Impact of ZnO Nanoparticles on Growth of Cowpea and Okra Plants under Salt Stress Conditions

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Salt stress causes a serious threat to agricultural productivity and global food security. It is one of the most pervasive crops limiting factor. This study examined the effect of six salinity concentrations (0, 10, 25, 50, 75 and 100% of seawater); on the growth of two crop species, cowpea (Vigna unguiculata L. var. california blackeye NO.46) and okra (Abelmoschus esculentus L. Moench var.Hasawi) in the presence or absence of (10 mg/L) of the green synthesized zinc oxide nanoparticles (ZnO NPs) or zinc oxide (bulk ZnO), as a foliar spray after (20, 40 and 60 days) from sowing. The results showed a gradual decrease in shoot and root lengths, fresh and dry weights of shoot, leaf area and relative growth rate (RGR) with the increase of seawater concentrations in both plants. However, application of ZnO enhanced the growth parameters compared to the control plants, but better results were observed in the plants treated with (ZnO NPs). Thus, nanoparticles of (ZnO) environmentally friendly, cheap cost, and can be considered as a promising application to alleviate the effects of salt stress on plants.

Keywords: Foliar Spray; Plant Growth; Nanotechnology; ZnO Nanoparticles.
the nanoparticles of metal oxides that are not found in their bulk counterparts like their shapes, size, surface reactivity, chemical stability and their large surface area to their volume ratio\(^{15}\).

Zinc (Zn) is a micronutrient and one of the essential nutrients for humans, animals and has an influential role in plant growth, development and protection. Generally, the plants uptake the Zn as a cation (Zn\(^{2+}\))\(^{16}\). The appropriate concentrations of zinc oxide nanoparticles (ZnO NPs) improved the growth and protection of different plant species\(^{15}\). Using the nanoparticles, which are synthesized by green methods like (ZnO NPs) as a foliar application on the plants is one of the promising methods to reduce water and soil pollutions by putting less input and producing less waste than ordinary approaches\(^{17}\). Fertilizers at the nano size improve the plant’s growth because of their diminutive size, which in turn could enhance the uptake of micronutrients in a controlled and gradual manner in the plants compared to the regular fertilizers\(^{18}\).

Cowpea considers as one of the most important economically cultivated legumes worldwide which provides many economic, agronomic and environmental advantages to millions of people worldwide. It is a feed, food and forage crop\(^{19}\). This species is a herbaceous warm-season annual plant grown in tropical and subtropical regions and in the semiarid regions\(^{20,21}\).

Okra is one of the most popular vegetables annually renewable crops cultivated during the hot summer seasons. It is a multipurpose crop which have been used in industrial and health applications, and it has nutritional quality\(^{22}\). It grows commercially in many countries\(^{23}\).

**Table 1.** Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on shoot length and root length (cm), fresh and dry weights of shoot and root (g) of Vigna unguiculata plants after 20 days of age

| Treatments | SW (%) | After (20 days) |
|------------|--------|-----------------|
|            | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Fresh weight of root (g) | Dry weight of shoot (g) | Dry weight of root (g) |
| control    | 0 15.73 | 17.27 | 3.48 | 0.49 | 0.76 | 0.31 |
|            | 10 14.63 | 15.31 | 3.17 | 0.34 | 0.57 | 0.26 |
|            | 25 13.50 | 13.77 | 2.63 | 0.28 | 0.44 | 0.20 |
|            | 50 11.97 | 10.26 | 1.96 | 0.20 | 0.27 | 0.13 |
|            | 75 9.37  | 8.70  | 1.07 | 0.12 | 0.21 | 0.07 |
|            | 100 7.50 | 6.77  | 0.86 | 0.07 | 0.16 | 0.02 |
| bulk ZnO   | 0 18.33 | 19.11 | 3.97 | 0.59 | 0.83 | 0.37 |
|            | 10 17.40 | 16.63 | 3.27 | 0.45 | 0.66 | 0.32 |
|            | 25 15.53 | 14.53 | 3.11 | 0.35 | 0.58 | 0.26 |
|            | 50 12.77 | 12.10 | 2.12 | 0.29 | 0.32 | 0.19 |
|            | 75 10.87 | 9.17  | 1.36 | 0.20 | 0.27 | 0.16 |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
MATERIALS AND METHODS

All chemicals employed in this study were of high purity, purchased from Sigma-Aldrich, USA. ZnO nanoparticles prepared by using [Phoenix dactylifera L. cv. Khalas] leaflets extract and characterized their formation and size by using the UV-visible spectroscopy [UV-1800] which demonstrated that the highest absorption peak was about [370 nm] using a transmission electron microscope (TEM) [Mic JEM 1011], and the size founded [from 16 to 35nm] (Fig.1). The concentration of seawater used to irrigate the plants prepared by diluted seawater to get (0, 10, 25, 50, 75 and 100 % seawater SW). The seeds of cowpea [Vigna unguiculata L. cv.California Blackeye NO.46] and okra [Abelmoschus esculentus L. Moench cv.Hasawi] were purchased from Modesto, California U.S.A and Altuajri, K.S.A. respectively. The powders of both ZnO types were mixed with deionized water.

Table 2. Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on shoot length and root length (cm), fresh and dry weights of shoot and root (g) of Vigna unguiculata plants after 40 days of age

| Treatments | SW (%) | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Fresh weight of root (g) | Dry weight of shoot (g) | Dry weight of root (g) |
|------------|--------|-------------------|------------------|--------------------------|--------------------------|------------------------|------------------------|
| control    |        |                   |                  |                          |                          |                        |                        |
| 0          | 22.50  | 20.48             | 3.94             | 0.58                     | 0.87                     | 0.40                   |
| 10         | 19.97b | 17.49b            | 3.36c            | 0.41a                    | 0.68c                    | 0.36c                  |
| 25         | 17.47b | 15.16b            | 3.11b            | 0.37a                    | 0.54b                    | 0.28b                  |
| 50         | 14.73b | 12.07b            | 2.12c            | 0.31a                    | 0.34c                    | 0.19b                  |
| 75         | 11.70b | 10.17a            | 1.78c            | 0.22a                    | 0.28b                    | 0.12c                  |
| 100        | 9.33a  | 8.70a             | 1.12c            | 0.10a                    | 0.21b                    | 0.07a                  |
| bulk ZnO   |        |                   |                  |                          |                          |                        |                        |
| 0          | 26.17b | 24.57b            | 4.07c            | 0.65c                    | 0.98c                    | 0.47c                  |
| 10         | 24.27a | 22.37b            | 3.44c            | 0.50b                    | 0.78c                    | 0.39c                  |
| 25         | 19.41b | 19.09b            | 3.15c            | 0.43c                    | 0.61c                    | 0.32c                  |
| 50         | 16.57b | 14.35b            | 2.18c            | 0.37c                    | 0.39c                    | 0.24c                  |
| 75         | 13.73b | 11.04b            | 1.84c            | 0.29c                    | 0.34c                    | 0.18c                  |
| 100        | 10.00c | 9.48b             | 1.18c            | 0.17c                    | 0.27c                    | 0.09c                  |
| ZnO NPs    |        |                   |                  |                          |                          |                        |                        |
| 0          | 36.00a | 33.40a            | 5.24d            | 0.82a                    | 2.34a                    | 0.63c                  |
| 10         | 34.07a | 31.54a            | 5.07a            | 0.78a                    | 2.25a                    | 0.57c                  |
| 25         | 31.63a | 30.13a            | 4.87a            | 0.64a                    | 2.16a                    | 0.49c                  |
| 50         | 28.23a | 27.57a            | 4.33a            | 0.53a                    | 1.87a                    | 0.40c                  |
| 75         | 25.37a | 23.66a            | 3.91a            | 0.46a                    | 1.45b                    | 0.34c                  |
| 100        | 21.03a | 19.53a            | 3.30a            | 0.33a                    | 1.18a                    | 0.22c                  |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
Fig. 2. Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on leaf area (cm²) of (a) *Vigna unguiculata* and (b) *Abelmoschus esculentus* plants.
RGR: Relative Growth Rate (g g⁻¹ day⁻¹)

\[ \text{In } = \text{ natural logarithm} \]

\[ \text{ln } W_1 = \text{The mean of the ln-transformed plant total dry weight at time } t_1. \]

\[ \text{ln } W_2 = \text{The mean of the ln-transformed plant total dry weight at time } t_2. \]

\[ t_1 = \text{number of days in the first time measurement (day)} \]

\[ W_1 \text{ and } W_2 \text{ are the dry weight of the plants at time } t_1 \text{ and } t_2 \text{ respectively.} \]

**Statistical Analysis**

All experiments were carried out using the statistical package SPSS software, version 20.

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**Fig. 3.** Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on relative growth rate (RGR; g g⁻¹ day⁻¹) of (a) *Vigna unguiculata* and (b) *Abelmoschus esculentus* plants
with three replicates (n=3) ±SE by a completely randomized design (CRD). Statistical analysis was carried out according to Snedecor and Cochran, using T test. Significant differences were obtained by calculating (LSD) at p<0.05.

RESULTS

Growth of cowpea (Vigna Unguiculata)

The results revealed that in V.unguiculata plants the shoot and root lengths, shoot and root fresh and dry matter decreased with the increase seawater concentrations at the three vegetative stages, (bulk ZnO) improved the growth parameters non-significantly and significantly. While these parameters increased significantly and high significantly with (ZnO NPs) relative to control plants except at (20 days) the increase was non-significant in root length with (75 and 100% SW) treatments, and the fresh weight of shoot with (10, 25 and 50 % SW) treatments (Tables 1,2,3). After 60 days, V.unguiculata leaf area was measured; seawater treatment showed a non-significant decrease in leaf area with increasing salinity. When applying (bulk ZnO) non-significantly increased the leaf area in all seawater concentrations, while with (ZnO NPs) showed a better significant increase as compared to (bulk ZnO) and control treatments (Fig. 2a).

The relative growth rate (RGR) decreased gradually with the increasing seawater concentrations. The non-fertilized V.unguiculata plants (control) showed non-significant decrease in (RGR) in the lower seawater concentrations (10 and 25% SW), while the decrease was significant in (50, 75 and 100% SW). The addition of (bulk ZnO) increased the (RGR) non-significantly in all seawater concentrations. However, (ZnO NPs) treatments.

Table 3. Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on shoot length and root length (cm), fresh and dry weights of shoot and root (g) of Vigna unguiculata plants after 60 days of age

| Treatments | SW (%) | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Dry weight of shoot (g) | Dry weight of root (g) |
|------------|--------|------------------|-----------------|---------------------------|-------------------------|------------------------|
| control    | 0      | 27.73            | 24.38           | 4.20                      | 0.72                    | 1.09                   | 0.56                   |
|            | 10     | 25.43c           | 22.60c          | 3.81c                     | 0.65c                   | 0.74b                  | 0.47b                  |
|            | 25     | 23.58b           | 17.88b          | 3.22b                     | 0.54b                   | 0.61b                  | 0.39b                  |
|            | 50     | 19.53b           | 15.72b          | 2.54a                     | 0.40b                   | 0.40b                  | 0.23b                  |
|            | 75     | 14.17a           | 12.51b          | 2.12a                     | 0.33b                   | 0.33b                  | 0.18b                  |
|            | 100    | 11.13a           | 10.94b          | 1.66a                     | 0.18b                   | 0.30b                  | 0.10b                  |
| bulk ZnO   | 0      | 30.23c           | 27.41c          | 4.27c                     | 0.81c                   | 1.31c                  | 0.62c                  |
|            | 10     | 28.62b           | 24.59c          | 3.98c                     | 0.71c                   | 0.81c                  | 0.53c                  |
|            | 25     | 25.57c           | 21.57c          | 3.31c                     | 0.60c                   | 0.69c                  | 0.43c                  |
|            | 50     | 20.30c           | 16.64c          | 2.61c                     | 0.49c                   | 0.45c                  | 0.26c                  |
|            | 75     | 15.37c           | 13.23c          | 2.18c                     | 0.39c                   | 0.41c                  | 0.21c                  |
|            | 100    | 11.97c           | 11.45c          | 1.73c                     | 0.23c                   | 0.34c                  | 0.13c                  |
| ZnO NPs    | 0      | 43.40a           | 40.28a          | 5.62a                     | 1.51a                   | 2.41a                  | 1.12a                  |
|            | 10     | 41.90a           | 37.63b          | 5.46a                     | 1.48a                   | 2.35a                  | 0.98a                  |
|            | 25     | 38.53a           | 34.27a          | 5.22a                     | 1.31b                   | 2.28a                  | 0.89a                  |
|            | 50     | 35.41a           | 29.10b          | 4.67a                     | 1.24a                   | 1.95a                  | 0.76a                  |
|            | 75     | 29.33a           | 25.47b          | 4.11a                     | 1.15a                   | 1.58b                  | 0.55b                  |
|            | 100    | 25.10a           | 20.07b          | 3.34a                     | 0.78b                   | 1.28b                  | 0.47b                  |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
increased these measures high significantly as compared to their corresponding controls (Fig. 3a).

**Growth of Okra (Abelmoschus Esculentus)**

In A. esculentus plants, all the growth parameters decreased gradually with the increase of seawater levels. After 60 days there was high significant inhibition reached (51.70, 55.90, 67.00, 71.43, 74.7 and 75.56%) in shoot and root lengths, shoot and root fresh weights, shoot and root dry weights respectively, compared to control treatments. It is worth mentioning that the plants treated with the green synthesized (ZnO NPs) give the best results to enhance the growth measurements compared to the plants treated with (bulk ZnO), (Tables 4,5,6). Present results show that the leaf area of A. esculentus plants treated with different concentrations tend to decrease non-significantly in (10% SW), while the decrease was high significant at all the other concentrations. The leaf area increased non-significantly above the different controls when (bulk ZnO) was used, while (ZnO NPs) increased high significantly the leaf area in all concentrations except the higher concentration (100% SW), (Fig. 2b).

The decrease in RGR was significant in plants treated with (10%) of seawater and highly significant in plants treated with (25, 50, 75 and 100 % SW). Addition of (bulk ZnO) increased the relative growth rate significantly at (0 and 10%) of seawater, while it increased non-significantly at (25, 50, 75 and 100 % SW). The addition of (ZnO NPs) gave positive increases than (bulk ZnO). The increase was highly significant in plants treated with all seawater concentrations (Fig. 3b).

**Table 4.** Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on shoot length and root length (cm), fresh and dry weights of shoot and root (g) of Abelmoschus esculentus plants after 20 days of age

| Treatments   | SW (%) | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Fresh weight of root (g) | Dry weight of shoot (g) | Dry weight of root (g) |
|--------------|--------|-------------------|------------------|---------------------------|--------------------------|------------------------|------------------------|
| control      | 0      | 14.680            | 16.23            | 2.81                      | 0.41                     | 0.56                   | 0.20                   |
|              | 10     | 14.27c            | 15.84c           | 2.30c                     | 0.30a                    | 0.45c                  | 0.17b                  |
|              | 25     | 13.60c            | 15.02b           | 1.87b                     | 0.25a                    | 0.35b                  | 0.13b                  |
|              | 50     | 11.48b            | 12.81a           | 1.04a                     | 0.18a                    | 0.24b                  | 0.09a                  |
|              | 75     | 10.03a            | 8.91a            | 0.77a                     | 0.11a                    | 0.11a                  | 0.02a                  |
|              | 100    | 8.07a             | 7.15a            | 0.38a                     | 0.05a                    | 0.04a                  | 0.0077a                |
| bulk ZnO     | 0      | 16.400c           | 17.50b           | 3.22c                     | 0.48b                    | 0.69c                  | 0.28b                  |
|              | 10     | 15.73c            | 16.45c           | 2.87c                     | 0.38b                    | 0.56c                  | 0.22b                  |
|              | 25     | 14.93c            | 16.11c           | 2.11c                     | 0.31b                    | 0.45c                  | 0.19b                  |
|              | 50     | 12.17c            | 13.18c           | 1.36c                     | 0.25b                    | 0.31c                  | 0.12b                  |
|              | 75     | 10.16c            | 9.12c            | 1.08c                     | 0.19b                    | 0.19c                  | 0.10b                  |
|              | 100    | 8.97c             | 7.73c            | 0.77c                     | 0.10c                    | 0.11c                  | 0.07b                  |
| ZnO NPs      | 0      | 20.176a           | 21.05a           | 4.41a                     | 0.64a                    | 2.07a                  | 0.46a                  |
|              | 10     | 19.44a            | 20.53a           | 4.11a                     | 0.56a                    | 1.57a                  | 0.35a                  |
|              | 25     | 18.74a            | 20.09a           | 3.86a                     | 0.45a                    | 1.33a                  | 0.27a                  |
|              | 50     | 17.20a            | 18.45a           | 3.03a                     | 0.34a                    | 1.15a                  | 0.21a                  |
|              | 75     | 12.61b            | 14.93a           | 2.32a                     | 0.27a                    | 1.02a                  | 0.18a                  |
|              | 100    | 11.55b            | 14.51a           | 1.95a                     | 0.14a                    | 0.52a                  | 0.15a                  |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
DISCUSSION

Salinity affects plant growth by ionic stress, oxidative stress, reducing cell enlargement and cell division and osmotic stress, which depends on the concentration of salts and the type of plant tissue\textsuperscript{27}. Salt stress can strongly affect the plants morphology\textsuperscript{28,29}, it has a great inhibition influence which can lead to apparent stunting of plant growth\textsuperscript{29,30}.

The growth of roots decreases when soil salinity exceeds (40mM)\textsuperscript{31,32}, thus inhibition of root growth leads to reduction in water use efficiency, water uptake capacity, leaf water potential and transpiration rate under salt stress\textsuperscript{33}. Also, Kaya et al\textsuperscript{34} pointed out that stressed plants resorted to close the stomata to retain the amount of water in the leaves and thus less entry of CO2 and rate of photosynthesis, which leads directly or indirectly to a decrease the amount of photosynthetic products.

Salt stress causes a reduction in turgor pressure, which leads to a major reduction in cell growth, cell elongation, cell division\textsuperscript{27}, and consequently the whole plant growth. The decrease in leaf area is a result of cell water relations, changes in cell wall features and reduction in photosynthetic rate\textsuperscript{35}. The reduction in fresh and dry weight is due to the formation of smaller and fewer leaves and a decrease in plant height\textsuperscript{33}.

The morphological parameters in the plants such as shoot and root lengths, shoot and root weights, leaf area as well as, relative growth rate (RGR) are indicate the plant health\textsuperscript{36}. The measured growth parameters in cowpea (V.unguiculata) and okra (A.esculentus) plants increased with the foliar application of (ZnO bulk) and (ZnO NPs) under salinity stress. (ZnO NPs) showed better results than other treatments. These data are in agreement with other studies such as Sah et al\textsuperscript{37} on Borago officinalis L.; Sabaghnia and Janmohammadi\textsuperscript{38}.

| Treatments | SW (%) | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Fresh weight of root (g) | Dry weight of shoot (g) | Dry weight of root (g) |
|------------|--------|------------------|-----------------|--------------------------|--------------------------|------------------------|------------------------|
| control    | 0      | 24.603           | 25.01           | 4.00                     | 0.70                     | 0.83                   | 0.45                   |
|            | 10     | 21.23a           | 22.14a          | 3.74c                    | 0.61b                    | 0.64c                  | 0.39c                  |
|            | 25     | 18.84a           | 19.31a          | 3.15a                    | 0.48b                    | 0.56a                  | 0.28a                  |
|            | 50     | 16.91a           | 16.87a          | 2.41a                    | 0.38b                    | 0.42a                  | 0.21a                  |
|            | 75     | 15.01a           | 14.14a          | 1.86a                    | 0.30b                    | 0.31a                  | 0.17a                  |
|            | 100    | 11.88a           | 11.03a          | 1.32a                    | 0.20a                    | 0.21a                  | 0.11a                  |
| bulk ZnO   | 0      | 25.883c          | 26.11c          | 4.36c                    | 0.77c                    | 1.02c                  | 0.53b                  |
|            | 10     | 21.93c           | 22.97c          | 4.12b                    | 0.69b                    | 0.79c                  | 0.44c                  |
|            | 25     | 19.09c           | 19.90c          | 3.62b                    | 0.54c                    | 0.65c                  | 0.34c                  |
|            | 50     | 17.12c           | 17.01c          | 2.91b                    | 0.44c                    | 0.53c                  | 0.27c                  |
|            | 75     | 15.95c           | 14.88c          | 2.07c                    | 0.39b                    | 0.43c                  | 0.22c                  |
|            | 100    | 12.08c           | 11.81c          | 1.63c                    | 0.24c                    | 0.28c                  | 0.17c                  |
| ZnO NPs    | 0      | 32.507a          | 34.21a          | 5.31a                    | 1.41a                    | 2.32a                  | 1.07a                  |
|            | 10     | 30.15a           | 32.16a          | 5.03a                    | 1.39a                    | 2.21a                  | 0.91a                  |
|            | 25     | 27.31a           | 29.51a          | 4.42a                    | 1.29a                    | 2.14a                  | 0.80a                  |
|            | 50     | 26.14a           | 24.96a          | 4.15a                    | 1.18b                    | 1.86a                  | 0.70a                  |
|            | 75     | 23.14a           | 21.51a          | 3.66a                    | 1.07a                    | 1.51a                  | 0.63a                  |
|            | 100    | 21.52a           | 18.92a          | 3.03a                    | 0.72a                    | 1.24a                  | 0.51a                  |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
Table 6. Effect of different concentrations of seawater (SW) in the presence or absence of (bulk ZnO) or (ZnO NPs) on shoot length and root length (cm), fresh and dry weights of shoot and root (g) of Abelmoschus esculentus plants after 60 days of age

| Treatments | SW (%) | Shoot length (cm) | Root length (cm) | Fresh weight of shoot (g) | Fresh weight of root (g) | Dry weight of shoot (g) | Dry weight of root (g) |
|------------|--------|-------------------|-----------------|---------------------------|------------------------|------------------------|------------------------|
| control    | 0      | 20.573            | 21.58           | 3.25                      | 0.51                   | 0.76                   | 0.31                   |
| 10         | 17.43a | 18.08a            | 3.03c           | 0.39b                     | 0.56a                  | 0.62a                  | 0.23b                  |
| 25         | 15.03b | 16.21c            | 2.09a           | 0.32a                     | 0.47a                  | 0.24                  | 0.19a                  |
| 50         | 14.55a | 14.12b            | 1.56a           | 0.26a                     | 0.31a                  | 0.14                  |
| 75         | 12.15b | 11.77a            | 1.22a           | 0.21a                     | 0.24a                  | 0.10                  |
| 100        | 9.92b  | 9.07a             | 0.98a           | 0.13a                     | 0.13a                  | 0.037a                |
| bulk ZnO   | 0      | 22.120b           | 22.80c          | 4.02b                     | 0.60c                  | 0.88c                  | 0.39b                  |
| 10         | 18.34c | 18.98c            | 3.36c           | 0.48c                     | 0.65c                  | 0.30c                  |
| 25         | 16.24b | 16.93c            | 2.54b           | 0.40c                     | 0.52c                  | 0.26c                  |
| 50         | 15.77b | 14.89c            | 1.74c           | 0.34c                     | 0.43c                  | 0.20c                  |
| 75         | 12.73c | 12.11c            | 1.37c           | 0.28c                     | 0.31c                  | 0.17b                  |
| 100        | 10.07c | 9.97c             | 0.99c           | 0.19c                     | 0.18c                  | 0.11b                  |
| ZnO NPs    | 0      | 26.570a           | 28.11a          | 5.03a                     | 0.73a                  | 2.21a                  | 0.56a                  |
| 10         | 24.34a | 26.50a            | 4.51a           | 0.67a                     | 2.06a                  | 0.51a                  |
| 25         | 22.65a | 23.88a            | 4.13a           | 0.57a                     | 1.86a                  | 0.43a                  |
| 50         | 20.55a | 20.11a            | 3.81a           | 0.46a                     | 1.68a                  | 0.30a                  |
| 75         | 18.47a | 18.88a            | 3.17a           | 0.34b                     | 1.32a                  | 0.26a                  |
| 100        | 16.42a | 15.71a            | 2.29a           | 0.28a                     | 1.12a                  | 0.20a                  |

Significance of values at p<0.05, a= (highly significant), b= (significant), c= (not significant).
release of Zn ion from the nanoparticles, which supplies a long-term provenance of Zn, and help to avoid toxicity by sudden uptake of Zn by plants at high concentrations\(^{50}\). The increase in plants growth with nanoparticles application might be due to rising of the efficiency of nutrient usage diminish soil toxicity which produces by over dosage of the addition of fertilizers and enhance the activities of antioxidant enzymes which help to protect the plants from injury caused by (ROS)\(^{51}\). Rising in the plant height may because of the improvements of auxin biosynthesis and synergistic relation between both nutrients nitrogen and iron\(^{52}\).

**CONCLUSION**

The results of this study showed that both treatments of (bulk ZnO) and (ZnO NPs) enhanced the growth parameters in the salt-stressful plants cowpea (V.unguiculata) and okra (A.esculentus). Notably, both of these plants showed good tolerance to salt stress. The nanoparticles of (ZnO) gave better results by improving plant salinity tolerance than their bulk size. The foliar application of the green synthesize (ZnO NPs) can be a good alternative to their bulks because they are ecologically friendly approaches with low-priced.

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