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Zinc Nutrition Optimization for Improving the Growth, Yield and Grain Quality of Wheat (*TriticumAestivum* L.)

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ABSTRACT

Wheat *(TriticumaestivumL.)*a member of Poaceae family a major source of nutrients and energy. It occupies a prominent position in the staple foods. It can provide 70% of daily calories and 20% of global protein consumption for each person. Zinc is needed for the synthesis of DNA (deoxyribonucleic acid) and RNA (ribonucleic acid), as well as for the stabilization of cell membranes and ribosomes and defense against free radicals.50% of the soil used to grow wheat yields harvests with low levels of bioavailable Zn or crops lacking Zn.According to reports, the fifth most common cause of sickness and mortality in underdeveloped nations is Zn deficiency in humans. To achieve this goal a comprehensive study is designed to optimize the different levels of Zn application for improving growth, yield and grain quality characteristics of wheat on alkaline calcareous soil. Experimental plan was comprised of seven treatments including control (no Zn application), 20, 40, 60, 80, 100 and 120 mg kg^1 Zn. Each treatment was replicated for five times. Zinc sulfateheptahydrate ($ZnSO_4.7H_2O$) was used as Zn source. Experiment was conducted according to “Complete Randomized Design” (CRD). Plant growth, physiological and yield contributing characteristics were recorded. Plant samples were analyzed for Zn concentration. After harvesting, wheat grains were also be analyzed for different quality parameters such as Zn concentration. Pre-sowing and post-harvest soil analysis was done for Zn concentration and other physic-chemical characteristics.

KEYWORDS

Zinc nutrition, wheat growth, grain yield and quality, plant physiology.

Introduction

Wheat (*Triticumaestivum* L.) is referred to as the king of cereals because of its contribution to human diet in terms of food security and safety (Mazhar et al. 2023). A global production of 215 million tons, it is grown on 1.6 billion hectares and is regarded as the 2nd most significant cereal crop after rice (Martínez et al. 2022). Being the main staple food, particularly in South Asian countries, it is playing a vital role in human dietary requirements. With an average yield of 2.84 tons per hectare and a total production of 31.4 million tons, it is cultivated on 8.9 million hectares in Pakistan. Mature wheat grains are composed of proteins (11%), minerals (2%), water content (13%), lipids (2%), polysaccharides (13%), and carbohydrates (58%) (Hayyat et al. 2020). It provides 20% of the proteins and calories needed for a typical human diet. Wheat is said to provide 70% of daily calories in a number of South Asian nations, including Bangladesh, India, Pakistan, and Nepal (Kamaral et al. 2020). Pakistan's average wheat productivity is significantly below its potential, primarily due to an unbalanced and insufficient supply of plant nutrients.

Micronutrients like copper (Cu), iron (Fe), boron (B) and. zinc (Zn.), Besides, a. wheat nutrient and micronutrient strategy should aggregate macronutrients, such like potassium (K), phosphorus (P) and nitrogen (N). However, current farming practice is mainly confined to (N) application which might have a drastic effect on wheat productivity in Pakistan (Singh et al. 2023). Furthermore, alkaline calcareous conditions owing to arid climate may aggravate the deficiency of micronutrients which leads to a significant decline in wheat growth and yield (Akbari. 2020). Zinc is quickly adsorbed onto the soil colloids upon soil application which significantly reduces its availability to plants. Because of these rapid variations, Zn bioavailability is complex. Zinc shortage in crops is especially problematic for plants cultivated in calcareous soils, where calcium carbonate ($CaCO_3$) frequently adsorbs or precipitates Zn. Calcareous soils range in pH from 7.0 to 8.5 and have a high $CaCO_3$ level in the parent material (Singh et al. 2021). The efficacy of Zn fertilizer application can be enhanced by lowering soil pH, and adding organic matter.

Among micronutrients, Zn has been found deficient in more than 70% of Pakistan soils. This element is mostly absorbed by plants as the divalent cation (Zn^{2+}), which is extracted from the soil solution via three different mechanisms: mass flow, diffusion, and root interception. Diffusion is the most common mode. Wheat grains are reported to have 28 mg kg^{-1} Zn which is much below the standard value of 45 mg kg^{-1} (Aziz et al. 2019). Low Zn concentration in wheat grains might be the principal factor for Zn deficiency in humans as 40% population in Pakistan has been found Zn deficient (Kihara et al. 2024). Zinc deficiency in wheat plants is most commonly characterized by reductions in plant height and leaf size. The leaves then develop whitish-brown necrotic patches (Ning et al. 2021). In both the developed and developing worlds, nutritional deficiencies are becoming a major problem that impair human development, immunological responses, behavior, cognitive and motor abilities, and intellectual performance, particularly in children. Zinc deficiency may responsible for a number of health disorders and functional abnormalities including blindness, cognitive decline, lowered IQ, stunting, early pregnancy deaths, and increased susceptibility to infectious diseases during pregnancy. Zinc is a crucial nutrient for plants since it controls a number of physiological functions that lead to the development of defensive mechanisms against many diseases (Natasha et al. 2022). According to EL Sabagh et al. (2021).yield was a complex trait that was significantly impacted by crop variety, management practices, and environmental factors (Rehman et al. 2020).

Zinc is considered essential for biological metabolism as well as plant's regular growth and development. It significantly affects a plant's ability to withstand stress, develop pollen tubes, express genes, improve chloroplasts, produce auxin, and regulate enzymatic activities (Yu et al. 2021). It is commonly known that soils with DTPA-extractable Zn levels below 0.5 mg kg^{-1} have insufficient amounts of Zn available for optimal plant growth, while calcareous soils exhibit greater deficiencies in this mineral (Gul et al. 2020). Over half of the world wheat is grown on soils deficient in Zn, which results in an inadequate supply of Zn minerals for human health. Due to a decrease in Zn absorption and accumulation in plants, Zn-deficient soils yield wheat grains with low Zn levels (Kar et al. 2021). Zinc deficiency can be readily remedied by applying $ZnSO_4 \cdot 7H_2O$ or ZnO to the soil. The most often used Zn source to address crop plant Zn deficiencies is $ZnSO_4 \cdot 7H_2O$. Zn application dose in the soil ranges from 10 to 100 kg ha^{-1}.

Due to limited Zn solubility and high Zn fixation in arid and semi-arid environments, Zn insufficiency is widespread. Only a small portion of the substantial amount of Zn in the soil matrix is accessible to plants (Hussain et al. 2022). Soils may be low in both total and accessible Zn due to a variety of soil characteristics and circumstances. It is believed that weathered parent material, clay mineral nature,alkaline pH, sandy texture, high salt concentrations, calcareousness, waterlogging or flooding, organic matter content, high magnesium and/or bicarbonate concentrations, more nutrient uptake than application, intensive cultivation, and the use of high analysis fertilizers (i.e., poor in micronutrients) (Santos &Schoenfeld.(2020). If Zn shortage persists, the condition becomes more severe, necrotic areas emerge on the leaves, and the central sections of the leaves frequently collapse, giving the impression of being "burnt." Typically, these Zn-deficient leaves have a Zn concentration of less than 10–12 ppm (Doolette et al. 2020). The optimum Zn concentrations in wheat leaves or the entire shoot during the vegetative growth stage are typically between 15-17 ppm. Depending on the plant species and the degree of the Zn shortage, net photosynthesis can be reduced by 50-70%. Hence, it is stated that the amount of Zn needed for optimal growth, yield, and grain quality may vary among plant species and varieties within species, nature of soil and climatic conditions.

Material and methods

A Pot experiment was conducted at the research area of the College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan having GPS values of Latitude 32.082°N, Longitude 72.669°E, and Altitude 190 m. The study was aimed to evaluate the effect of varying levels of Zn supply on the growth, yield and grain quality of wheat (*Triticumaestivum*L.) under alkaline calcareous conditions. Experiment was conducted in wire house having glass roof with no control over temperature, humidity and light as the sides were opened having only a wire net to prevent from birds. Soil was collected from cultivated field under wheat-maize cropping system. The soil was passed through 2 mm sieve. Each pot was filled with 20 kg soilandfive healthy and uniform seeds of wheat cultivar Dilkash-2019 were sown in each pot. The recommended dose of N 120 kg ha^{-1} (2.61 g pot^{-1} urea), P_2O_5 90 kg ha^{-1} (5 g pot^{-1} as single superphosphate), and K_2O 60 kg ha^{-1} (1.2 g pot^{-1} as potassium sulfate) were applied. Whole of P and K while one-third N were applied at the time of sowing while remaining N was applied at 30 and 60 days after germination. Zinc was applied as $ZnSO_4.7H_2O$ in the respective pots in accordance with treatment plan. At seeding stage, two plants were maintained in each pot. The uprooted plants were incorporated into the same pots. Weeding was done manually. Irrigation was done twice a week using one liter tap water for each pot. Experimental plan was comprised of seven treatments. $ZnSO_4.7H_2O$ was used as Zn source including control, 20, 40, 60, 80, 100, and 120 kg ha^{-1}. Each treatment was replicated for five times. The pots were arranged in accordance with complete randomized design.

Measurement of growth and yield parameters

After 45 days of treatment application, one plant from each pot was harvested, washed with distilled water, and measured the fresh biomass using electric balance (GS-K-901600). These plant samples were air dried, and then oven dried in an oven (ED-115, Binder, Germany) at 70^0C for constant weight to record oven dry biomass. These plant samples were analyzed. The 2nd plant was allowed to grow up to maturity. At maturity, plant growth and yield attributes including plant height, number of tillers $plant^{-1}$, spike length, number of grains $spike^{-1}$, 1000-grain weight, and grain yield $plant^{-1}$ were recoded.

Soil characterization

For textural class determination, Bouyoucos hydrometer was used to record the suspension's reading. The values were converted into percentages, and international textural triangle was used for determining the soil textural class. For soil pH measurement, 50 g soil was used to prepare 1:1 soil suspension by adding distilled water. The pH was measured using pH meter (JENWAY-3510-UK). The electrical conductivity of soil was measured by conductivity bridge method as described by Jackson's (1967). Soil suspension in 1:10 ratio was prepared, and EC of soil suspension was measured using conductivity meter (JENWAY-4510-UK). Saturation percentage (SP) is the moisture content of a soil at which it is said to be completely saturated and forms a paste. This method involves making a saturated soil paste by adding distilled water to an air-dried soil sample until it becomes the desired consistency. The SP was determined using following formula;

$$\text{Saturation percentage} = \frac{loss\ in\ weight\ on\ oven\ drying}{oven\ dried\ soil\ weight\ (g)} \text{x}100$$

Soil organic matter was determined according to the method described by Walkley and Black (1934). Kjeldahl digestion and distillation process was used to calculate the total soil nitrogen as described by Bremer and Tabatabi (1972). The N was determined by following formula:

$$\text{N}= \frac{(v1 - vo)\ \ c(\text{H}+)\ \text{x}\ MN}{m}$$

Olsen's method was used for the determination of available P in soil as described by Olsen *et al.* (1954). The reading was recorded on spectrophotometer (Analyticjena, specrod-200, Germany). Extractable K in soil was determined by the method described by Richards (1954). Flame photometer (PFP-7, Jenway) used to measure K concentration. The chlorophyll contents in wheat leaves were determined by the method described by Arnon (1949). Reading was recorded using spectrophotometer (Hitachi-120, Japan). The shoot samples were collected 45 days after germination, and washed with distilled water to remove impurities. The shoot samples were first air dried, and then oven dried at 70^{0}C in an oven (ED-115-Binder-Germany) till constant weight. Zinc concentration in the plant was measured on atomic absorption spectrophotometer (Analyticjena, 400-P, Germany). Zinc uptake in shoots and grains was calculated by following formula suggested by (Marschner, 1995).

$$\text{Zinc uptake (mg plant}^{-1}\text{) = Zinc concentration Dry weight}$$

Zinc use efficiency was calculated using following formula as suggested by (Fageria, 2001).

$$\text{ZUE} = \frac{Grain\ yield\ with\ Zn - Grain\ yield\ without\ Zn}{amount\ of\ Zn\ applied}$$

Statistical analysis

All the data were evaluated using the statistical program Statistics 10, and the differences between the treatment means were examined using the least significant difference (LSD) test at 0.05 probability level (Steel *et al.*, 1997).

Results

Plants physiological attributes

Minimum shoot fresh biomass was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improved shoot fresh biomass. The highest improvement in shoot fresh biomass was 172.32% with 40 mg kg^{-1} Zn, followed by 127.38% with 60 mg kg^{-1} Zn, 76.19 % with 80 mg kg^{-1} Zn, 64.88 % with 20 mg kg^{-1} Zn, 57.14 % with 100 mg kg^{-1} Zn and 36.01 with 120 mg kg^{-1} Zn compared to the plants without Zn supplementation.

The concentration of shoot dry biomass was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that minimum shoot dry biomass in wheat plants in control treatment where plants were grown without Zn nutrition. Zinc supplement under alkaline calcareous conditions markedly increased shoot dry biomass. The highest improvement in shoot dry biomass was 152.51% when plants were treated with 60 mg kg^{-1} Zn followed by 88.48 % with 40 mg kg^{-1} Zn, 80 % with 80 mg kg^{-1} Zn, 73.42 % with 20 mg kg^{-1} Zn, 64.3% with 100 mg kg^{-1} Zn and 21.01% with 120 mg kg^{-1} Zn compared to plants without Zn application.

Plant growth attributes

Highest plant height of 20.46 % in wheat plants was found at Zn application level of 60 mg kg^{-1} followed by 17.58 % at 40 mg kg^{-1} and 11.32 % at 80 mg kg^{-1} in descending order. However minimum plant height of 1.93 % was recorded at Zn application level of 120 mg kg^{-1} respectively.

Minimum number of tillers was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improved number of tillers plant^{-1}. The highest improvement in number of tillers plant^{-1} was 38.55 % with 80 mg kg^{-1}Zn, followed by 36.12 % with 40 mg kg^{-1}Zn, 24.89 % with 60 mg kg^{-1}Zn, 9.25 % with 100mg kg^{-1} Zn, 7.49 % with 20 mg kg^{-1} Zn and 4.41 with 120 mg kg^{-1} Zn compared to the plants without Zn supplementation.

The concentration of spike length was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that spike length in wheat plants in control treatment where plants were grown withoutZn nutrition. Zinc supplement under alkaline calcareous conditions markedly increased spike length. The highest improvement in spike length was 31.29% when plants were treated with 40 mg kg^{-1}Zn followed by 26.48 % with 60 mg kg^{-1}Zn, 18.2 % with 80 mg kg^{-1}Zn, 10.22 % with 100 mg kg^{-1}Zn,4.7% with 20 mg kg^{-1} Zn and 4.5 % with 120 mg kg^{-1} Zn compared to plants without Zn application.

Highest number of spikes plant^{-1} of 27.13 % in wheat plants was found at Zn application level of 40 mg kg^{-1}followed by 25.3 % at 60 mg kg^{-1}and 17.07 % at 80 mg kg^{-1} in descending order. However minimum number of spikes plant^{-1}of 5.18 % was recorded at Zn application level of 20 mg kg^{-1} respectively.

Plant yield attributes

Minimumnumber of grains spike^{-1} was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improvednumber of grains spike^{-1}. The highest improvement in number of grains spike^{-1}was 37.31 % with 40 mg kg^{-1}Zn, followed by 32.72 % with 60 mg kg^{-1}Zn,24.6% with 80 mg kg^{-1}Zn, 15.92 % with 20 mg kg^{-1} Zn,13.65 % with 100 mg kg^{-1} Zn and 8.52 with 120 mg kg^{-1} Zn compared to the plants without Zn supplementation.

The concentration of number of grains plant^{-1} was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that number of grains plant^{-1}in control treatment where plants were grown withoutZn nutrition. Zinc supplement under alkaline calcareous conditions markedly increased number of grains plant^{-1}. The highest improvement in number of grains plant^{-1} was 74.57 % when plants were treated with 40 mg kg^{-1}Zn followed by 66.3 % with 60 mg kg^{-1}Zn, 45.88 % with 80 mg kg^{-1}Zn, 22.8 % with 100 mg kg^{-1}Zn,21.92% with 20 mg kg^{-1} Zn and 16.95 % with 120 mg kg^{-1} Zn compared to plants without Zn application.

Highest 1000-grain weight of 23.4 % in wheat plants was found at Zn application level of 40 mg kg^{-1}followed by 21.84 % at 60 mg kg^{-1}and 16.34 % at 80 mg kg^{-1} in descending order. However minimum 1000-grain weight of 5.77 % was recorded at Zn application level of 20 mg kg^{-1} respectively.

Minimumgrain weight plant^{-1} was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improvedgrain weight plant^{-1}. The highest improvement in grain weight plant^{-1}was 115.3 % with 40 mg kg^{-1}Zn, followed by 102.55 % with 60 mg kg^{-1}Zn,69.66% with 80 mg kg^{-1}Zn, 38.93 % with 100 mg kg^{-1} Zn,28.86 % with 20 mg kg^{-1} Zn and 28.19 with 120 mg kg^{-1} Zn compared to the plants without Zn supplementation.

Available Zn concentration in plant and soil

The shoot Zn concentration was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that minimum shoot Zn concentrationin control treatment where plants were grown withoutZn nutrition. Zinc supplement under alkaline calcareous conditions markedly increased shoot Zn concentration. The highest improvement in shoot Zn concentration was 348.79 % when plants were treated with 120 mg kg^{-1}Zn followed by 282.93 % with 100 mg kg^{-1}Zn, 233.58 % with 80 mg kg^{-1}Zn, 171.36 % with 60 mg kg^{-1}Zn,111.24% with 40 mg kg^{-1} Zn and 62.41 % with 20 mg kg^{-1} Zn compared to plants without Zn application.

Highest shoot Zn uptake of 587.57 % in wheat plants was found at Zn application level of 60 mg kg^{-1}followed by 530.18 % at 100 mg kg^{-1}and 501.78 % at 80 mg kg^{-1} in descending order. However minimum shoot Zn uptake of 182.25 % was recorded at Zn application level of 20 mg kg^{-1} respectively.

Highest physiological efficiency of 114.65 g mg^{-1}was found at Zn application level of 40 mg kg^{-1}followed by 70.78g mg^{-1}at 20mg kg^{-1}and 43.10 g mg^{-1}at 60 mg kg^{-1} Zn in descending order. However minimum physiological efficiency of 16.11g mg^{-1}was recorded at Zn application level of 120 mg kg^{-1} respectively.

Minimumgrain Zn concentration was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improvedgrain Zn concentration. The highest improvement in grain Zn concentration was 170.44 % with 20 mg kg^{-1}Zn, followed by 152.94 % with 100 mg kg^{-1}Zn,129.73% with 80 mg kg^{-1}Zn, 96.94 % with 60 mg kg^{-1} Zn,78.09 % with 40 mg kg^{-1} Zn and 34.31 with 20 mg kg^{-1} Zn compared to the plants without Zn supplementation.

The grain Zn uptake was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that minimum grain Zn uptakein control treatment where plants were grown withoutZn nutrition. Zinc supplement in wheat plants under alkaline calcareous conditions markedly increased grain Zn uptake. The highest improvement in grain Zn uptake was 300.76 % when plants were treated with 60 mg kg^{-1}Zn followed by 291.6 % with 80 mg kg^{-1}Zn, 284.73 % with 40 mg kg^{-1}Zn, 252.67 % with 100 mg kg^{-1}Zn,248.09% with 120 mg kg^{-1} Zn and 74.05 % with 20 mg kg^{-1} Zn compared to plants without Zn application.

Biochemical composition attributes

Highest agronomic efficiency of 0.945 g $mg^{-1}$was found at Zn application level of 40 mg kg^{-1}followed by 0.560 g mg^{-1}at 60mg $kg^{-1}$and 0.472 g mg^{-1}at 20 mg kg^{-1} Zn in descending order. However minimum physiological efficiency of 0.092 g $mg^{-1}$was recorded at Zn application level of 120 mg kg^{-1} respectively.

Highest protein content of 36.68 % in wheat plants was recorded at Zn application level of 60 mg kg^{-1}followed by 36.35 % at 40 mg $kg^{-1}$and 26.43 % at 80 mg kg^{-1} in descending order. However minimum protein content of 6.36 % was recorded at Zn application level of 120 mg kg^{-1} respectively.

Minimumfat content was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improvedfat content in wheat plants. The highest improvement in fat content was 50 % with 40 mg kg^{-1}Zn, followed by 40.82 % with 60 mg kg^{-1}Zn,31.12% with 80 mg kg^{-1}Zn, 21.43 % with 20 mg kg^{-1} Zn,19.9 % with 100 mg kg^{-1} Zn and 11.22 with 120 mg kg^{-1} Zn compared to the plants without Zn supplementation.

The fiber content was significantly ($P \leq 0.05$) improved under Zn supplementation. Results presented in table revealed that minimum fiber contentin control treatment where plants were grown withoutZn nutrition. Zinc supplement in wheat plants under alkaline calcareous conditions markedly increased fiber content. The highest improvement in fiber content was 56.94 % when plants were treated with 60 mg kg^{-1}Zn followed by 52.6 % with 80 mg kg^{-1}Zn, 47.3 % with 100 mg kg^{-1}Zn, 40.37 % with 120 mg kg^{-1}Zn,40.27 % with 40 mg kg^{-1} Zn and 24.08 % with 20 mg kg^{-1} Zn compared to plants without Zn application.

Highest Zn concentration of 1079.17 % in soil was recorded at Zn application level of 120 mg kg^{-1}followed by 925 % at 100 mg kg^{-1}and 866.67 % at 80 mg kg^{-1} in descending order. However minimum protein content of 429.17 % was recorded at Zn application level of 20 mg kg^{-1} respectively.

Table 1: Plant height, number of tillers, spike length, number of spikes, number of grains, 1000 grain weight, grain weight per plant^{-1} accumulation in wheat grown with different levels of $ZnSO_4.7H_2O$ under alkaline calcareous conditions.

Treatments	Plant height	Number of tillers plant^{-1}	Spike length	Number of spikes Plant^{-1}	Number of grains plant^{-1}	1000 grain weight	Grain weight plant^{-1}
Control	72.54	4.54	9.78	6.56	34.87	32.56	7.45
20 mg kg^{-1}	77.22	4.88	10.24	6.9	40.42	34.44	9.6
40 mg kg^{-1}	85.29	6.18	12.84	8.34	47.88	40.18	16.04
60 mg kg^{-1}	87.38	5.67	12.37	8.22	46.28	39.67	15.09
80 mg kg^{-1}	80.75	6.29	11.56	7.68	43.45	37.88	12.64
100 mg kg^{-1}	77.86	4.96	10.78	7.29	39.63	36.86	10.35
120 mg kg^{-1}	73.94	4.74	10.22	7.07	37.84	35.7	9.55

Table 2: Shoot Zn concentration, Shoot Zn uptake, Grain Zn concentration, Grain Zn uptake of wheat grown with different levels of $ZnSO_4.7H_2O$ under alkaline calcareous conditions.

Treatments	Shoot Zn concentration	Shoot Zn uptake	Grain Zn concentration	Grain Zn uptake
Control	21.44	0.169	17.66	0.131
20 mg kg^{-1}	34.82	0.477	23.72	0.228
40 mg kg^{-1}	45.29	0.901	31.45	0.504
60 mg kg^{-1}	58.18	1.044	34.78	0.525
80 mg kg^{-1}	71.52	1.017	40.57	0.513
100 mg kg^{-1}	82.1	1.065	44.67	0.462
120 mg kg^{-1}	96.22	0.92	47.76	0.456

Table 3: Protein content, fat content, fiber content of wheat grown with different levels of $ZnSO_4.7H_2O$ under alkaline calcareous conditions.

Treatments	Protein content	Fat content	Fiber content
Control	9.27	1.96	10.38
20 mg kg^{-1}	10.18	2.38	12.88
40 mg kg^{-1}	12.64	2.94	14.56
60 mg kg^{-1}	12.67	2.76	16.29
80 mg kg^{-1}	11.72	2.57	15.84
100 mg kg^{-1}	10.44	2.35	15.29
120 mg kg^{-1}	9.86	2.18	14.57

Table 4: Soil EC, Soil Ph, Soil organic matter, Soil available Phosphors, Soil available potassium of wheat grown with different levels of $ZnSO_4.7H_2O$ under alkaline calcareous conditions.

Treatments	EC dS^{-1}	Soil Ph	O.M%	P (mg kh^{-1})	K (mg kg^{-1})
Control	0.95	7.8	1	26.7	360
20 mg kg^{-1}	0.79	7.8	1.11	46	298

40 mg kg^{-1}	0.98	7.6	0.91	29.2	346
60 mg kg^{-1}	0.81	7.7	0.84	46.5	318
80 mg kg^{-1}	0.7	7.8	1.11	21.5	254
100 mg kg^{-1}	0.71	7.7	0.7	28.5	286
120 mg kg^{-1}	0.97	7.8	0.84	43.7	320

Figure 1: Shoot fresh biomass

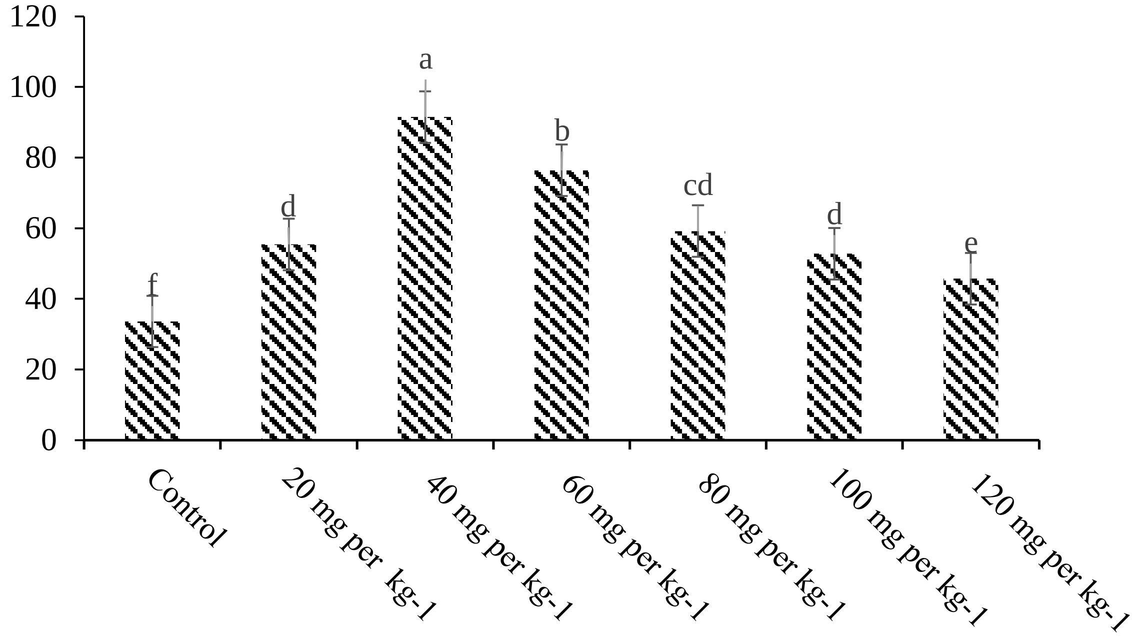


Figure 2: Shoot dry biomass

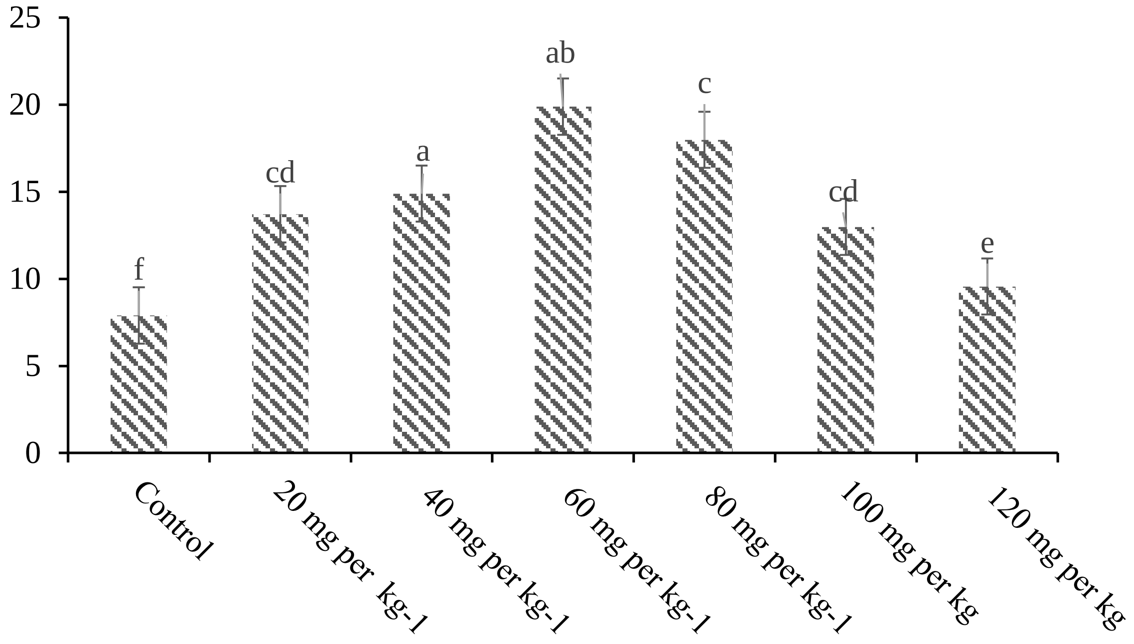


Figure 3: Agronomic use efficiency

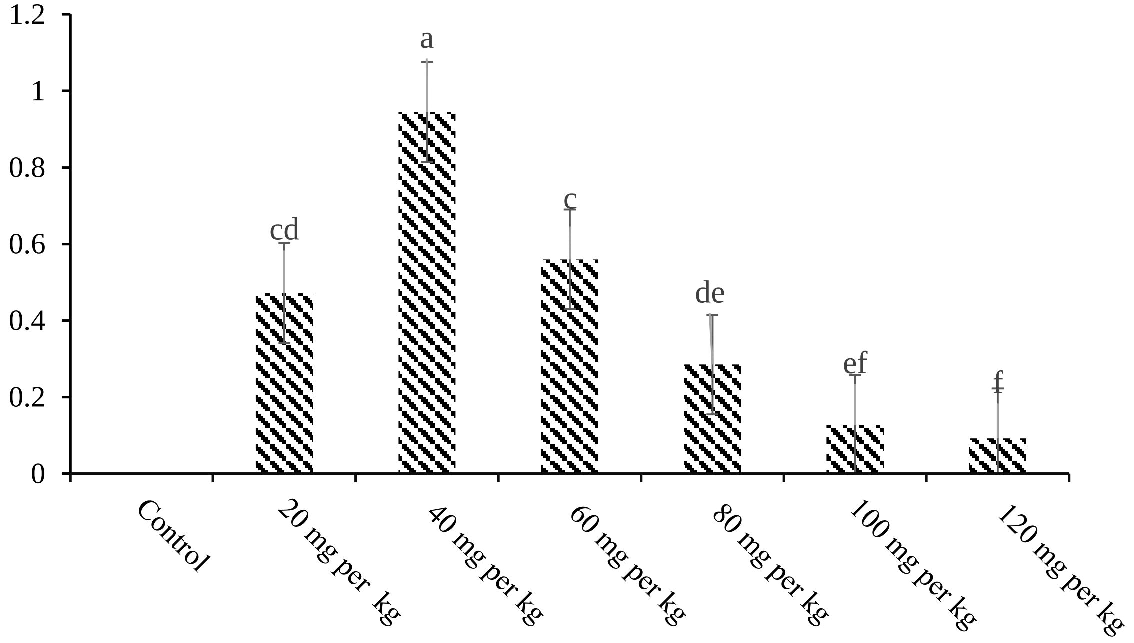


Figure 4: Physiological use efficiency

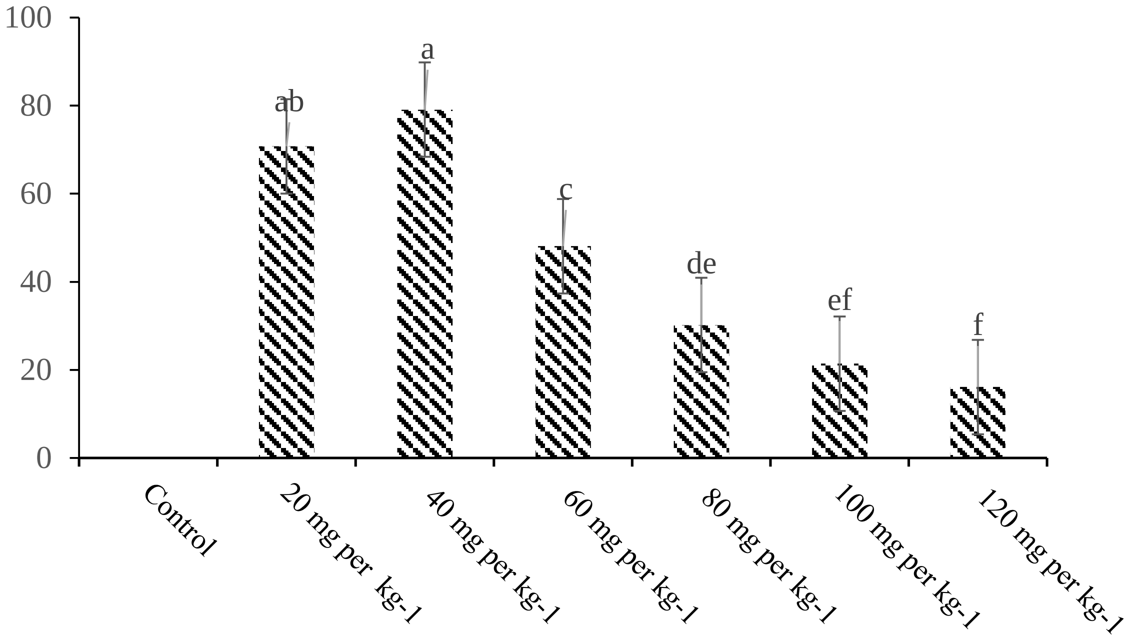
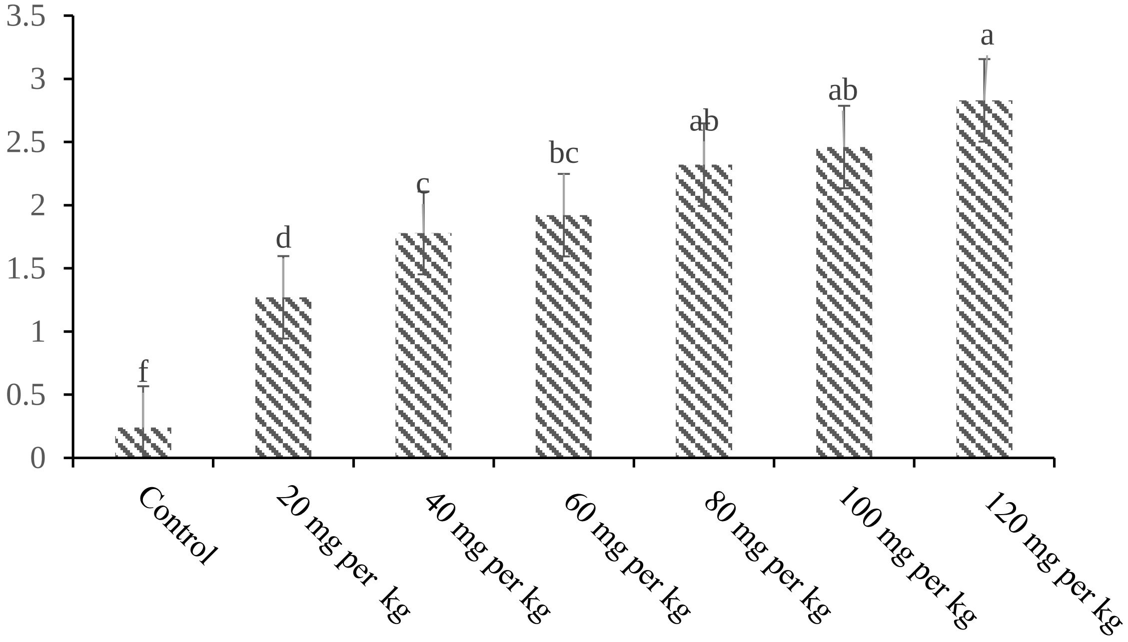


Figure 5: Zn concentration in soil



Conclusion

Zinc is considered as essential nutrients for seed germination, seed establishment, and improving crop yield. In plant physiologically it also improves chlorophyll content, photosynthetic rate, photosynthetic translocation. Furthermore, it can play a crucial role in synthesis of proteins, lipids, carbohydrates, and fiber which greatly affect on grain quality and yield. The present research was planned to asses the impact of different level of Zn nutrition on wheat plant growth and productivity. Zinc sulfate heptahydrate was used as Zn source to optimize Zn nutrition level for improving growth, yield,and grain quality characteristics of wheat under alkaline calcareous conditions.A pot experiment was conducted in the research area, College of Agriculture, University of Sargodha, Sargodha, Punjab, Pakistan to assess the impact of different level of Zn nutrition on wheat plant growth and productivity. Experimental plan was comprised of 7 treatments i.e. control, 20, 40, 60, 80, 100 and 120 mg kg^{-1}. Each pot contained 20 kg soil, and five uniformly healthy seeds of the wheat cultivar Dilkash-2019 were sown in each pot. The recommended dose of N, P and K were applied. At maturity, different plant growth, yield, ionic and grain quality characteristics were measured using standard procedures.

Results showed that Zn supplementation at different levels significantly affected the plant growth, yield and physiological characteristics of wheat. When plants were treated with 40 mg kg^{-1} Zn, their shoot dry biomass was maximally increased by 151.77% followed by 127.59% with 60 mg kg^{-1} $ZnSO_4.7H_2O$, 80% with 80 mg kg^{-1} $ZnSO_4.7H_2O$, 73.42% with 20 mg kg^{-1} $ZnSO_4.7H_2O$, 64.3% with 100 mg kg^{-1} $ZnSO_4.7H_2O$, and 21.01% with 120 mg kg^{-1} $ZnSO_4.7H_2O$ compared to the control.

The maximum increase in the number of grains spike-1 was 37.31% when 40 mg kg-1 $ZnSO_4.7H_20$ was used. followed by 32.72% with 60 mg kg^{-1} $ZnSO_4.7H_2O$, 24.6% with 80 mg kg^{-1} $ZnSO_4.7H_2O$, 15.92% with 20 mg kg^{-1} $ZnSO_4.7H_2O$, 13.65% with 100 mg kg^{-1} $ZnSO_4.7H_2O$, and 8.52% with 120 mg kg^{-1} $ZnSO_4.7H_2O$. Minimum shoot Zn concentration was found in case of control where plants were grown without Zn nutrition. Zinc supplementation under alkaline calcareous conditions significantly ($P \leq 0.05$) improved shoot Zn concentration. The highest improvement in shoot Zn concentration was 348.79% with 120 mg kg^{-1}$ZnSO_4.7H_2O$, followed by 282.93% with 100 mg kg^{-1}$ZnSO_4.7H_2O$, 233.58% with 80 mg kg^{-1}$ZnSO_4.7H_2O$, 171.36% with 60 mg kg^{-1}$ZnSO_4.7H_2O$, 111.24% with 40 mg kg^{-1}$ZnSO_4.7H_2O$ and 62.41% with 20 mg kg^{-1}$ZnSO_4.7H_2O$ compared to the plants without Zn supplementation.Zinc application significantly affected the grain Zn concentration in wheat. Highest increase in grain Zn concentration was found 170.44% with 20 mg kg^{-1}$ZnSO_4.7H_2O$, followed by 152.94% with 100 mg kg^{-1}$ZnSO_4.7H_2O$, 129.73% with 80 mg kg^{-1}$ZnSO_4.7H_2O$, 96.94% with 60 mg kg^{-1} $ZnSO_4.7H_2O$, 78.09% with 40 mg kg^{-1} $ZnSO_4.7H_2O$ and 34.31% with 20 mg kg^{-1} $ZnSO_4.7H_2O$ compared to the plants without Zn application.

Highest increase in grain Zn uptake of 300.76% was found at $ZnSO_4.7H_2O$ application level of 60 mg kg^{-1} followed by 291.6% at 80 mg kg^{-1} and 284.73% at 40 mg kg^{-1} in descending order compared to the control. However, minimum increase in grain Zn uptake of 74.05% was recorded at Zn application level of 20 mg kg^{-1} $ZnSO_4.7H_2O$. Highest increase in grain protein content was 36.68% at Zn application level of 60 mg kg^{-1} $ZnSO_4.7H_2O$ followed by 36.35% at 40 mg kg^{-1} $ZnSO_4.7H_2O$ and 26.43% at 80 mg kg^{-1}$ZnSO_4.7H_2O$ in descending order. However minimum increase in grain protein content was 6.36% at Zn application level of 120 mg kg^{-1}$ZnSO_4.7H_2O$ compared to the control.The fiber contents were maximally improved by 56.94% when plants were treated with 60 mg kg^{-1} $ZnSO_4.7H_2O$ followed by 52.6% with 80 mg kg^{-1} $ZnSO_4.7H_2O$, 47.3% with 100 mg kg^{-1} $ZnSO_4.7H_2O$, 40.37% with 120 mg kg^{-1} $ZnSO_4.7H_2O$, 40.27% with 40 mg kg^{-1} $ZnSO_4.7H_2O$ and 24.08% with 20 mg kg^{-1} $ZnSO_4.7H_2O$ compared to the control.

Future research directions

Wheat is the main staple food in many countries of the world, particularly Asian countries. It contributes significantly to human diet. However, the global grain Zn concentration of wheat was very low compared to the standard recommendation. The low grain Zn concentration in wheat leads to acute Zn deficiency in animals and humans. It has been reported that many people in the world are suffering from Zn deficiency disorder. The situation is more critical in Pakistan where 40% people are Zn deficient. There is a need to device appropriate strategy for improving Zn accumulation in food products. In this regards, agronomic bio-fortification of wheat with Zn can be a promising strategy to combat Zn malnutrition in humans. Plant Zn requirements for optimum wheat grain yield and quality vary greatly depending upon plant species and varieties within species, soil nature and climatic conditions. Therefore, future research should be crop and site specific for Zn nutrition to get higher profitability. Furthermore, Zn use efficiency may vary considerably depending upon Zn source, methods of application, and properties of soil. There is a dire need to evaluate different Zn sources and methods of application including soil addition, foliar spray and seed treatment for achieving higher Zn use efficiency, and better crop productivity. Zinc use efficiency in different types of soil also required to evaluate for improving wheat productivity, and reducing production cost.

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