PLANT RESPONSE TO ABIOTIC STRESS

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REVIEW

Abstract
Plants are subjected to a wide range of abiotic stresses such as heat, cold, drought, salinity, flooding and heavy metals. In general, abiotic stress has a negative impact on plant growth and development that affects agricultural productivity, causing security problems and leading to economic losses. To reduce the negative effects of environmental stress on crop plants, new technologies such as nanotechnology have emerged. The implementation of nanotechnology in modern agriculture can also help to increase water efficiency, prevent plant diseases, ensure food security, reduce environmental pollution and increase sustainability. In this sense, nanoparticles (NPs) can help combat deficiencies. nutrients, promoting stress tolerance and increasing crop yield and quality. In this review article based on research studies from the last five years, the effect of several types of abiotic stress (drought, salinity, heavy metals) on physiological and biochemical parameters on plants is described. The role of NPs as a tool to mitigate the harmful effects of stress induced by abiotic stress in crops and crop plants are also summarized and presented in this article. Studies in the literature highlight that NPs are gaining more and more interest for their application in agriculture, especially for reducing the negative effects induced by abiotic stress.

Keywords: drought, salinity, heavy metals, nanoparticles
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INTRODUCTION

Abiotic stressors that can affect modern agricultural productivity worldwide include high or low temperature, water logging, drought, salinity, heavy metals (HMs) and ultraviolet (UV) radiation (Seleiman et al., 2020a; Badawy et al., 2021). The response of plants to abiotic stress involves changes in various morphological, physiological and biochemical processes, depending on the type of crop, the type of stress and the time of exposure (Semida et al., 2014; Desoky et al., 2020a; Rady et al., 2021; Abd El-Mageed et al., 2022; Shaaban et al., 2022). To meet the growing global food demand, researchers are striving to ameliorate the harmful effects induced by abiotic stress, increase crop yield and food production, and achieve food sustainability and security. Indeed, to address these urgent global concerns, researchers must continue to develop innovative technologies or solutions.

Nanotechnology is a fascinating and rapidly growing field of research, leading to various innovations (El-Saadony et al., 2020; Abd El-Ghany et al., 2021). In particular, nanotechnology can help provide effective solutions to agriculture-related problems and achieve a sustainable and secure future for agriculture (Seleiman et al., 2021b). In recent years, nanotechnology has received significant attention due to its wide range of applications in medicine, drug delivery, energy, poultry production, and agri-food (Seleiman et al.; 2020a; Yousry et al., 2020; Salem et al., 2021). In agriculture, nanotechnology is mainly used in the application of nanofertilizers and nanopesticides to track product and nutrient levels to increase growth and productivity and improve plant resistance to pests and microbial diseases. (Shang et al., 2019; Bhatt et al., 2020)

In this article, data from recent literature have been synthesized regarding the physiological and biochemical changes of plants in the case of abiotic stress such as drought, salinity, heavy metals. In the second part of the article, the roles of NPs in reducing the negative effects induced by different abiotic factors are presented.

THE EFFECT OF DROUGHT ON PLANTS

Plants are exposed to various environmental stresses during growth and development under natural and agricultural conditions. Among them, drought is one of the most severe environmental stresses affecting plant productivity. About 80-95% of the fresh biomass of the plant body is composed of water, which plays a vital role in various physiological processes, including many aspects of plant growth, development and metabolism. The effects of drought on agriculture are compounded by the depletion of water resources and the increased demand for food due to an alarming increase in the world's population together with high economic growth and rising living standards mean that demand already exceeds supply in many countries or will do so work in the following decades (O'Connell,2017). Moreover, in some cases plants are unable to capture water from the soil, even if sufficient moisture is present in the root zone, a phenomenon known as physiological or pseudo drought -drought (Daryanato et al., 2020).

Water deficit outbreaks are due to the occurrence of less or no precipitation, which leads to low soil moisture content and low water potential in the aerial parts of the plant, such as leaves and stems (Ristvey et al., 2019). When this happens, the rate of water loss through leaf transpiration exceeds the rate of water uptake through roots in dry environments (Goche et al., 2020). Roots strive to absorb more water through expansion and this ultimately adapts plants to minimize stomatal water loss when there is a water deficit (Martínez-Vilalta J et al.,2016). Typical symptoms of drought stress in plants include leaf rolling, yellowing of leaves, scorching of leaves, permanent wilting (Corso et al., 2020). **Table 1** shows the effects of drought on some plants.

THE EFFECT OF HEAVY METALS ON PLANTS

HMs are a group of metallic chemical elements with relatively high density, atomic weight and atomic number. Common heavy metals/metalloids include cadmium (Cd), mercury (Hg), lead (Pb), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni), and chromium (Cr). These heavy metals/metalloids come from natural or anthropogenic sources, such as water produced from the oil and gas industry (Neff et al., 2011), the use of fertilizers in agriculture (Rafique et al., 2016), sewage sludge (Farahat et al., 2015), the application of pesticides (Iqbal et al., 2016), electroplating and fossil fuel burning . HMs are non-degradable by any biological or physical process and are persistent in the soil for a long period of time, which poses a long-term threat to the environment (Suman et al.,2018). Depending on their role in biological systems, HMs can be grouped as essential and non-essential. Essential HMs such as Cu, Fe, Mn, Ni and Zn are required for physiological and biochemical processes during the life cycle of plants, however, they can become toxic when present in excess. Non-essential HMs such as Pb, Cd, As and Hg are highly toxic with no known function in plants (Fasani et al.,2017) and can cause environmental pollution and severely affect a variety of physiological and biochemical processes in crop plants and reduce agricultural productivity. They can enter the food chain through crops and accumulate in the human body through biomagnification, thus representing a great threat to human health (Rehman et al., 2017). The effect of some HMs on the physiological and biochemical parameters of *Helianthus annuus* and *Allium sativum* are presented in **Table 1**.

CLIMATE CHANGE AND SALINITY

Soil salinity is one of the impacts of climate change on coastal farmland, as sea level rise has increased salinity from 1 to 33% in 25 consecutive years. Sea level rise includes flooding and salinization and has implications for water resources. Sea level rise increases the salinity of both surface and groundwater through saltwater intrusion (Ullah et al.,2021).

The continuous increase in salinity in arable land due to poor cultivation practices and climate change have devastating global effects, and it is estimated that about 50% of arable land will be lost by the middle of the 21st century. To date, about 1,125 million hectares of agricultural lands have already been seriously affected by salinity, thus it is considered a serious threat to agriculture (Kumar et al.,2021).

NANOPARTICLES TO COMBAT PLANT STRESS

NPs are microscopic particles with at least one size in the 1-100 nm size range. They possess different physical, chemical and electrical properties compared to their bulk counterparts and thus open new avenues in the field of science, including the agricultural sector(Khan et al., 2019). The pathway by which NPs enter plants alters many plant processes, including germination, antioxidant activity, macro and micronutrients, chlorophyll content, chloroplast number and photosynthesis (Jalil et al.,2019). NPs can penetrate the cell membrane and cell wall to to be transported in the epidermis, xylem, central cylinder and leaves . NPs are transported via the active pathway through osmotic pressure, capillary forces, cell wall pores and plasmodesmata in plant roots or via the symplastic pathway (Usman et al., 2020). **Table 2** shows different types of NP and their effect against plant stress.

Table 1

The effect of several types of stress on plants

Type of stress	Factors	Plants	Effects	References
Drought	Lack of water and heat	*Solanum lycopersicum*	- Reduction of stomatal conductance and diminished concentrations of photosynthetic pigments - Chlorophyll and carotenoid concentrations decreased by 80% and 57%, respectively, in tomato plants	Ahluwalia, et al., 2021
	In vitro (0.1, 0.2, and 0.3 mol sorbitol/L); In the field (moisture content of 60, 40	21 cultivars *Solanum tuberosum*	- Reduced plant growth, - Reduced physiological traits, - Reduced potato tuber yield	Zaki et al.,2022
	stopping irrigation for 10 days	*Salvia nemorosa* L. cultivars	-reduced relative water content, chlorophyll *a*,*b* and total chlorophyll increased total soluble sugar increased proline content, total phenols and flavonoids enhanced the activity of antioxidant enzymes	Bayat et al., 2019
HMs	Ni, Cd, Cr, Ar, Pb, Ni	*Helianthus annuus*	- Increases the amount of proline - It inhibits the germination and growth of sorghum - Stomatal opening	Ejaz et al., 2023
	In vitro study, Cd, Co, Ni, Al, Cu, Cr, Pb (0-500 µM)	*Allium sativum* L.	- decreases of plant length, - reduced the root, leaves length - reduced number of leaves - decrease root development	Baktemur, 2022
Metal+Drought	Cd:0, 100, 150, 200 mg kg^{-1} 00%, 75% and 50% of field capacity	*Raphanus sativus* L.	- decrease of growth plant - decrease chlorophyll a, chlorophyll b and total chlorophyll content - increase electrolyte leakage, leaf relative water content, antioxidant enzyme activity, hydrogen peroxide, malondialdehyde, proline, sucrose and mineral element content	Tuver et al., 2022
Salinity	Control: water with EC* of 0.4 dS/ m Moderat salt stress: solution with ECs 2 dS/m Elevated salt stress: solution with4 dS /m.	Two strawberry cultivars (Camarosa and Rociera)	- osmotic stress, - water deprivation - reduced of the plant growth parameters, reduced the number of leaves and plant water content - negative impact on phytochemical included carbohydrates, organic acids, anthocyanins,	Denaxa et al.,2022
Salinity+ drought	NaCl: 0.75 and 150 mM 0%, 75% and 50% of the water to reach the field capacity	*Capsicum annuum* L.	- reduction in plant height, leaf number and leaf area - decrease of chlorophyll pigments content - decrease in photosynthetic activity, stomatal conductivity and transpiration rate - increased the amount of H_2O_2, MDA, proline and sucrose - -increase of POD, CAT and SOD	Yildirim et al., 2022

*EC-electrical conductivity; MDA-malondialdehyde; POD-Peroxidase; CAT-catalase; SOD-superoxide dismutase

Table 2.

The effect of different NPs on physiological and biochemical processes in different plants

The field of use of NPs	NPs	Plants	Effects	References
Salinity (NaCl (0, 50 mM))	CeO_2 (500 mg kg-1 dry sand)	*Brassica napus*	- improved plant photosynthesis - modify plant root anatomy - altered Na^+ fluxes and transport	Rossi et al., 2017
Salinity	Potassium sulfate (K_2SO_4	*Medicago sativa* L.	- Reducing electrolyte leakage - increase in proline content - increasing the activity of the antioxidant enzyme (catalase)	El-Sharkawy et al., 2017
Drought	Si	*Punica granatum*	- Further improvements to their photosynthetic pigments,	Zahedi et al., ,2021
	Fe_3O_4	*Solanum lycopersicum*	- Improving nutritional status, physical and chemical parameters, phenolic content	Alabdallah et al.,2021
Heavy metals	Fe_3O_4	Medicinal plants	- Cd metal in soil was reduced	Wang et al.,2020
	Hydroxyapatite	Agricultural plants	- They reduce the toxic effects of HMs and maintains pH	Cui et al.,2018

CONCLUSIONS

Abiotic stress is one of the most worrying types of stress faced by plants, regardless of whether it is drought, salinity, heavy metals.

To achieve sustainable agriculture, the research community needs to identify ecologically appropriate solutions to address crop yield loss induced by abiotic stress.

Nanotechnology is an innovative and effective means to promote crop yield and quality, improve the agricultural sector and manage global food demand. The potential role played by several NPs in mitigating abiotic stress-induced damage and improving plant development and crop yield is under intense investigation. NPs can reduce the negative effects of abiotic stress by activating plant defense mechanisms by inducing ROS production and phytotoxicity. NPs, given their small size, can also easily penetrate plant tissues, after which they positively influence plant morphological, physiological, and biochemical processes, promote plant development, and improve plant productivity under various abiotic stresses. Moreover, NPs have a large surface area that improves the absorption and delivery of various targeted nutrients.

REFERENCES

Abd El-Ghany, W. A., Shaalan, M., Salem, H. M.,2021. Nanoparticles applications in poultry production: an updated review. Worlds Poult. Sci. J. 77, 1001–1025.

Abd El-Mageed, T.A., Rady, M.O.A., Abd El-Wahed, M.H., Abd El-Mageed ,S.A., Omran, W. M., Aljuaid, B. S., et al. 2022. Consecutive seasonal effect on yield and water productivity of drip deficit irrigated sorghum in saline soils. Saudi J. Biol. Sci. 29, 2683–2690.

Ahluwalia,O, Singh,P.C., Bhatia,R.2021.A review on drought stress in plants: Implications, mitigation and the role of plant growth promoting rhizobacteria. Resources, Environment and Sustainability.5;100032.

Alabdallah, N.M., Hasan, M., Hammami, I., Alghamdi, A.I., Alshehri, D., Alatawi, H.A.,2021. Green Synthesized Metal Oxide Nanoparticles Mediate Growth Regulation and Physiology of Crop Plants under Drought Stress.Plants.10:1730.

Badawy,S. A., Zayed ,B. A., Bassiouni, S. M. A., Mahdi, A. H. A., Majrashi ,A., Ali, E. F., et al. 2021. Influence of nano silicon and nano selenium on root characters, growth, ion selectivity, yield, and yield components of rice (Oryza sativa L.) under salinity conditions.Plants, 10:1657.

Baktemur,G.2022.The Effect of Some Heavy Metals on the Growth of Garlic under In Vitro Conditions. HortScience ,58;1-5.

Bayat, H., Moghadam, A.N.2019. Drought effects on growth, water status, proline content and antioxidant system in three *Salvia nemorosa* L. cultivars. *Acta Physiol Plant* **41**,149

Bhatt ,D., Bhatt ,M. D., Nath ,M., Dudhat ,R., Sharma ,M., Bisht ,D. S. 2020.Application of nanoparticles in overcoming different environmental stresses,in Protective Chemical Agents in The

Amelioration of Plant Abiotic Stress. Biochemical and Molecular Perspectives, 635–654.

Corso,D., Delzon,D.,Lamarque,L.J, Cochard,H., Torres-Ruiz,J.M, King,A.,Brodribb,T.2020. Neither xylem collapse, cavitation, or changing leaf conductance drive stomatal closure in wheat. *Plant, Cell & Environment* ,43;854-865.

Cui ,H.,Shi,Y., Zhou,J. , Chu,H. , Cang,L. , Zhou,D.2018.Effect of different grain sizes of hydroxyapatite on soil heavy metal bioavailability and microbial community composition. Agriculture, Ecosystems & Environment ,267;165-173.

Daryanto, S., Wang, L., Jacinthe, P.A. 2020.Global synthesis of drought effects on cereal, legume, tuber and root crops production: A review. Agric. Water Manag. ;179:18–33.

Denaxa,N.K.,Nomikou,A.,Malamos,N,Liveri,E., Roussos,P.A., Papasotiropoulos,V.2022. Salinity Effect on Plant Growth Parameters and Fruit Bioactive Compounds of Two Strawberry Cultivars, Coupled with Environmental Conditions Monitoring.Agronomy,*12*(10), 2279

Desoky,E. S. M., Merwad ,A. R. M., Semida, W. M., Ibrahim ,S. A., El-Saadony ,M. T., Rady ,M. M.2020a. Heavy metals-resistant bacteria (HM-RB): potential bioremediators of heavy metals-stressed Spinacia oleracea. Plant. Ecotoxicol. Environ. Saf ,198:110685.

Ejaz,U., Khan,S.M, Khalid,N. ,Ahmad,Z. Jehangir,S., Rizvi,Z.F., Lho,L.H., Han,H. , Raposo,A..2023.Toxicity, Mechanism, and Remediation:Detoxifying the heavy metals: a multipronged study of tolerance strategies against heavy metals toxicity in plants. Environmental Pollutants in Agroecosystem

El-Saadony,M. T., Abd El-Hack, M. E., Taha, A. E., Fouda ,M., Ajarem ,J. S., Maodaa,N. S., et al. 2020. Ecofriendly synthesis and insecticidal application of copper nanoparticles against the storage pest Tribolium castaneum. Nanomaterials ,10;587

El-Sharkawy, M.S., El-Beshsbeshy,T.R., Mahmoud,E.K., Abdelkader,N.I., Al-Shal,R.M., Missaoui,A.M.2017. Response of Alfalfa under Salt Stress to the Application of Potassium Sulfate.Nanoparticles. American Journal of Plant Sciences8:1751–1773.

Farahat,E.,Linderholm,H.W..2015. The effect of long-term wastewater irrigation on accumulation and transfer of heavy metals in Cupressus sempervirens leaves and adjacent soils. Science of The Total Environment ,512-513;1-7

Fasani,E., Manara,A., Martini,F.,Furini,A., DalCorso,G..2017. The potential of genetic engineering of plants for the remediation of soils contaminated with heavy metals. Plant,Cell&Enviorement ,41;1201-1232.

Goche,T. , Shargie,N,G , Cummins,I. , Brown, A.P, Chivasa,S , Ngara,R.2020.Comparative physiological and root proteome analyses of two sorghum varieties responding to water limitation. Scientific reports .10(1):11835.

Iqabal,M.,Iqbal,N., Bhatti ,I.A., Ahmad ,N., Zahid,M..2016.Response surface methodology application in optimization of cadmium adsorption by shoe waste: A good option of waste mitigation by waste. Ecological Engineering ,88;265-275.

Jalil ,S.U.,Ansari,M.I.2019. Plant Signaling Nanoparticles and Abiotic Stress Tolerance in Plants: Synthesis, Action, and Signaling Mechanisms.Molecules.549-561.

Khan,Z., Upadhyaya,H..2019.Impact of Nanoparticles on Abiotic Stress Responses in Plants. Nanomaterials in Plants, Algae and Microorganisms .2;305-322.

Kumar ,S.,Li,G., Yang,J.,Huang,X.,Ji , Q., Liu ,Z., Ke,W., Hou,H..2021.Effect of Salt Stress on Growth, Physiological Parameters, and Ionic Concentration of Water Dropwort (Oenanthe javanica) Cultivars. Front. Plant Sci .12

Martínez-Vilalta,J., Garcia-Forner,N.2016.Water potential regulation, stomatal behaviour and hydraulic transport under drought: deconstructing the iso/anisohydric concept. *Plant, Cell & Environment* ,40: 962-976

Muradoglu,F., Gundogdu,M., Ercisli,S., Encu,T., Balta,F ., Jaafar,H.Z.E., Zia-Ul-Haq,M.2015. Cadmium toxicity affects chlorophyll a and b content, antioxidant enzyme activities and mineral nutrient accumulation in strawberry,Biol Res, 48(1):11

Neff,J.,Lee,K., DeBlois,E.M..2011. Overview of Composition, Fates, and Effects Produced Water,3-54.

O'Connell,E.2017.Towards adaptation of water resource Systems to climatic and socio-economic change. Water resources management ,31:2965–2984.

Rady ,M. M., Boriek ,S. H. K., Abd El-Mageed, T. A., Seif El-Yazal, M. A., Ali ,E. F., Hassan ,F. A. S., et al. 2021. Exogenous gibberellic acid or dilute bee honey boosts drought stress tolerance in Vicia faba by rebalancing osmoprotectants, antioxidants, nutrients, and phytohormones.Plants,10:748.

Rafique,N.,Tariq,S.R.2016. Distribution and source apportionment studies of heavy metals in soil of cotton/wheat fields. Environmental Monitoring and Assessment

Rehman,M., Rizwan ,M., Ali ,S., Ok,Y.S., Ishaque ,W., Saifullah , Nawaz ,M.F, Akmal ,F. Waqar,M.2017. Remediation of heavy metal contaminated soils by using Solanum nigrum: A review. Ecotoxicology and Environmental Safety ,143;236-248.

Ristvey,A.G,,Belayneh,B.E, Lea-Cox.J.D.,2019.A Comparison of Irrigation-Water Containment Methods and Management Strategies Between Two Ornamental Production Systems to Minimize Water Security Threats.Water,*11*(12), 2558

Rossi, L., Zhang ,W., Ma ,X.2017.Cerium oxide nanoparticles alter the salt stress tolerance of Brassica napus L. by modifying the formation of root apoplastic barriers. Environ. Pollut. Environmental Pollution ,229;132–138.

Salem,H. M., Ismael,E., Shaalan,M. 2021. Evaluation of the effects of silver nanoparticles against experimentally induced necrotic enteritis in broiler chickens. Int. J. Nanomedicine. 16; 6783–6796.

Seleiman ,M. F., Almutairi ,K. F., Alotaibi ,M., Shami ,A., Alhammad ,B. A., Battaglia ,M. L. 2021b. Nano-fertilization as an emerging fertilization technique: why can modern agriculture benefit from its use?Plants.10:2.

Seleiman ,M. F., Alotaibi ,M. A., Alhammad ,B. A., Alharbi ,B. M., Refay, Y., Badawy ,S. A. 2020a. Effects of ZnO nanoparticles and biochar of rice straw and cow manure on characteristics of contaminated soil and sunflower productivity, oil quality, and heavy metals uptake.Agronomy.10;790.

Semida ,W. M., Abd El-Mageed ,T. A., Howladar ,S. M. 2014. A novel organo-mineral fertilizer can alleviate negative effects of salinity stress for eggplant production on reclaimed saline calcareous soil.Acta Hortic. 1034 ;493–499.

Shaaban ,A., Al-Elwany ,O. A., Abdou, N. M., Hemida ,K. A., El-Sherif, A., Abdel-Razek, M. A., et al. 2022. .Filter mud enhanced yield and soil properties of water-stressed Lupinus termis L. in saline calcareous soil. Soil Sci. Plant Nutr .22 ;1572–1588.

Shang, Y., Hasan ,M., Ahammed ,G. J., Li ,M., Yin ,H., Zhou ,J.2019. Applications of nanotechnology in plant growth and crop protection: a review.Molecules. 24:2558.

Suman ,J., Uhlik ,O., Viktorova ,J.,Macek,T.2018. Phytoextraction of Heavy Metals: A Promising Tool for Clean-Up of Polluted Environment?, Front. Plant Sci ,9:1476.

Tuver, G.Y., Ekinci, M. & Yildirim, E. 2022. Morphological, physiological and biochemical responses to combined cadmium and drought stress

Yousry ,C., Zikry, P. M., Salem, H. M., Basalious, E. B., El-Gazayerly, O. N. 2020. Integrated nanovesicular/self-nanoemulsifying system (INV/SNES) for enhanced dual ocular drug delivery: statistical optimization, in vitro and in vivo evaluation. Drug Deliv. Transl. Res. 10 801–814.

Zahedi,S.M., Hosseini,M.S, Meybodi,N.D.H., Peijnenburg,W..2021.Mitigation of the effect of drought on growth and yield of pomegranates by foliar spraying of different sizes of selenium nanoparticles. **The** *Journal of the Science of Food and Agriculture* .101:5202-5213

Zaki,H.E.M.,& Radwan,K.S.A.2022. Response of potato (Solanum tuberosum L.) cultivars to drought stress under in vitro and field conditions. Chem. Biol. Technol. Agric.9:1

in radish (*Raphanus sativus* L.). *Rend. Fis. Acc. Lincei* **33**, 419–429 .

Ullah,A., Bano,A., Khan,N.,2021.Climate Change and Salinity Effects on Crops and Chemical Communication Between Plants and Plant Growth-Promoting Microorganisms Under Stress. Plant Growth-Promoting Microorganisms for Sustainable Agricultural Production

Usman ,M., Farooq ,M., Wakeel ,A.,Nawaz,A.,Cheema ,S.A.,Rehman ,H., Ashraf ,I.,Sanaulla,M..2020. Nanotechnology in agriculture: Current status, challenges and future opportunities. Science of The Total Environment 721;137778

Wang,Y., Liu ,Y. Zhan ,W., Zheng ,K., Lian ,M., Zhang , C.,Ruan ,X., Li,T..2020.Long-term stabilization of Cd in agricultural soil using mercapto-functionalized nano-silica. Ecotoxicology and Environmental Safety .197;110600

Yildirim, E., Ekinci, M., Turan, M. *et al.2022.* Physiological and Biochemical Changes of Pepper Cultivars Under Combined Salt and Drought Stress. *Gesunde Pflanzen* **74**, 675–683