Plant Archives Volume 20 No. 2, 2020 pp. 8065-8071 **e-ISSN:2581-6063 (online), ISSN:0972-5210**

EFFECT OF COPPER NANOPARTICLES AND MAGNETIZED SALTY WATER IN ENZYMATIC AND NON-ENZYMATIC ANTIOXIDANTS OF TOMATO (*LYCOPERSICON ESCULENTUM* L.)

Noora I.H. Al-Shemmary[1], Basheer A.H. Al-Alwani[2*] and Rihab E. Kadhim[2]

[1]Ministry of Education, Babylon-Iraq.
[2*]Department of biology, College of Science, University of Babylon, Babylon-Iraq.

Abstract

This study was conducted in the department of Biology, College of Science, University of Babylon, Iraq, to evaluate the effect of copper nanopartical and magnetized salty water in superoxide dismutase enzyme activity, catalase enzyme activity, glutathione content, proline content and malondialdehyde content of tomato (*Lycopersicon esculentum* L.). The overall number of pots at 144 (48 treatments and 3 replicates per treatment). The results of study showed that Cu nanoparticles at concentration of (0.5ppm and 9ppm) and the magnetic intensity (2000 Gauss) caused decreasing in SOD activity of tomato leaves significantly. The rest of the treatments increased SOD activity significantly comparing with the control treatment. The treatment of the drainage water (E.C.4 mmohs/cm) with Cu NPs. of 5ppm caused the highest value of SOD (666.7 unit), the Cu NPs of the concentration (9ppm) caused decreasing in CAT activity of tomato leaves significantly comparing with control also with treatment of magnetic river water (E.C. 2.83mmohs/cm) at 2000 Gauss. The concentrations of almost treatments increased the CAT activity significantly comparing with control, the treatment of drainage water (7 mmohs/cm) with the concentration (5ppm) for Cu NPs. caused the highest value of CAT (158.6 unit). that Cu NPs. at concentration of 5 ppm with magnetized distilled water caused decreasing in GSH content of tomato leaves significantly. The highest value at the drainage water (E.C.4 mmohs/cm) caused enhancement in GSH content (0.304 µmol) comparing with control and treatment of drainage water at (7 mmohs/cm) alone, the Cu NPs at concentration of 5ppm caused decreasing of proline content of tomato leaves significantly. All concentrations of all treatments increased the content of proline significantly comparing with control. The treatment of drainage water (E.C. 4mmohs/cm) with magnetic water of 2000 Gauss and the concentration (0.5ppm) caused the highest value of proline content (8.87 µmol/g), the Cu NPs at concentration of 5ppm and the magnetic intensity 3000 Gauss with the drainage water (7 mmohs/cm) caused decreasing of MDA content of tomato leaves significantly. The treatment of river water (E.C.2.83mmohs/cm) with magnetic water of 3000 Gauss and the concentration (5ppm) caused the highest value of MDA content (14.91mmoler).

Key words*:* Salinity, Cu NPs, Magnetic water, *Lycopersicon esculntum* L.

Introduction

A saline soil have a high concentration of soluble salts, high enough to affect plant growth .Salt stress is one of the major abiotic threats to plant life and significantly reduces crop yield in affected areas. Excessive salt above what plants need limits plant growth and productivity and can lead to plant death. About 20% of all irrigated land is affected by soil salinity, decreasing crop yields (Kader and Lindberg, 2010). Salinity posses two major threats to plant growth: osmotic stress and ionic stress (Flowers and Colmer, 2008). Several studies have been conducted to investigate the salinity effect in plant growth and productivity (Shah, 2007). Nanoparticles are minute's finites with lengths ranging from 1-100 nanometers. They have unique physical and chemical properties. They have a large surface area to their size, making them highly motivating on influencing the growth and development of different types of plants, these effects may be either positive or negative (Ma *et al*., 2010).

Copper is one of the essential nutrients for plant growth in low concentrations because it needs very small quantities, copper is involved in many vital processes to form protein and is the main component in the synthesis

***Author for correspondence :** E-mail : basalwani@yahoo.com

of many plant enzymes that activate oxygen reduction reactions such as cytochrome oxides, ascorbic acid oxides and lactase (Xiong *et al*., 2006). Copper is widely distributed in plant tissues and is essential micronutrient for growth and involved in many physiological processes (Sommer, 1931 and Chibber *et al*., 2013). It is widely used in agricultural industries, cosmetics, coatings, environmental remediation, fungicides, food industry, chemical industry, textile industries, medical industry, paints, plastics, wastewater treatment and electronics (Rafique, *et al*., 2017). Copper as an element converts toxic above a threshold level, which depends on the type of crop plants (An, 2006). The magnetic field is defined as the magnetic force that arises in the area surrounding the magnetic body or in other words can be described as the area surrounded the magnet and shows the effect (in a given material), the magnetization of matter under the influence of an external magnetic field is due to the alignment of atoms or molecules of matter when the material exposed to the magnetic field becomes dipole of its atoms and its molecules are aligned towards the field used (AL-Qaisi, 2004). Magnetic treatment of water has been reported to change some of the physical and chemical properties of water, mainly hydrogen bonding, polarity, surface tension, conductivity, pH and solubility of salts, these changes in water properties may be capable of affecting the growth of plants (Grewal and Maheshwari, 2011). Lin and Votvat, (1990) reported an increase in water productivity in both crop and livestock production with magnetically treated water. Maheshwari and Grewal, (2009) showed that the magnetic treatment of irrigation water resulted in statistically significant increases in the yield and water productivity for celery and snow pea plants in some instances. Antioxidants are an inhibitor of the process of oxidation, antioxidant constituents of the plant material act as radical scavengers and helps in converting the radicals to less reactive species, a variety of free radical scavenging antioxidants is found in dietary sources like fruits, vegetables and tea (Hall, 2001). Superoxide dismutase (SOD) enzyme is present in the cytoplasm, mitochondria and chloroplast, that free radicals are often associated with photochemical reactions the cells in which photosynthesis takes place are prone to oxidative stress because they contain rows of light-sensitive molecules that produce and consume oxygen (Stofieth, 2012). The activity of the SOD enzyme in the roots of two cowpea varieties, one of which is sensitive to salinity and the other is resistant to salinity is different, as it is not affected in the first category, while increasing in the second (Maia, *et al.,* 2010). It was also found that different types of tomato (*Lycopersicon pannellii* L. and *Lycopersicon esculentum* L.) showed different directions in their response to saline stress, as the treatment of plants with salt concentrations (70 and 140) m mol of different periods, this cause an increase in the activity of the enzyme for the first hit at the concentration of 140 mM on the sixth day and for the second hit at the concentration of 70 mM for the same period (Koca, *et al*., 2006). Catalase is mainly localized in the peroxisomes, in higher plants, it is present in all differentiated peroxisomes including the peroxisomes of leaves, cotyledons, roots, and glyoxysomes and unspecialized peroxisomes (Su, *et al*., 2012). Sivanadanam, *et al.,* (2012) also found that high salinity concentrations caused an increase in the activity of the enzyme when treating *Rhizophora apiculata* and *Acanthus ilicifolius*. The effectiveness of the enzyme CAT decreases when the plant produces large quantities of free radicals and therefore the enzyme is unable to break them (Esfandiari, *et al*., 2007). Caval-cantia, *et al*., (2007) reported that the treatment of 200 mM *Phaseolus vulgaris* with six days caused a rapid and permanent decrease in the activity of the enzyme one day after saline treatment. glutathione is a short peptide consisting of three amino acids glutamic acid, cysteine and Glycine (Y-Glu-Cys-Gly) (Gangwar, *et al*., 2014). Glutathione is an important source of non-protein sulfur in both animal and plant cells, and it has a primary function in the defense of cells, it defends the plant cell as it acts as an antioxidant (Rahier, *et al*., 2008). This triple peptide is part of a cycle Ascorbate glutathione that helps protect or reduce the risk from free oxygen radicals (ROS), this mechanism is summarized by oxidizing the sulfur group as a compound GSSG (Glutathione-disulfate-G) the danger of free radicals lies in changing the level of peptides in tissues and plant fluids subject to environmental stress conditions such as saline stress and stress of heavy metals such as uranium and cadmium (Chen and Viljoen, 2010 and Wang, *et al*., 2001). In many species, compatible osmoprotectant, such as proline and soluble sugars, is produced to protect the cells against the adverse effects from salt stress. High accumulation of proline is associated with tolerance to stress (Hokmabadi, *et al*., 2005). Consequently, the ability to accumulate proline has often been suggested as a valuable criterion for the selection of salt tolerant genotypes (Ashraf and Harris, 2004). The relationship between cell membrane stability and salinity tolerance is sufficient to differentiate between crop types (Sairam and Srivastava, 2002), for example, lipid peroxidation in an important physiological process that determines and chooses a stress in tolerant plant (Sanchez-Rodriguez, *et al*., 2010).

Tomato (*Lycopersicon esculentum* L.) belongs to the solanaceae and genus solanum is grown in temperate and warm regions (Rick, *et al*., 1990). Tomato, is a wide-spread crop that is widely adapted to the different conditions of agriculture and is used in food industries as well as for fresh consumption (Delaplace, *et al*., 2009). The aim of this study is to treat the salinity by the use of magnetized water as well as the copper nanoparticale and the interaction between them , when apply in tomato.

Materials and Methods

Tomato (*Lycopersicon esculentum* L.) seedlings class California with two month-old were planted at 2 December, 2018. These seedlings were transferred to plastic pots containing a mixed soil: batmos with a ratio of 1:1, capacity of 1.5 kg and 144 pots (48 treatments and 3 replicates per treatment). The physical and chemical properties of soil were analyzed table 1 in the laboratories of the Soil Department/College of Agriculture/Al-Qasim Green University.

Table 1: Physical and chemical properties of soil.

Sand	720	g /kg
Silt	179	g kgm^{-1}
Clay	101	g kgm^{-1}
Ph.	7.45	
Ec	1.32	dSm^{-1}
Ca	4.60	$mlmolkg^{-1}$
Mg	2.81	$mlmolkg^{-1}$
Na	3.39	$mlmolkg^{-1}$
K	0.60	$mlmolkg^{-1}$
Cl	6.92	$mlmolkg^{-1}$
SO_4	3.21	$mlmolkg^{-1}$
CO_3	Nill	$mlmolkg^{-1}$
HCO_3	2.13	$mlmolkg^{-1}$

The seedlings in the greenhouse were grown at a temperature (25±), the seedlings were treated with salt water (0,2.83, 4, 7 mmohs /cm), magnetized water (0, 2000, 3000 Gauss) and Cu nanoparticles in concentrations (0, 0.5, 5, 9 M) and interaction experiments between the three factors were treated with salt water and magnetized water by watering, while the nanomaterial was sprayed.

The experiment was completed in February 1, 2019, and the leaves were taken at the age of four months of plant , the leaves between the third and fifth of the top of plant taken to determine of superoxide dismutase enzyme by method (Marklund and Marklund, 1974) and catalase enzyme by method (Goth, 1991) from fresh samples and glutathione by method (Ellman, 1959), prolineby method (Bates, *et al.,* 1973) and malondialdehyde by method (Buege and Aust, 1978) from the dry weight.

Completely Randomized Design (CRD) was used with a three-factor and three-replication, including salinity, magnetic water and Cu nanoparticles concentrations. The values were statistically analyzed by the statistical system GenS tat Release 12.1. Least significant difference (L.S.D.) was used. On the level of probability of 0.05 to compare the differences between the averages (AL-Rawee and Abd AL-Azize, 2000).

Results

Table 2 refers that Cu nanoparticles at concentration of (0.5ppm and 9ppm) and the magnetic intensity (2000 Gauss) caused decreasing in SOD activity of tomato leaves significantly. The rest of the treatments increased SOD activity significantly comparing with the control treatment. The treatment of the drainage water (E.C.4 mmohs/cm) with Cu NPs. of 5ppm caused the highest value of SOD (666.7unit).

Table 2: Effect of copper nanoparticle and magnetized salty water in the activity of SOD enzyme(unit) of tomato (*Lycopersicon esculentum* L .).

Salt concentration mmohs/cm	Cu NPs. ppmMag. waterGauss	0	0.5	5	9
d. W0	0	469.9	347.1	453.5	464.2
	2000	454.0	375.8	459.0	461.5
	3000	587.9	507.9	468.8	492.7
River Water 2.83	0	494.0	420.5	515.7	435.5
	2000	422.1	454.6	484.5	552.4
	3000	499.5	440.1	505.0	441.0
Drainage Water 4	0	435.5	572.2	486.5	357.2
	2000	543.9	632.1	602.0	602.2
	3000	536.6	452.6	557.9	562.8
Drainage Water 7	0	579.5	583.1	666.7	582.7
	2000	517.7	501.6	481.7	597.9
	3000	564.2	569.4	600.6	594.7
$L.S.D._{(0.05)} = 5.78$					

Table 3 refers that Cu NPs of the concentration (9ppm) caused decreasing in CAT activity of tomato leaves significantly comparing with control also with treatment of magnetic riverwater (E.C. 2.83mmohs/cm) at 2000 Gauss. The concentrations of almost treatments increased the CAT activity significantly comparing with control. The treatment of drainage water (7 mmohs/cm) with the concentration (5ppm) for Cu NPs. caused the highest value of CAT(158.6 unit).

Table 4 indicates that Cu NPs. at concentration of 5 ppm with magnetized distilled water caused decreasing in GSH content of tomato leaves significantly. The highest value at the drainage water (E.C.4 mmohs/cm) caused enhancement in GSH content (0.304µmol) comparing with

Table 3: Effect of copper nanoparticle and magnetized salty water in the activity of CAT enzyme(unit) of tomato (*Lycopersicon esculentum* L.).

Salt conce-ntration mmohs/cm	Cu NPs. ppmMag. waterGauss	0	0.5	5	9
d. W0	0	111.8	82.6	124.2	110.5
	2000	108.0	89.4	109.2	109.8
	3000	143.1	120.9	111.5	117.2
River Water 2.83	0	117.6	100.2	120.8	93.4
	2000	117.6	126.2	115.3	78.1
	3000	118.9	102.0	120.2	103.7
Drainage Water 4	0	103.6	82.0	115.8	85.0
	2000	129.4	147.7	143.3	143.3
	3000	127.7	129.1	137.5	129.8
Drainage Water 7	0	137.9	132.7	158.6	138.6
	2000	123.2	119.3	114.6	141.2
	3000	134.3	135.5	142.9	141.5
$L.S.D._{(0.05)} = 1.34$					

Table 4: Effect of copper Nanoparticle and magnetized salty water on the content of glutathione (µmol) of tomato (*Lycopersicon esculentum* L .).

Salt conce-ntration mmohs/cm	Cu NPs. ppmMag. waterGauss	0	0.5	5	9
d. W0	0	0.195	0.231	0.095	0.021
	2000	0.052	0.162	0.053	0.099
	3000	0.149	0.144	0.022	0.193
River Water 2.83	0	0.218	0.130	0.046	0.245
	2000	0.166	0.110	0.180	0.256
	3000	0.182	0.237	0.301	0.232
Drainage Water 4	0	0.304	0.170	0.214	0.030
	2000	0.012	0.115	0.128	0.131
	3000	0.159	0.247	0.129	0.039
Drainage Water 7	0	0.065	0.117	0.042	0.194
	2000	0.164	0.129	0.176	0.160
	3000	0.073	0.273	0.254	0.263
$L.S.D._{(0.05)} = 0.004$					

control and treatment of drainage water at 7 mmohs/cm alone.

Table 5 refers that Cu NPs at concentration of 5ppm caused decreasing of proline content of tomato leaves significantly. All concentrations of all treatments increased the content of proline significantly comparing with control. The treatment of drainage water (E.C. 4mmohs/cm) with magnetic water of 2000 Gauss and the concentration (0.5ppm) caused the highest value of proline content (8.87µmol/g).

Table 6 refers that Cu NPs at concentration of 5ppm and the magnetic intensity 3000 Gauss with the drainage

Table 5: Effect of copper Nanoparticle and magnetized salty water on the content of Proline (µmol/g) of tomato (*Lycopersicon esculentum* L.).

Salt conce-ntration mmohs/cm	Cu NPs. ppmMag. waterGauss	0	0.5	5	9
d. W0	0	6.83	3.95	3.60	4.23
	2000	3.88	4.96	5.96	4.09
	3000	4.18	2.78	7.78	2.25
River Water 2.83	0	6.77	2.98	5.24	1.65
	2000	2.63	3.54	3.43	4.18
	3000	3.25	2.07	3.69	2.86
Drainage Water 4	0	2.52	3.30	2.34	2.28
	2000	2.67	8.78	3.15	4.26
	3000	2.27	3.85	3.28	2.09
Drainage Water 7	0	1.75	2.30	1.29	1.93
	2000	5.10	2.34	2.13	5.11
	3000	3.15	3.06	4.81	1.63
$L.S.D._{(0.05)} = 0.111$					

Table 6: Effect of copper Nanoparticle and magnetized salty water on MDA (mM) of tomato (*Lycopersicone-sculentum* L .).

Salt conce-ntration mmohs/cm	Cu NPs. ppmMag. waterGauss	0	0.5	5	9
d. W0	0	5.10	3.45	4.01	6.37
	2000	9.84	6.00	10.68	5.90
	3000	5.36	8.54	5.59	5.25
River Water 2.83	0	9.26	6.10	6.46	10.18
	2000	5.48	8.26	12.70	3.81
	3000	9.41	9.02	14.91	10.54
Drainage Water 4	0	5.92	10.25	6.24	4.68
	2000	5.93	10.09	9.79	5.54
	3000	7.17	7.01	5.95	5.08
Drainage Water 7	0	6.60	4.98	4.54	7.16
	2000	6.68	5.66	6.94	5.11
	3000	3.51	4.51	2.92	7.81
$L.S.D._{(0.05)} = 0.161$					

water 7 mmohs/cm caused decreasing of MDA content of tomato leaves significantly. The treatment of river water (E.C. 2.83mmohs/cm) with magnetic water of 3000 Gauss and the concentration (5ppm) caused the highest value of MDA content (14.91mM).

Discussion

The salinity of water affects the biochemical aspects of enzymatic antioxidants (SOD and CAT) and non-enzymatic antioxidants (GSH, proline and MDA), when irrigated the plant with salty water it may lead to the formation of free radicals by producing ROS and stimulating oxidative stress, and by following tables 2 and 3 an increase in SOD and CAT activity have appeared and this is consistent with the results (Hassanein, *et al*., 2009). Generation of ROS, which is induced by NPs directly or indirectly, plays a critical role in phytotoxicity mechanism, the production of ROS is based on the physicochemical properties of NPs as well as the test species, various determinants, such as size and shape, solubility and particle dissolution, metal ions released from metal and metal oxide NPs, biotransformation of NPs, light and so forth, may cause the ROS generation and phytotoxicity (Dimkpa, *et al*., 2012; Rui, *e t al*., 2015 and Zhang, *et al*., 2015). In the two tables 2 and 3 we observed an increase in the activity of SOD and CAT with increasing salinity and increasing magnetization of water as well as with increasing concentration of Cu NPs and this indicates that they are effective enzymes as antioxidants and also indicates the minimization of the plant for salinity, this is agreement with, (Ma, *et al*., 2016 and Zhang, *et al*., 2017), that SOD was related to the increase in tolerance of plants against environmental stress, such as NP toxicity, which means that SOD could act as an indirect selection criterion for researching oxidative stress. While working on tomato and several studies has revealed increased SOD activity in salt-tolerant genotypes of pea, cotton and tomato, and this induction of SOD activity was suggested as a reason for improved tolerance to salinity in these cases (Hernandez, *et al*., 2000 and Mittova, *etal*., 2004). CAT, among all of the antioxidant enzymes, is the enzyme that was first discovered and characterized and plays an indispensable role in ROS detoxification under stress (Garg and Manchanda, 2009). CAT is involved in scavenging of H_2O_2 during salt stress and other abiotic stress conditions (Willekens, *et al*., 1997). The increase in CAT activity under salt stress may indicate that CAT is a major enzyme detoxifying H_2O_2 in tomato. This increased activity of CAT upon salt stress was often related to the enhanced tolerance to salt stress (Mittova, *et al*., 2004).

Salt stress is oxidative stress, and these primary effects cause secondary effects ROS, such H_2O_2 as reducing cell amplitude and production, and as a result of these effects, cells die in extreme cases, the concentration GSH also decreased with increased the salinity in table 4 and this is consistent with what was indicated (Tsai, *et al.,* 2004). The treatment of drainage water (E.C. 4mmohs/cm) with magnetic water of 2000 Gauss and the concentration (0.5ppm) caused enhanced the proline content in table 5, in tomato leaves significantly, this indicate as a biochemical marker of salt stress level, that was agree with (Shamshiri and Fattahi, 2014). In the present study, moderate and high salinityinduced a significant increase in the free proline content in the leaves. Our results are in agreementwith those previously reported for *pistacia* species (Chelli-Chaabouni, *et al*., 2010), *P. vera* variety (Hokmabadi, *et al*., 2005 and Karimi and Maleki, 2014), in addition, proline plays a protective role against saltstress in plants. Therefore, the level of MDA, a decomposition product of polyunsaturated fatty acids produced during peroxidation of membrane lipids, is often used as an indicator of oxidative damage (Mittler, 2002). It has been reported that salt treatment increases lipid peroxidation in plant tissues (Hernandez, *et al*., 1993). Moreover, ROS-mediated membrane damage has been demonstrated to be a major cause of the cellular toxicity by salt stress in rice, tomato and citrus (Dionisio and Tobita, 1998 and Mittova, *et al.,* 2004).

Conclusions

1- The drainage water (7 mmohs/cm) enhanced the SOD and CAT activity and MDA, while it decreased GSH and proline content.

2- The concentration 5 ppm of CuNPs enhanced SOD and CAT activity and inhibition in MDA, GSH and the proline content in the treatments of drainage water (7 mmohs/cm).

The river water (2.83 mmohs/cm) was the suitable for irrigation until with almost treatments of magnetized water and CuNPs, while the drainage water (4 and 7 mmohs/cm) cased increasing in enzymatic and non-enzymatic antioxidants in this research. The treatments with magnetic water especially of 2000 Gauss and CuNPs in different concentrations enhanced the damage mitigation of salinity.

References

Al-Qaisi, G.Y. (2004). Electrical and Magnetic. Dar Al Maysara for publishing, distribution and printing. First Edition. Amman, Jordan. pp512.

Al-Rawee, K.M. and M.K. Abd Al-Azize (2000). Design and analysis of agricultural experiments. Dar Al Kutub For Printing & Publishing. University of Mosul/Iraq.

An, Y.J. (2006). Assessment of comparative toxicities of lead and copper using plant assay. *Chemosphere,* **62:** 1359–1365.

Ashraf, M. and P.J.C. Harris (2004). Potential biochemical indicators of salinity tolerance in plant. *Plant Sci.,* **166:** 3-16.

Bates, L.S., R.P. Waldren and I.D. Tears (1973). Rapid determination of free proline for water-stress studies. *Plant and Cell,* **39:** 205-207.

Buege, J.A. and S.D. Aust (1978). Microsomal lipid peroxidase.

Methods in Enzymology, **52:** 302-310.

Cavalcantia, F.R., J.P.M.S. Limaa, S.R.L. Ferreira-Silvaa, R.A. Vie´Gasb and J.A.G. Silveiraa (2007). Roots and leaves display contrasting oxidative response during salt stress and recovery in cowpea. *Journal Of Plant Physiology*, **164:** 591-600.

Chelli-Chaabouni, A., A. Ben Mosbah, M. Maalej, K. Gargouri, R. Gargouri- Bouzid and N. Drira (2010). In vitro salinity tolerance of two pistachio rootstocks: *Pistacia vera* L. and P. atlantica Desf. *Environ. Exp. Bot.,* **69:** 302–312.

Chen, W. and A.M. Viljoen (2010). Geraniol-a review of a commercially important fra- grance material. *S. Afr. J. Bot*., **76:** 643–651.

Chibber, S., S.A. Ansari and R. Satar (2013). New vision to CuO, ZnO and TiO_2 nanoparticles: their outcome and effects. *Journal of nanoparticle Research,* **15:** 1–13.

Delaplace, P., P. Frettinger, M.E. Ghanem, A. Blondiaux, J. Bauwens, S. Cotton, C. Clerck, A. Dewalque, J. Guy, F. Heuze, A. Massoz, T. Tassignon, G. Van Aubel, P. du Jardin and M.L. Fauconnier (2009). Lipoxygenase pathway and antioxidant system in salt stressed tomato seedling (*Lycopersicon esculentum* Mill.). *Biotechnol. Agron. Soc. Environ.,* **13(4):** 529-536.

Dimkpa, C.O., J.E. McLean, D.E. Latta, E. Manangón, D.W. Britt, W.P. Johnson, M.I. Boyanov and A.J. Anderson (2012). Cuo and ZnO nanoparticles: phytotoxicity, metal speciation, and induction of oxidative stress in sand-grown wheat. *J. Nanopart Res.,* **14:** 1–15.

Dionisio-Sese, M.L. and S. Tobita (1998). Antioxidant responses of rice seedlings to salinity stress. *Plant Sci.,* **135:** 1–9.

Ellman, G.L. (1959). *Arch. Biochem. Bioply.,* **822:** 70. In: Shalata, A. and P.M. Neumann (2001). Exogenous ascorbic acid (Vitamin acid) increases resistance to salt stress and reduces lipid peroxidation. *J. Exp. Bot.,* **52:** 2207-2211.

Esfandiari, E., F. Shekari, F. Shekari and M. Esfandiari (2007). The effect of salt stress on antioxidant enzymes' activity and lipid peroxidation on the wheat seedling. *Not. Bot. Hort. Agrobot. Cluj.*, **35(1):** 48-56.

Flowers, T.J. and T.D. Colmer (2008). Salinity tolerance in halophytes. *New Phytol.,* **179:** 945–963.

Gangwar, M., M.K. Gautam, A.K. Sharma, Y.B. Tripathi, R.K. Goel and G. Nath (2014). Antioxidant capacity and radical scavenging effect of polyphenol rich Mallotusphilip-penensis fruit extract on human erythrocytes: an in vitro study. The Scientific World Journal.

Garg, N. and G. Manchanda (2009). ROS generation in plants: boon or bane?. *Plant Biosys.,* **143:** 8-96.

Goth, L. (1991). A simple method for determination of serum catalase activity and revision of reference range. *Clinicachimicaacta*, **196(2-3):** 143-151.þ

Grewal, H.S. and B.L. Maheshwari (2011). Magnetic treatment of irrigation water and snow pea and chickpea seeds enhances early growth and nutrient contents of seedling. *Bioelectromagnetic,* **32:** 58-65.

Hall, C. (2001). Sources of natural antioxidants: oilseeds, nuts, cereals, legumes, animal products and microbial sources. In: Pokorny, J., N. Yanishlieva, M. Gordon, editors. Antioxidants in food: practical applications, *Cambridge England: Woodhead Publishing Limited,* 159-209.

Hassanein, R.A., F.M. Bassuony, D.M. Baraka and R.R. Khalil (2009). Physiological effects of nicotinamide and ascorbic acid on *Zea mays* plant growen under salinity stress: I. changes in growth, some relevant metabolic activities and oxidative defense systems. *Res. J. Agric. Sci.,* **5(1):** 72-81.

Hernàndez, J.A., F.J. Corpas, M. Gómez, L.A. del R1o and F. Sevilla (1993). Salt-induced oxidative stress mediated by activated oxygen species in pea leaf mitochondria. *Physiol. Plant.,* **89:** 103-110.

Hernàndez, J.A., A. Jiménez, P.M. Mullineaux and F. Sevilla (2000). Tolerance of pea (*Pisumsativum* L.) to long-term salt stress is associated with induction of antioxidant defenses. *Plant Cell Environ.,* **23:** 853–862.

Hokmabadi, H., K. Arzani and P.F. Grierson (2005). Growth, chemical composition and carbon isotope discrimination of pistachio (*Pistacia vera* L.) rootstock seedlings in response to salinity. *Aust. J. Agric. Res.,* **56:** 135–144.

Kader, M.A. and S. Lindberg (2010). Cytosolic calcium and pH signaling in plants under salinity stress. Plant Signaling and Behaivor, **5(3):** 233-238.

Karimi, H.R., R. Maleki Kuhbanani (2014). Evaluation of inter-specific hybrid of P. atlantica × P. vera *cv.* 'Badami-Rize-Zarand' as pistachio rootstock to salinity stress according to some growth indices, echophysiological and biochemical parameter. *J. Stress Physiol. Biochem.,* **10(3):** 5–17.

Koca, H., F. Ozdemir and I. Turkan (2006). Effect of salt stress on lipid peroxidation and superoxide dismutase and peroxidase activities of *LycopersiconEsculentum*and L. *Pennellii. Biologia Plantarum,* **50(4):** 745-748.

Lin, I.J. and J. Votvat (1990). Exposure of irrigation and drinking water to a magnetic field with controlled power and direction. *Journal of Magnetism and Magnetic Materials,* **83:** 525-526.

Ma, C., H. Liu, H. Guo, C. Musante, S.H. Coskun, B.C. Nelson, J.C. White, B. Xing and O.P. Dhankher (2016). Defense mechanisms and nutrient displacement in Arabidopsis thaliana upon exposure to CeO_2 and $In2O_3$ nanoparticles. *Environ. Sci. Nano.,* **3:**1369-1379.

Ma, X., J. Geisler-Lee, Y. Deng and A. Kolmakov (2010). Interactions between engineered nanoparticles (ENPs) and plants: Phytotoxicity, uptake and accumulation. *Sci. Total Environ.,* **408:** 3053–3061.

Maheshwari, B.L. and H.S. Gerwal (2009). Magnetic treatment of irrigation water : its effects on vegetable crop yield and water productivity. *Agriculthure Water Management,* **96:** 1229-1236.

Maia, J.M., E.L. Voigt, C.E.C. Macêdo, S.L. Ferreira-Silva and J.A.G. Silveira (2010). Salt-induced changes in antioxidative enzyme activities in root tissues do not account for the differential salt tolerance of two cowpea cultivars. *Braz. J. Plant Physiol*., **22(1):** 113-122.

Marklund S. and G. Marklund (1974). Involvement of the Superoxide Anion Radical in the Autoxidation of Pyrogallol and a Convenient Assay for Superoxide Dismutase. *Eur. J. Biochem.,* **47:** 469-474.

Mittler, R. (2002). Oxidative stress, antioxidants and stress tolerance. *Trends Plant Sci.,* **7:** 405–410.

Mittova, V., M. Guy, M. Tal and M. Volokita (2004). Salinity upregulates the antioxidative system in root mitochondria and peroxisomes of the wild salt-tolerant tomato species *Lycopersiconpennellii*. *J. Exp. Bot.,* **55:** 1105–1113.

Rafique, M., A.J. Shaikh, R. Rasheed, M.B. Tahir, H.F. Bakhat, M.S. Rafique and F. Rabbani (2017). A review on synthesis, characterization and applications of copper nanoparticles using green method. *Nano.,* **12:** 04.

Rick, C.M., J. De Verna and R.T. Chetelat (1990). Experimental Ingression to the Cultivated tomato from related wild nightshades In: AB Bennett and SDO'Neill (eds), Horticultural Biotechnology. New York 19-30.

Rouhier, N., S.D. Lemaire and J.P. Jacquot (2008). The role of glutathione in photosynthetic organisms: emerging functions for glutaredoxins and glutathionylation. *Annu. Rev. Plant Biol.,* **59:** 143166.

Rui, Y., P. Zhang, Y. Zhang, Y. Ma, X. He, X. Gui, Y. Li, J. Zhang, L. Zheng, S. Chu, *et al.,* (2015). Transformation of ceria nanoparticles in cucumber plants is influenced by phosphate. Environ. Pollut., **198:** 8–14.

Sairam, R.K. and G.C. Srivastava (2002). Change in antioxidant activity in sub-cellular fraction of tolerant and susceptible wheat genotypes in response to long term salt stress. *Plant Sci.,* **162:** 897-904.

Sanchez-Rodriguez, E., M.M. Rubio-Wilhelmi, L.M. Cervilla, B. Blasco, J.J. Rios, M.A. Rosales, L. Romero and J.M. Ruiz (2010). Genotypic differences in some physiological parameters symptomatic for oxidative stress under moderate drought in tomato plants. *Plant Sci.,* **178:** 30-40.

Shah, S.H. (2007). Effects of salt stress on mustard affected by gibberellic acid application. *Gen. Appl. Plant Physiology,* **33(1-2):** 97-106.

Shamshiri, M.H. and M. Fattahi (2014). Evaluation of two biochemical markers for salt stress in three pistachio rootstocks inoculated with arbuscularmycorrhiza (Glomusmosseae). *J. Stress Physiol. Biochem.,* **10(1):** 335–346.

Sivanadanam, V., R. Neelamegam and K.P. Chellappan (2012). Salinity effect : ix on catalase, polyphenol oxidase and peroxidase enzyme activity in *Rhizophoraapiculata* Blume and *Acanthus ilicifolius*Linn seedlings. *Plant Archives* **12 (1):** 195-199.

Sommer, A.L. (1931). Copper as an essential for plant growth. *Plant Physiology,* **6:** 339–345.

Stofleth, J. (2012). Understanding free radicals: Isolating active thylakoid membranes and purifying the cytochrome *b6 f* complex for superoxide generation studies, *Journal of Purdue Undergraduate Research,* **2:** 64–69.

Su, Y., J. Guo, H. Ling, S. Chen, S. Wang, L. Xu, A.C. Allan and Y. Que (2014). Isolation of a novel peroxisomal catalase gene from sugarcane, which is responsive to biotic and abiotic stresses. PLoS One.

Tsai, Y.C., C.Y. Hong, L.F. Liu and C.H. Kao (2004). Relative importance of Na^+ and Cl^- in NaCl induced antioxidant systems in roots of rice seedlings. *Physiologia Plantarum*, **122(1):** 86-94.þ

Wang, Y., S. Mopper and K.H. Hasentein (2001). Effects of salinity on endogenous ABA, IAA, JA and SA in *Iris hexagona*. *J. Chem. Ecol.,* **27:** 327-342.

Willekens, H., S. Chamnongpol, M. Davey, M. Schraudner and C. Langebartels (1997). Van Montagu M. Catalase is a sink for H_2O_2 and is indispensable for stress defence in C3 plants. *EMBO J.,* **16:** 4806–4816.

Xiong, Z.T., C. Liu and B. Geng (2006). Phytotoxic effects of copper on nitrogen metabolism and plant growth in Brassica pekinensisRupr. *Ecotoxicol Environ Safety,* **64:** 273-280.

Zhang, P., Y. Ma, S. Liu, G. Wang, J. Zhang, X. He, J. Zhang, Y. Rui and Z. Zhang (2017). Phytotoxicity, uptake and transformation of nano-CeO_2 in sand cultured romaine lettuce. *Environ. Pollut.,* **220:** 1400-1408.

Zhang, P., Y. Ma, Z. Zhang, X. He, Y. Li, J. Zhang, L. Zheng and Y. Zhao (2015). Species-specific toxicity of ceria nanoparticles to Lactuca plants. *Nanotoxicology,* **9:** 1-8.