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RESEARCH PAPER

Influence of Soil and Foliar Zinc Sulfate Treatments on Growth and Development of Cut Ornamental Sunflower

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Abstract

Zinc (Zn), an essential micronutrient, plays critical roles in plant growth and physiological regulation. In *Helianthus annuus* L., proper Zn management is necessary to support plant development and the quality parameters that affect commercial performance. However, studies that evaluate different zinc treatment methods and doses in this species simultaneously remain limited. This study was conducted to determine the effects of different Zn doses applied foliarly and through the soil, as well as combinations of these treatments, on growth, quality, and post-harvest performance in *Helianthus annuus* 'Solano Orange Summer' F_1. The experiment consisted of 18 predefined Zn treatment regimes ($ZnSO_4$ $7H_2O$, 20% Zn), including combined treatments representing practical Zn management strategies. Within the scope of the study, flower stem length, stem thickness, flower diameter, number of leaves, branch weight, SPAD value, harvest date, and vase life parameters were evaluated. Among the combined foliar and soil treatments, the highest stem length was obtained in the ZF_8+$ZT_{0.5}$ (8 mg L^{-1} from foliar treatment + 0.5 mg L^{-1} from soil treatment) treatment, while branch weight increased in the ZF_4+$ZT_{1.5}$ (4 mg L^{-1} from foliar treatment + 1.5 mg L^{-1} from soil treatment) treatment. Leaf number increased in the ZF_2+$ZT_{2.5}$ (2 mg L^{-1} from foliar treatment + 2.5 mg L^{-1} from soil treatment) treatment, whereas the earliest harvest and longest vase life were determined in the ZF_8+$ZT_{1.0}$ (8 mg L^{-1} from foliar treatment + 1.0 mg L^{-1} from soil treatment) treatment. The SPAD value was particularly high in the ZF_8 treatment (8 mg L^{-1} via foliar treatment). It was determined that all combined Zn treatments resulted in higher branch weight and leaf number compared to the control treatment. In conclusion, this study revealed that Zn treatments have different effects on growth, quality, and postharvest performance in cut ornamental sunflowers depending on the dose and application method.

1. Introduction

Ornamental sunflower (*Helianthus annuus* L.) is an important ornamental plant encompassing both cut flower and potted varieties. Its commercial value stems primarily from its morphological characteristics, such as flower color, size, and form. Beyond cultivation for aesthetic landscaping and decorative uses, it also holds a significant place in the rapidly growing global cut flower industry (Cvejić et al., 2025; Hajano et al., 2025). In this context, nutrient management is a crucial factor in enhancing quality and physiological performance in cut ornamental sunflowers, and the role of zinc, a micronutrient, in plant production is particularly notable.

Zinc sulfate ($ZnSO_4$) is the most commonly used inorganic form of zinc fertilizer applied to soil; the main reason for this is that its solubility is higher than that of oxides and carbonates, and its cost is lower than that of synthetic chelates and complexes (Gonzalez et al., 2007). Zinc (Zn) is an essential micronutrient for growth and development in plants, involved in the structure or activation of numerous enzymes; however, since excess can be toxic, there is a "narrow optimum range" for plants. Therefore, Zn treatment is a critical management element in terms of both yield/quality in field crops and morphological characteristics that determine the market value in ornamental plants (Broadley et al., 2007). Zinc deficiency is a widespread problem worldwide, especially in calcareous-alkaline soils; under these conditions, the availability of Zn to plants can decrease, and the response to fertilizer treatments can become more pronounced (Cakmak et al., 1996). In Türkiye, Zn deficiency is also a significant problem limiting agricultural production. Zinc deficiency has been reported in large cultivated areas, and it has been emphasized that appropriate Zn management is necessary for yield increase (Cakmak et al., 1996; Cakmak et al., 1999). In this context, providing Zn at the correct dose and through the correct treatment method is crucial for both the nutrient reaching the plant and achieving the targeted growth and development responses. In ornamental sunflowers, cultivation success depends on marketable quality parameters such as plant height, leaf development, stem diameter/strength, flowering time, and harvest window; therefore, determining the effect of Zn treatments on these developmental indicators is necessary both scientifically and practically. It is suggested that Zn treatments in sunflowers may have significant effects on vegetative development and physiology (Jafari et al., 2024; Raghavendra et al., 2020).

In terms of treatment method, soil treatment of Zn aims to increase the availability of the nutrient in the root zone, while foliar treatments are considered a rapid "corrective" strategy, especially in conditions where Zn uptake is restricted due to processes such as binding/precipitation in the soil (Broadley et al., 2007). However, detailed isotope/tracking studies have shown that the translocation of foliar Zn treatments within the plant may be limited; a significant portion of the applied Zn remains in the leaf, and its distribution changes over time towards the vascular tissues (Li et al., 2022). Therefore, it is possible that sufficient Zn transport to the target organs (e.g., stem, head) cannot be achieved with foliar treatment alone; this strengthens the rationale for "soil + leaf" combinations (Li et al., 2022). Studies evaluating the combined use of soil and foliar treatments often show that combination strategies can generate stronger agronomic responses compared to single treatments. For example, it has been reported that the combined treatment of Zn and Fe to the soil and foliar areas can have a beneficial effect on growth and yield in sunflowers (Raghavendra et al., 2020). Similarly, it has been reported that the foliar treatment of $ZnSO_4$ at certain developmental stages (phenological stages such as "star bud" in some studies) can have effects on growth indicators and parameters related to the transition to flowering; explanations have been made through Zn's contribution to chlorophyll and photosynthesis-related processes (Rex Immanuel et al., 2019; Rex Immanuel et al., 2020). Furthermore, considering the limited transport dynamics of Zn in the plant, combining regular supply from the root zone with rapid foliar supplementation can help ensure a balanced supply of Zn in terms of both continuous and short-term requirements (Broadley et al., 2007; Li et al., 2022).

Although Zn nutrition has been investigated in various ornamental and agronomic crops, studies comparing foliar and soil Zn treatments together with their combined dose effects in cut ornamental sunflower production are limited. Unlike previous studies that mainly evaluated Zn treatments separately, the present study comparatively investigates individual and combined soil and foliar $ZnSO_4$ treatments to determine their effects on plant growth and flower quality parameters. Against this background, this study aims to develop practical Zn fertilization strategies for cut ornamental sunflower production.

2. Material and Methods

2.1. Location and plant material

This study was conducted in a glass greenhouse with top and side ventilation, lacking a heating and cooling system, at the Tokat Gaziosmanpaşa University Agricultural Applications and Research Center during the summer of 2025. During the study period (June 15-August 30), the average daily radiation intensity ranged from 580 to 710 µmol $m^{-2} s^{-1}$. The average indoor temperature during the study period ranged from 28.5 to 35.4°C, and the relative humidity ranged from 60% to 70%. The lowest temperature recorded was 10.2°C, and the highest temperature was 52.7°C (HOBO U12 Temp/RH/Light External Data Logger (U12-012), ONSET, United States of America). Ventilation was provided by automatic roof vents.

The plant material used was cut ornamental sunflower (*Helianthus annuus* ‘Solano Orange Summer’ F_1) seeds, commonly used for cut flower production.

2.2. Growing conditions and cultural practices

Seeds were sown at a depth of approximately 1-2 cm in a pre-prepared growing medium consisting of a 3:1 (v/v) mixture of peat (Klasmann TS1, Lithuania) and perlite. The peat substrate was composed of white sphagnum peat commonly used in horticultural production and characterized by low nutrient content and acidic properties (pH 3.0–3.5, $CaCl_2$), with no added fertilizers or lime according to the manufacturer specifications. This standardized substrate with minimal inherent nutrient content allowed the evaluation of plant responses primarily to the applied Zn treatments. The experiment was conducted in production trays with drainage holes (20 cm height × 40 cm width × 60 cm length). During the growing season, all plants were fertilized twice weekly with a water-soluble NPK fertilizer (20-20-20 + TE; Van Iperen International, Netherlands) at an electrical conductivity of 1.5 dS m^{-1}. The fertilizer contained micronutrients including Zn (0.008% w/w, EDTA-chelated). This basal fertilization program was uniformly applied to all treatments to maintain adequate plant nutrition. Therefore, differences observed among treatments were primarily attributed to the additional Zn treatments supplied through soil and foliar $ZnSO_4$ treatments. Using a drip irrigation system, the daily water requirement was balanced by providing 100 mL of water per plant in the early morning and late evening. Planting distances were arranged in a double-row system, with spacing determined by the plot dimensions. Accordingly, plants were positioned at a planting density of 6 plants per m^2 with a spacing of 15 × 15 cm between plants.

2.3. Zinc treatments and treatment methods

The experiment was conducted using 18 treatment groups, including a control, representing different zinc ($ZnSO_4$) doses applied through foliar, soil, and combined treatment methods. Details of treatment compositions are presented in Table 1. Zinc treatments were initiated when plants reached the 4-6 true leaf stage after transplanting. Treatments were repeated at weekly intervals and continued until flower buds became visibly distinguishable. Zinc solutions were applied either as foliar spray or soil treatment depending on the treatment group. Treatment volume was adjusted according to plant growth, starting from 25 mL per plant and gradually increased up to 100 mL per plant during the experimental period. Tween-20 was added to all treatment solutions at 0.1% (v/v) as a surfactant to improve solution adherence and absorption (Thind et al., 2021). Control plants received the same volume of distilled water containing Tween-20 at identical concentrations. Zinc sulfate heptahydrate ($ZnSO_4.7H_2O$, 20% Zn) was preferred as the Zn source. Zinc treatment doses and treatment methods were selected according to effective and non-phytotoxic ranges reported in previous studies on ornamental plants and cut flowers, taking into account foliar and soil nutrient uptake pathways as well as potential interaction effects (El-Naggar et al., 2018; Saeed et al., 2013). Foliar Zn doses were selected at low and medium concentrations, while soil treatments were arranged in a gradually increasing sequence. Furthermore, combination treatments using both foliar and soil treatments were created, based on a combination of medium doses, to allow for comparison of the effects of both treatment methods individually and together.

2.4. Measured parameters

The end of vase life was determined when approximately 60% of petals exhibited wilting, browning, and abscission symptoms, indicating loss of decorative quality (Friedman et al., 2007; Schoellhorn et al., 2003; Shatoori et al., 2021). This period is considered the stage that provides optimum decorative quality and vase life for cut ornamental sunflowers.

Plant growth and flower quality parameters were evaluated at harvest and postharvest stages. Flower stem length was measured using a ruler

Table 1. Predefined zinc treatment regimes used in the experiment.

Treatment no	Code	Content
1	C	Control (EC 1.5 dS m^{-1}, 20+20+20+ TE)
2	ZF_2	Foliar 2 mg L^{-1}
3	ZF_4	Foliar 4 mg L^{-1}
4	ZF_6	Foliar 6 mg L^{-1}
5	ZF_8	Foliar 8 mg L^{-1}
6	$ZT_{0.5}$	From the soil 0.5 mg L^{-1}
7	$ZT_{1.0}$	From the soil 1.0 mg L^{-1}
8	$ZT_{1.5}$	From the soil 1.5 mg L^{-1}
9	$ZT_{2.5}$	From the soil 2.5 mg L^{-1}
10	ZF_2+$ZT_{1.0}$	Foliar 2 mg L^{-1} + From the soil 1.0 mg L^{-1}
11	ZF_4+$ZT_{0.5}$	Foliar 4 mg L^{-1} + From the soil 0.5 mg L^{-1}
12	ZF_4+$ZT_{1.5}$	Foliar 4 mg L^{-1} + From the soil 1.5 mg L^{-1}
13	ZF_6+$ZT_{1.0}$	Foliar 6 mg L^{-1} + From the soil 1.0 mg L^{-1}
14	ZF_6+$ZT_{2.5}$	Foliar 6 mg L^{-1} + From the soil 2.5 mg L^{-1}
15	ZF_8+$ZT_{0.5}$	Foliar 8 mg L^{-1} + From the soil 0.5 mg L^{-1}
16	ZF_8+$ZT_{1.0}$	Foliar 8 mg L^{-1} + From the soil 1.0 mg L^{-1}
17	ZF_4+$ZT_{2.5}$	Foliar 4 mg L^{-1} + From the soil 2.5 mg L^{-1}
18	ZF_2+$ZT_{2.5}$	Foliar 2 mg L^{-1} + From the soil 2.5 mg L^{-1}

C: Control treatment (EC 1.5 dS m^{-1}, 20–20–20 + TE fertilizer); ZF: Foliar Zinc ($ZnSO_4$) Treatment; ZT: Soil Zinc ($ZnSO_4$) Treatment; EC: Electrical conductivity; TE: Trace elements.

from the substrate surface to the flower head (Smith and Ennos, 2003), while stem thickness and flower diameter were determined using a digital caliper at harvest and full bloom stages, respectively. The number of leaves per plant was determined by manual counting, and branch weight was measured using a precision balance at harvest. Chlorophyll content was assessed using a SPAD-502 chlorophyll meter during the full vegetative development period. Vase life was determined through daily observations and recorded as the number of days from harvest until the loss of decorative value, according to standard postharvest evaluation procedures (Friedman et al., 2007; Schoellhorn et al., 2003; Shatoori et al., 2021). Harvest dates were recorded using calendar-based observations.

2.5. Experimental design and statistical analysis

The experiment was conducted on ornamental sunflower (*Helianthus annuus* L.) using a randomized complete block design with three replications. Each experimental unit consisted of eight plants, resulting in a total of 432 plants (18 treatments × 3 replications × 8 plants). To minimize border effects, measurements were taken on six centrally located plants per experimental unit, and the average values were used for statistical analysis.

Treatments consisted of 18 Zn treatment regimes, including foliar, soil, and combined treatments at different doses. Although Zn treatments involved both foliar and soil treatments, the experimental design was not arranged as a full factorial combination of factors. Instead, treatments represented predefined Zn management regimes including individual and selected combined treatments commonly used under practical production conditions. Therefore, treatments were considered independent experimental units and analyzed using one-way ANOVA. Data were subjected to a one-way analysis of variance (ANOVA), with treatment as a fixed effect and block (replication) as a random effect, using SPSS (IBM SPSS Statistics for Windows, Version 26.0; Armonk, NY, USA). When significant differences were detected, mean comparisons were performed using Duncan’s multiple range test at $P \leq 0.05$. Graphs and heat map visualizations (it is not provided here) were generated using GraphPad Prism (Version 10.0.0 for Windows; GraphPad Software, Boston, MA, USA).

3. Results and Discussion

The effects of the treatments on morphological and post-harvest characteristics were evaluated using one-way analysis of variance (ANOVA). According to the ANOVA results, statistically significant differences were found between the treatments in terms of flower stem length ($P = 0.003$), number of leaves ($P < 0.001$), branch weight ($P = 0.037$), harvest date ($P < 0.001$), vase life ($P = 0.018$), and SPAD value ($P = 0.008$). However, no significant differences were found between the treatments in terms of flower stem thickness ($P = 0.509$) and flower diameter ($P = 0.785$).

The length of the flower stems varied significantly depending on the treatments. The lowest stem length was determined as 88.2 cm in the C treatment, while the highest value was found as 121.1 cm in the $ZF_8+ZT_{0.5}$ treatment. Among the single soil treatments, $ZT_{1.0}$ (115.7 cm) and $ZT_{1.5}$ (112.5 cm) treatments resulted in relatively high stem lengths. Combination treatments $ZF_4+ZT_{2.5}$ (118.6 cm) and $ZF_4+ZT_{1.5}$ (117.8 cm) also stood out with their high stem lengths.

There was no statistically significant difference in flower stem thickness between the treatments, with values generally ranging from 7.1 to 8.7 mm. Similarly, flower diameter was not significantly affected by the treatments, with averages ranging from 97.5 to 111.8 mm.

Branch weight showed a significant difference depending on the treatments. The lowest branch weight was determined as 71.63 g in the C treatment, while the highest value was recorded as 108.27 g in the $ZF_4+ZT_{1.5}$ treatment. Furthermore, a significant increase in branch weight compared to the control treatment was also observed in the $ZF_8+ZT_{0.5}$ (101.37 g) and $ZF_2+ZT_{2.5}$ (99.83 g) treatments (Figure 1).

Leaf number was significantly affected by the treatments (Figure 2). The lowest leaf number was determined as 17.4 in the ZF_6, while the highest value was found as 21.0 in the $ZF_2+ZT_{2.5}$. In the C treatment, the leaf number was 19.1, and it was observed that the leaf number increased compared to the control treatment, especially in some combination treatments.

Harvest date varied significantly according to the treatments. The earliest harvest occurred in the $ZF_8+ZT_{1.0}$ treatment at 52.4 days, while the latest harvest was recorded in the C treatment at 57.2 days. These results suggest that certain Zn treatments can reduce the time it takes for plants to reach harvest. Significant differences were determined between the treatments in terms of vase life.

The shortest vase life was 5.8 days in the ZF_4 treatment, while the longest vase life was 9.3 days in the $ZF_8+ZT_{1.0}$ treatment. Furthermore, an increase in vase life was observed in the $ZF_4+ZT_{1.5}$ (8.8 days) and $ZF_6+ZT_{2.5}$ (8.7 days) treatments.

SPAD values varied significantly depending on the treatment. The highest SPAD value was determined as 41.77 in the ZF_8 treatment, while the lowest value was found as 36.87 in the $ZF_8+ZT_{1.0}$ treatment. In the C treatment, the SPAD value was 40.37, and it was observed that SPAD values fell below the control in some combination treatments (Figure 2).

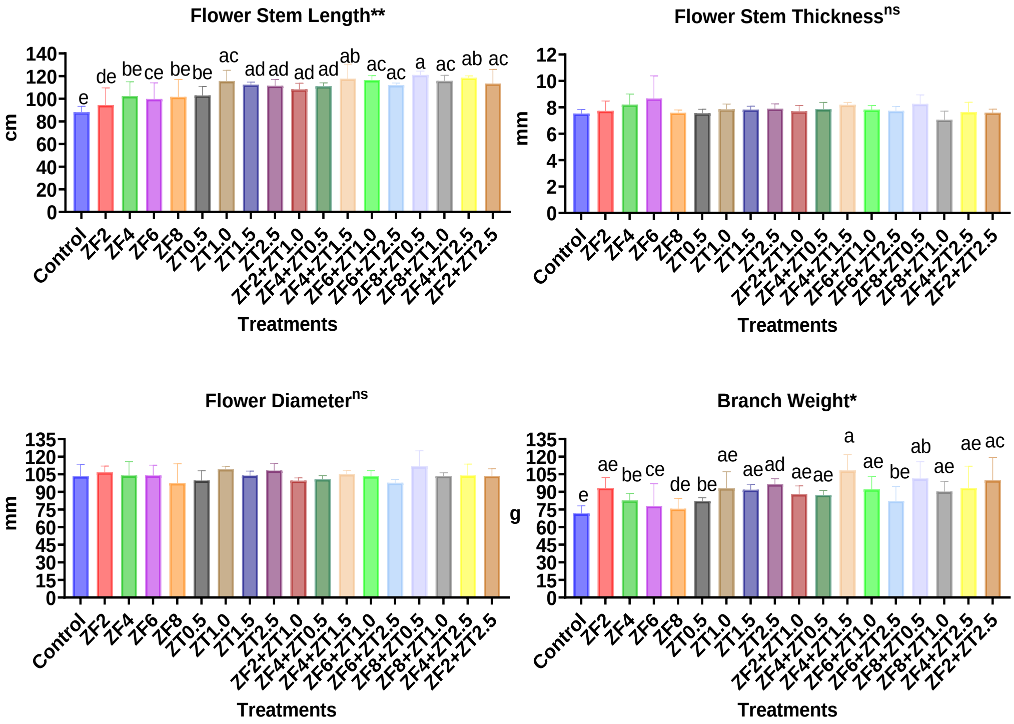

Figure 1. Effects of different ZnSO$_4$ concentrations and treatment methods on flower stem length, flower stem thickness, flower diameter, and branch weight in ornamental sunflower (Values shown in columns represent the mean values, and bars represent the standard errors of three replicates. *: $P<0.05$, **: $P<0.001$, ns: $P>0.05$).

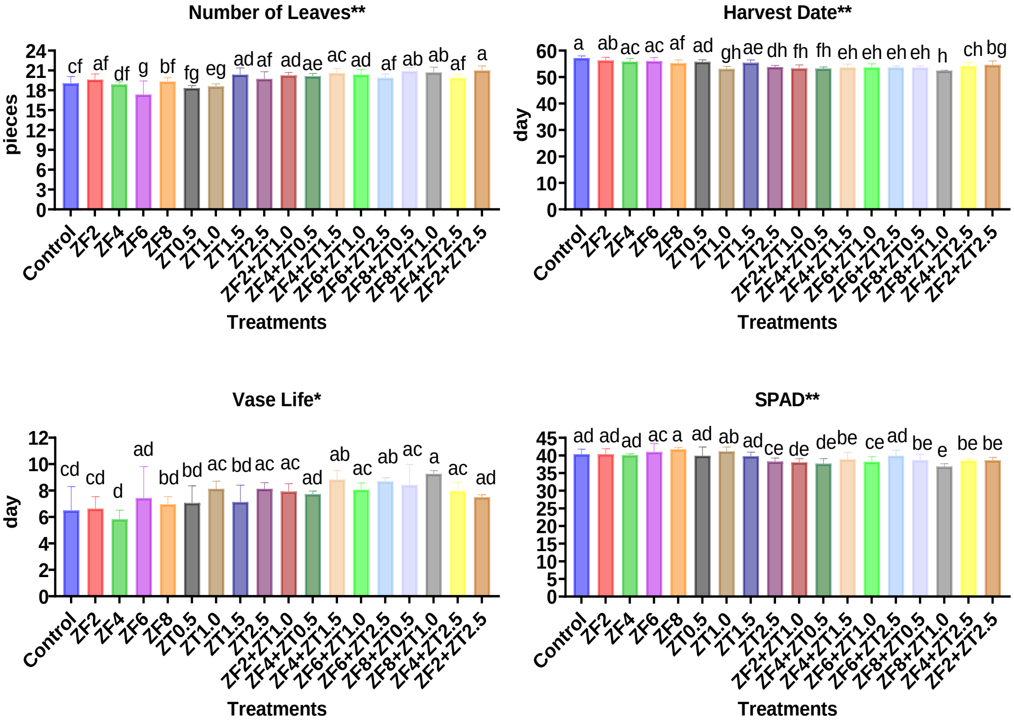

Figure 2. Effects of different ZnSO$_4$ concentrations and treatment methods on leaf number, harvest date, vase life, and SPAD values in ornamental sunflower (Values shown in columns represent the mean values, and bars represent the standard errors of three replicates, *: $P<0.05$, **: $P<0.001$. C: Control, EC 1.5 dS m^{-1}, 20+20+20+ TE, ZF$_2$: Foliar 2 mg L^{-1}, ZF$_4$: Foliar 4 mg L^{-1}, ZF$_6$: Foliar 6 mg L^{-1}, ZF$_8$: Foliar 8 mg L^{-1}, ZT$_{0.5}$: From the soil 0.5 mg L^{-1}, ZT$_{1.0}$: From the soil 1.0 mg L^{-1}, ZT$_{1.5}$: From the soil 1.5 mg L^{-1}, ZT$_{2.5}$: From the soil 2.5 mg L^{-1}, ZF$_2$+ZT$_{1.0}$: Foliar 2 mg L^{-1} + From the soil 1.0 mg L^{-1}, ZF$_4$+ZT$_{0.5}$: Foliar 4 mg L^{-1} + From the soil 0.5 mg L^{-1}, ZF$_4$+ZT$_{1.5}$: Foliar 4 mg L^{-1} + From the soil 1.5 mg L^{-1}, ZF$_6$+ZT$_{1.0}$: Foliar 6 mg L^{-1} + From the soil 1.0 mg L^{-1}, ZF$_6$+ZT$_{2.5}$: Foliar 6 mg L^{-1} + From the soil 2.5 mg L^{-1}, ZF$_8$+ZT$_{0.5}$: Foliar 8 mg L^{-1} + From the soil 0.5 mg L^{-1}, ZF$_8$+ZT$_{1.0}$: Foliar 8 mg L^{-1} + From the soil 1.0 mg L^{-1}, ZF$_4$+ZT$_{2.5}$: Foliar 4 mg L^{-1} + From the soil 2.5 mg L^{-1}, ZF$_2$+ZT$_{2.5}$: Foliar 2 mg L^{-1} + From the soil 2.5 mg L^{-1}).

Zinc (Zn) is one of the essential micronutrients involved in the growth and development processes of plants, and when applied in appropriate doses, it has positive effects on plant performance (Sattar et al., 2022; Wang et al., 2020). The results obtained in this study revealed that zinc treatments created significant differences in cut flower quality characteristics, especially depending on the treatment method and dose. The increase in flower stem length with both foliar and soil Zn treatments compared to the control treatment clearly demonstrates the plant growth-promoting effect of Zn. In particular, the highest stem length was observed in the $ZF_8+ZT_{0.5}$ treatment, supporting the notion that zinc treatment at appropriate levels promotes plant growth, as reported in previous studies (Afshar et al., 2020; Kamran et al., 2023).

In single soil treatments, the relatively high stem lengths achieved with $ZT_{1.0}$ and $ZT_{1.5}$ doses indicate that Zn is absorbed through the root environment, contributing to plant growth. However, the similar high stem lengths observed in some combinations of foliar and soil treatments ($ZF_4+ZT_{2.5}$ and $ZF_4+ZT_{1.5}$) highlight the importance of the interaction between treatment method and dose, as emphasized in previous studies (Hassan et al., 2021; Sher et al., 2022). This suggests that Zn uptake through both the leaf surface and the roots can affect plant growth (Ahmed et al., 2025; Wei et al., 2022).

The lack of significant impact on flower stem thickness and flower diameter suggests that Zn treatments may have a limited effect on some morphological characteristics. In contrast, the significant increase in branch weight, particularly in combination treatments, indicates that Zn supports plant biomass formation. The highest branch weight was obtained with the $ZF_4+ZT_{1.5}$ treatment, consistent with the yield and quality-enhancing effects of Zn treatments reported in previous studies (El-Habbasha et al., 2015; Sher et al., 2022). The significant change in leaf number, depending on the treatments (Figure 2), supports the role of Zn on vegetative development. The fact that the highest leaf number was reached with the $ZF_2+ZT_{2.5}$ treatment, in particular, indicates that low-to-medium dose combinations can promote leaf development. The increase in leaf number observed in some Zn combinations compared to the control treatment can be attributed to zinc's regulatory role in plant metabolism; indeed, Zn deficiency is reported to negatively affect auxin synthesis, leading to a decrease in leaf formation (Wei et al., 2022). The significant change in harvest date depending on the treatments revealed that Zn treatments can affect the plant's development time. The earliest harvest occurred with the $ZF_8+ZT_{1.0}$ treatment, indicating that some Zn doses can shorten the time it takes for plants to reach harvest. Similarly, previous studies have reported that Zn treatments can affect the rate of plant growth and physiological maturation (Xing et al., 2018; Zhang et al., 2012). The results obtained in terms of vase life show that Zn treatments also have an effect on post-harvest quality. The fact that the longest vase life was observed in the $ZF_8+ZT_{1.0}$ treatment and that vase life increased in some combinations compared to the control treatment suggests that Zn treatments can positively impact flower resistance. The variation in SPAD values according to the treatments shows that Zn treatments are related to leaf chlorophyll content. The fact that the highest SPAD value was obtained with a high Zn dose applied foliarly suggests that foliar treatments may have an effect on parameters related to photosynthetic capacity. However, the fact that SPAD values fell below the control in some combinations indicates that Zn dose and treatment method should be carefully managed. This result is consistent with studies in the literature, which report that both Zn deficiency and excessive Zn treatment can have a negative impact on plant performance (Afshar et al., 2020).

4. Conclusion

The study revealed that zinc treatments had varying effects on the examined characteristics, depending on the treatment method and dose. In terms of flower stem length, both foliar and soil-applied zinc combinations were found to produce higher values compared to the control treatment, with the highest stem length obtained in the $ZF_8+ZT_{0.5}$ (foliar 8 mg L^{-1} + soil 0.5 mg L^{-1}) treatment. In single soil treatments, it was observed that medium and high doses increased stem length. However, flower stem thickness and flower diameter were not significantly affected by the treatments. Significant differences were found between treatments in terms of branch weight and leaf number, with some combinations using both foliar and soil treatments providing higher values compared to the control treatment. Regarding harvest date, it was determined that some zinc treatments shortened the time it took for plants to reach harvest, while harvesting occurred later in the control treatment. Vase life results showed that zinc treatments also had an effect on post-harvest quality. In particular, it was found that vase life was significantly extended in some combination treatments. In terms of SPAD values, significant differences were determined among the treatments; higher doses of zinc applied foliarly resulted in higher SPAD values, while in some combinations, SPAD values fell below the control level. The study revealed that zinc treatments have different effects on growth, quality, and post-harvest performance parameters in cut flowers depending on the dose and treatment method. In particular, some zinc combinations using both foliar and soil treatments together yielded more positive results compared to the control treatment for many of the examined characteristics.

Overall, the findings of this study indicate that zinc treatments have varying effects on growth, quality, and post-harvest performance in cut flowers, depending on the dose and treatment method. Specifically, some combinations using both foliar and soil treatments together yielded more positive results compared to single treatments and the control group. These results suggest that zinc treatments can be an effective tool for improving quality in plant production.

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