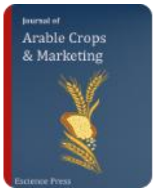

Available Online at EScience Press

Journal of Arable Crops and Marketing

ISSN: 2709-8109 (Online), 2709-8095 (Print)
https://esciencepress.net/journals/JACM

Effect of Different Sources and Application of Zn on Growth and Yield of Summer Maize (*Zea mays* L.) under Calcareous Soil Conditions

[ab]Muhammad Adnan Yousaf*, [a]Rao Wali Muhammad, [b]Zeemal Urooj, [c] Altaf Hussain, [a]Muhammad Asif Zulfiqar

[a]*PARC, Research and Training Station, Bahauddin Zakariya University, Multan, Pakistan.*

[b]*Institute of Agronomy, Faculty of Agricultural Sciences and Technology, Bahauddin Zakariya University, Multan, PK.*

[c]*Directorate of Agricultural Research Sibi, Balochistan, Pakistan.*

**Corresponding Author Email: adnanyousaf@parc.gov.pk*

ABSTRACT

Zinc is an important micronutrient and is essential for plants. Zinc deficiency in soil is a worldwide issue that leads to lower crop production, especially in cereals. In Pakistan, most of the soils are zinc deficient. This study aimed to assess the different application methods and different doses of zinc in maize under zinc-deficient calcareous soil. The experiment consisted of seven treatments including control (no zinc application), granular zinc 33% soil application, foliar application of zinc 33%, granular zinc 33% soil application combined with foliar application of zinc 33%, EDTA-chelated Zn 5% soil application, EDTA-chelated Zn 5% foliar application, and 1% EDTA-chelated granular zinc and 1% EDTA-chelated zinc foliar application. Morphological and yield attributes i.e., plant height (21.37%), stem diameter (50.41%), cob diameter (18.35%), cob length (56.84%),100-grain weight, 1000-grain weight, grain yield (20.25%) and biological yield (45.34%) showed a significant increase in growth, size, and weight after the application of zinc treatment (1% EDTA-chelated granular zinc and 1% EDTA-chelated zinc foliar) under calcareous soil conditions. Likewise, the application of treatment consisting of 1% EDTA G-Zn+1% EDTA F-Zn treatment demonstrated a significant increase in chlorophyll content (47.12%), starch content (22.56%), protein content (28.36%), oil content (5.35%), and Zn content (50.41%) in maize grains under calcareous soil conditions as compared to the control treatment of zinc.

Keywords: Zinc sources, zinc application, summer maize, calcareous soils

INTRODUCTION

Maize is an important cereal crop belonging to the Pinaceae family (Sood, 2019). It is often referred to as the "queen of cereals" Maize is one of the three major global cereal crops after wheat and rice (Saritha et al., 2020). It not only caters to the nutritional needs of humans but also serves as a significant food source for poultry and livestock sectors (Mandal et al., 2023. Corn seeds and grains are utilized as raw materials in various industries such as the production of starch, oil, proteins, and alcoholic beverages. Maize cultivation contributes 3% of the value added in agriculture. Maize contributes 0.7% GDP of Pakistan. In 2022-2023, maize crop was cultivated in 1720 thousand hectares of land in Pakistan (Pakistan Economic Survey 2022-23). The world maize production was estimated as 1235730 (1000MT), with the United States being the largest producer, contributing to 32% of the total global maize production. Pakistan ranked 14th, contributing approximately 1% of the total production. In 2023, the annual production of maize in Pakistan was estimated at 10500 tons (1000MT) (USDA-2023).

Due to the increasing global population, the demand for maize has also increased. However, there are many reasons behind low maize yields in Pakistan. The main constraints are mainly: poor quality of seed, low inbred lines, imbalanced use of fertilizers, lack of resources, and the non-use of micronutrients (Waqas et al., 2021; Erenstein et al., 2022; Yin and Leng, 2022). Deficiency of zinc may have a remarkable influence on maize crops, which may result in chlorophyll loss, stunted growth, and reduced enzymatic activity (Saboor *et al*., 2021). It may lead to lower crop yields and remarkably damage the country's economy. One of the basic reasons of zinc deficiency in soil is the latter's calcareous nature, which lead to binds with zinc rendering it unavailable for plants growth (Hafeez *et al*., 2013.). Conventional cultivation is another sufficient contributor to the deficiency of zinc in soil.

The most significant method to address zinc deficiency in soil is its chemical application. Zinc monohydrate, zinc heptahydrate, and chelated-EDTA zinc are used to provide available forms of zinc. Chelated forms of zinc such as EDTA have been used in this process (Suganya *et al*., 2020.). Various methods have been utilized to apply zinc to plants, with soil and foliar applications being the most effective and widely used approaches for this purpose. The combination of soil and foliar application is also used to address the problems related to zinc deficiency in soil (Saleem *et al*., 2022).

The most important function of a plant's defense system is to protect the integrity of its cell membranes. Zinc plays a very vital role in this process as it affects the auxin hormone that promotes root and hair growth (Hussain *et al*., 2015). Zinc also works in alliance with other essential micronutrients like N and K. However, it is important to be cognizant that the relationship between phosphorus and zinc has an antagonistic nature.

To overcome zinc deficiency in developing countries, the utilization of food with zinc supplementation is crucial. Different methods, such as food biofortification and food diversification, have been implemented to address this deficiency (Praharaj *et al*., 2021). The objective of this experiment is to identify the most effective source and method for addressing soil zinc deficiency. Specifically, this study aims to evaluate the effectiveness of two application methods soil and foliar applications and determine the most suitable zinc source for alkaline calcareous soils. Additionally, it will explore the differences between non-chelated and EDTA-chelated zinc to provide comprehensive insights into combating zinc deficiency.

Given the situation regarding zinc deficiency in maize plants, it's crucial to research the optimal source and application technique of zinc to promote growth. This is not only essential for plant vitality, but also to combat zinc deficiency in humans. It's been reported that roughly 70% of soils in Pakistan lack sufficient zinc levels. To tackle this issue in both plants and humans, a technique known as biofortification is employed to enhance the zinc content in food. To determine the most efficient approach, our study utilized a range of chelated and non-chellated zinc sources and application methods.

MATERIALS AND METHODS

Field Description

The study was performed at the Research Farm, Faculty of Agriculture Science and Technology, Bahauddin Zakriya University located in Multan, Pakistan during 2022-2023. The climate of Multan is categorized as semi-arid, subtropical with mean annual precipitation of 175 mm and mean annual temperature of 25.6 °C. Soil samples taken from the research site before sowing and after land preparation were collected randomly at a depth of 0-30 cm for analysis prior to fertilizer application. Soil analysis revealed a sandy clay loam texture (68% sand, 15% silt, and 17% clay), an electrical conductivity (EC) of 1.68 ds.m-1, a pH around 8.3, 4.67% CaCO3, and 0.57% organic matter.

Experiment Steps

To assess the role of zinc application on maize, a field experiment was laid out in a randomized complete block design (factorial). The experiment was replicated thrice. Each replication consisted of 7 plots, resulting in a total of 21 plots. The size of each plot was 2m x 5m. Maize seeds were purchased from the Multan local market. The maize hybrid variety P-4040 from Pioneer company was used in this experiment. Sowing was performed on 10 February 2023 using a dibbling method at 75 cm apart. The experiment focused on different sources and application methods of zinc, including control (no zinc application), granular zinc 33% soil application, foliar application of zinc 33%, granular zinc 33% soil application combined with foliar application of zinc 33%, EDTA-chelated Zn 5% soil application, EDTA-chelated Zn 5% foliar application, and 1% EDTA-chelated granular zinc and 1% EDTA-chelated zinc foliar application.

At the time of sowing, the recommended dose of N:P:K at a rate of 92:58:37 kg/acre was soil amended. The nitrogen fertilizer was applied in three split doses. Thinning was performed at the fourth leaf stage to maintain the recommended plant population. Soil application of zinc was performed at the time of sowing, while foliar application of zinc was performed at the fifth leaf stage of maize. The first irrigation was given at the time of sowing, with subsequent irrigations according to the crop water need. The doses of insecticide and weedicide were applied across all treatments, and agronomic practices were kept uniform for all treatments. The crop was harvested at the time of physical maturity.

Data Recording

Morphological Attributes

Ten plants were arbitrarily selected from every treatment plot to determine quantitative data. Morphological attributes and parameters of yield such as plant height, stem diameter, cob diameter, cob length, leaf area, number of cobs per plant, number of grains per cob, number of grain rows per cob, grain weight per cob, 100-grain weight, 1000-grain weight, and plant population were measured at physiological maturity and after harvesting. Three samples of 1 m^2 were collected from each plot to determine grain and biological yields at harvest time.

Physiochemical Analysis

For the physiochemical analysis of plants, leaf near plants ear were collected from selective plants in the two central rows of each treatment plant. All samples were washed with distilled water. The samples were sun-dried for 24 hours; and then oven-dried at 70 °C for two days. Samples were ground using a stainless-steel electrical grinder and then sieved. The final samples were transferred to plastic bags for physiochemical analysis. Zinc concentration in maize was determined by sample digestion using an atomic absorption spectrophotometer (AAS) (PerkinElmer, 2380). The wet digestion process was conducted in which 1 g of the final prepared samples were placed in a Pyrex flask. After that, concentrated HNO3 of 10 ml was mixed, kept for one night, and then concentrated HCLO4 4mL was added. The digestion of the samples was done using a hot plate, and then, the sample was filtered using filter paper of Whatman no 42 into a flask of 50 mL (Walsh and Beaton, 1977).

Maize starch was calculated via iodine test using glucose as standard as described by Sullivan (1935). Dried samples from the above zinc analysis were added into an iodine solution of 1 ml (1.27 g iodine and 4 g potassium iodide) for 10 minutes. The absorbance reading was observed at 660 nm with an AAS.

For protein, final prepared samples were used. Protein was determined via the Biuret method as elaborated by Gornall *et al*. (1949). Bovine serum albumin was used as the standard protein. To prepare the biuret reagent, 0.9 g of sodium potassium tartrate, 0.5 g of potassium iodide (KI), and 0.3 g of copper sulfate pentahydrate (CuSO4·5H2O) were dissolved in distilled water, and the volume was adjusted to 100 mL.

The biuret reagent of the same concentration was mixed with samples of maize grains as well as standards. According to the procedure, OD was noted spectrophotometrically at 540 nm.

Oil content was calculated using the extract method. Soxhlet apparatus was used for the calculation of oil content as elaborated by Ajayi *et al*. (2004). 15 g of samples were taken and kept in a thimble. Then, the samples were transferred to a chamber filled with n-hexane by 2/3rd cycles of n-hexane repeated 15 to 20 times. Afterwards, the oil extraction was stopped. Next, n-hexane and oil were split on a rotary evaporator. The weight and percentage of the oil content were calculated using the formula;

$$\begin{aligned} &Oil\ percentage(\%) \\ &\qquad = Final\ weight(g) - Initital\ weight\ (g) \times 100 \\ &\qquad \div\ total\ weight\ of\ sample \end{aligned}$$

The chlorophyll content (SPAD value) was determined using a SPAD meter (SPAD-502, Minolta, Osaka, Japan). A mature leaf from each treatment block was selected, specifically third leaf of the plant to measure the chlorophyll. The reading was recorded in the early morning at 10:00 am. Ten plants were randomly selected from each treatment block and the mean was calculated. The transpiration and photosynthetic rates were determined using an IRGA (Infrared gas analyzer) instrument after 45 days of sowing the top leaves of maize plants.

Statistical Aanalysis

Comprehensive data analysis was performed using Statistix 8.1, following standard procedures. The analysis of variance technique and Tukey test at a 5% probability level was used to compare the differences among treatment means (Steel *et al*., 1997).

RESULTS

Plant height, Stem diameter, Cob Diameter and Cob Length

In this study, the effect of zinc was assessed on maize plant morphological parameters under calcareous soil conditions. Zinc application significantly enhanced plant height, stem diameter, cob diameter, and cob length compared to control (Figure 1). The application of 33% G-Zn, 33% F-Zn, and 33% G-Zn+33% F-Zn resulted in significant increases in plant height (3.38%, 7.43%, and 21.37%), stem diameter (0.73%, 14.91%, and 51.64%), cob diameter (4.86%, 8.85%, and 18.00%), and cob length (11.51%, 26.62%, and 56.84%) in comparison with the control as shown in Figure 1. Moreover, the application of 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn showed increases in plant height (9.64%, 17.26%, and 29.33%), stem diameter (19.27%, 32.73%, and 69.27%), cob diameter (11.09%, 16.05%, and 20.53%), and cob length (37.20%, 49.89%, and 69.84%) compared to control (Figure 1 A-D)..

Leaf area, Number of Cob, Number of Grains, and Number of Grain row

The application of zinc on maize under calcareous soil conditions significantly increased leaf size and yield contributing components (Figure 2 A-D). A significant increase in leaf area (19.46%, 46.43%, and 72.66%), no. of cob/plant (0%, 10.00%, and 33.33%), no. of grain cob (5.05%, 7.22%, and 18.70%), and no. of grain rows/cob (7.89%, 10.53%, and 18.42%) was observed after adding 33% G-Zn, 33% F-Zn, and 33% G-Zn and 33% F-Zn treatment compared to the control. Using 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn exhibited increases in leaf area (55.30%, 58.99, and 99.76%), no. of cob/plant (20.00%, 26.67%, and 60.67%), no. of grain cob (9.60%, 13.07%, and 25.05%), and no. of grain rows/cob (13.16%, 18.42%, and 31.58%) in comparison with the control (Figure 2A-D).

Maximum values for these parameters were recorded Plant Population, Grain weight,100-grain weight, and 1000-grain weight

Zinc application significantly increased the number of plants and grain weight of maize under calcareous soil conditions compared to control (Figure 3 A-D). The data presented in Figure 3A showed that plant population increased respectively by 1.79%, 2.33%, and 4.49%, with 33% G-Zn, 33% F-Zn, and 33% G-Zn and 33% F-Zn treatments, grain weight/cob rise by 1.27%, 20.99%, and 46.00%, 100-grain weight increased by 3.38%, 7.43%, and 21.37%, and 1000-grain weight increased by 3.32%, 5.54%, and 20.41% compared to control. With 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn significant increases in Plant population (3.04%, 3.88%, and 6.11%), Grain weight/cob (30.50%, 39.25%, and 54.68%), 100-grain weight (9.64%, 17.26%, and 29.33%), and 1000-grain weight (14.56%, 17.25%, and 29.11%) were recorded compared to control (Figure 3A-D). Grain Yield, Biological Yield, and Chlorophyll Content

The data presented in Figure 4 showed significant increases in main grain yields, biological yield, and chlorophyll content in leaves of maize plants compared to control ones under calcareous soil conditions. The application of 33% G-Zn, 33% F-Zn, and 33% G-Zn and 33% F-Zn treatment resulted in significant increases in grain yield (1.67%, 5.27%, and 14.71%), biological yield (4.64%, 16.03%, and 36.89%), and chlorophyll content (9.62%, 27.88%, and 47.12%) in comparison with the control (Figure 4 A-C). Adding 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn treatment caused increases in grain yield (8.26%, 12.07%, and 20.40%), biological yield (22.46%, 31.15%, and 45.34%), and chlorophyll content (36.54%, 43.27%, and 51.92%) compared to control (Figure 4- C). Transpiration rate, Photosynthetic rate, and Starch Content

A significant increase in transpiration rate, photosynthetic rate, and starch content in grains was recorded with the application of zinc in maize plants under calcareous soil conditions (Figure 5 A-C). For instance, the application of 33% G-Zn, 33% F-Zn, and 33% G-Zn+33% F-Zn showed significant increases in transpiration rate (25.45%, 41.82%, and 89.70%), photosynthetic rate (8.44%, 13.88%, and 25.89%), and starch in grain (10.37%, 15.24%, and 22.56%) compared to control (Figure 5A-C). Similarly, using 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn showed increase in transpiration rate (56.97%, 69.70%, and 100.00%), photosynthetic rate (16.89%, 19.70%, and 29.83%), and starch in grain (18.29%, 19.51%, and 32.93%) in comparison with the control (Figure 5-C).

Protein content, Oil content, and Zn content in grain

Zinc application to maize plants significantly enhanced the protein content, oil content, and zinc concentration in maize grains compared to control under calcareous soil conditions (Figure A-D). The application of 33% G-Zn, 33% F-Zn, and 33% G-Zn and 33% F-Zn treatment resulted in significant increases in protein content (7.77%, 13.55%, and 28.36%), oil content (1.13%, 2.59%, and 5.35%), and Zn content in grains (25.60%, 37.33%, and 50.41%) compared to control (Figure A-D). Similarly, the application of 5% EDTA G-Zn, 5% EDTA F-Zn, and 1% EDTA G-Zn+1% EDTA F-Zn treatments caused increases in protein content (21.36% 24.61%, and 42.76%), oil content (3.73%, 4.62%, and 6.32%), and Zn content in grains (40.41%, 36.95%, and 10.41%) in comparison with the control (Figure 6- C).

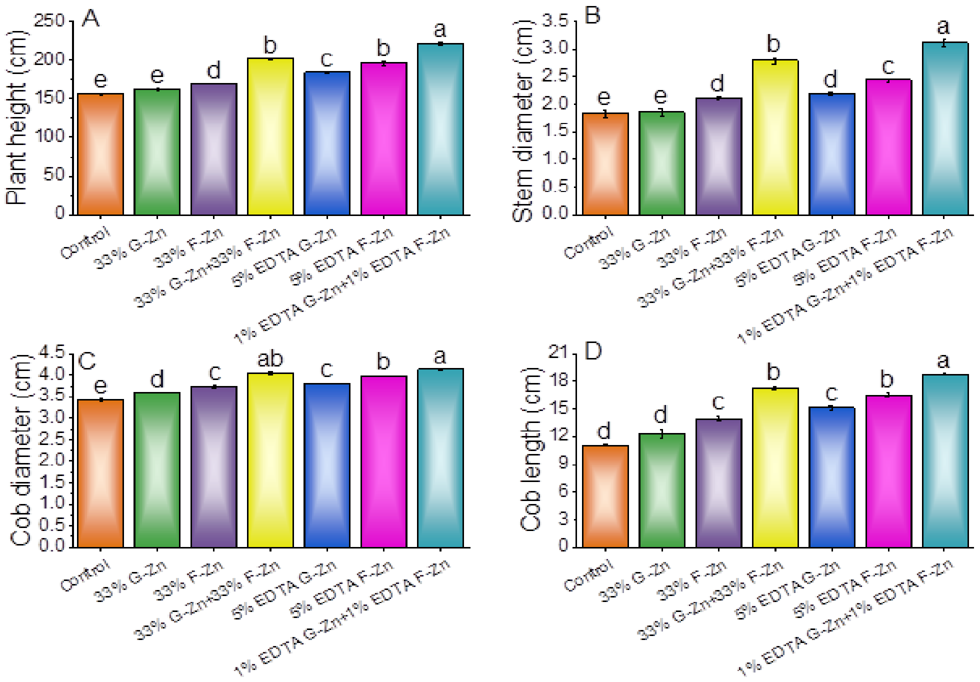

Figure 1. The effect of different treatments on plant height (A), stem diameter (B), cob diameter (C), and cob length (D) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

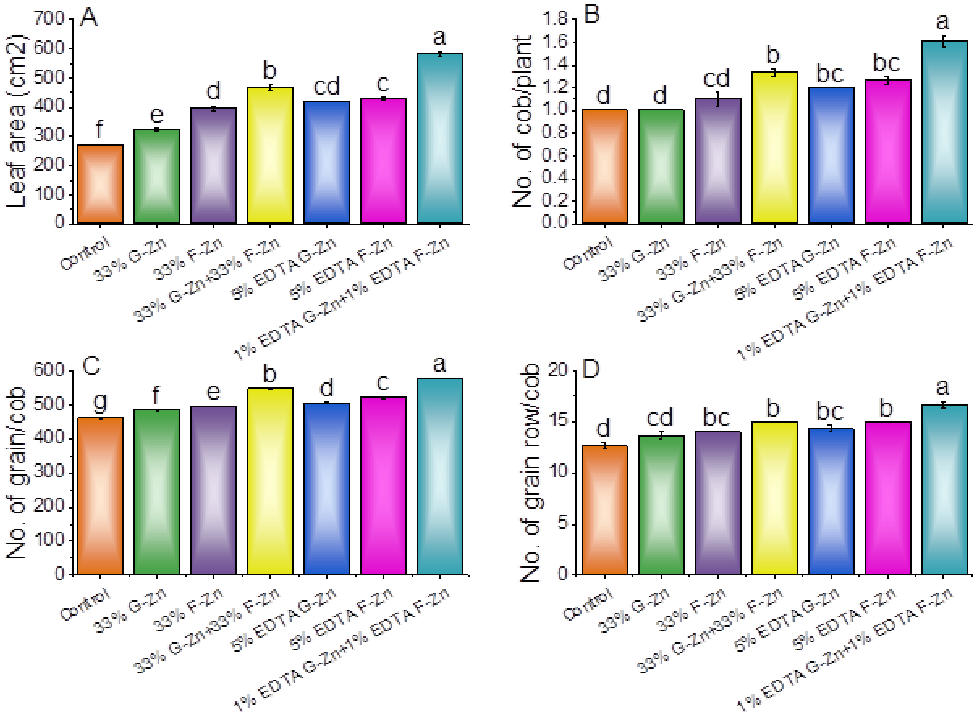

Figure 2. The effect of different treatments on leaf area (A), no. of cob/plant (B), no. of grain cob (C), and no. of grain rows/cob (D) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

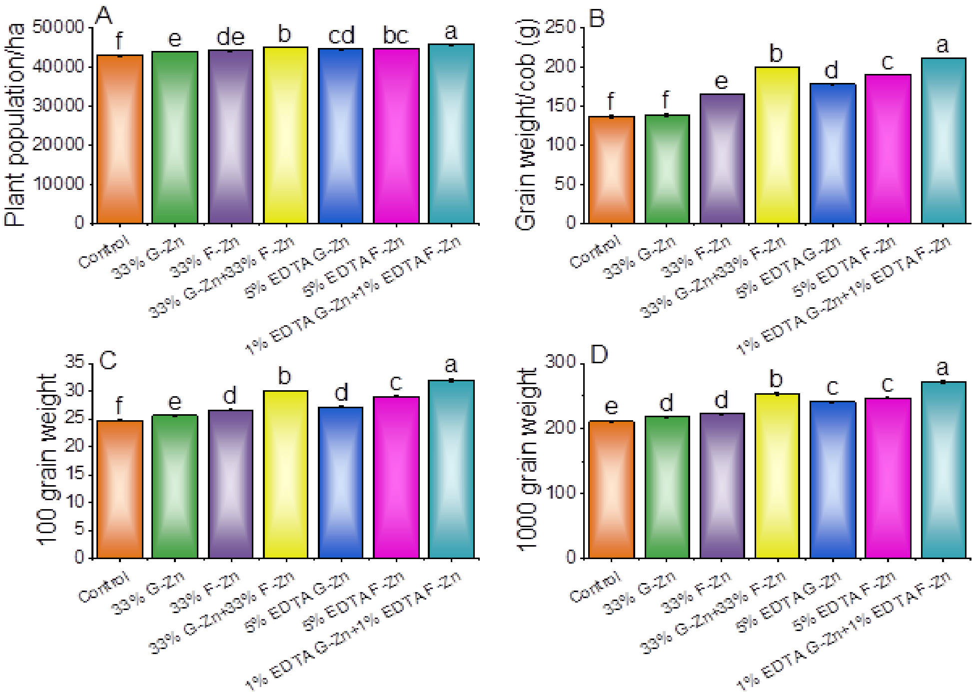

Figure 3. The effect of different treatments on plant population (A), grain weight/cob (B), 100 grain weight (C), and 1000 grain weight (D) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

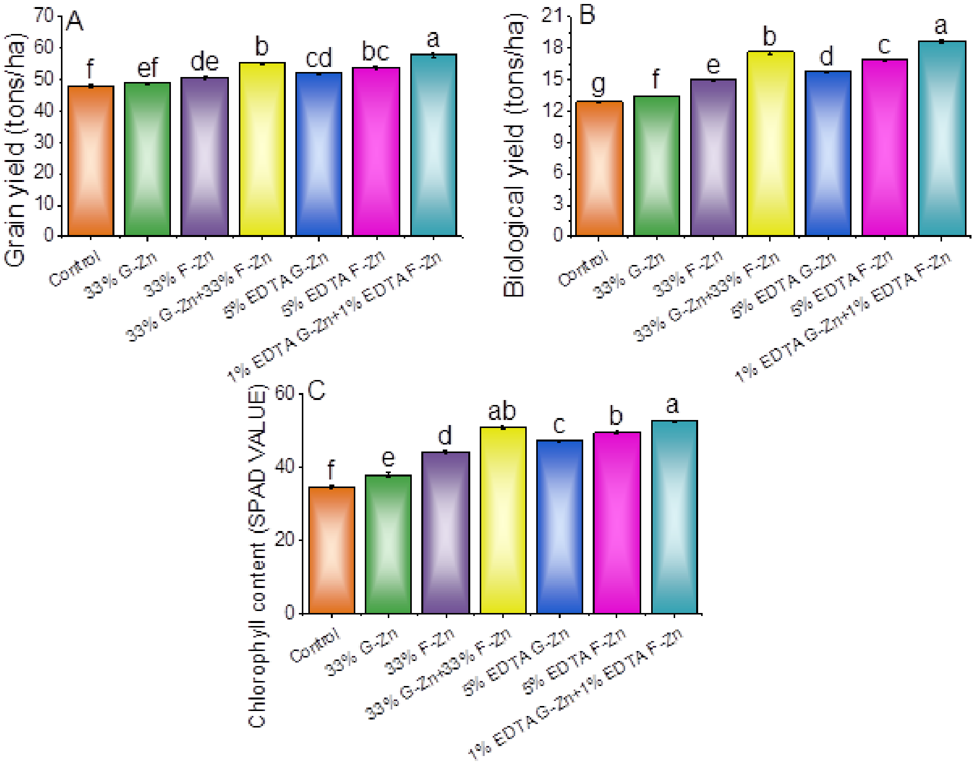

Figure 4. The effect of different treatments on grain yield (A), biological yield (B), and chlorophyll content (C) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

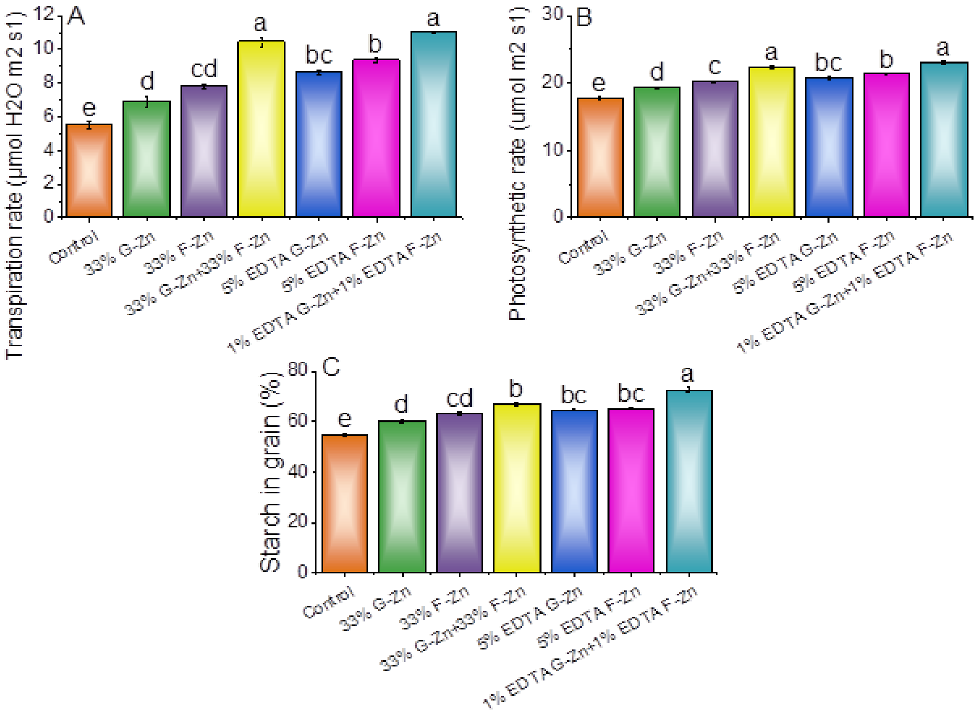

Figure 5. The effect of different treatments on transpiration rate (A), photosynthetic rate (B), and starch in grain (C) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

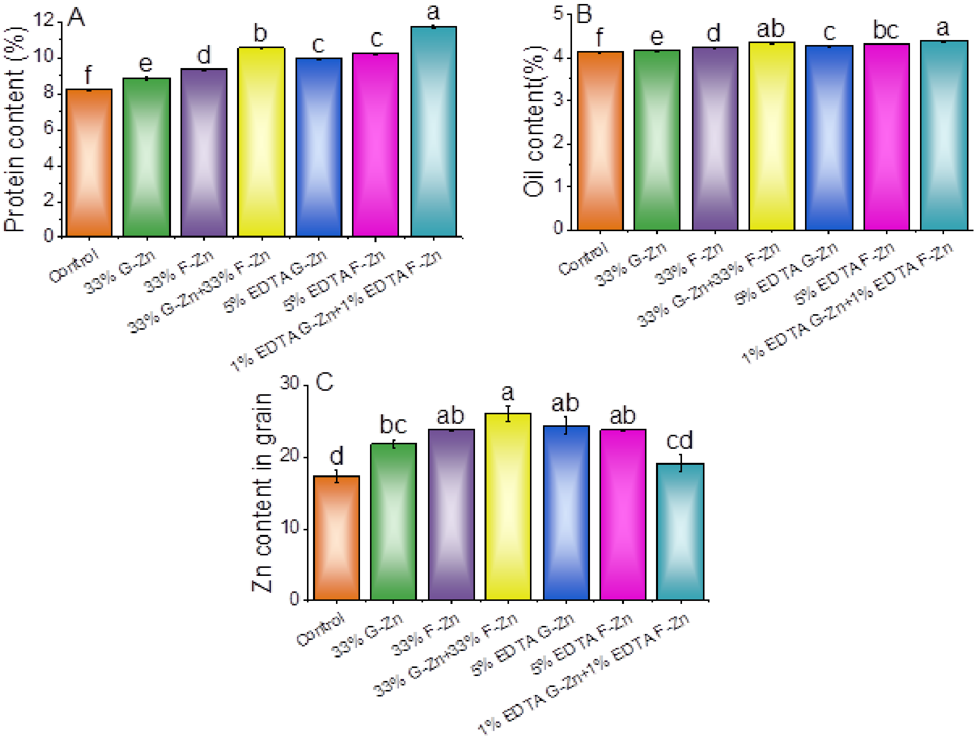

Figure 6. The effect of different treatments on protein content (A), oil content (B), and Zn content in grain (C) of maize. The Tukey test measured significant differences at ($p < 0.05$); distinct letters on the bars are the mean of seven replicates.

DISCUSSION

The significant increases in plant height, stem diameter, cob diameter, and cob length observed with both granular and foliar zinc applications can be attributed to Zinc's role in enhancing cell division and elongation (Amin, 2022). Zinc is a co-factor for numerous enzymes involved in DNA synthesis and protein metabolism (Chasapis *et al*., 2020). This advances the production of auxins, which are plant hormones essential for cell elongation and division. Zinc also works in alliance with other essential micronutrients like N and K. Particularly, as a comparison of single application methods of Zinc, the combined application of 33% G-Zn + 33% F-Zn and 1% EDTA G-Zn + 1% EDTA F-Zn have shown more significant nutrition of zinc, strengthening these growth processes more effectively. The involvement of zinc in the synthesis of chlorophyll is a reason for the enlargement in leaf area (Suganya *et al*., 2020). Zinc plays an important role in the synthesis of auxin and other hormones, including indole-3-acetic acid (IAA), which is derived from tryptophan and promotes growth and expansion of leaf. Its importance in plant development is well documented (Zhang *et al*., 2022). The increase in number of cobs per plant, number of grain rows per cobs, and number of grains per cob show the remarkable improvement in the reproductive development of maize after zinc application. It may be due to improved fertilization because zinc is required for the formation of pollen tubes (Kandil *et al*., 2022). Proper zinc availability can enhance plant population and grain weight, maximizing seed germination and seedling vigor. The findings of this experiment are likewise to that of zinc in enhancing yield and grain quality in rice (Patel *et al*., 2022), wheat (Lakshami *et al*., 2021), maize (Djalovic *et al*., 2022), tomato (Sardar *et al*., 2021) and common bean (Hacisalihoglu *et al*., 2004). Zinc increases ribosomal RNA synthesis, which is required to produce proteins during seed germination (Suganya *et al*., 2020). In addition to this, the increase in 100-grain weight and 1000-grain weight shows that it may be due to improved photosynthetic capability and nutrient translocation after zinc application. Zinc application also plays a part in improving photosynthetic activity and chlorophyll content (Palacio-Márquez *et al*., 2021). Zinc also plays a vital role in the integrity of chloroplast structure. Chlorophyll content improves the photosynthetic activity of plants stimulating synthesis of biomass and grain yield. The results obtained in this study demonstrate that the application of zinc enhances chlorophyll content in maize plants grown under calcareous soil conditions. Likewise, Liu *et al*. (2016) and Wasaya *et al*. (2017) reported that the application of zinc in zinc-deficient soil can increase chlorophyll content in maize plants. In this experiment, the last treatment containing 1% EDTA G-Zn+1% EDTA F-Zn was found to have a higher biological yield, showing that the growth of a plant is supported by optimum zinc uptake and utilization (Xu *et al*., 2022). The transpiration rates and photosynthetic activity are increased because of the role of zinc in the regulation of stomatal capability. Zinc also affects carbonic anhydrase, an enzyme that plays a vital role in CO2 fixation during photosynthesis (Rudenko *et al*., 2021). The treatment (1% EDTA G-Zn+1% EDTA F-Zn) demonstrates that increased photosynthetic rates cause grains to accumulate more starch. These physiological processes appear to be expanding because the chelated forms of zinc (EDTA) appear more effective at maintaining optimal zinc levels within the plant. Zinc's contribution to nitrogen metabolism and unsaturated fatty acid synthesis is responsible for the rise in grain protein and oil content (Keshavarz *et al*., 2024). Zinc is an essential component of the protein synthesis enzyme RNA polymerase. Grain protein content rises because of increased protein synthesis (Suganya *et al*., 2020). The increase in oil content may also be due to role of zinc in the synthesis of enzymes that are involved in lipid metabolism. The increase in zinc content in grains of maize with zinc applications shows significant translocation and accumulation of zinc inside the grains of maize, increasing their nutritional quality (Zhang *et al*., 2020). The process of zinc uptake and transport in plants can explain the higher performance of the combined treatments (G-Zn + F-Zn and EDTA chelated forms). Granular zinc, applied to the soil significantly increases zinc availability for the growth of roots (Abdullah *et al*., 2022), while foliar application of zinc provides immediate zinc availability to the foliage, bypassing soil-related limitations, such as pH and zinc-binding compounds (Ahmed *et al*., 2021). Chelated EDTA zinc develops zinc dissolvability, accessibility and movement inside the plant. A more beneficial and effective supply of zinc is possible with the combined application of EDTA-chelated zinc in the soil as well as foliar application strategies, ensuring improved growth and yield parameters.

CONCLUSION

The aim of this experiment was to check the effects of different sources of zinc with foliar, soil, combined applications to soil, and foliar application of chelated EDTA zinc and non-chelated zinc. The findings of this study revealed that the treatment (1% EDTA G-Zn+1% EDTA F-Zn) proved maximum increase in morphological as well as physiochemical attributes of maize grains under calcareous soil conditions. It can be suggested that the combined application of EDTA granular zinc to the and EDTA zinc as a foliar spray significantly enhances both the quantitative and qualitative attributes of maize. Future research could focus on optimizing the timing, dosage, and environmental impact of combined EDTA granular and foliar zinc applications to enhance maize productivity across different varieties and agro-climatic conditions.

REFERENCES:

Abdullah, B., M.B.K. Niazi, Z. Jahan, O. Khan, A. Shahid, G.A. Shah, B. Azeem, Z. Iqbal and A. Mahmood. 2022. Role of zinc-coated urea fertilizers in improving nitrogen use efficiency, soil nutritional status, and nutrient use efficiency of test crops. Front. Environ. Sci., 10: 888865.

Ahmed, R., M. Yusoff Abd Samad, M.K. Uddin, M.A. Quddus and M.A.M. Hossain. 2021. Recent trends in the foliar spraying of zinc nutrient and zinc oxide nanoparticles in tomato production. Agronomy, 11: 2074.

Amin, H. 2022. Synergistic effects of foliar application of zinc oxide and copper oxide nanoparticles in barley grown in metal polluted soil. Ondokuz May{\i}s Üniversitesi, Lisansüstü E{\u{g}}itim Enstitüsü.

Chasapis, C.T., P.-S.A. Ntoupa, C.A. Spiliopoulou and M.E. Stefanidou. 2020. Recent aspects of the effects of zinc on human health. Arch. Toxicol., 94: 1443–1460.

Chadd, S., 2007, November. Future trends and developments in poultry nutrition. In Proceedings of the Poultry in the 21st century: Avian influenza and beyond. In Proceedings of the International Poultry Conference, Bangkok, Thailand (pp. 5-7).

Djalovic, I., Riaz, M., Akhtar, K., Bekavac, G., Paunovic, A., Pejanovic, V., Zaheer, S. and Prasad, P.V., 2022. Yield and grain quality of divergent maize cultivars under inorganic N fertilizer regimes and Zn application depend on climatic conditions in calcareous soil. Agronomy, 12(11), p.2705.

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K. and Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. Food security, 14(5), pp.1295-1319.

Hacisalihoglu, G., Ozturk, L., Cakmak, I., Welch, R.M. and Kochian, L., 2004. Genotypic variation in common bean in response to zinc deficiency in calcareous soil. Plant and soil, 259, pp.71-83.

Hafeez, B.M.K.Y., Khanif, Y.M. and Saleem, M., 2013. Role of zinc in plant nutrition-a review. American journal of experimental Agriculture, 3(2), pp.374-391.

Hamzah Saleem, M., Usman, K., Rizwan, M., Al Jabri, H. and Alsafran, M., 2022. Functions and strategies for enhancing zinc availability in plants for sustainable agriculture. Frontiers in Plant Science, 13, p.1033092.

Hussain, A., Arshad, M., Zahir, Z.A. and Asghar, M., 2015. Prospects of zinc solubilizing bacteria for enhancing growth of maize. Pakistan journal of agricultural sciences, 52(4).

Kandil, E.E., A.A.A. El-Banna, D.M.M. Tabl, M.I. Mackled, R.Y. Ghareeb, A.A. Al-Huqail, H.M. Ali, J. Jebril and N.R. Abdelsalam. 2022. Zinc nutrition responses to agronomic and yield traits, kernel quality, and pollen viability in rice (*Oryza sativa* L.). Front. Plant Sci., 13: 791066.

Keshavarz, H., S.-M. Seify and H. Sabourifard. 2024. Manganese and zinc effect on yield, fatty acid ratio, and maternal seeds germination of canola cultivars upon late-season drought stress. J. Plant Nutr., 1–16.

Lakshmi, P.V., Singh, S.K., Pramanick, B., Kumar, M., Laik, R., Kumari, A., Shukla, A.K., Abdel Latef, A.A.H., Ali, O.M. and Hossain, A., 2021. Long-term zinc fertilization in calcareous soils improves wheat (*Triticum aestivum* L.) productivity and soil zinc status in the rice–wheat cropping system. Agronomy, 11(7), p.1306.

Liu, H., Gan, W., Rengel, Z. and Zhao, P., 2016. Effects of zinc fertilizer rate and application method on photosynthetic characteristics and grain yield of summer maize. Journal of soil science and plant nutrition, 16(2), pp.550-562.

Mandal, S., Singh, V.K., Chaudhary, D., Kaur, A., Kumar, R., Panwar, A., Ojre, A., Singh, R.K. and Kaushik, P., 2023. From Grain to Gain: Revolutionizing Maize

Nutrition.

Mueller, N.D., Gerber, J.S., Johnston, M., Ray, D.K., Ramankutty, N. and Foley, J.A., 2012. Closing yield gaps through nutrient and water management. Nature, 490(7419), pp.254-257.

Pakistan Economic Survey 2022-23

Patel, P.S., Singh, S.K., Patra, A. and Jatav, S.S., 2022. Root dipping, foliar and soil application of zinc increase growth, yields, and grain zinc in rice (*Oryza sativa* L.) grown in moderate zinc soil of inceptisol order. Communications in Soil Science and Plant Analysis, 53(15), pp.1917-1929.

Palacio-Márquez, A., C.A. Ram\'\irez-Estrada, N.J. Gutiérrez-Ruelas, E. Sánchez, D.L. Ojeda-Barrios, C. Chávez-Mendoza and J.P. Sida-Arreola. 2021. Efficiency of foliar application of zinc oxide nanoparticles versus zinc nitrate complexed with chitosan on nitrogen assimilation, photosynthetic activity, and production of green beans (*Phaseolus vulgaris* L.). Sci. Hortic. (Amsterdam)., 288: 110297.

Rudenko, N.N., M.M. Borisova-Mubarakshina, L.K. Ignatova, T.P. Fedorchuk, E.M. Nadeeva-Zhurikova and B.N. Ivanov. 2021. Role of plant carbonic anhydrases under stress conditions. Plant Stress Physiol, 4: 7–38.

Saboor, A., Ali, M.A., Hussain, S., El Enshasy, H.A., Hussain, S., Ahmed, N., Gafur, A., Sayyed, R.Z., Fahad, S., Danish, S. and Datta, R., 2021. Zinc nutrition and arbuscular mycorrhizal symbiosis effects on maize (*Zea mays* L.) growth and productivity. Saudi Journal of Biological Sciences, 28(11), pp.6339-6351.

Sardar, H., Naz, S., Ejaz, S., Farooq, O., Rehman, A.U., Sameen, M. and Akhtar, G., 2021. Effect of foliar application of zinc oxide on growth and photosynthetic traits of cherry tomato under calcareous soil conditions. Acta Scientiarum Polonorum Hortorum Cultus, 20(1), pp.91-99.

Saritha, A., Ramanjaneyulu, A.V., Sainath, N. and Umarani, E., 2020. Nutritional importance and value addition in maize. Biotica Research Today, 2(9), pp.974-977.

Sood, S., Joshi, D.C., Chandra, A.K. and Kumar, A., 2019. Phenomics and genomics of finger millet: current status and future prospects. Planta, 250, pp.731-751.

Suganya, A., A. Saravanan and N. Manivannan. 2020. Role of zinc nutrition for increasing zinc availability, uptake, yield, and quality of maize (*Zea mays* L.) grains: An overview. Commun. Soil Sci. Plant Anal, 51: 2001–2021.

Tariq, M., Khan, F., Shah, A.H., Fahad, S., Wahid, F., Ali, J., Adnan, M., Ahmad, M., Irfan, M., Zafar-ul-Hye, M. and Battaglia, M.L., 2020. Effect of micronutrients foliar supplementation on the production and eminence of plum (*Prunus domestica* L.). Quality Assurance and Safety of Crops & Foods, 12(SP1), pp.32-40.

Tariq, M. and Iqbal, H., 2010. Maize in Pakistan–an overview. Agriculture and Natural Resources, 44(5), pp.757-763.

USDA-2023

Waqas, M.A., Wang, X., Zafar, S.A., Noor, M.A., Hussain, H.A., Azher Nawaz, M. and Farooq, M., 2021. Thermal stresses in maize: effects and management strategies. Plants, 10(2), p.293.

Wang, H. and Jin, J.Y., 2005. Photosynthetic rate, chlorophyll fluorescence parameters, and lipid peroxidation of maize leaves as affected by zinc deficiency. Photosynthetica, 43, pp.591-596.

Yin, X. and Leng, G., 2022. Observational constraint of process crop models suggests higher risks for global maize yield under climate change. Environmental Research Letters, 17(7), p.074023.

Xu, M., L. Du, M. Liu, J. Zhou, W. Pan, H. Fu, X. Zhang, Q. Ma and L. Wu. 2022. Glycine-chelated zinc rather than glycine-mixed zinc has lower foliar phytotoxicity than zinc sulfate and enhances zinc biofortification in waxy corn. Food Chem., 370: 131031.

Zhang, M., C. Gao, L. Xu, H. Niu, Q. Liu, Y. Huang, G. Lv, H. Yang and M. Li. 2022. Melatonin and indole-3-acetic acid synergistically regulate plant growth and stress resistance. Cells, 11: 3250.

Zhang, W., Y.-F. Xue, X.-P. Chen, F.-S. Zhang and C.-Q. Zou. 2020. Zinc nutrition for high productivity and human health in intensive production of wheat. Adv. Agron., 163: 179–217.