

Research Paper

Improving of drought stress by application of zinc and iron nanoparticles in tomato plant

Moslem Dehani¹, Hossein Mozafari², Hassan Salari^{2*}

1-M.Sc student, Department of Ecology, Institute of Sciences and High Technology and Environmental Sciences, Graduate University of Advanced Technology Kerman, Iran

2-Assistant professor, Department of Ecology, Institute of Sciences and High Technology and Environmental Sciences, Graduate University of Advanced Technology, Kerman, Iran

Article information

Abstract

Available online: Mar. 2024
Copyright © 2024 Kerman Graduate University of Advanced Technology. All rights reserved.

Keywords:
Drought stress
tomato
nanoparticle
Chlorophyll *a* and *b*

Drought stress affects many morphological characteristics and biochemical processes related to plant growth and development. In this sense, drought, as a multidimensional stress, has various destructive effects on plants. By inhibiting the transfer of electrons, this stress creates a secondary stress in the production of reactive oxygen species, causing double damage to cell membrane, photosynthetic pigments, and other physiological parameters. Today, the use of metal nanoparticles such as zinc and iron in improving activities and dealing with plant stresses can create beneficial effects in plant and agricultural biotechnology. The treatments include drought stress at two levels (drought stress and no drought stress) as the main factor and three levels of iron, zinc separately and integrative of iron and zinc nanoparticles. The results showed that all investigated traits were affected by drought stress conditions. Under drought stress the fresh and dry weight, Chlorophyll *a* and *b*, decreased and the usage of iron and zinc nanoparticles reduced the effects of drought stress in growth parameters in tomato plants. Therefore, the application of the above nanoparticles can be very effective in improving the growth of tomato plants, especially in dry areas.

1. Introduction

Drought, as a multidimensional stress, has many destructive and adverse effects on sensitive and semi-sensitive plants. This important abiotic stress affects many morphological characteristics and physiological processes of plants related to growth and development. This stress causes the production of reactive oxygen species, damage to

cell membranes, inhibition of electron transfer, reduction of photosynthetic pigments and protein. The reaction of different plants to drought stress is a complex process that includes molecular changes and its spread to all metabolic activities and its effect on the growth, morphology and phenology of plants under this stress (Wang et al. 2018).

* Corresponding author: Assistant professor, Department of Ecology, *Institute of Sciences and High Technology and Environmental Sciences*, Graduate University of Advanced Technology, Kerman, Iran
Email: hsalari57@gmail.com

creating the cell's defense system against reactive oxygen species, modulating free radicals and their destructive effects in membrane systems, and as a result, tolerance increases plants to drought stress. The interaction of plant cells with nanoparticles leads to changes in plant gene expression and related cell pathways, which ultimately affects plant growth and development. It has been proven that nanoparticles produced by biological methods are more stable compared to chemical methods. Zinc and iron nanoparticles have many applications in the field of antimicrobial diagnosis, treatment, analysis and microelectronics.

Some recent advances in plant and agricultural sciences show the use of nanoparticles in the effective and safe use of chemicals for plants, plants as a source of synthesis of nanoparticles. They show different effects on growth and metabolic function and genetic modification using nanoparticles. However, the interaction of plant cells with nanoparticles leads to the change of plant gene expression and related biological pathways, which ultimately affects the optimal growth and development of the plant. As a source of nanoparticles synthesis, plants show various effects on growth and metabolic function and genetic change using nanoparticles. Exogenous application of nanoparticles with optimal conditions and suitable type such as zinc and iron with specific size and concentration can cause better and greater resistance to drought stress in wheat, which was investigated in this research. Subsequently that studies have been done to distinguish zinc oxide and iron oxide nanoparticles, but some typefaces of these two important nanoparticles in terms of sacking drought stress and more struggle of plants to stresses such as drought continue to be studied further. Consequently, the mutual checkup of these two types nanoparticles are imperative from

the aspects of size and type of nanoparticles in the conditions of drought stress in critical plants including wheat. Therefore, the broad binder of this research was to investigate the interface effect of iron oxide nanoparticles (25 nm) with two forms of zinc nanoparticles (25 and 50 nm) at a concentration of 50 mg/liter on grander struggle of wheat plant and refining its growth under drought stress conditions.

According to new studies and confirmed reports about the exclusive role of zinc and iron nanoparticles as well as the high sensitivity of tomato to drought stress conditions, there is a possibility that the combined use of iron oxide nanoparticles and zinc oxide will increase the drought stress in this plant. Therefore, in this research, the possibility of increasing the resistance of tomato plants under drought stress was investigated using zinc oxide nanoparticles in two sizes of 25 and 50 nm individually and in combination, and then the morphological growth parameters were measured under drought stress conditions.

2. Material and methods

2-1. Research design and treatment groups

This research was carried out in the form of a completely random factorial design with 3 replications in the greenhouse of Kerman University of Advanced Industrial and Technological Education in 1401-1402. The tested plant of this research was tomato, the seeds of which were obtained from the flat seed company of Iran-Tehran.

The treatments of this study included nanoparticles of iron oxide and zinc oxide, which were obtained from Iranian Pishgaman Nano Company. The specifications of nanoparticles used are listed in Tab 1.

Tab 1: Characteristics of nanoparticles used in this research.

Characteristics of nanoparticles	(ZnO)-50nm	(ZnO)-25nm	(Fe ₂ O ₃) 25nm
Nanoparticle diameter	50-60	10-30	40-20
Purity	99.92%	99%	98%
Color	Milk white	white	red brown
Shape	Almost spherical	Almost spherical	spherical
pH	-	-	7.5
apparent density	5.56 g/cm ³	-	1.20 g/cm ³
Real density	-	5.606	5.24 /cm ³

2-2.Preparation of seeds:

Tomato seeds were planted in plastic pots (3 seeds in each pot). The pots were transferred to greenhouse and kept at 23°C in the dark and 25°C in the light, the photoperiod was 16/8 hours of darkness/light, the humidity 45%, and the light intensity of 12 Klux.

2-3.Cultivation of seeds:

The pot culture medium, including a mixture of perlite and peat moss in a ratio of 4:1, which was obtained from Kerman agricultural companies. The seeds washed and moistened with distilled water until they were ready for seed cultivation. During the seed planting period, the pots were watered with distilled water twice a day, in the morning and in the evening, and Hoagland's solution was also given to the plants after sprouting. The treatment of the plants started after the plants reached the 3-leaf stage and iron and zinc nanoparticles were given to the plants twice a day at 10 am and 4 pm for 10 days.

One half of the pot was given drought stress and nanoparticles, and the other half of the pot was given only nanoparticles, and the plants were our witnesses. After 10 days of treatment, the plants were collected and after harvesting, the growth indices of the plant were measured.

2-4.Measurement of growth parameters: The fresh weight of roots and aerial parts in fresh tomato samples was measured using a scale with an accuracy of 0.001 g.

2-5.Measurement of photosynthetic pigments:

Photosynthetic pigments were measured according to Lichtenthaler's 1987 (Lichtenthaler, 1987).

3.Statistical Analysis

The data obtained from the experiment was statistically analyzed in the form of completely random design and in the form of factorial experiment and 3 repetitions using SPSS version 24 statistical software. Average growth parameters were compared using Duncan's multiple range test at the 5% level. The graph of the mentioned parameters was drawn using Excel 2019 software

4.Results

The occurrence of drought stress compared to the control led to a decrease in aerial part length. In this way, drought stress in the form of 5 days of water shortage caused a 27% decrease in root length and a 28% decrease in stem length compared to control plants without drought stress. According to table 1 in conditions without drought stress, the application of both types of zinc oxide nanoparticles without or combined with iron oxide nanoparticles at a level of 5% had a significant effect on root length compared to the control. The results showed that in the conditions of applying drought stress, the interaction of 25 nm zinc oxide nanoparticles and 25 nm iron oxide led to a significant increase in stem and root length even more than the control (Tab 2).

Tab 2: The effect of zinc oxide and iron oxide nanoparticles under control or drought stress conditions on the common growth parameters of tomato plants. Different letters indicate significant differences based on Duncan post hoc test ($P < 0.05$). Error bars show standard error (SE).

Drought stress	Nanoparticles mgL ⁻¹	Aerial part Length (Cm/plant)	Root Length (Cm/plant)	Aerial part fresh weight (gr/plant)	Root fresh weight (gr/plant)	Ch. a (mg/gFW)	Ch. b (mg/gFW)	Car (mg/gFW)
5	0+0	19.07±0.96 _{ab}	34.6±2.265 _b	11.11±0.94 _{ab}	4.04±0.41 ^a	5.47±0.35 _{bc}	1.06±0.64 ^a	3.70.47 ^{bc}
5	0+100	20.53±1.32 _a	35.47±1.58 _b	11.37±1.02 _a	4.16±0.5 ^a	9.66±0.58 ^a	1.98±0.6 ^c	4.45±0.32 ^a
5	10+0	20.67±0.57 _a	38.59±1.98 _{g a}	11.38±1.16 _a	2.41±0.26 ^c	6.63±0.8 ^{cd}	2.34±0.51 _{ab}	3.2±0.15 ^{bc}
5	10+100	21.48±1.55 _a	33.9±1.85 _b	11.75±0.49 _a	4.07±0.46 ^a	8.5±0.72 ^b	2.76±0.55 ^b	3.8±0.3 ^{ab}
10	0+0	8.87±0.96 ^d	16.1±1.29 ^d	2.45±0.38 ^c	0.98±0.16 ^d	1.95±0.34 ^e	1.73±0.31 ^c	1.29±0.3 ^d
10	0+100	16.26±0.78 _c	33.9±1.38 _b	9.98±0.7 ^b	4.13±0.2 ^a	7.11±1.55 ^c	1.68±0.39 ^c	1.3±0.94 ^c
10	10+0	18.2±2.3 ^{bc}	26.1±2.65 ^c	10.64±0.81 _{ab}	2.2±0.27 ^c	5.59±0.28 ^d	1.31±0.5 ^c	2.8±0.23 ^c
10	10+100	20.38±2.43 _a	32.07±2.07 _b	11.28±0.09 _a	3.41±0.31 ^b	8.5±0.88 ^{ab}	3.6±0.6 ^a	3.7±0.49 ^{ab}

The application of drought stress compared to control led to a decrease in root length. According to table 2 in conditions without drought stress, the application of both types of zinc oxide nanoparticles without or combined with iron oxide nanoparticles at a level of 5% had a significant effect on root length compared to the control. The results showed that in the conditions of applying drought stress, the interaction of zinc oxide nanoparticles and iron oxide led to a significant increase in root length even more than the control (Tab 2).

The applying of drought stress compared to the control led to a decrease in root and aerial part fresh weight. In conditions without drought stress, the application of both types of zinc oxide nanoparticles without or combined with iron oxide nanoparticles at a level of 5% had a significant effect on root and aerial part fresh weight compared to the control. The results showed that in the conditions of applying drought stress, the interaction of zinc oxide nanoparticles and iron oxide led to a significant increase in root and aerial part fresh weight even more than the control (Tab 2, 3).

Tab 3: variance analysis of the growth parameters at a significant level of 5%. (*) means a significant effect of the treatment on the desired parameter with 95% accuracy.

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Aerial part length	Between Groups	179.237	15	11.949	1.066	.0413*
	Within Groups	482.000	63	11.209		
	Total	661.237	78			
Root length	Between Groups	262.182	15	17.479	1.107	.0179*
	Within Groups	678.750	63	15.785		
	Total	940.932	78			
Aerial part fresh weight	Between Groups	267.009	15	10.801	31.680	.0120*
	Within Groups	11.555	63	.361		
	Total	188.564	78			
Root fresh weight	Between Groups	177.009	15	11.21	32.680	.020*
	Within Groups	10.545	63	.351		
	Total	186.524	78			
Chl. a	Between Groups	682.323	15	45.488	49.788	.030*
	Within Groups	29.237	63	.914		
	Total	711.559	78			
Chl. b	Between Groups	292.041	15	19.469	166.231	.041*
	Within Groups	3.748	63	.117		
	Total	295.789	78			
Cart	Between Groups	88.955	15	5.930	184.974	.024*
	Within Groups	1.026	63	.032		

The applying of drought stress compared to the control led to a decrease in photosynthetic pigment. In conditions without drought stress, the application of both types of zinc oxide nanoparticles without or combined with iron oxide nanoparticles at a level of 5% had a significant effect on Chl. *a* and Chl. *b*. compared to the control. The results showed that in the conditions of applying drought stress, the interaction of zinc oxide nanoparticles and iron oxide led to a significant increase on Chl. *a* and Chl. *b*. even more than the control (Tab 2).

5. Discussion

Environmental stresses, especially drought, have a negative effect on plant growth and productivity worldwide and cause significant yield reductions in crops. Meanwhile, the world's population will reach about 10 billion people in 2050, which will greatly affect food security for human nutrition.

(Hossain et al. 2015; Webber et al. 2018). In the current study, we showed that zinc and iron nanoparticles could enhance drought tolerance in tomato.

This may help to maintain photosynthesis and protective mechanism and lead to balance in growth and response to drought stress, ultimately can affect plant production and seed productivity in tomato under drought stress conditions. In fact, the preservation of photosynthetic pigments and protective mechanism leads to growth balance and response to drought stress, which can ultimately affect plant biomass and seed productivity in tomato under drought stress conditions.

The positive effect of zinc and iron nanoparticles in improving plant biomass in tomato under non-stress condition and drought conditions documented in table 1. These results were supported by previous studies that Zn and Fe

plays an important role in plant growth and development (Ngo et al. 2014; Tamez et al. 2019).

Chloroplasts, having photosynthetic pigments, play a very important role in photosynthesis, which are closely related to plant biomass and productivity. (Tamez et al. 2019; Yamauchi 2018). In drought stress conditions, plants in the face of stresses, especially drought stress, accumulate a high level of oxidative stress molecules, including ROS (Farooq et al. 2019), which can directly affect chloroplasts, which are known as the most sensitive organelles to oxidative stress conditions (Yamauchi 2018).

In plants, carotenoids act as an antioxidant to protect chlorophyll from oxidative stress, thus maintaining chlorophyll content under stress conditions. (Emiliani et al. 2018). The results showed that nanoparticles increase the carotenoid content during drought in tomatoes, which can help the plant against the process of chlorophyll degradation and lead to maintaining a higher chlorophyll content.

Generally, ROS accumulation increases under stress, which acts in plant defense responses through specific signal transduction pathways (Huang et al. 2019; Xie et al. 2019). Excessive concentration of ROS increases in cells and causes oxidative damage to membranes, proteins, RNA and DNA molecules and can even lead to oxidative destruction of the cell in a process called oxidative stress (Xie et al. 2019).

6.CONCLUSION

Our comparative results in this research showed valuable information about the role of iron and zinc nanoparticles in the regulation of plant growth and development as well as the response to drought stress in tomato. In general, iron and zinc nanoparticles significantly affect plant biomass in normal and dry conditions. In addition, the use of these nanoparticles preserve the content of chlorophyll and carotenoids under drought stress conditions.

7.Acknowledgments

This research is part of the master's thesis in Graduate University of Advanced Technology (Kemran-Iran). The authors of the article are grateful to the university authorities for their support.

8.References

- 1.Emiliani J, D'Andrea L, Lorena Falcone Ferreyra M, Maulion E, Rodriguez E, Rodriguez Concepcion M, Casati P. A role for beta, beta-xanthophylls in Arabidopsis UV-B photoprotection. *J Exp Bot* 2018; 69: 4921-4933. <https://doi.org/10.1093/jxb/ery242>
- 2.Farooq MA, Niazi AK, Akhtar J, Farooq M, Souri Z, Karimi N, Rengel Z. Acquiring control: The evolution of ROS-Induced oxidative stress and redox signaling pathways in plant stress responses. *Plant Physiol Biochem* 2019; 141: 353-369. <https://doi.org/10.1016/j.plaphy.2019.04.039>
- 3.Hasanuzzaman M, Nahar K, Gill SS, Fujita M. Drought stress responses in plants, oxidative stress, and antioxidant defense. *Climate change and plant abiotic stress tolerance* 2014; 209-250.
- 4.Hossain MA, Bhattacharjee S, Armin SM, Qian P, Xin W, Li HY, Burritt DJ, Fujita M, Tran LSP. Hydrogen peroxide priming modulates abiotic oxidative stress tolerance: insights from ROS detoxification and scavenging. *Front Plant Sci* 2015; 6, 420. <https://doi.org/10.3389/fpls.2015.00420>
- 5.Huang H, Ullah F, Zhou DX, Yi M, Zhao Y. Mechanisms of ROS regulation of plant development and stress responses. *Front Plant Sci* 2019; 10: 800. <https://doi.org/10.3389/fpls.2019.00800>
- 6.Lichtenthaler HK. Chlorophyll fluorescence signatures of leaves during the autumnal chlorophyll breakdown. *J Plant Physiol* 1987; 131: 101-110.
- 7.Ngo BQ, Dao TT, Nguyen CH, Tran XT, Nguyen TV, Khuu TD, Huynh TH. Effects of nanocrystalline powders (Fe, Co and Cu) on the

germination, growth, crop yield and product quality of soybean (Vietnamese species DT-51). *Adv Nat Sci-Nanosci* 2014; 5: 015016.

8. Tamez C, Morelius EW, Hernandez-Viezcas JA, Peralta-Videa JR, Gardea-Torresdey J. Biochemical and physiological effects of copper compounds/nanoparticles on sugarcane (*Saccharum officinarum*). *Sci Total Environ* 2019; 649: 554-562. <https://doi.org/10.1016/j.scitotenv.2018.08.337>

9. Wang Z, Li G, Sun H, Ma L, Guo Y, Zhao Z, Gao H, Mei L. Effects of drought stress on photosynthesis and photosynthetic electron transport chain in young apple tree leaves. *Biology open* 2018; 7(11): 035279.

10. Webber H, Ewert F, Olesen JE, Müller C, Fronzek S, Ruane AC, Bourgault M, Martre P,

Ababaei B, Bindi M, Ferrise R. Diverging importance of drought stress for maize and winter wheat in Europe. *Nat Commun* 2018; 9(1): 4249. <https://doi.org/10.1038/s41467-018-06525-2>

11. Xie X, He Z, Chen N, Tang Z, Wang Q, Cai Y. The roles of environmental factors in regulation of oxidative stress in plant. *Biomed Res Int* 2019; 9732325. <https://doi.org/10.1155/2019/9732325>

12. Yamauchi Y. Integrated chemical control of abiotic stress tolerance using biostimulants. In: Andjelkovic V (Ed) *Plant Abiotic Stress and Responses to Climate Change*. Intech Open, London 2018; 133-143. <https://doi.org/10.5772/intechopen.74214>