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GROWTH, YIELD, AND ZINC ACCUMULATION OF ONION IN RELATION TO VARYING APPLICATION RATES OF CHEMICAL AND NANO ZINC FERTILIZERS

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Abstract

Onion (*Allium cepa* L.) is an important food crop which is consumed all over the world. Zinc (Zn), an important micronutrient, is deficient in more than half of the arable lands of Pakistan. Zinc oxide nanoparticles (ZnO-NPs) are an efficient source of Zn nutrition as they increase growth, yield, and plant Zn accumulation over conventional Zn sources. A field experiment was conducted to estimate the growth, yield, and Zn accumulation of onion in relation to varying application rates of chemical and nano zinc fertilizers at the research fields of Nuclear Institute of Agriculture (NIA), Tandojam, during the Rabi season of 2022-23 in a Randomized Complete Block Design with five treatments and three repeats. The treatments included T_1: control (no Zn application), T_2: 5.0 kg Zn ha^{-1} through Zinc sulphate, T_3: 2.5 kg Zn ha^{-1} through Zinc oxide, T_4: 2.5 kg Zn ha^{-1} through Zinc oxide nanoparticles, T_5: 1.25 kg Zn ha^{-1} through Zinc oxide nanoparticles. The findings suggested that supplementation of Zn significantly increased the growth and yield attributes, and bulb Zn enrichment of onion over no Zn application treatment. The maximum increase in bulb weight (66.8%), polar diameter (35.7%), equatorial diameter (45.2%), bulb yield (70.1%), and Zn concentration in bulbs (94.4%) was noticed under the treatment receiving Zn at the reduced application rate (1.25 kg ha^{-1}) through ZnO-NPs when compared to control. Conventional zinc sulphate ($ZnSO_4$) was found to be the best Zn source in producing a maximum of 79.9 g leaf biomass (42.8%) and 65.4 cm leaf length (55.5%) at the vegetative stage. This study concluded that the application of ZnO-NPs over chemical $ZnSO_4$ is an effective strategy for enhancing the productivity and Zn accumulation of onion while ensuring an eco-friendly environment.

Key words: Onion, Zinc deficiency, Zinc oxide nanoparticles, Zinc sulphate, Zn accumulation and Conventional Zn.

Introduction

Onion (*Allium cepa* L.) is one of the most important vegetable crops all over the world. Global production of onions is around 100 million tons per year. This highlights the increasing significance of onions in the global vegetable market, especially when considering the growing shares of onions. In Pakistan, onion is an important crop. Pakistan is ranked in the global production of onions sixth (Anon., 2021). Onion covers the area of about 140.8 thousand hectares, which produces around 2062.3 thousand tons with an average yield of 14.6 tons ha^{-1} in Pakistan. Provincially, Sindh stood first in total share of onion area about 62.0 thousand hectares and production about 837.5 thousand tons compared to other provinces (Anon., 2023).

Zinc (Zn) is an essential micronutrient for proper growth and development of plants. It is involved in various physiological processes, such as maintaining the integrity of membranes, enzyme activation, chlorophyll synthesis, and photosynthesis (Rehman *et al.,* 2018). It also plays significant roles in regulating plant growth, development, and all metabolic activities, highlighting its significance in maintaining optimal plant health and productivity (Cakmak *et al.,* 2023). In Pakistan, soils typically have low zinc availability due to their alkaline and calcareous nature. Recent data reveals that 51% of arable sites in Pakistan suffer from Zn deficiency. This highlights the urgent need to address Zn deficiency for sustainable agriculture and food security in Pakistan (Rashid *et al.,* 2022).

Chemical Zn fertilization significantly contributes to increased yields (Mehmood *et al.,* 2023). Conventional fertilizers are not only expensive for farmers, but also harmful to humans, soil and the environment. The overuse of chemical fertilizers not only compromises the quality of vegetable crops, including onion, but also poses a significant threat to our environment through increasing pollution (Salim *et al.,* 2016). Moreover, chemical fertilizers may exert bad effects on soil fertility and soil physico-chemical properties (Beltayef *et al.,* 2023). For this reason, scientists are looking for novel eco-friendly fertilizers, having higher nutrient use efficiency to cope with the growing environmental risks and food insecurity (Naseer *et al.,* 2024).

In recent times, a growing interest has emerged in utilizing nanotechnology in contemporary agriculture and environmental sciences. This is primarily attributed to the remarkable and adaptable traits shown by nanoparticles, responding to the escalating needs in these fields (Prabha *et al.,* 2022). As the name suggests, nanoparticles have a size range of 1-100 nm. They possess distinctive physico-chemical properties that distinguish them from larger bulk materials. These nanoparticles play significant roles in a wide range of scientific areas, showcasing unique properties due to their size (Karuvelan *et al.,* 2025). Fertilizer based on nanoparticles known as nanofertilizers have shown varying effects on different aspects of agriculture, influencing seed germination, promoting plant growth and development and enhancing crop production (Duhan *et al.,* 2017; Haydar *et al.,* 2021). Nanofertilizers can potentially boost the absorption of nutrients and overall plant yield by controlling the presence of fertilizers in the root zone. Furthermore, nanoparticles that include micronutrients, such as copper and Zn dissolve quickly within the soil and plant surroundings (Du *et al.,* 2019).

Zinc nano fertilizers are a more straightforward and sustainable for delivering a soluble and readily available form of Zn to plants because of their enhanced reactivity (Duhan *et al.,* 2017). Nano-Zn is an innovative and promising source of plant Zn nutrition due to low solubility, small size and efficient uptake of Zn for crops to fulfill its deficiency (Yang *et al.,* 2021). Zinc oxide nanoparticles play a vital role in enhancing various aspects of plant growth and potentially act as a more effective source of Zn, contributing to enhanced growth (Umar *et al.,* 2021). Alongside plant growth enhancement, ZnO-NPs play crucial roles in providing plants with stress resilience against different environmental stressors (Hassan *et al.,* 2024). Currently, numerous research investigations have been conducted to check the impact of chemical Zn fertilizers and ZnO-NPs on different crops such as wheat, eggplant, onion peanuts, and tomatoes (Ahmed *et al.,* 2023).

Keeping in mind the above discussion, current field study was conducted with the hypothesis that nano-Zn fertilizers can be better in improving growth, yield and Zn accumulation of onions. The aims of this research were to study the impact of varying application rates of chemical and nano zinc fertilizers on growth, yield, and zinc content of onion.

Material and Methods

Experiment details: A field experiment was conducted at the research fields of the Nuclear Institute of Agriculture (NIA), Tandojam, Sindh. The nursery of onion variety Nasarpuri was sown during the Rabi season of 2022-23. Total area was divided into 15 equal experimental units and each unit was 10.5 m^2 (3 m × 3.5 m). The experiment was laid out in a Randomized complete block design with five treatments and three repeats. Before transplanting seedlings, soil samples were collected at a depth of 0-20 cm from the experimental area. The representative soil samples were analyzed for various physico-chemical properties (Ryan *et al.,* 2001). The soil under study was found to be medium-textured, non-saline, slightly alkaline, poor in organic matter, low in ABDTPA-P & Zn, and medium in ABDTPA-K (Table 1).

Table 1. Soil physico-chemical properties of the experimental field.

Parameter	Value
Texture	Silt Loam
EC (dS m^{-1})	0.40
pH	7.03
Organic matter (%)	0.72
Phosphorus (mg kg^{-1})	4.8
Potassium (mg kg^{-1})	97
Zinc (mg kg^{-1})	0.51

Execution of experiment: The seedlings of 35 days were transplanted to the prepared field. At transplanting, recommended doses of N, P, and K were applied at the rate of 100-50-50 kg ha^{-1} through urea, DAP, and SOP. Analytical grade $ZnSO_4.H_2O$ and ZnO were used as chemical zinc sources. Zinc oxide nanoparticles were synthesized through chemical synthesis (Buledi *et al.,* 2020). The treatments involved, T_1: Control (No Zn applied), T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. Zinc was applied to onion crop at the time of first irrigation according to treatment plan through side dressing, after mixing with small quantity of fine sand for the homogenous distribution. The crop was irrigated four times throughout the cropping season. When the plants reached at maturity stage and bulbs were ripe, the crop was harvested.

Agronomic observations: Five healthy plants were selected from each plot at random to record various agronomic observations and analyze onion Zn concentration. Leaf biomass (g) and leaf length (cm) were recorded at the vegetative stage. While bulb weight (g), polar diameter (cm), equatorial diameter (cm), and bulb yield (kg ha^{-1}) were recorded at the maturity stage.

Plant analysis: The concentration of Zn in bulbs of onion samples was analyzed. To determine the concentration of Zn in plant, first the standards and then the samples were run on an atomic absorption spectrophotometer following Ryan *et al.,* (2001).

Statistical analysis: The recorded data were subjected to ANOVA using Statistix ver. 8.1. The means of all treatments were compared using LSD test with a significance level of 0.05 ($p<0.05$).

Results

Agronomic parameters of onion: Zinc fertilizer application through chemical and nano-Zn fertilizers significantly ($p<0.05$) increased leaf biomass of onion in comparison to control (no Zn applied). The application of chemical Zn through $ZnSO_4$ at 5.0 kg ha^{-1} recorded a maximum leaf biomass of 79.9 g (42.8%); however, 2.5 kg Zn ha^{-1} through ZnO, the other chemical fertilizer source, showed leaf biomass of 65.6 g with a least relative increase of 17.3% over no Zn application. On the other hand, ZnO-NPs at lower dose (1.25 kg Zn ha^{-1}) boosted the leaf biomass by 34.7% (75.3 g) and at higher dose (2.5 kg Zn ha^{-1}), an increase of 39.7% (78.2 g) over control was noted (Fig. 1).

Statistically, the maximum leaf length (65.4 cm) was found under the chemical Zn fertilizer treatment (5.0 kg Zn ha^{-1} through $ZnSO_4$), and minimum (42.0 cm) under control treatment, where no Zn was applied. A leaf length of 52.3 cm was observed in the chemical ZnO treatment. Furthermore, with the increasing rate of ZnO-NPs, a small increase in the leaf length was noticed. Nano-ZnO at higher (2.5 kg Zn ha^{-1}) and lower dose (1.25 kg Zn ha^{-1}) produced a leaf length of 63.9 cm and 62.0 cm, respectively (Fig. 2).

The bulb weight of onion was substantially enhanced by Zn application in comparison to where Zn was not applied. It was noticed that the maximum bulb weight (135.4 g) was obtained where ZnO-NPs were applied at reduced rate followed by ZnO-NPs at increased rate (128.3 g) with an increase of 66.8% and 58.1% over control, respectively. The application of Zn, chemically, through $ZnSO_4$ and ZnO recorded the bulb weight of (126.7 g) and (99.5 g) with 56.2% and 22.6% increase when compared with control (Fig. 3).

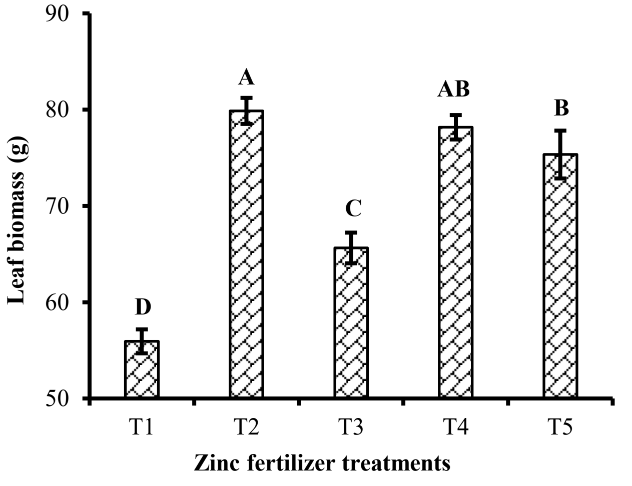

Fig. 1. Leaf biomass of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$.).

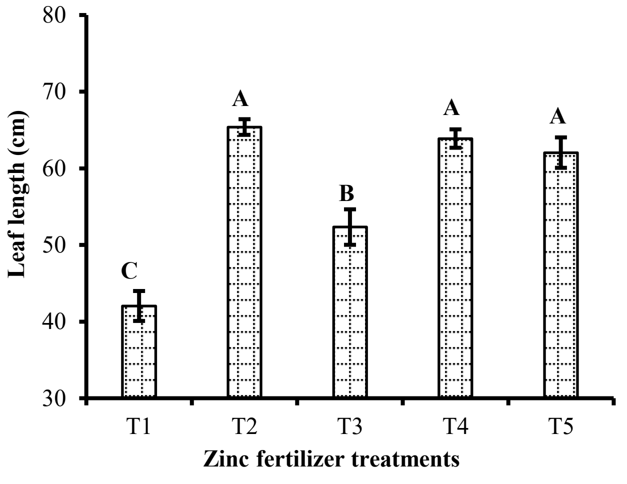

Fig. 2. Leaf length of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$.)

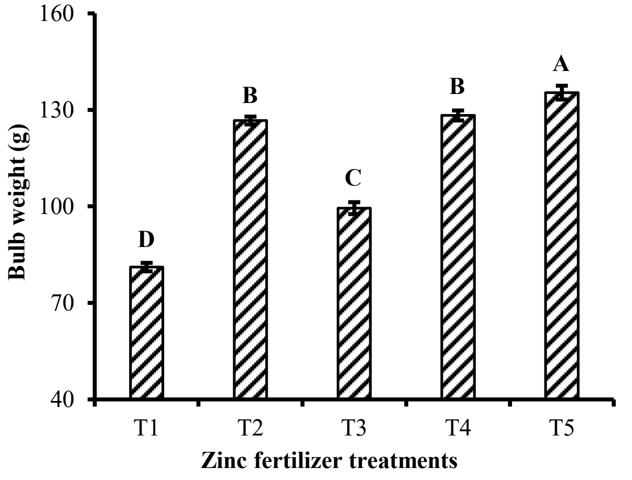

Fig. 3. Bulb weight of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$).

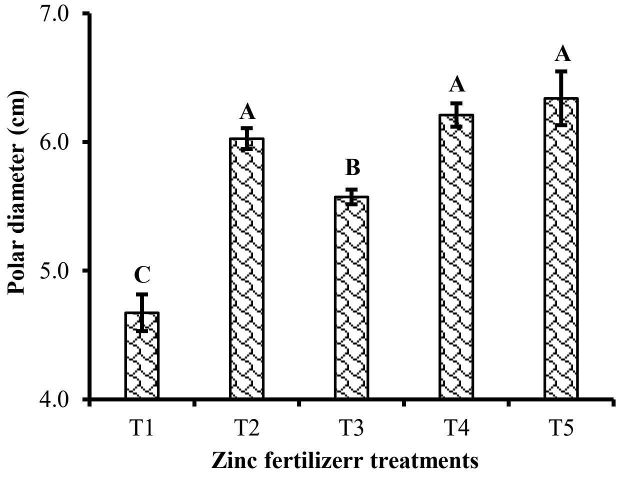

Fig. 4. Polar diameter of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$).

The ANOVA at LSD 0.05 showed that polar diameter of onion was statistically ($p<0.05$) altered by Zn fertilizer application. The plants supplemented with 1.25 kg Zn ha^{-1} through ZnO-NPs, recorded the maximum polar diameter (6.3 cm). A 35.7% increase with respect to no Zn applied treatment (4.7 cm). The application of Zn through $ZnSO_4$ at 5.0 kg ha^{-1} (6.0 cm), ZnO at 2.5 kg ha^{-1} (5.6 cm), and ZnO-NPs at 2.5 kg ha^{-1} (6.2 cm) showed an increase in polar diameter of 29.0%, 19.3%, and 32.9%, respectively, in comparison to control (Fig. 4).

The equatorial diameter ranged from 4.1 cm (control) to 5.9 cm (ZnO-NPs at 1.25 kg ha^{-1}). The later treatment remained the best performer of all with an overall increase of 45.2% over control. The least percent increase among Zn treatments over no Zn application treatment was observed where chemical Zn was applied at lower rate (2.5 kg Zn ha^{-1} through ZnO). Moreover, the application of $ZnSO_4$ at 5.0 kg Zn ha^{-1} and ZnO-NPs at increased rate produced an equatorial diameter of 5.3 cm and 5.6 cm with 30.9% and 38.0% increase respectively, when compared with no Zn application (Fig. 5).

Bulb yield of onion was increased with respect to chemical and nano-Zn fertilization. The maximum bulb yield (24477 kg ha^{-1}) was noted in treatment receiving ZnO-NPs at reduced rate, and minimum (14390 kg ha^{-1}), under the treatment receiving no Zn application. Further, the statistical data revealed that bulb yield was non-significant ($p>0.05$) between chemical Zn treatment at increased rate ($ZnSO_4$ at 5.0 kg Zn ha^{-1}) (22700 kg ha^{-1}) and ZnO-NPs at higher dose (23057 kg ha^{-1}). However, a considerable decrease in bulb yield (17747 kg ha^{-1}) was observed when onion was supplied with chemical Zn fertilizer at a reduced rate (2.5 kg Zn ha^{-1} through ZnO) (Fig. 6).

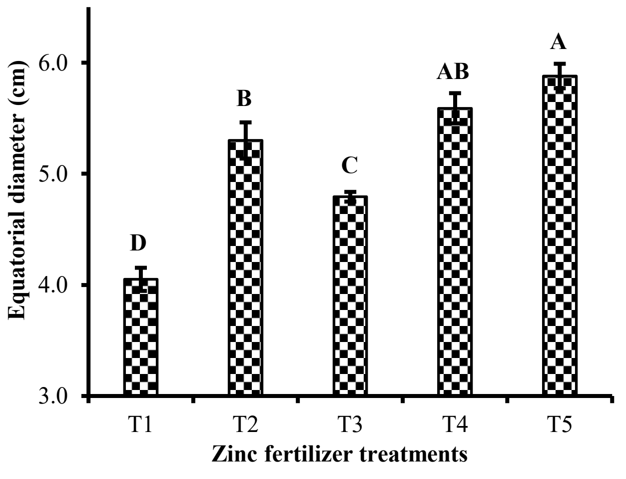

Fig. 5. Equatorial diameter of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$).

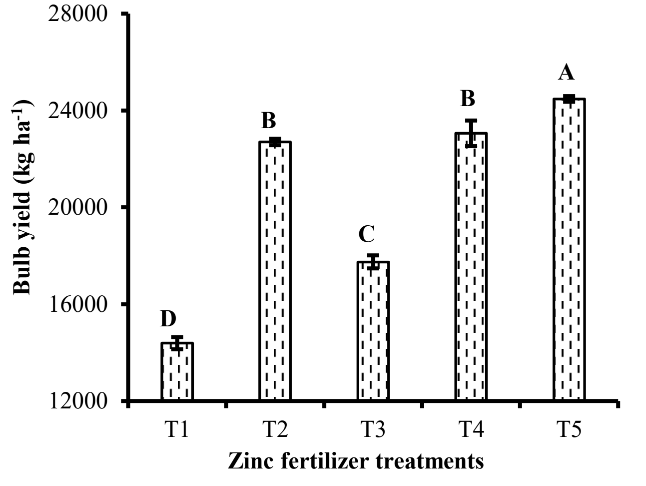

Fig. 6. Bulb yield of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$).

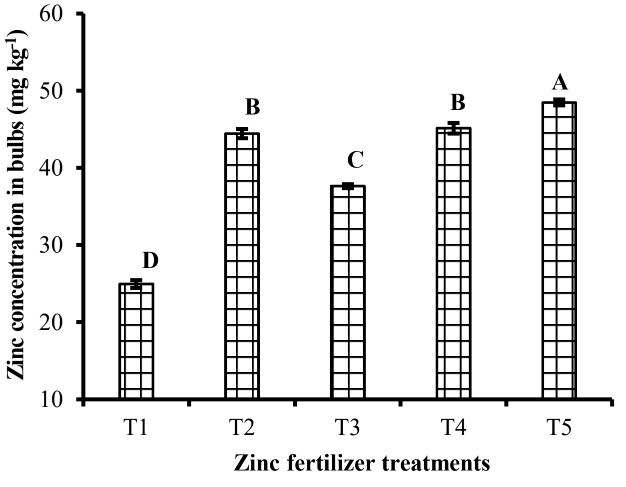

Fig. 7. Zinc concentration in bulbs of onion as affected by varying rates of chemical and nano zinc fertilizers (Zinc fertilizer treatments: T_1: Control, no Zn application, T_2: 5.0 kg Zn ha^{-1} through $ZnSO_4$, T_3: 2.5 kg Zn ha^{-1} through ZnO, T_4: 2.5 kg Zn ha^{-1} through ZnO-NPs, T_5: 1.25 kg Zn ha^{-1} through ZnO-NPs. The bars represent the average of three replicates, with standard error (n=3). Means with different letters significantly vary at $p \leq 0.05$).

Onion bulb Zinc concentration: Zinc concentration in bulbs of onion was significantly affected by the application of Zn fertilizers through various sources when compared with control. The results revealed that maximum bulb Zn concentration was found in nano-Zn application at lower dose (48.5 mg kg^{-1}) with an increase of 94.4% over control (24.9 mg kg^{-1}). The least relative increase over control was recorded in chemical Zn application through ZnO (37.6 mg kg^{-1}) with 50.9%. Furthermore, no significant difference in the bulb Zn content was observed between conventional Zn application through $ZnSO_4$ (44.4 mg kg^{-1}) and ZnO-NPs at higher dose (45.1 mg kg^{-1}) with 78.2% and 81.0% increase over control, respectively (Fig. 7).

Discussion

Influence of nano-Zn fertilizer on Agronomic parameters of onion: The application of nanofertilizers, and nano mixed micronutrient fertilizers, including Zn, significantly affects growth, yield, and quality of onion crops (Samiksha *et al.,* 2024). The exogenous application of Zn fertilizer was proved to be highly influential in terms of enhancing the growth attributes of onion (Tsewang *et al.,* 2024). The present study focused on the growth, yield, and bulb Zn accumulation of onion under various rates of conventional and nano-Zn fertilizers. Application of Zn fertilizers through different sources had a significant effect on various parameters of onion crops. A substantial increase in leaf biomass, leaf length, bulb weight, polar and equatorial diameter, and bulb yield was noticed when onion crop was supplemented with Zn nutrition. However, the effect on different growth parameters of onion varied with respect to Zn fertilizers sources. The application of Zn through ZnO-NPs at 1.25 kg ha^{-1} was found beneficial over all other treatments including the conventional Zn source, $ZnSO_4$ in enhancing agronomic and yield parameters. However, leaf biomass and leaf length were found maximum where Zn was supplied in the highest amount across the treatments ($ZnSO_4$ at 5.0 kg Zn ha^{-1}).

To the best of our knowledge, only a limited number of studies have been carried out on the response of onion crops to the application of nano-Zn. However, only one of these studies evaluated the parameters concerned with current investigation. The rest of the studies focused mostly on seed germination, early seedling growth (Raskar & Laware, 2014), and plant height of onion under the application of nano-Zn (Bala *et al.,* 2021).

The results of current research conform to those presented by Singh *et al.,* (2022) who reported that the application of ZnO-NPs resulted in the maximum leaf length, bulb diameter, bulb weight, and bulb yield. This may be due to the small size of nanoparticles which facilitate their swift penetration, and dispersion within the plant system. Additionally, the evidence suggests that ZnO-NPs play a major role not only in plant growth but also enhance the uptake and accumulation of Zn in the produce (Awad *et al.,* 2021). Furthermore, growth parameters of onion responded positively to Zn fertilizer application (Begum *et al.,* 2015). Samiksha *et al.,* (2024) suggested that nanofertilizers have proved to be highly effective when tested on onion. The application of nano mixed micronutrients, including Zn, increased polar diameter, equatorial diameter, and quality of bulbs. Moreover, the application of Zn fertilizer significantly affected leaf length, and bulb weight, yield and quality (Bhat *et al.,* 2018).

According to the results of the current study, ZnO-NPs at lower dose produced the maximum growth and yield. While the higher dose of ZnO-NPs showed a significant decrease among the recorded parameters. These results are supported by Ahmed *et al.,* (2023), mentioning that ZnO-NPs at a higher rate reduced the growth, yield, and quality of tomato crop. They further mentioned that ZnO-NPs nanoparticles at higher rate resulted in the Zn phytotoxicity and further research for the demonstration of proper dose of ZnO-NPs in plants is needed. Moreover, chemical Zn applied through ZnO responded the least among Zn applied treatments. This indicated that the bulk ZnO is less efficient than other Zn sources. Umar *et al.,* (2021) further discussed that chemical ZnO in soil is less available to plants compared to $ZnSO_4$ and ZnO-NPs.

Influence of nano-Zn fertilizer on Zn concentration in bulbs: The results revealed that bulb Zn concentration of onion was increased by the application of Zn fertilizer. The results are in line with those presented by Rafie *et al.,* (2017), suggesting that supplementing onion crop with Zn nutrient improved its bulb quality and lead to an increase in Zn accumulation in bulbs. Similarly, the addition of Zn fertilizer resulted in considerably enhanced the quality of bulbs by enriching them with Zn (Bertino *et al.,* 2022). Moreover, the application of Zn through a micronutrient grade fertilizer increased the bulb Zn concentration (Asodariya *et al.,* 2022).

In the present research, the maximum Zn concentration in bulbs was found under the treatment of ZnO-NPs at reduced rate. However, a considerable decrease in bulb Zn content was noticed under the higher dose of ZnO-NPs. This response of ZnO-NPs treatment is consistent with Du *et al.,* (2019). They determined that ZnO-NPs at higher dose reduced the Zn accumulation in the reproductive part of the plant. It was found that ZnO-NPs outperformed the chemical Zn source, $ZnSO_4$. This may be because of the smaller size, greater surface area, slow release of nutrients, and greater diffusion of nanoparticles which make them highly reactive and efficient, leading to the enhanced translocation to the productive parts (Alenzy & Al-Hadethi, 2022).

Conclusions

Zn fertilizers significantly increased the growth, and yield of onion over control treatment. It was noticed that the lower rate of ZnO-NPs was superior to its higher rate and conventional Zn sources ($ZnSO_4$ and ZnO) in terms of improving the yield and Zn concentration of onion. While $ZnSO_4$ was found beneficial in producing the maximum plant height and biomass production. This highlights that nano-Zn fertilization at lower application rate increases yield, and decreases deleterious environmental effects caused by chemical fertilizers. The application of ZnO-NPs could be an efficient strategy for increasing productivity and Zn accumulation of onion. Further experiments are warranted to demonstrate the potential of ZnO-NPs in different crops and under varying climatic conditions.

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