zn at 2.5 kg ha^{-1} in alkaline soils. Potassium and phosphorous grain concentrations were enhanced by Zn addition to the crop regardless of the application method. The Zn application significantly increased the grain protein content from 9.40% in control to a maximum of 11.83 % at an application rate of soil Zn of 10 kg ha^{-1}. Therefore, Zn application (soil + foliar) is recommended to increase wheat grain production and quality in alkaline soils. Further research could be conducted to optimize the timing, dosage, and method of zinc application to crops to maximize its efficiency and minimize any potential negative effects. Additionally, the use of Zn in agricultural practices could be expanded to increase the productivity and quality of crops other than wheat, particularly in regions with Zn-deficient soils.

AUTHOR CONTRIBUTIONS

Farhat Ullah Khan and Adnan Anwar Khan conducted the research**; Qu Yuanyuan and Qi Zhang** performed lab analysis and provided the resources; **Muhammad Adnan, Shah Saud, Shah Hassan and Shah Fahad** reviewed and edited the manuscript; **Fatima Gul and Muhammad Ismail** analyzed the data. **Xu Xuexuan** supervised the experiment.

CONFLICT OF INTEREST

This article's publication does not include any conflicts of interest.

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Table 1(on next page)

Wheat grain, biological yield, tiller per plant, and thousand grain weight as affected by different levels of soil and foliar applied Zn

Table 1. Wheat grain, biological yield, tiller per plant, and thousand grain weight as affected by different levels of soil and foliar applied Zn

Zn (kg ha^{-1})		Grain yield (kg ha^{-1})	Biological yield (kg ha^{-1})	Tiller per plant	Thousand grain weight (g)
Soil	Foliar				
0	0	2712.67 ^{f}	6033.33^{g}	6.59 ^{d}	40.36 ^{c}
5	0	2928.00 ^{e}	6422.33 ^{f}	7.22^{abc}	43.57^{bc}
3.75	1.25	3130.00 ^{d}	6921.67 ^{e}	7.07^{abcd}	45.11^{ab}
2.5	2.5	3237.00 ^{d}	7034.67 ^{e}	6.69 ^{d}	46.08^{ab}
1.25	3.75	3252.33 ^{d}	7246.67 ^{d}	6.87^{cd}	46.68^{ab}
0	5	3378.00 ^{c}	7387.67 ^{d}	6.89^{cd}	47.38^{ab}
10	0	3454.67 ^{c}	7631.00 ^{c}	7.02^{bcd}	47.47^{ab}
7.5	2.5	3639.67 ^{a}	8002.33 ^{a}	7.44^{ab}	48.37 ^{a}
5	5	3608.67^{ab}	7994.00 ^{a}	7.50^{ab}	47.15^{ab}
2.5	7.5	3588.00^{ab}	7890.33^{ab}	7.44^{ab}	45.38^{ab}
0	10	3504.00^{bc}	7786.33^{bc}	7.56 ^{a}	47.01^{ab}

*Values carrying different letter (s) in columns are significantly different at $P \leq 0.05$

Table 2(on next page)

Grain Zn, K and P as affected by different levels of Zn as soil and foliar

Table 2. Grain Zn, K and P as affected by different levels of Zn as soil and foliar

Zn (kg ha^{-1})		Zn	K	P
Soil	**Foliar**	**_____ Concentration (%) _____**		
0	0	0.51^{a}	0.50^{bcd}	0.12^{c}
5	0	0.49^{a}	0.51^{ab}	0.13^{bc}
3.75	1.25	0.45^{b}	0.49^{de}	0.13^{abc}
2.5	2.5	0.44^{b}	0.48^{ef}	0.14^{abc}
1.25	3.75	0.46^{b}	0.47^{f}	0.14^{ab}
0	5	0.44^{b}	0.52^{a}	014$^{ab.}$
10	0	0.45^{b}	0.45^{b}	0.14^{ab}
7.5	2.5	0.44^{b}	0.50^{bc}	0.14^{ab}
5	5	0.39^{c}	0.50^{bcd}	0.15^{a}
2.5	7.5	0.39^{c}	0.49^{cde}	0.15^{a}
0	10	0.39^{c}	0.50^{cde}	0.15^{a}

*Values carrying different letter (s) in columns are significantly different at $P \leq 0.05$

Table 3 (on next page)

Protein in grain as affected by different levels of Zn as soil and foliar application

Table 3. Protein in grain as affected by different levels of Zn as soil and foliar application

Zn (kg ha^{-1})		Protein in Grain	Increase over control
Soil	**Foliar**	%	(%)
0	0	9.40 a	
5	0	9.63 de	2.48
3.75	1.25	9.83 cde	4.6
2.5	2.5	10.13 bcde	5.32
1.25	3.75	10.20 bcde	8.51
0	5	10.53 abcde	12.05
10	0	11.83 a	25.88
7.5	2.5	11.46 ab	21.99
5	5	11.23 abc	19.5
2.5	7.5	10.96 abcd	16.67
0	10	10.76 abcde	14.54

*Values carrying different letter (s) in columns are significantly different at $P \leq 0.05$

Table 4(on next page)

Table 4. Pearson's correlation coefficients

Table 4. Pearson's correlation coefficients

	1000 Grain Weight	Tiller Per Plant	Grain yield	Biological yield	Grain Protein	Grain K concentration	Grain P concentration	Grain Zn concentration
1000 Grain Weight	1	0.349*	0.649**	0.645**	0.459**	-0.008	0.333	-0.474**
Tiller Per Plant		1	0.604**	0.597**	0.324	0.247	0.438*	-0.608**
Grain yield			1	0.971**	0.631**	0.039	0.678**	-0.832**
Biological yield				1	0.652**	0.068	0.739**	-0.838**
Grain Protein					1	0.348*	0.472**	-0.466**
Grain K concentration						1	-0.21	0.048
Grain P concentration							1	-0.685**
Grain Zn concentration								1

** indicate significance at 95% level. Zn, K, and P are concentration in wheat grain.