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Foliar Application of Zn-Nanoparticles and Zn-EDTA to Induce Salinity Resistance in Safflower Irrigated by Diluted Seawater

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Abstract: In order to evaluate the influence of the foliar spray of nanoparticle- or chelated-zinc combined with the saline water irrigation on the growth and the mineral status of safflower plants, a pot experiment was conducted in the greenhouse of the National Research Centre, Dokki, Cairo, Egypt. The treatments included foliar spraying; comprises of zinc nanoparticles (Zn-NP) and chelated zinc (Zn-EDTA) along with no zinc application (ZnC) treatments, with the combination of three levels of saline water irrigation prepared by dilution of seawater (tap water: 270 ppm, medium saline water: 3000 ppm, high saline water: 6000 ppm). Results showed that increasing salinity of irrigation water significantly reduced the dry weight of the aboveground biomass as well as the carbohydrate and protein content of safflower leaves. The negative impact of salinity was also extended to the elements' content in the plant leaves. Regardless of the salinity of irrigation water, both zinc sources significantly enhanced the dry weight of the aboveground biomass, total carbohydrate and protein content along with uptake of K, Ca, Mg, Fe, Zn, Mn and Cu in plant leaves comparable with ZnC. Meanwhile, Zn-NP was more effective in these responses. Under any salinity level, spraying of Zn-NP augmented the dry weight of aboveground biomass as well as the protein and carbohydrate content in leaves in comparison with any other Zn treatment. These enhancements reached 123, 163 and 259 %, respectively, compared to ZnC under 6000 ppm salinity. The minerals acquisitions were impacted by the combination between salinity levels and different zinc sources. The highest uptake was obtained by interacting Zn-NP with tap water irrigation or Zn-NP with medium saline water irrigation. In addition, zinc spray under medium and high salinity conditions reduced the sodium/elements ratios (Na/K and Na/Ca ratios), alleviating the repressive influence of salinity. This work pointed out the amelioration ability of Zn nanoparticles toward the mitigation of salinity effects, enhancing the growth of safflower plants grown under different salinity levels.

Key words: Zn-NP · Safflower · Salinity stress · growth · Nano fertilizer · Protein · Mineral uptake · carbohydrate

INTRODUCTION

Agricultural and food security are among other sectors threatened by global climate change. Since it influences the spatial and temporal distribution of rainfall and water availability and changes the irrigation requirements [1]. Despite the recent efforts that focused on improving the irrigation systems' efficiencies, it is estimated that the net irrigation requirements may be augmented globally up to 45 % by 2080 [2]. Looking for additional water resources was taken into consideration as a governmental plan, facing the expected water demand. Seawater or saline well water are among other unconventional resources for irrigation water just after the subjection to different desalination techniques. However, the cost and difficulties of these techniques would be obstacles for the wide application and sustainability in agriculture. Lately, various investigations have considered the direct application of saline water in irrigation systems, focusing on advanced and smart agricultural management to eliminate the deleterious effect of salinity on plants. These studies covered the development and breeding of some salt-resistant plants, selecting salinity-tolerant plant species for cultivation,

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employing the alternating irrigation technique between fresh water and diluted saline water and strengthen the nutritional status of a plant to enhance the resistance potential to salinity damage [3, 4, 5].

Safflower (*Carthamus tinctorius* L.) is one of the important plants gaining attention due to its various utilities. Its flowers are produced for food seasoning, medicinal purposes, coloring dye and animal feed. The seeds are used as birdseed and for edible oil production [6]. It is an economical oil crop, yields about 40 % oilseed, used for biofuel production. The safflower plant is characterized by its potential for cultivation under different stress conditions such as drought, high temperature and salinity [7]. Proper management is needed for the cultivation of this plant in arid and semiarid lands, in which salinity is one of the major problems for production [3, 8, 9].

Salinity of soil and water is one of the main factors that lead to stagnation of agricultural productivity in arid and semi-arid areas, affecting distinctly plant distribution and productivity. Salinity exposes plants to different stresses such as the osmotic stress initiated by increasing salt concentration at the rhizosphere area, thus limits soil water potential, inhibiting water uptake and reducing plant growth [10, 11]. Another undesirable effect of salinity is the balance disruption of nutrient uptake, which might lead to ionic toxicity [12, 13]. Increasing the salinity restricts plant growth and reduces the yield. Previous studies reported various symptoms on safflower plants when irrigated by saline water, such as reduction of the dry weight, fresh weight, plant height, stem diameter and the haste of flowering and maturity [14, 15, 16]. Physiologically, salinity affects diversely on growth parameters of a plant that was expressed by a decrease in chlorophyll and total soluble protein contents, as well as nitrite reductase activities and an increase in the proline and carbohydrate contents. While the most notable influence of salinity was a reduction of cell growth, thus, in turn, reflected on leaf area and biomass, leading to yield decrease [15, 17]. Management strategy such as applying leaching requirements as well as utilizing low saline water for irrigation until plant emergence before using the saline water were deemed as recommended processes to implement through the cultivation of safflower crop in a saline environment [3]. Attention to strengthening the nutritional status of the plant may be another suggested technique to alleviate the negative impact of salinity.

Fertilizers are the main source of nutrients that plays a key in inducing plant tolerance against different environmental stresses, in addition to their essential roles in the vital functions in the plant and productivity [12, 18, 19, 20]. Zinc is one of the intrinsic elements for humans, animals and plants' lives. That drew the attention toward the nutritional advantage of elevating Zn content in the basic food crops [21]. It exists in the plant tissues as ions or as an essential component assimilating into protein. Zn ion and its components played a vital role in plants metabolism and biomass production. It is among other elements that played a direct or indirect role in carbohydrate breakdown and involved in protein synthesis [22, 23]. It is performed as a regulatory factor for many enzymes and incorporated in several activities such as gene expression, hydrogenase and carbonic anhydrase and energy production, along with chlorophyll and cytochrome synthesis [24, 25, 26, 27, 28]. Further, zinc has a crucial function in plant’s strategies against salinity, drought and pathogens [29, 30, 31, 32]. Accordingly, the deficiency of this nutrient led to several physiological processes disruptions, reducing crop production and yield quality. Thus, the supply of soils and field crops by zinc fertilizers is crucial for crop productivity [33].

On the other hand, zinc is a heavy metal, the long use of its fertilizers upon large-scale areas, particularly with excess application leads to the accumulation of this element. In this case, zinc is directly absorbed in excessive amounts into the plant tissues, which inhibits the metabolic functions and causes absorption competition between zinc and other essential nutrients such as iron and phosphorus, reducing the growth and the yield [34, 35, 36]. Additionally, the continuous accumulation of zinc might drive to ionic toxicity, damaging soil microflora, affecting negatively the ecosystem [37]. The proper fertilization method and rate are the basis of any efficient agricultural management system. Nano-fertilizers utilization could be an approach to handle this issue, which controls the fertilizer amount and enhances the utilization efficiency, reducing environmental pollution [38].

Nanotechnology can be identified as a science, technology carried out using materials, atoms, or molecules in dimensions ranged 1-100 nm [39]. The inclusion of nanoscience in biotechnology applications such as biopesticides and fertilizers contributes to a rapid progress in field of food safety and quality [40, 41, 42, 43]. Nanotechnology can revolutionize the agricultural sector by providing innovative strategies for understanding and conquering stress phenomena in the environment and assists in increasing food production [44]. Nowadays, there is a growing interest in the beneficial application of nano-fertilizers in consolidate crops to withstand biotic and abiotic stresses [45, 46, 47, 48]. Nano-fertilizers are fertilizers produced in nanoscale by chemical, physical or biological methods that enhance their characteristics and improve their performance compared to conventional fertilizers [49]. The application of nano-fertilizers promotes plant growth and enhances nutrients absorption, moreover, it reduces the used amount of fertilizers and induces the plant tolerance towards various risks. Hussien *et al*. [19] demonstrated that using of nano-phosphorus fertilizer increased the uptake of macro- and micro-nutrients and improved the growth of cotton plants cultivated under drought conditions as well as under conventional irrigation. Nanohybrids urea-hydroxyapatite was formed as a slow nitrogen fertilizer and a rich source of phosphorus, which exhibited efficiency for growing rice crops, aiming to reduce the used fertilizers rate [50]. Further, a recent investigation studied the influence of nano Zn-Fe oxide and biofertilizer on the growth parameters and yield of wheat cultivated under salinity conditions [51]. Thereby the results indicated that the applied fertilizers had the amelioration ability toward the negative effect of any employed salinity level. Narendhran *et al*. [52] illustrated the importance of the biological Zn-NP treatment on improving the growth of *Sesamum indicum*, which was grown under Zn deficient soil. Moreover, Shang *et al*. [53] mentioned that using fertilizers in nanoscale increased the nutrients use efficiency in a plant, increasing the yield productivity.

Thus, this study aimed to investigate the influence of two sources of foliar Zn fertilizer (Zn nanoparticles and Zn-EDTA) on the growth and mineral status of safflower plants cultivated under various salinity levels. To achieve this aim the study was designed to test the following hypotheses: i) the irrigation of safflower plant with saline water affects negatively the growth (indicated by shoot dry weight), as well as the uptake and balance of nutrients. ii) Foliar application of Zn nanoparticles enhances the growth and nutrients acquisitions in safflower plants, compared to chelated Zn (Zn-EDTA) or no Zn application. iii) Spraying of Zn nanoparticles and Zn-EDTA induce the salinity tolerance of safflower plants cultivated under various salinity levels.

MATERIALS AND METHODS

Assessment the response of the growth and nutrients status of safflower plants grown under salinity conditions and sprayed with Zn-nanoparticles or chelated-Zn fertilizers was investigated via conducting a pot experiment in the greenhouse of the National Research Centre, Dokki, Cairo, Egypt. The experiment included nine treatments which were the interaction between three salinity treatments and three foliar fertilization treatments. The saline irrigation treatments comprised of two levels of saline water, prepared by dilution of seawater (EC = 54 dS^{-1}; pH = 7.9), to obtain medium saline irrigation water (EC = 3000 ppm; named MSW) and high saline irrigation water (EC = 6000 ppm; called HSW) besides the tap water (EC = 270 ppm; TW) as a control. Zinc nanoparticles (denoted Zn-NP) and chelated-zinc (denoted Zn-EDTA) materials were employed for the foliar fertilization treatments, along with distilled water (denoted ZnC) as a control (zero zinc treatment). The foliar fertilizers at a concentration of 150 Zn mg l^{-1}; were sprayed twice after 21 and 35 days from the planting time.

An earthenware pot, 40 cm in diameter and 50 cm in height, was filled with 30 kg clay loam soil. The soil was characterized by a pH of 7.4, an EC of 8.7 dS m^{-1}, a calcium carbonate content of 2.3 % and organic matter = 0.7 %. Safflower (Carthamus tinctorius L.) seeds were sown on November 15th in the 2015/2016 winter season. To avoid the osmotic shock, seeds had two weeks of tap water irrigation before employing the salinity treatments. Calcium superphosphate (15.5 % P_2O_5) and potassium sulfate (48.5 % K_2O) at the rate of 3 g pot^{-1} were broadcasted on the soil surface before sowing. Ammonium sulfate fertilizer (20.5 % N) was applied in two equal doses; the first was after 21 days from sowing and the second was applied two weeks later.

Two plants of each replicate were collected and the dry weight of the aboveground biomass was measured. The leaves were collected, cleaned, oven dried (at 60 ºC) and ground in a stainless steel mill, afterward were kept for the mineral analysis. The ground materials (leaves) were digested using a mixture of acids and the minerals were analyzed using the methods described by Cottenie [54]. The total nitrogen was estimated by the Kjeldahl method and phosphorus was determined by the ammonium-vanadate and molybdate method according to Motsara and Roy[55]. Sodium, potassium and calcium were measured by a flame photometer and the analyses of iron, zinc, manganese, copper and magnesium were carried out by atomic absorption spectrometry. Total carbohydrates in plant leaves were determined by the phenol - sulphuric acid method according to Dubois *et al*. [56]. Protein was calculated by multiplying the nitrogen content with the conversion factor of 6.25 [57].

The experiment was set up in a complete randomized block design with three replicates. The collected data were subjected to proper statistical analysis and the differences between means at probability of 5% were differentiated using Fisher LSD Method.

RESULTS AND DISCUSSIONS

Irrigation by Different Water Salinity: Influence of saline irrigation water on dry weight of the aboveground biomass; protein and carbohydrate content in leaves of safflower plants are presented in Fig. 1 and Table 1. Generally, salinity had significant influence on all investigated parameters. Increasing the salinity significantly reduced the dry weight as well as the carbohydrate and protein content. The reduction for the dry weight was 14.1 % with the medium saline irrigation water (MSW) and reached to 48.3 % with the high saline irrigation water (HSW) compared with the irrigation by tap water (TW). Similar trend were recorded for both carbohydrate and protein content in plant leaves. In which their content reduced up to 17 and 21 %, respectively, by MSW compared to the TW. However, the reduction percentages of those components reached to around 50% with the irrigation by HSW. The irrigation by saline water had also a negative impact on the minerals contents in plant leaves (Fig. 2 and Table 1). In general, uptake of minerals was declined significantly due to the irrigation with saline water, where the reduction was aggravated by increasing the water salinity level. The drastic decline recorded more than 40 % for K, Ca, Mg, P and Mn uptake; and reached up to 50 and 64 % for Cu and Fe, respectively, compared to the control. The measured sodium concentration (%) in leaves increased as the salinity of irrigation water increased (not shown data), while the estimated Na uptake (mg plant^{-1}) decreased conjugated with the declining of leaves' dry weight. The calculated sodium ratios of elements under the saline stress are shown in Fig. 3 and Table 2. Wherein Ca/Na, Mg/Na, Ca/K, Ca/(K+Na) and Mg/(K+Na) ratios were declined by the irrigation with MSW compared to the irrigation with TW, except for K/Na ratio and further declining of the ratios were recorded after the irrigation by HSW.

Foliar Application of Different Zinc Forms: Apart from salinity of irrigation water, the impact of foliar application by different Zn sources on the growth of safflower plants were investigated in this study. Wherein zinc nanoparticles (Zn-NP) and chelated zinc (Zn-EDTA) were applied and their impact on the dry weight of the aboveground biomass; protein and carbohydrate content of leaves of safflower plants were recorded. Regardless to the Zn source, the zinc foliar application elevated the dry matter as well as the carbohydrate and protein content (Fig. 4). The enhancements were 24.5, 109 and 57.6 % by using Zn-EDTA and reached to 82.3, 147 and 78.9 % by Zn-NP, respectively. Accordingly, foliar zinc fertilizers influenced significantly the content and uptake of nutrients in the plants leaves; the data are represented in Fig. 5 and Table 1. Foliar zinc enhanced the uptake of N, K, P, Ca, Mg, Fe, Mn and Cu up to 56, 28, 72, 38, 97, 78, 49 and 44 %, respectively, by Zn-EDTA and 74, 44, 105, 58, 151, 105, 80 and 80%, respectively, by Zn-NP. Likewise, Zn-NP increased substantially uptake of Zn in plant leaves (up to 60 %) compared with that by using Zn-EDTA. On the other hand, significant reduction in sodium concentration (%) in plant leaf was observed after the application of Zn spray (not shown data), while the direction was reversed when the concentration value was related to the dry weight to obtain leaf sodium uptake (mg plant^{-1}) (Fig. 5). Further, the results revealed that the values of Ca/Na, Mg/Na, Ca/K, Ca/(K+Na) and Mg/(K+Na) ratios were increased after applying the foliar fertilization treatments compared to the control (Fig. 7). However, there were no significant differences in the ratios values between the two Zn foliar types (Table 2).

Interaction of Salinity and Sources of Zn Fertilizers: Effect of the interaction between salinity (TW, MSW, HSW) X foliar fertilization (ZnC, Zn-EDTA, Zn-NP) on the dry weight of above-ground parts of safflower plants along with carbohydrate and protein contents in plants leaves were depicted in Fig. 7 and Table 1. Under TW treatment (no saline condition), application of Zn foliar fertilizers boosted the dry weight and the superiority was registered for the Zn-NP treatment; as it increased up to 78 % than the control. The improvement effect of Zn was also noted for both protein and carbohydrate content, achieving significant enhancements up to 75 % for protein and 149 % for carbohydrate content by Zn-NP application compared to the control.

Further, the data in Fig. 7 pointed out that Zn-EDTA treatment increased the dry weight, protein and carbohydrate content by 7, 36 and 89 %, respectively, under MSW and 87, 150 and 241 %, respectively, under HSW compared to control treatment (ZnC). However, those records were changed to 69, 47 and 101 %, respectively, under MSW and 123, 163 and 259 %, respectively, under HSW condition by using of Zn-NP fertilizer. The acquisitions of minerals in plants leaves were influenced by the interaction of salinity and foliar

Table 1: Summary of analysis of variance (ANOVA) for dry weight of aboveground biomass, protein, carbohydrate and mineral content of safflower leaves as affected by foliar spray of Zn-NP and Zn-EDTA under different salinity environments

Treatment	Dry weight	Carbohydrate	Protein	N	P	K	Na	Ca	Mg	Fe	Zn	Mn	Cu
Salinity	***	**	***	***	***	***	***	***	***	***	***	**	***
Foliar fertilizer (Zn)	***	***	***	***	***	***	***	***	***	***	***	***	***
Salinity x Zn	***	ns.	**	ns.	ns.	ns.	***	ns.	ns.	ns.	ns.	ns.	ns.

ns: non-significant, * $P \leq 0.05$, ** $P \leq 0.01$, *** $P \leq 0.001$

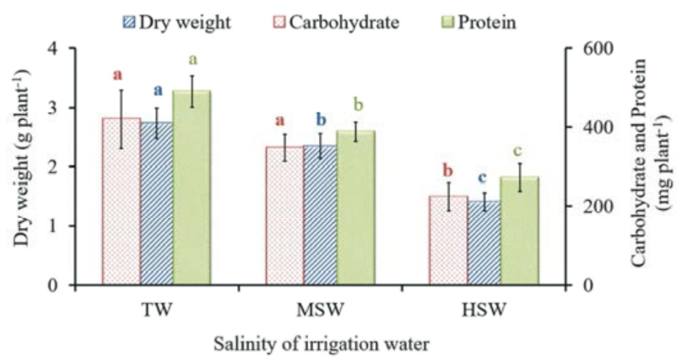

Fig. 1: Dry weight of the above-ground biomass, along with the protein and carbohydrate content in leaves, of safflower plants affected by different salinity levels of irrigation water. TW is tap water; MSW and HSW are the medium and high saline water, respectively. Values are means (n = 3) and the vertical bars represent standard errors. Different letters have the same color within each characteristic are significantly different at $P \leq 0.05$ according to Fisher's LSD method

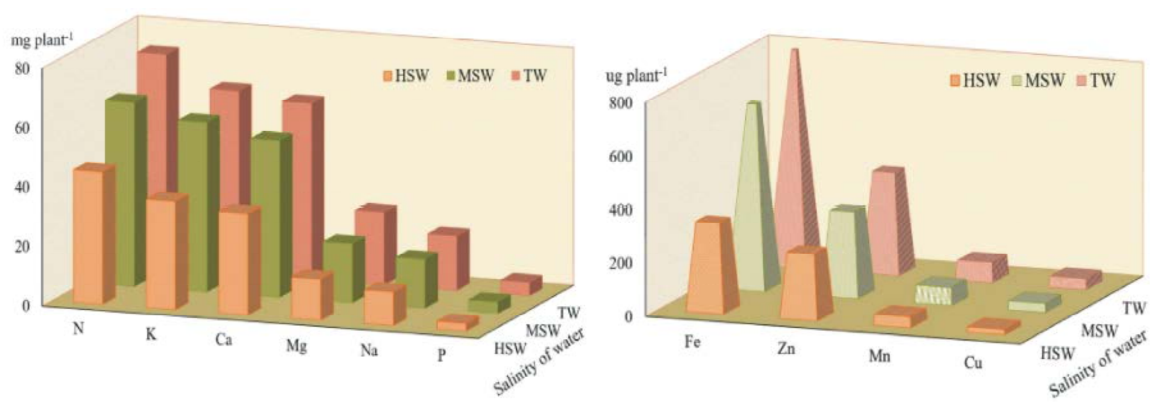

Fig. 2: Response of elements contents in leaves of safflower plant to different salinity levels of irrigation water. TW is tap water; MSW and HSW are the medium and high saline water. Values are means of three replicates

application of zinc (Fig. 8 and Table 1). The obtained data revealed that among all treatments the foliar application of Zn-NP recorded the highest uptake of minerals at any level of salinity. In general, the highest uptake was achieved by the combination of Zn-NP treatment with TW irrigation as well as Zn-NP under MSW irrigation. Further, using of zinc spray under MSW and HSW irrigation resulted in reduction in sodium/elements ratios (Fig. 9). In which Na/K and Na/Ca ratios were declined after applying of Zn-EDTA and Zn-NP spray under all salinity treatments. On the other hand the interaction of those treatments elevated the ratios of Mg/Na, Ca/(Na+K) and Mg/(Na+K) compared to distilled water spray (ZnC) at the same salinity level.

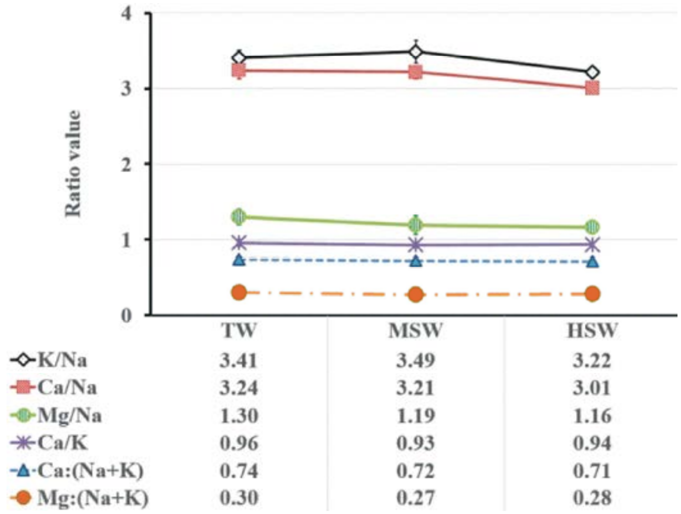

Fig. 3: Sodium ratios affected by the salinity of the irrigation water. TW is tap water; MSW and HSW are the medium and high saline water, respectively. Values are means (n = 3) and the vertical bars represent standard errors

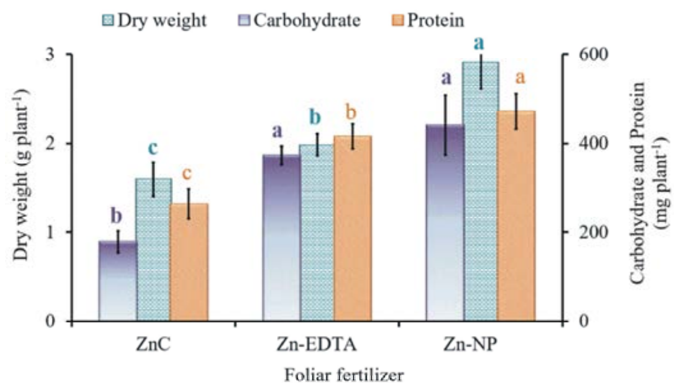

Fig. 4: Effect of foliar fertilization with different Zn sources on the dry weight of the aboveground biomass, as well as the protein and carbohydrate contents in leaves, of safflower plant. ZnC is no Zn treatment (control). Zn-EDTA and Zn-NP are the chelated and Nano sources of zinc, respectively. Values are means (n = 3) and vertical bars represent standard errors. Different letters have the same color within each characteristic are significantly different at $P \leq 0.05$ according to Fisher's LSD method

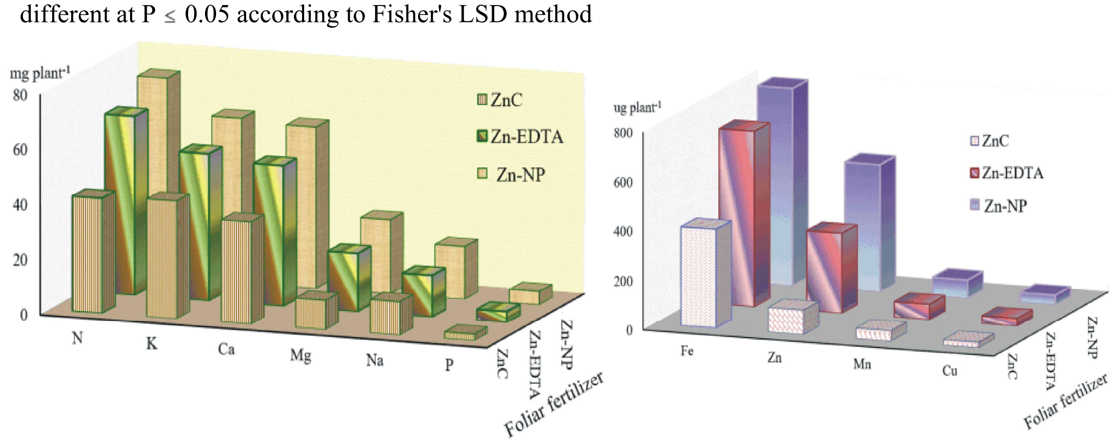

Fig. 5: Effect of foliar fertilization of Zn-nanoparticles (Zn-NP) and chelated zinc (Zn-EDTA) on the mineral absorption in safflower leaves. ZnC is no Zn treatment (control). Values are means of three replicates

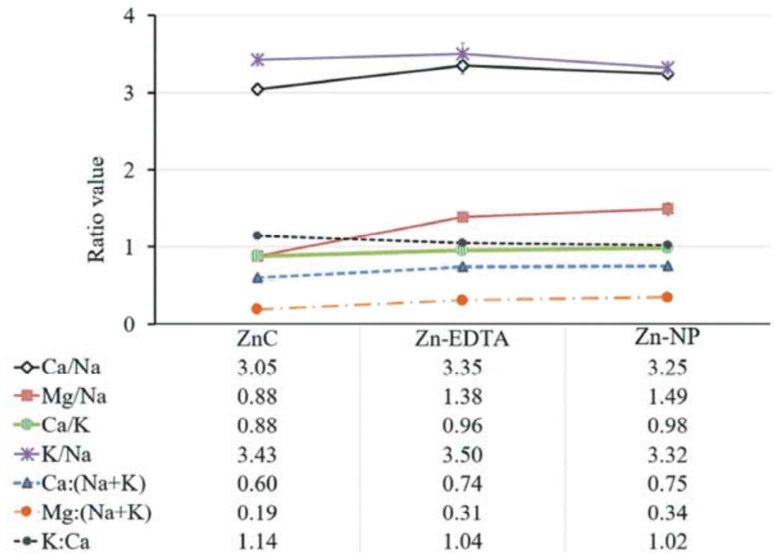

Fig. 6: Effect of foliar fertilization of Zn-nanoparticles (Zn-NP) and chelated zinc (Zn-EDTA) on the sodium/mineral ratios. ZnC is no Zn treatment (control). Values are means (n = 3) and vertical bars represent standard errors

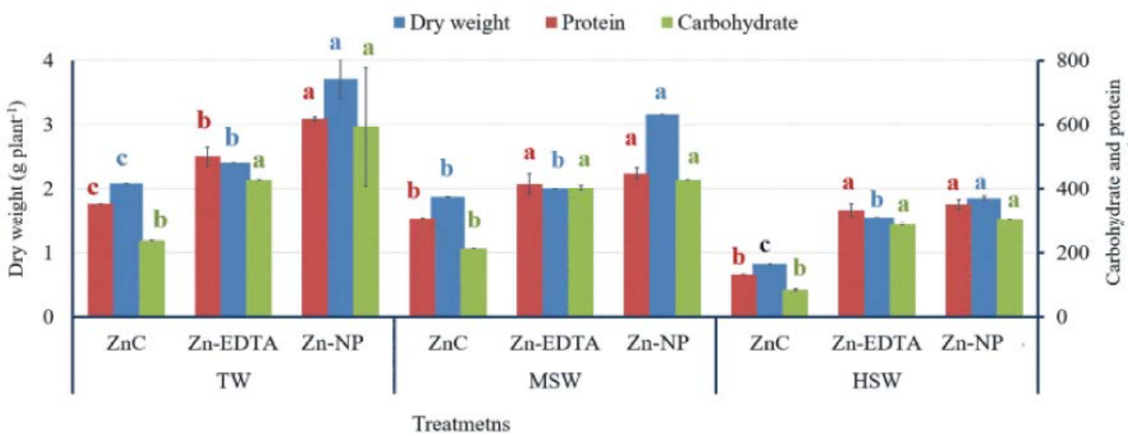

Fig. 7: Interaction effect of salinity (TW, MSW and HSW) and sources of Zn fertilizer (ZnC, Zn-EDTA and Zn-NP) on the dry weight of the above-ground biomass and the protein and carbohydrate contents in leaves of safflower plant. Data are the mean value of three replications and vertical bars represent standard errors. Significant different at P ≤ 0.05 among foliar Zn fertilizer under each salinity level are indicated by the letters have same color.

Table 2: Analysis of variance (ANOVA) for sodium/mineral ratios in safflower leaves as affected by foliar spray of Zn-NP and Zn-EDTA under different salinity environments

Treatment	Na/K	K/Na	Na/Ca	Na/Mg	K/Ca	Ca:(Na+K)	Mg:(Na+K)
Salinity	ns.	ns.	ns.	ns.	ns.	ns.	ns.
Foliar fertilizer (Zn)	*	*	ns.	***	ns.	ns.	***
Salinity x Zn	ns.	ns.	ns.	ns.	ns.	ns.	ns.

ns: non-significant, * P ≤ 0.05, ** P ≤ 0.01, *** P ≤ 0.001

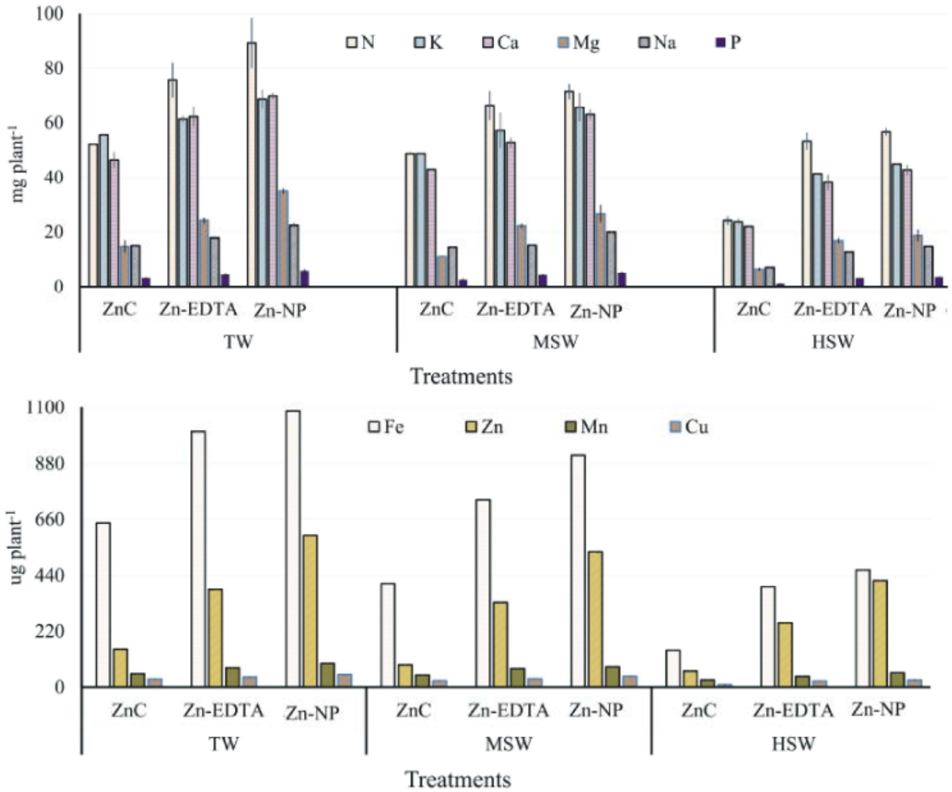

Fig. 8: Interaction effects of salinity (TW, MSW and HSW) and the sources of Zn fertilizer (ZnC, Zn-EDTA and Zn-NP) on minerals uptake in leaves of safflower plants. Values are means (n = 3) and the vertical bars represent standard errors

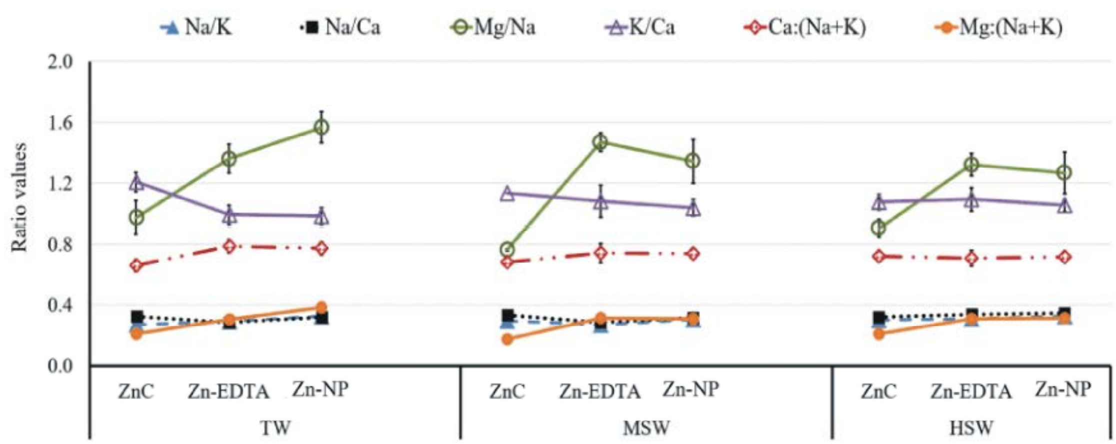

Fig. 9: Interaction effects of salinity (TW, MSW and HSW) and the sources of Zn fertilizer (ZnC, Zn-EDTA and Zn-NP) on sodium ratios. Values are means (n = 3) and vertical bars represent standard errors

DISCUSSIONS

Involvement of saline water in the irrigation systems represent an urged solution to fill the gap between increasing water need and limited freshwater resources in arid and semiarid areas [58]. However, using of such type of water has adverse effects on agriculture production. In this study, safflower plant was grown under salinity stress conditions via the irrigation by different dilution levels of seawater. The salinity impaired the growth of plants, indicated by the reduction of dry weight of the aboveground biomass. The results illustrated that increasing salinity of the irrigation water negatively influenced the acquisition of essential nutrients and reduced ratios of nutrients to sodium, leading to nutrient imbalance and adversely affected the carbohydrate and protein content, which accordingly inhibited the growth (Figs. 1, 2 and 3). These effects were more severe by increasing the salinity level of the irrigation water (HSW). Most literature mentioned the negative effects of saline environments on the yield, plant fresh and dry weight and on the physiological processes inside the plants [12, 13, 17, 59, 60, 61]. They indicated that the harmful impact of salinity initiated via decreasing water potential at the rhizosphere area, due to the accrual of salts; increasing the osmotic pressure; reducing stomatal conductance; disruption of nutrients balance and increasing ratio of Na content to the other minerals in plant cells. Thereby, causing reduction in nutrients absorption and translocation inside the plant, ultimately inhibited plant growth [62]. Nevertheless, other studies cleared that extent of the deleterious effect of salinity is correlated to the tolerance degree of the plant varieties [11, 63, 64, 65, 66, 67]. Thus, the situation calls for finding different managements approaches in order to keep the sustainability of involving seawater or saline well water in the irrigation system being visible. Zinc fertilization could be an option in the agricultural management processes to abate salinity risk, helping the plant for better growth [68].

The current investigation inverted high significant responses of all studied parameters to the foliar application of Zn fertilizers regardless of the Zn source. Since spraying of Zn-NP and Zn-EDTA promoted the growth of safflower plant, which was indicated by the enhancement of the dry weight of aboveground biomass at the normal growth condition (no saline irrigation; TW treatment). Similar effect was extended to all measured attributes, involving the protein and carbohydrate content, along with the absorbed amounts of minerals (Figs. 4 and 5). The efficacy of foliar Zn application for the improvement of plant growth and productivity was recently illustrated by different investigations [69, 70, 71, 72]. However, our results pointed out a remarkable improvement in the studied parameters by spraying of Zn-NP compared to other Zn source (Fig. 4). The superiority of Zn-NP treatment was in accordance with that mentioned by Laware and Raskar [73]and Taheri *et al.* [74]. Awan *et al.* [75]; Sadak and Bakry [76] stated that using ZnO nanoparticles improved the growth, various physiological processes such as carbohydrate content and production of Broccoli and flax plants compared with the treatment by traditional Zn sulfate or distilled water. Similar trend were reported on black cumin plant [77]. Also, the study outcomes are of concurrence with that stated by El-Kereti *et al*. [78], who pointed out increasing the dry matter weight as well as the concentrations of N, P, K, Fe, Zn and Cu for the sweet basil plants with the elevation of applied concentrations of ZnO nanoparticles from 0 to 20 mgl^{-1}. While the further increase of the utilized concentrations reduced the absorption of the nutrients. A study lately demonstrated that foliar zinc (200 mg l^{-1}) enhanced the absorbance of some nutrients such as Ca, S, Mn and Fe in apple leaves; however, its accumulation in the plant leaves had an opposite effect, limiting the uptake of Mn and Fe [79]. The study also pointed out that there was a spatial overlap between Zn and P, particularly when a high foliar Zn concentration was used. In the present study, spraying of Zn-NP induced the uptake of macro and micronutrients in comparison with that sprayed by Zn-EDTA or with the control treatment (ZnC), which implied the suitability of the used concentration of the nanomaterial for growth of safflower plant. The aforementioned draws attention towards the value of determining the optimal concentration of Zn-NP. In a study on a germination of tomato seed supplemented by 1.2 - 6.1 mM Zn nanoparticles (Zn-NP) or Zn-sulfate, Singh *et al.* [80] observed that effect of Zn-NP were concentration dependent and increasing the germination and seedling vigor index achieved by low ZnNP concentration. They also recorded enhancement in protein and sugar content by Zn-NP compared with the zinc sulfate form.

Furthermore, the present experimental results confirmed that Zn spray counteracted the harmful effect of salinity on the dry weight of the aboveground biomass and a superiority role of Zn-NP was distinctly seen. Likewise, protein and carbohydrate contents were also enhanced by combining salinity irrigation with foliar Zn-NP treatment compared with ZnC combined with saline irrigation. The results agreed with that obtained by Alabdallah and Alzahrani [81], who used foliar nano ZnO to enhance the growth of cowpea and okra plants irrigated with saline water and concomitant with the finding of Fathi *et al.* [82] who stated the positive response of wheat to foliar spray of ZnO nanoparticles under salinity condition.

The inducing effect of Zn-NP fertilizer on the plant's salinity tolerance could be attributed to the intrinsic role of the Zn ion. Since it regulates some antioxidant enzymes such as catalase, superoxide dismutase (SOD), peroxidase (POD) and enhancing enzymatic activities. Also, it is involving in the cell defense system against the reactive oxygen species and increases the production of carbohydrates and protein, hence ultimately is improving the yield production [23, 26, 47, 53, 83, 84]. Conformity with those El-Fouly *et al.* [85] pointed out that micronutrients spray had an important role in enhancing salinity tolerance of wheat. Moreover, the size of nanoparticle fertilizer could be another reason to interpret Zn-NP influence on the plant salinity tolerance. A recent investigation stated that the small particle size and the wide specific surface area of the nanoscale fertilizers eased and increased the ion penetration into the plant via orifices of stomata, providing access through the vascular system to the phloem, then transportation to other parts [86]. Thereby, the application of Zn fertilizer in nanoparticle size, enabling it to functionalize more efficiently, enhancing the germination and growth of the seedling, improving different physiological processes like nutrients metabolism; enzymatic activity; photosynthesis; chlorophyll content in the plant [87]. These mentioned functions of Zn-NP increased eventually the capability of plants to abate different abiotic risks such as the salinity stress [46, 64].

Furthermore, in the current study, spraying of Zn-NP augmented the uptake of macro- and micro-nutrients compared to the ZnC treatment under saline irrigation. This phenomenon might be related to the function of Zn on keeping the integrity of a cell membrane, regulating some internal plant bioprocesses, accumulating phospholipids and transferring nutritional substances, thus, alleviating the harmful influence of saline water on the internal plant structure [23, 26, 82, 88, 89, 90]. Moreover, the absorbed nutrient via foliar application could be reached to the roots through the stem, so prevented the premature senescence of root and thus improved the uptake ability of nutritional minerals [91]. Further, sodium ratios are considered a sign of the salinity tolerance of a plant, thereby decreasing of K/Na, Ca/Na and Mg/Na ratios are indicators to exposing plants to salinity stress, therefore, maintaining or increasing those ratios depicted nutrients absorption balance, improving salinity tolerance of the plants [92]. As illustrated from the current investigation, Na/K and Na/Ca ratios were decreased under the Zn foliar application combined with saline irrigation treatments compared to the control (ZnC+MSW and ZnC+HSW). However, Ca/(Na+K) and Mg/(Na+K) ratios were balanced maintained under those treatments, indicating the positive role of Zn-NP and Zn-EDTA spray for healing the adverse effect of salinity. The study outcomes are aligned with those mentioned by Jan *et al.* [23]; Noohpisheh *et al.* [92]; Soliman *et al.* [93] and Saeidnejad *et al.* [94].

CONCLUSIONS

The study illustrated the negative influence of saline irrigation water on the growth of safflower plant, which was depicted by the reduction recorded for the dry weight of aboveground biomass as well as the carbohydrate, protein and nutrients content in plant leaves.

Remarkable enhancements were recorded in the shoot dry weight and all other studied parameters with the foliar spray of Zn as nanoparticle form (Zn-NP) compared to that applied as a chelate form (Zn-EDTA). It can be inferred from the study that spraying of Zn-NP conferred more resistance to the harmful impact of salinity, enabling salt-stressed safflower plant to complete growth.

More attention should be paid to the concentration and the rate of the applied Zn-NP in order to enhance the efficiency of the fertilizer and reduce pollution

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