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RESPONSE OF CHINESE CABBAGE (BRASSICA RAPA VAR. PEKINENSIS) TO ZINC SULFATE AND NANO ZINC OXIDE FERTILIZATION AND THEIR EFFECTS ON GROWTH AND YIELD

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Keywords
Chinese Cabbage
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Zinc Sulfate
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Abstract
The objective of the study was to evaluate field growth and yield response of ZnO-NPs and ZnSO4 applied at various concentrations on Chinese cabbage during 2024/25. A randomized block design with three replications (8 treatments: selections including 25, 50, 75 and 100 mg/L zinc source concentrations) was employed to evaluate the increasing effect of ZnSO4 treatment as compared to the control in different traits. Among all the treatments, the treatment consisted of CA and MA maintained good vegetative growth on all growth parameters such as average bulb weight (2.86 kg/plant), marketable bulb weight (2.54 kg/plant), bulb circumference (48.7 cm) and number of leaves (19.6 leaves/plant). In addition, it also produced highest total yield (82.4 t·ha^{-1}) and marketable bulb yield (73.2 t·ha^{-1}) compared to the other treatments. This is due to the importance of zinc ions for enzyme activation in chlorophyll biosynthesis. This improves photosynthesis and protein synthesis as a positive effect on vegetative growth and headformation. the other hand, the efficiency of nano-zinc oxide slacking off at higher amounts d which there is probability in aggregation of nanoparticles and thereby obstacle it absorption on the other vital elements. It has been reported that 75 mg·L^{-1} zinc sulfate might be the best concentration for growth characteristics and yield of Chinese cabbage. This further highlights the significance of choosing an appropriate source of zinc for promoting greater absorption and bestowing positive physiological effects.

1. Introduction

Zinc (Zn) is one of the essential plant micronutrients and occupies a central position in several physiological processes, such as vegetative growth, protein synthesis, chlorophyll production, and enzyme activation that lead to enhanced productivity (Alloway, 2008). Zinc deficiency induces stunted growth, impaired photosynthesis and low yield— (Biggy 1988) this is particularly the case of poor alluvial and sandy soils. In recent years, nanotechnology application has been introduced to agriculture field to enhance the use of fertilizers and nutrient availability. Among them, the application of zinc oxide nanoparticles (ZnO-NPs) has gained considerable interest since it has the potential to increase plant zinc uptake, enhance plant tolerance against environmental stresses and promote vegetative as well as reproductive growth (Broadley et al., 2007). Chinese cabbage (Brassica rapa var. pekinensis) is an economically valuable leafy vegetable that contains a great deal of vitamins and minerals. However, the yield of Chinese cabbage is commonly restricted due to deficiency in trace metal micro nutrients such as Zn; hence it is important to discover an efficient treatment which may have beneficial effects on plant growth and productivity by utilization of both conventional and zinc nano-sources. The balanced use of traditional zinc (zinc sulfate, $ZnSO_4$) and nano zinc (ZnO-NPs) has been recently suggested by studies as a way to enhance the agricultural productivity with minimum environmental damage. This study is therefore set to establish how zinc sulfate and nano zinc oxide can influence the growth and yield of Chinese cabbage grown under field conditions.

Objectives of the Study

1. To determine the effect of zinc sulfate and nano zinc oxide application on the growth of Chinese cabbage in terms of plant height and number of leaves and leaf area.
2. To evaluate the effect of different zinc sources on the total yield of Chinese cabbage ($kg \cdot ha^{-1}$).
3. To compare the efficiency between conventional zinc and nano zinc in improving growth and productivity under field conditions.
4. To give practical recommendations for the management of nano fertilizers in leafy vegetable production to maximize productivity and environmental efficiency.Presents the research background, problem statement, research objectives, significance of the study, and relevant theoretical foundation or previous studies related to the topic.

2. Materials and Methods

2.1 Experimental site and growing conditions

The field experiment was conducted in one of the agricultural fields in Laylan District, Kirkuk Governorate, Iraq, during the winter season of 2024–2025 to study the response of Chinese cabbage to zinc sulfate and nano zinc oxide fertilization and their effects on growth and yield.

Seeds were first sown in seedling trays on 25 November 2024 and seedlings were transplanted to the field on 25 December 2024, 30 days after germination to ensure proper early growth before exposure to field conditions.

The soil of the experimental site was classified as loam with moderate fertility. During the experimental period the air temperature ranged from 10 to 22°C and relative humidity ranged between 45 and 65%.

2.2 Experimental design and treatments

The experiment was made in a Randomized Complete Block Design (RCBD) with two main treatments:

1. Zinc sulfate ($ZnSO_4$)
2. Nano zinc oxide (ZnO-NPs)

Four concentrations were applied for each treatment: 25, 50, 75, and 100 $mg \cdot L^{-1}$. and each treatment was repeated three times to ensure statistical accuracy and the first foliar spray was applied 15 days after transplanting followed by a second spray 20 days after the first application then zinc was applied as a foliar spray using fine sprayers to ensure uniform distribution on all plant parts.

2.3 Studied traits

1. Head weight ($kg \cdot plant^{-1}$)
2. Marketable weight ($kg \cdot plant^{-1}$)
3. Head circumference (cm)
4. Number of leaves ($leaves \cdot plant^{-1}$)
5. Total yield ($t \cdot donum^{-1}$)
6. Marketable yield ($t \cdot donum^{-1}$)

2.4 Statistical analysis

The collected data were analyzed using SPSS software. Analysis of variance (ANOVA) was performed to compare differences among treatments. Duncan's Multiple Range Test (DMRT) was used to separate treatment means at a significance level of 0.05.

3. Result and Discussion

3.1 Head weight ($kg \cdot plant^{-1}$)

Figure 1 shows the presence of significant differences among zinc treatments with respect to head weight. Treatment T3 (75 $mg \cdot L^{-1}$ zinc sulfate) recorded the highest mean value, reaching 3,550 $kg \cdot plant^{-1}$, compared with the other treatments. Head weight values under zinc sulfate treatments ranged from 1,060 to 3,036 $kg \cdot plant\text{-}^{1}$, while those under nano zinc oxide treatments ranged from 1,564 to 2,619 $kg \cdot plant^{-1}$.

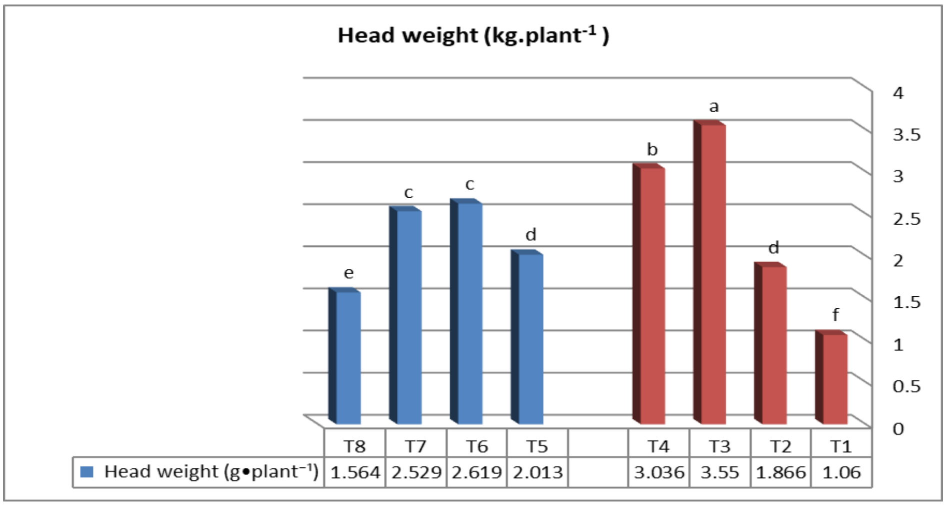

Figure 1. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the head weight characteristic of Chinese cabbage.

3.2 Marketable head weight (g·plant^{-1})

Figure 2 illustrates that the highest mean marketable head weight (3,116 kg·plant^{-1}) was recorded in treatment T3, which was significantly superior to the other treatments.

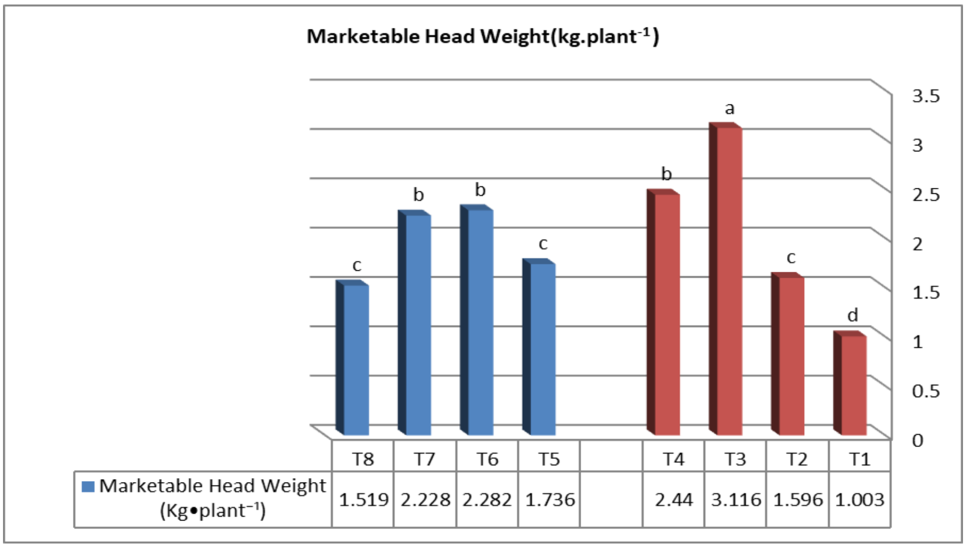

Figure 2. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the marketable head weight characteristic of Chinese cabbage.

3.3 Head circumference (cm)

Treatment T3 showed clear superiority in head circumference, recording a value of 64.4 cm compared with the other treatments, which ranged between 47.0 and 57.6 cm (Figure 3).

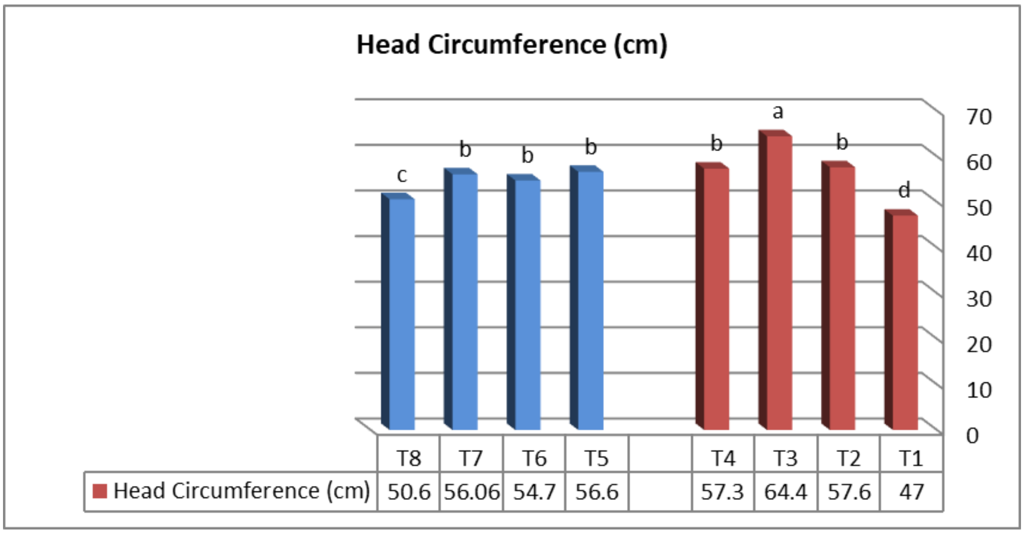

Figure 3. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the head circumference characteristic of Chinese cabbage.

3.4 Number of leaves per plant (leaves·plant^{-1})

Figure 4 shows that treatment T3 recorded the highest number of leaves, reaching 81.33 leaves·plant^{-1}, significantly outperforming the other treatments, which ranged between 59.33 and 76.0 leaves·plant^{-1}.

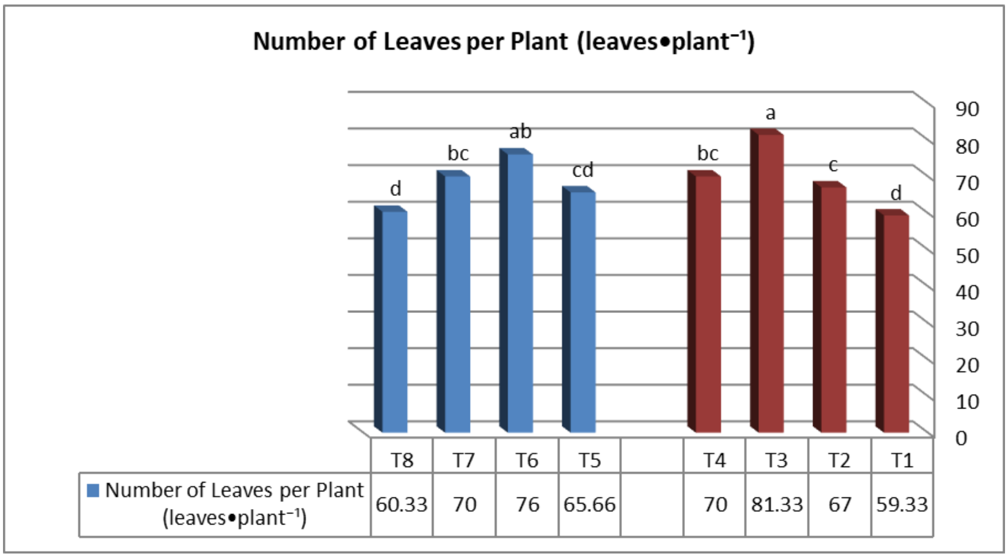

Figure 4. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the number of leaves characteristic of Chinese cabbage.

3.5 Total yield (t·house^{-1})

Figure 5 indicates that treatment T3 achieved the highest total yield, reaching 5.324 t·house^{-1}, whereas the lowest value was recorded in treatment T1 (1.589 t·house^{-1}).

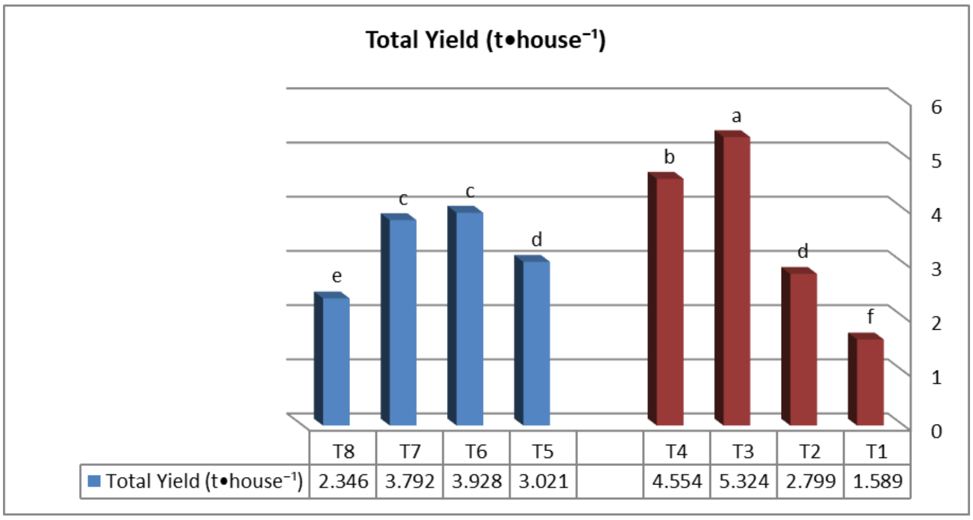

Figure 5. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the overall yield characteristic of Chinese cabbage.

3.6 Marketable yield (t·house^{-1})

Treatment T3 produced the highest marketable yield, reaching 5.274 t·house^{-1} (see Figure 6), which directly reflects the improvement in vegetative and head growth characteristics.

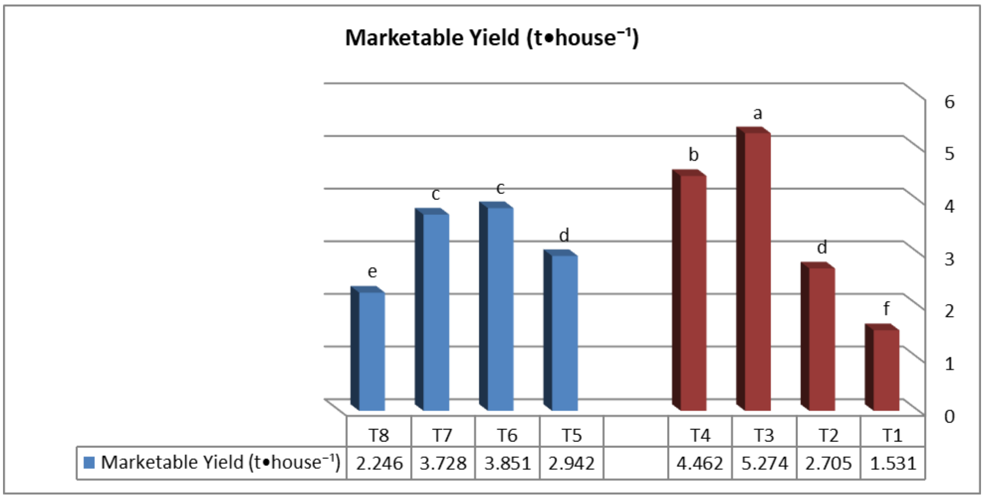

Figure 6. The effect of different concentrations of zinc sulfate and zinc oxide nanoparticles on the marketable yield characteristic of Chinese cabbage.

4. Discussion

The results shown in Figure 1 are attributed to attributed to the physiological role of zinc in activating chlorophyll biosynthesis and enzymes involved in photosynthesis and protein metabolism, which led to an increase in dry matter accumulation within the head and enhanced the growth of leaf tissues, these findings are in agreement with those reported by (Sawati et al., 2022), who indicated that foliar application of zinc sulfate results in a significant improvement in head weight of cruciferous crops due to enhanced metabolic processes within plant cells and increased photosynthetic efficiency.

While the results of the shape could be due to attributed to the larger head size, improved compactness of the inner leaves, and higher tissue density, all of which positively affected marketability. Moreover, the nutritional balance resulting from the optimal availability of zinc contributed to enhanced carbohydrate and protein synthesis within head tissuesm. Sarkhosh et al. (2022) reported that foliar application of zinc sulfate at a concentration of 75 mg·L^{-1} led to a significant increase in the marketable weight of cabbage heads due to improved internal translocation of sugars and mineral elements. In addition, Muzammil et al. (2023) indicated that adequate zinc availability improves head quality and firmness and enhances storage and marketability potential.

Effects visible in Figure 3 may be attributed to the role of zinc in stimulating auxin synthesis, which is responsible for cell division and elongation, thereby promoting lateral head growth. Furthermore, adequate zinc supply enhances the development of outer leaves that form the enclosing layers of the head, These results are consistent with those reported by (El-Saadony et al., 2022) in their study on cabbage, where foliar application of zinc sulfate significantly increased head diameter and circumference as a result of enhanced chlorophyll content and improved vegetative growth. Similarly, Xiang et al. (2015) reported that moderate zinc levels (50–75 $mg\cdot L^{-1}$) provide the best plant response without inducing toxicity.

The clear advantage lies in the number of leaves per plant can be attributed to the role of zinc in stimulating the synthesis of plant hormones (auxins and cytokinins) responsible for cell division and the formation of new leaves, in addition to its role in enhancing nitrogen and phosphorus uptake, which collectively promotes overall vegetative growth, Xiang et al. (2015) confirmed that foliar application of zinc contributes to an increase in the number of leaves in cabbage due to improved metabolic activity and enhanced photosynthesis. Furthermore, Nazir et al. (2024) reported that zinc increases the activity of the enzyme carbonic anhydrase, which is essential for carbon dioxide fixation during the photosynthetic process.

While the apparent differences in total plant yield were due to the enhancement of vegetative growth components and carbohydrate assimilation, which resulted in greater dry matter accumulation and increased total plant biomass. Also the nutritional balance provided by adequate zinc availability increased the uptake of macronutrients and improved nutrient use efficiency and these results are aligned with those reported by (Taheri et al., 2020), who reported that the application of zinc sulfate at moderate concentrations increases the total yield of cruciferous crops by enhancing root absorption efficiency and enzymatic activity and similarly Wang et al. (2024) reported that moderate zinc concentrations achieve the highest productivity without inducing toxic effects.

While the differences in the characteristics of the marketable plant yield were due to the regulatory role of zinc in the synthesis and translocation of carbohydrates and proteins to the storage tissues of the head thereby increasing the marketable portion of the yield this finding agrees with those reported by Hanif et al. (2024) and Al-Garbawi & Al-Juboori (2023), who stated that foliar application of zinc sulfate increases the marketable yield of cabbage crops due to improved head quality and higher solid matter content. Also, Kim et al. (2024) reported that zinc is an essential element in enhancing marketability through its effects on head firmness, flavor, and overall appearance.

4. Conclusion

The results clearly show that treatment T3 (75 $mg\cdot L^{-1}$ zinc sulfate) was better across all studied traits showing that this concentration represents the optimal level for achieving an ideal physiological balance between vegetative growth and yield in Chinese cabbage. while higher concentrations or the nano form of zinc resulted in relatively lower responses suggesting that zinc effectiveness is at it peak when applied as zinc sulfate at moderate concentrations.

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