International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 8 Issue 3, May-June 2024 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Role of Nanoparticles in Alleviation of Salinity Stress in Plants: A Review

Priya Kushwaha[1], Pallavi Dixit[2], Amit Kumar Singh[3]

[1]Research Scholar, Plant Nutrition and Stress Physiology Laboratory,
Department of Botany, University of Lucknow, Lucknow, Uttar Pradesh, India
[2]Associate Professor, Department of Botany, Mahila Vidyalaya Degree College, Lucknow, Uttar Pradesh, India
[3]Assistant Professor, Department of Botany, University of Lucknow, Lucknow, Uttar Pradesh, India

ABSTRACT

Soil salinity emerged as a major problem for better production of cops in all over the world. Global food security is at risk due to physiological abnormalities caused by agricultural salinization, which is a significant long-term underlying abiotic stress that inhibits plant growth and development. This is primarily caused by the accumulation of salt in the soil due to human activities such as irrigation, inadequate growth, and excessive fertilization. Soil degradation affects almost 147 million hectares of land, with water erosion affecting about 94 million ha of them, salinity/alkalinities/acidification about 50% and water depletion/flooding about 60% of the land wind erosion on 9 million and 7 million hectares due to the combination of factors caused by different forces. To ensure food security for an increasing population, the Indian government has set a goal to restore 26 million hectares of degraded land by 2030, including those affected by salt. Estimates suggest that salinization treatment covers approximately 10% of the soil added each time. In 2050, approximately 50% of agricultural land would be caused by salt. Nanotechnology, which is a highly advanced and potent technology in this area, yields excellent outcomes. While nanotechnology has been shown to have a beneficial impact on plants when subjected to salinity stress, the connection between nanoparticles and intracellular mechanisms in plant life remains unclear. In this review, we have discussed about the types of nanoparticles, its uptake by plants and effects on the molecular, biochemical and physiological aspects of the plant.

***How to cite this paper**:* Priya Kushwaha | Pallavi Dixit | Amit Kumar Singh "Role of Nanoparticles in Alleviation of Salinity Stress in Plants: A Review" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-8 | Issue-3, June 2024, pp.879-892, URL: www.ijtsrd.com/papers/ijtsrd65006.pdf

IJTSRD65006

***KEYWORDS:** Salinity stress, Agricultural salinization, Nanotechnology, Nanoparticle*

INTRODUCTION

Abiotic and biotic restrain cut downs plant's biomass and its overall development and this is known as plant stress (Grime, 1977). Plant's development, quality and quantity of yield are affected by biotic and abiotic stress (Shi-Ying et al., 2018). Biotic stress includes damage by pest and various types of pathogen that cause harm to plants. Abiotic stress includes drought, temperature (heat and cold), salinity, heavy metal and organic contaminants. Of all abiotic stress salinity is the major and affects major crop productivity (Zorb et al., 2019). The salt content of the soil is one of the main issues that adversely affect agricultural productivity in arid and semi-arid regions of the world (El hasini et al., 2019). Due to increasing in salinity in the agricultural land, the increasing food demands are unable to fulfil requirement and the expected elevation of salt is by 8.5 billion in next 25 years. In current scenario, about 1125 ha of land is constrained by salinity stress out of which 76 million ha is owing to anthropogenic activities (Wicke et al., 2011). Salinization of soil has significant impacts on agricultural productivity and quality, crop selection, biodiversity, water quality (including binding on minerals to produce hydrocarbons), water supply for human and industrial needs, as well as long-term agriculture.

Land availability for sustainable agriculture is severely restricted by soil salinity, which has become a significant obstacle to global food security. It is estimated that salinity currently affects about 62 million hectares (20% of the world's cultivated land) of the world's irrigated land, and this number is increasing every day, especially in arid and semi-arid regions in the world (Etesami and Noori, 2019). Salinity stress has a very destructive effect on both 'glycophytic' and 'halophytic' plants (Komaresofla et al., 2019).Various physiological, biochemical, and metabolic processes related to plant growth and productivity are negatively impacted by salinity stress, which causes morphologically-related changes. Salinity stress can cause plants to experience a decrease in soil osmotic potential and an increase in specific ion toxicity (Ionic stress)Secondary stresses, including oxidative stress (like ROS production) and nutritional/hormonal imbalances in plants), also have an impact on salinity (Kumar et al., 2019). Plant productivity is significantly reduced under salinity stress conditions due to these adverse effects (Parihar et al., 2015).

A solution to the problem of diminishing global food production is to breed salt-tolerant plants and cultivate crop varieties that tolerate salt well. In spite of their potential benefits, conventional breeding methods that involve interspecific or inter-generic hybridizations have not been highly effective in enhancing crop stress tolerance (Fita et al., 2015). Several studies have recently focused on new strategies to deal with salinity to minimize its negative effects on plantss (Etesami and Glick, 2020). The use of nanoparticles (NPs) has been gaining attention as one of the most promising ways to enhance plant growth and performance under salinity stress in recent years (Ahmad and Akhtar, 2019). Small components, with a range of 100 nm or less, play varying roles in the macro-level properties of nanomaterials. The surface area of nanomaterials is relatively larger than that of the same mass of material in a larger form. NPs can enhance the chemical reactivity of materials, leading to changes in their strength or electrical characteristics. Due to their high surface-to-volume ratio, NPs are highly reactive and have the potential to be biochemically active (Das and Das, 2019). NPs have been shown to modify hormone levels, antioxidant enzyme activity, ion homeostasis, gene expression and defense systems to regulate salinity tolerance in various plants (Zulfiqar and Ashraf, 2021). The effects vary depending on the environmental conditions and plant species, as well as the size, shape, and concentrations of NPs involved (Mohamed et al., 2017; Wahid et al., 2020). Although some studies have confirmed the positive/negative effects of NPs on plants under salinity stress, a complete understanding of the relationship and interaction between nanoparticles and intracellular mechanisms in plants under salinity stress conditions is lacking.

The utilization of nanotechnology-based solutions is on the rise in various fields of human activity, including agroecosystems. For example, applications of certain nanomaterials (e.g. single/multi-wall C-based nanotubes, poly-chitosan, graphene, fullerol, fullerene), nanoparticles (nano-fertilizers, nano-pesticides) and nano-based technologies and approaches (nanofiltration) in brackish water reservoirs for irrigation, transport and accumulation of trace elements into crop tissues have been shown to be useful and secondary strategies for mitigating nutrient deficiencies and increasing crop food production under various abiotic conditions, including excess salinity and induced salinity deficiency (Ditta et al., 2016). Furthermore, the presence of TiO_2 NPs can promote the growth promotion through photosterilization and photogeneration of reactive oxygen radicals, which enhances stress resistance and facilitates the absorption of H_2O and O_2 necessary for rapid germination.

Nano-based phytonutrients have been shown to be more effective than conventional fertilizer salts due to their unique mechanisms of action, such as increased active surface area, improved application efficiency, slow release, reduced nutritional losses, and reduced deterioration of the environment, considering their lower application doses (Rossi et al., 2019). Furthermore, most plant nutrients can be incorporated into the nanostructures of naturally occurring zeolites, i.e., Si-Al minerals, which have a huge active surface area and 10x higher cation exchange capacity than soil (Ditta et al., 2016).

Saline soils are posing a threat to India's national food security and economic development. Therefore, it is imperative to alter the country's food production policy and methodology. Food security efforts must focus on both expanding agricultural sectors and increasing crop productivity. Restoring food security in the country could be possible through the reclamation of degraded land, such as those damaged by salt. In order to achieve this objective, the Government of India has established a target to restore 26 million damaged lands by 2030.

TYPES AND UPTAKE OF NANOPARTICLES IN PLANT

Various preparation methods for NPs have been developed, which can be used to create a range of sizes and shapes. There are two methods for producing nanomaterials, namely "bottom-up" processes like self-assembly which produce nanoscale materials from atomic and molecular transport, and "top-down" (such as milling) that produce the nanoscale materials, materials from their macro-sized counterparts. Nanomaterials have the ability to be either 1-D (e.g., surface films), 2-D (like threads or fibers) and 3-D (such as particles). They can take the form of single, spherical, tubular, or irregular shapes that are fused and agglomerate in shape (Das and Das, 2019). Furthermore, NPs are divided into four main groups based on their chemical nature:

1. Metal NPs such as Au, Ag, Pt, Zn, and Ni;
2. Carbon-based nanoparticles such as single- and multi-walled carbon nanotubes, fullerenes, graphene, etc.;
3. Polymeric compounds; and
4. Metal oxides (ceramics) such as TiO_2, ZnO and FeO_2 (Khan et al., 2019a; Paramo et al., 2020).

NPs' biological activity is determined by their physicochemical properties, concentration, and application technique (Ali et al., 2021). NPs are employed in priming, irrigation, hydroponic substrate, foliar application, and direct spraying (Abou-Zeid et al., 2020; Mahdy et al., 2020). Upon contact with plants, NPs enter the plant tissue through the root junction and wound regions, penetrate through the root lateral cell wall and cell membrane (e.g., endocytosis, carrier proteins, plasmodesmata, or pore formation) and are transported by a complex series of events to the vascular bundle (xylem) of the plant (eg, another symplast or apoplast two ways), accumulates in cellular or subcellular organelles and moves symbolically to the stele to transfer into leaves(P´erez-de-Luque, 2017; Tripathi et al., 2017a). The NPs can travel through the cuticles, stomata, and hydathodes and then into the cell cytoplasm (Sharif et al., 2013).The presence of NPs in seeds can be directly absorbed by entering the shell through the spaces between parenchyma cells and then diffusing into the cotyledon (Tripathi et al., 2017b).

Microorganisms associated with roots and leaves can affect the mobility of NPs when applied as foliar sprays or in soil. *Trifolium repens* L. roots may experience reduced absorption of Ag-NPs due to mycorrhiza, as demonstrated by one of study by Feng et al., (2013). Uptake of phosphorus and selenium nanoparticles increased in the presence of microorganisms (Duran et al., 2013), while uptake of iron and silver NP decreased in vegetables in the presence of microorganisms (Guo and Chi, 2014). The size, concentration, climate, and application method were all factors that determined the effective adsorption of NPs after foliar application (Wang et al., 2013). The presence of leaf secretions and waxes, leaf morphology and chemical composition, and the presence of trichrome also play an important role in how NPs adhere to the leaf surface (Larue et al., 2014). Most studies also reported that the pore size of the cell wall is the main limitation for the entry of NPs into the plant cell. Osmotic pressure and capillary forces can cause small NPs to either penetrate plant roots or directly penetrate root epidermal cells (Lin and Xing, 2008; Ali et al., 2021).

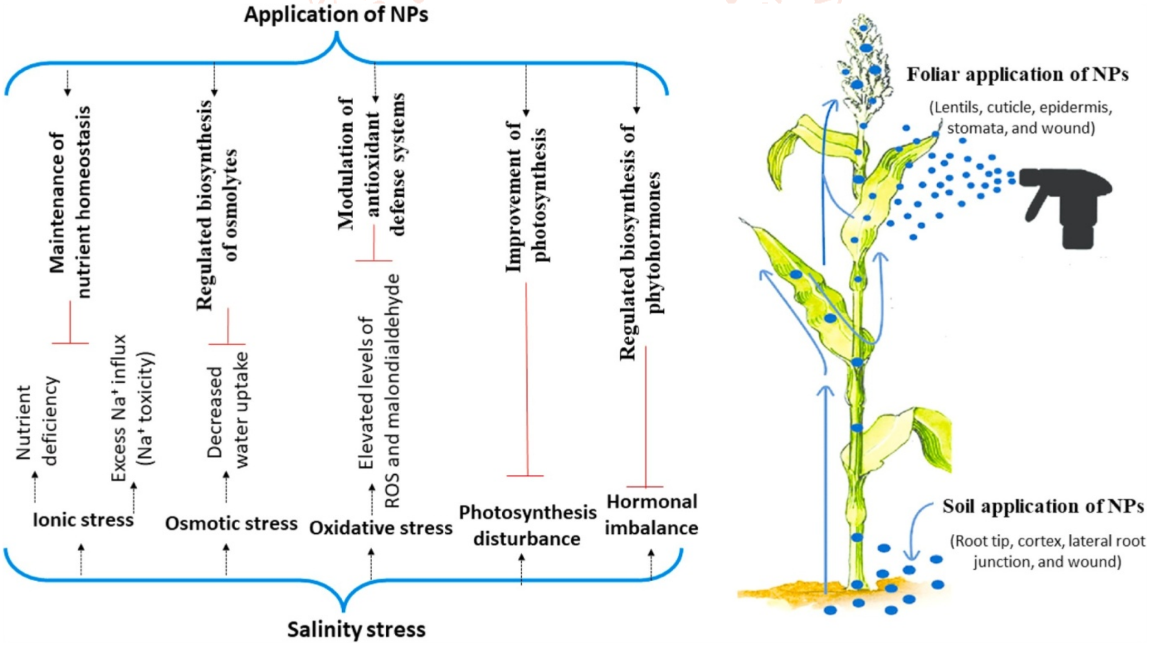

Figure 1: Some mechanisms of nanoparticles (NPs) induced salinity stress tolerance in plants. (Source: H. Etesami et al., 2021)

MOLECULAR, BICHEMICAL AND PHYSIOLOGICAL AFFECT OF NANPPARTICLES IN PLANT

A. EFFECT OF NPs ON MOLECULAR ASPECTS:

Without disrupting cellular mechanisms and gene expression, NPs cannot be effective due to the impact of salinity stress, which causes changes in genes involved in various cell and plant products. A study has been conducted on the expression of microRNAs in NP-treated cells (Kumar et al., 2013). The expression of miR398 and miRA408, which control seed germination, root growth and plant development, and antioxidants/free radical metabolism are all affected by the NP as per these researchers. The NP-mediated increase in root growth is due to the down regulation of miR164 expression, which is involved in auxin hormone signaling. The increase of miR169 expression and the decrease of miR167 expression can lead to the production of lateral roots and the acceleration of flowering (Tolaymat et al., 2017).

Foliar application of Zn-NPs to rapeseed (*Brassica napus* L.) under salinity stress caused a change in the expression of stress-related genesto decrease somegenes (e.g. SKRD2, MYC and MPK4) and some other genes. (eg., ARP and increased expression of MPK) associated with many physiological, hormonal and developmental responses, as well as MYC and SKRD2, associated transcription factor and increased tolerance to abiotic stress (Hezaveh et al., 2019). At 100 mM NaCl salinity, the effect of manganese (III) oxide (0.1, 0.5 and 1 mg L) NPs on pepper plants was studied by Ye et al., (2020a). The researchers found that the NPs penetrated the seed coat form a corona-NP composite. A noteworthy point of this study was the key role of manganese NPs, especially at a concentration of $1mgL^{-1}$, in the increased expression of superoxide dismutase (SOD) genes, resulting in the production of SOD as one of the important enzymes to scavenge ROS under salinity stress.

Multi-walled carbon nanotubes have been found to be effective in modulating SOS1 gene expression in canola plants when exposed to salinity stress (Zhao et al., 2019). Investigation of carbon nanomaterials (eg., carbon nano-dots, nanofibers, nano-beads, and nano-diamonds) on their effects on salinity-affected plants is rare and therefore requires future research. The positive effect of cerium oxide NPs also showed a significant decrease in ROS levels and an increase in calcium content in treated plants. Terpene, synthesis genes (CAD1 and TPS) were also affected by cerium NPs (An et al., 2020).The use of cerium NPs to promote plant salinity tolerance is not extensively researched. Therefore, future studies should aim to evaluate the modes of action of cerium NPs on the molecular mechanisms of plants that are under salinity stress due to climate change.

Silicon was found to have an effect on the light harvesting complexes, ATP synthase and Cytb6f genes in tomato plants when exposed to salinity stress through proteomic analysis (Muneer et al., 2014). The use of Cu-NPs was tested in tomatoes under salt stress in 2018, and it was found to promote tomato growth by promoting SOD and jasmonic acid (JA) gene expression, which alleviated ionic and oxidative stresses. The researchers concluded that the use of Cu-NPs could effectively enhance salinity tolerance, as it would activate both the antioxidant defense mechanism and the jasmonateoctadecanoid pathway (Hern´ andez-Hern´andez et al., 2018).

B. EFFECT OF NPs ON BIOCHEMICAL ASPECTS:

I. MODULATION OF ANTIOXIDANT DEFENCE SYSTEM:

Plant responses to abiotic stresses, such as salinity stress, include the production of ROS, and they have developed antioxidant enzymes to manage excess ROS signal in plant cells that are exposed to salinity (You and Chan, 2015). The scientists identified NPs that exhibit traits of particular antioxidant enzymes and assist plants in managing oxidizing conditions. For example, cobalt, iron and cesium NPs act similarly to the enzyme catalase (CAT), and cesium, manganese, copper, and iron NPs also act similarly to the enzyme peroxidase (POD) (Rico et al., 2015). Seed priming effect of these Ag NPs (10, 20 and 30 mM) on pearl millet (*Pennisetum glaucum* L.) under salinity stress (0, 120 and 150 mMNaCl). They found that in presence of this NP, the growth characteristics of such plant were significantly increased: there was an increase in antioxidant enzymes (SOD, CAT, and glutathione peroxidase) and a decrease in the sodium to potassium ratio. In a study investigating the effect of TiO_2-NPs on *Dracocephalum moldavica* at concentrations of 0, 50, 100, and 200 mg L^{-1} under salinity stress (0, 50, and 100 mMNaCl), increases the concentration of antioxidant and reduced H_2O_2, especially at 100 mgL^{-1} (Gohari et al., 2020a). Multi-walled carbon nanotubes were functionalized with carboxylic acid in a study, and their effects were evaluated under salinity stress conditions at concentrations of 0, 25, 50, 100 mM,) at concentrations of 0, 25, 50 and 100 mgL^{-1} were investigated in basil seedlings (*Ocimum basilicum* L.). The results of this study showed that the optimal concentration of this plant was 50 mg L^{-1} and its application during salinity stress could improve the concentration of photosynthetic pigments and enzymatic and non-enzymatic antioxidants (Gohari et al., 2020b).

II. REGULATION OF SYNTHESIS OF PHYTOHORMONES:

The ability of plants to adapt to different environments is largely dependent on phytohormones. These phytohormones generally improve the plant's ability to withstand salinity stress (Fahad et al., 2015). The presence of silver NPs in rice plants caused significant variations in the levels of ABA, ethylene, and gibberellins (Manickavasagam et al., 2019). A study also found significant differences between these compounds. The Se-NP-mediated increase in IAA and ABA levels was found to enhance the root biomass and maintain the appropriate osmotic state of cells in salinity-stressed strawberry plants (Zahedi et al., 2019). During salt stress, Ag-NPs in wheat have been found to influence germination and grain yield by modulating photosynthetic efficiency and concentrations of plant hormones such as 6-benzeneacetic acid, 1-naphthalenic acid and indole-3-butyric acid increased, while those of ABA decreased (Abou-Zeid and Ismail, 2018).

III. REGULATION OF COMPATIABLE SOLUTE:

In plants, the proportion of compatible solutes (or osmolytes) increases as salinity rises. By stabilizing proteins and their complexes and membrane structures under salt stress, compatible solutes can counteract the inhibitory effects of high ion concentrations (Na^+ and Cl^-) on enzyme activity (Etesami and Jeong, 2018). Numerous studies indicate that NPs can enhance plant resilience to salinity stress by changing the overall solute content, such as amino acids (e.g. proline) and soluble sugars (Avestan et al., 2019; Abdoli et al., 2020), which minimizes the osmotic shock (Na^+ and Cl^-) induced by NaCl stress due to ion toxicity. For example, Farouk and Al-Amri., (2019) reported that the application of Zn-NPs to salt-stressed canola plants (*Brassica napus* L.) alleviated salt-induced adverse effects through osmolyte biosynthesis and ion regulation. Mohamed et al., (2017) discovered that the use of Ag-NPs in pre-sowed wheat seedling treatment improved the growth, proline and soluble sugar levels among plants exposed to salt. In a recent study (Wan et al, 2020), the effect of carbon nano-horns on *Sophoraacetoides* seedlings was studied with attention to salinity stress. Foliar spraying of NPs was found to increase the fresh weight, soluble sugar content, and protein content of leaves and roots. The salt stress of wheat seedlings was found to be improved by priming with polyhydroxyfullerene NPs, which increased the concentration of amino acids, soluble sugars and K^+ and P (Shafiq et al., 2019).

C. EFFECT OF NPs OF PHYSIOLOGICAL ASPECTS:

I. MAINTAINANCE OF PHOTOSYNTHESIS:

Photosynthesis is one of the most important processes that are affected by salinity stress, which varies depending on the type of plant and salt used (Hnilickova et al., 2021). The effects of salinity stress on plants were investigated in several studies, and it was found that the majority of available NPs could increase the concentration of photosynthetic pigments (Abdoli et al., 2020; Zulfiqar and Ashraf, 2021). Manganese participates in various parts of the cell (e.g. mitochondria, chloroplasts, the structure of some enzymes, etc.) and increases the speed of photosynthetic electron transport and oxygen evolution (Pradhan et al., 2013). Mn-NPs were discovered to play a role in maintaining optimal photosynthetic rates under varying types of abiotic stresses (Ye et al., 2020a). A study conducted under salinity stress conditions reported that manganese supplementation of *Vigna radiata* plants improved membrane stability index, chlorophyll content and nitrate reductase activity (Shahi and Srivastava, 2018). Maize plants treated with Cu in a previous study reduced the effects of salinity on water balance and photosynthesis (Iqbal et al., 2018). During the Calvin cycle, RuBisCO is an essential enzyme that plays a crucial role in the fixation of carbon dioxide. Xuming et al., (2008), found through genetic analysis of the smaller RuBisCO subunit that foliar application of TiO_2-NPs significantly increased the amount of this enzyme and plant photosynthesis.

The addition of silicon can decrease the permeability of the plasma membrane of leaf cells and enhance the upper structure of chloroplasts, significantly reducing damages caused by stress (Etesami et al., 2020). SiO_2NP treatment significantly increased photosynthetic rate due to increased activity of carbonic anhydrase and photosynthetic pigment synthesis (Siddiqui and Al-Whaibi, 2014). Baz et al., (2020), found that carbon NPs on lettuces under salt stress. They use of carbon NPs was found to enhance the germination of seeds under salinity stress (150 mM) and high temperature. Carbon NPs were also used to promote root growth and the buildup of photosynthetic pigment in seedlings. A study revealed that applying cerium oxide NPs to *Arabidopsis* under salinity stress (100 mMNaCl) foliar significantly increased the chlorophyll content and photosystem II efficiency of injected plants. The research further demonstrated the assimilation of carbon and photosynthesis in leaf-sprayed plants (Wu et al., 2018). Zn is an important plant trace element, while ZnO NPs increased chlorophyll content in peanuts (1000 mg kg^{-1}) (Prasad et al., 2012). Tomato plants were treated with ZnNPs (10, 50, and 100 mg L^{-1}) to increase their chlorophyll content and photosynthetic rate while being exposed to salinity stress (150 mMNaCl) (Faizan et al., 2021).

The Hill response was enhanced by introducing Zn-NPs to canola plants that were under salinity, which also resulted in decreased ion leakage (Hezaveh et al., 2019). Fe functions in many important cellular processes, including chlorophyll biosynthesis, respiration and photosynthesis (Kim and Guerinot, 2007). According to Rawat et al. (2017), iron NPs can boost gene expression in both small and large subunits of photosynthesis enzymes, leading to an increase in photosynthesis activity. Under salinity stress, the use of silver NPs has been shown to enhance plant chlorophyll content and chlorophyll fluorescence (Sami et al., 2020).

II. REGULATION OF ION HOMEOSTASIS:

Excessive nutrient deficiency in plants is caused by salinity stress (Etesami and Maheshwari, 2018). Plant mineral nutrition can benefit from the involvement of NPs, which can impact the assimilation, translocation, and eventual distribution (Kopittke et al., 2019). According to reports, the high potassium/sodium ratio is a crucial factor in plant resistance to salinity stress. It is known that NPs can increase the plant's osmotic potential, which can help it grow and resist salinity stress conditions (Sytar et al., 2019). For example in one study, Nano SiO_2 increased the growth of soybean seedlings under salt stress by enhancing leaf K^+ (Farhangi-Abriz and Torabian, 2018). The use of Cu-NPs in tomato plants' foliar application alleviated salt stress by improving their growth and decreasing their Na^+/K^+ ratio (P´ erez-Labrada et al., 2019). Another research project focused on Fe2O3 NPs, which helped alleviate salinity stress by improving the K^+/Na^+ and Fe content of *Trachyspermum ammi (*Abdoli et al., 2020).

The researchers suggest that cerium NPs have a higher ability to eliminate OH^- over time than other materials. It also activates the plasma membrane K-selective channels (GORK), which move potassium into the cell (Wu et al., 2018).Studies indicate that NPs can alleviate salinity stress in plants by preventing Na^+ uptake and impacting the uptake of specific nutrients.

III. MAINTAINANCE OF PLANT WATER BALANCE:

Salinity stress causes a decrease in the amount of water and plant absorption. High salt concentrations in the soil increase osmotic stress, which limits the plant's water uptake and in turn affects leaf water content, stomatal conductance, leaf growth (acceleration of leaf aging and leaf death) and photosynthesis (decreased chlorophyll levels) and ultimately leads to reduced plant growth (Munns and Tester, 2008). Furthermore, NPs have been found to enhance transpiration, the stomatal conductance, and consequently leaf water content, as well as hydraulic conductance and ROS in plants (Zulfiqar and Ashraf, 2021).

Plant water relations are heavily influenced by aquaporins, channel proteins, which are part of the most important super family of intracellular proteins. In plants, aquaporins are mainly responsible for the transportation of water and other small neutral molecules across the cell biological membranes (Kapilan et al., 2018). It has been reported that NPs can increase root hydraulic conductivity by increasing the expression of plasma membraneintrinsic aquaporin proteins, which may contribute to increased water absorption and reduce oxidative stress and membrane damage (Ali et al., 2021). NPs are hypothesized to be regulated by seed coat aquaporins (Ali et al., 2021). Multi-walled carbon nanotubes are also reported to increase aquaporin transduction in broccoli, resulting in better water uptake, which mediates salinity tolerance (Martínez-Ballesta et al., 2016). Silicon plays a crucial role in the enhancement of aquaporins during salinity stress (Rios et al., 2017). The regulation of essential antioxidant enzymes can be achieved through NP application in order to improve the water balance of plants under salinity, but further research is required.

Table 1: A list of the studies showing the positive effects of various NPs on plants under salinity stress.

Types of NPs	Tested plants	Application method	Salt concentration	NPs concentration	NPs positive effect	References
Fe NPs	*Pistacia vera*	Nutrient solution	0, 100, and 200 mM	2.9 mg L^{-1}	Decreased plasma membrane damage and chlorophyll degradation	Karimi et al. (2020)
	Trachyspermum ammi	Foliar spraying	4, 8, and 12 dS m^{-1}	3 mM	Enhanced K^+uptake, K^+/Na^+ ratio, Fe content, endogenous levels of SA, and activities of antioxidant enzymes	Abdoli et al. (2020)
	Dracocephalum moldavica	Foliar spraying	50–100 mM	30, 60, and 90 mg L^{-1}	Increased enzymatic and non-enzymatic	Moradbeygi et al. (2020)

					antioxidant activities (e, g., POD, CAT, ASO, phenol, Flavonoid and anthocyanin)	
ZnO NPs	*Abelmoschus esculentus*	Foliar spraying	0%, 10%, 25%, 50%, 75% and 100% sea water	10 mg L^{-1}	Increased chlorophyll and antioxidant enzyme activity such as SOD and CAT and decreased proline and sugars content	Alabdallah and Alzahrani (2020)
	Teriticum aestivum	Priming	200 mM	50 mg L^{-1}	Enhanced trapped energy flux and electron transport flux, sucrose biosynthesis AND activated the antioxidant system	Wan et al. (2020)
	Trigonella foenumgraecum	Foliar spraying	0, 75, 150, and 225 mM	1000 and 3000 mg L^{-1}	Increased the trigonelline content	Noohpisheh et al. (2021)
Carbon NPs	*Lactuca sativa*	Priming	0.3%	150 and 200 mM	Inhibited the elongation of primary roots and promoted lateral root growth and accumulation of chlorophyll content of seedlings	Baz et al. (2020)
	Ocimum basilicum	Nutrient solution	50 and 100 mM	25, 50 and 100 mg L^{-1}	Increased chlorophyll and enzymatic and non-enzymatic antioxidant such as CAT, APX, GP and phenolic content	Gohari et al. (2020b)
	Sophoraalo pecuroides	Foliar spraying	100 mM	50 mg L^{-1}	Increased PSII activity, total protein contents of leaves and roots, leaf soluble sugar content and Cu content in the leaves, reprogrammed carbon/nitrogen metabolism and promoted glycolysis and TCA cycle to generate energy and increased the levels of unsaturated fatty acids to maintain membrane integrity under salt stress	Wan et al. (2020)

Chitosan NPs	*Vigna radiata*	Priming	-	0,4 and 8 dS m^{-1}	Reduction in H_2O_2 and MDA contents over control leading to the better growth and increased chlorophyll content and metabolism.	Sen et al. (2020)
Ag NPs	*Satureja hortensis* L.	Priming	0, 40, 60, and 80 mg L^{-1}	0, 30, 60, 90, and 120 mM	Improved germination average; plants shoot length and plants resistance to salinity	Nejatzadeh (2021)
	Eustoma grandiflorum	Priming	2, 4, and 6gL^{-1}	5, 10, and 20 mg L^{-1}	Decreased the POD activity and increased the activity of both SOD and CAT enzymes.	Youssef et al. (2020)
Mn NPs	*Capsicum annuum*	Priming	100 mM	0.1, 0.5, and 1 mg L^{-1}	Improved morphological traits such as root development	Ye et al. (2020b)
TiO_2 NPs	*Zea mays* L.	Priming	200 mM	40, 60 and 80 mg L^{-1}	Improved morphological traits, K concentration, activity of enzymatic antioxidant, proline, and phenolic content	Shah et al. (2021)
	Dracocephalum moldavica L.	Nutrient solution	0, 50 and 100 mM	0, 50, 100, and 200 mg L^{-1}	Increased antioxidant enzyme activity and essential oil	Gohari et al. (2020a)
Si NPs	*Musa acuminate*	Foliar spraying	-	0, 200, 400 and 600 mgL^{-1}	Improved photosynthesis, and increased K^+ and K^+/Na^+ percent. Shoot growth, and chlorophyll content.	Mahmoud et al. (2020a)
	Lycopersicon esculentum	Growing medium	50 mM	250 and 500 mgL^{-1}	Maintained concentration of chlorophylls, GSH, vitamin C, and PAL activity	Pinedo-Guerrero et al. (2020)
Si, Se and Cu NPs	*Capsicum annuum*	Nutrient solution	25 and 50 mM	10 and 50 mgL^{-1} Se-NPs, 200 and 1000 mgL^{-1} Si- NPs, and 100 and 500mgL^{-1} Cu NPs	Increased chlorophylls, lycopene and glutathione peroxidase activity in the leaves and increased AXO, POD, CAT and	Gonz´alez-García et al. (2021)

					phenylalanine ammonia lyase activity, and also phenols, flavonoids, glutathione, β-carotene, and yellow carotenoids in fruits	
Zn, B, Si and Zeolite NPs	*Solanum tuberosum* L.	Soil	4.2 dS m^{-1}	20 mg L^{-1} Zn NPs, 1 mg L^{-1} B NPs, 15 mg L^{-1} Si, and 1.3 L ha^{-1} zeolite	Improved morphological traits, increased the concentration of nutrients (N, P, K, Ca, Zn, and B), GA3, carbohydrates, and antioxidant enzymes (e.g., PPO and POD).	Mahmoud et al. (2020c)

(Source: H. Etesami et al., 2021)

CONCLUSION

It was determined through a comprehensive analysis of the literature that NPs can aid in both plant growth and alleviating salinity stress. According to these studies, the positive effects of NPs on plants affected by salinity at physiological, biochemical and molecular levels were very important and depended on the properties, application method and concentration of NPs. The utilization of NP concentrations can result in better plant health and are crucial for low-input sustainable agriculture, both within the food and non-food sectors. Furthermore, research needs to be focused on (i) Comparative studies of the interactions between different NPs and plants, which are rare, could provide insight into the mechanisms controlling salinity stresses; (ii) It is necessary to conduct applied research to determine the appropriate NP concentration for crops and the timing and techniques for application, particularly during salt stress; (iii) The studies mentioned above revealed that plants are subjected to multiple stresses in nature, despite the fact that they were used separately and for short periods of time under salinity stress. Considering that most environmental stresses, such as salinity and drought in agricultural fields, occur simultaneously, it is recommended to investigate the impact of NP on salinability, drought, and other factors; (iv) To alleviate salinity stresses, it is important to compare the effects of NPs and other salinability-tolerant microorganisms on plants individually or in pairs. The mechanisms underlying NPs regulated plant salinity tolerance microorganism interactions have not yet been identified in plants; (v) the application strategy must consider the NP base dose, exposure duration, translocation and accumulation, and mechanism of action on plants. Developing a more comprehensive understanding of the interactions between plants and different NPs could aid in understanding the mitigation of salinity stress and potentially improving prediction on plant response.

REFERENCES

[1] Grime, J.P., 1977. Evidence for the existence of three primary strategies in plants and its relevance to ecological and evolutionary theory. *The american naturalist*, *111*(982), pp.1169-1194.

[2] Zhang ShiYing, Z.S., Fan Cong, F.C., Wang YongXia, W.Y., Xia YunSheng, X.Y., Xiao Wei, X.W. and Cui XiaoLong, C.X., 2018. Salt-tolerant and plant-growth-promoting bacteria isolated from high-yield paddy soil.

[3] Zörb, C., Geilfus, C.M. and Dietz, K.J., 2019. Salinity and crop yield. *Plant biology*, *21*, pp.31-38.

[4] Halima, O.I., Azzouzi, M.E., Douaik, A., Azim, K. and Zouahri, A., 2019. Organic and inorganic remediation of soils affected by salinity in the Sebkha of Sed El Mesjoune–Marrakech (Morocco). *Soil and Tillage Research*, *193*, pp.153-160

[5] Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburg, W. and Faaij, A., 2011. The global technical and economic potential of bioenergy from salt-affected soils. *Energy & Environmental Science*, *4*(8), pp.2669-2681.

[6] Kumar, M., Etesami, H. and Kumar, V. eds., 2019. *Saline soil-based agriculture by halotolerant microorganisms* (Vol. 1). Springer Singapore.

[7] Parihar, P., Singh, S., Singh, R., Singh, V.P. and Prasad, S.M., 2015. Effect of salinity stress on plants and its tolerance strategies: a review. *Environmental science and pollution research*, *22*, pp.4056-4075.

[8] Fita, A., Rodríguez-Burruezo, A., Boscaiu, M., Prohens, J. and Vicente, O., 2015. Breeding and domesticating crops adapted to drought and salinity: a new paradigm for increasing food production. *Frontiers in Plant Science*, *6*, p.978.

[9] Etesami, H. and Glick, B.R., 2020. Halotolerant plant growth–promoting bacteria: Prospects for alleviating salinity stress in plants. *Environmental and Experimental Botany*, *178*, p.104124.

[10] Ahmad, I. and Akhtar, M.S., 2019. Use of nanoparticles in alleviating salt stress. *Salt Stress, Microbes, and Plant Interactions: Causes and Solution: Volume 1*, pp.199-215.

[11] Zulfiqar, F. and Ashraf, M., 2021. Nanoparticles potentially mediate salt stress tolerance in plants. *Plant Physiology and Biochemistry*, *160*, pp.257-268.

[12] Mohamed, A.K.S., Qayyum, M.F., Abdel-Hadi, A.M., Rehman, R.A., Ali, S. and Rizwan, M., 2017. Interactive effect of salinity and silver nanoparticles on photosynthetic and biochemical parameters of wheat. *Archives of Agronomy and Soil Science*, *63*(12), pp.1736-1747.

[13] Rossi, L., Fedenia, L.N., Sharifan, H., Ma, X. and Lombardini, L., 2019. Effects of foliar application of zinc sulfate and zinc nanoparticles in coffee (Coffeaarabica L.) plants. *Plant Physiology and Biochemistry*, *135*, pp.160-166.

[14] Khan, I., Saeed, K. and Khan, I., 2019. Nanoparticles: Properties, applications and toxicities. *Arabian journal of chemistry*, *12*(7), pp.908-931.

[15] Paramo, L.A., Feregrino-Pérez, A.A., Guevara, R., Mendoza, S. and Esquivel, K., 2020. Nanoparticles in agroindustry: Applications, toxicity, challenges, and trends. *Nanomaterials*, *10*(9), p.1654.

[16] Ali, S., Mehmood, A. and Khan, N., 2021. Uptake, translocation, and consequences of nanomaterials on plant growth and stress adaptation. *Journal of Nanomaterials*, *2021*(1), p.6677616.

[17] Abou-Zeid, H.M., Ismail, G.S.M. and Abdel-Latif, S.A., 2021. Influence of seed priming with ZnO nanoparticles on the salt-induced damages in wheat (Triticumaestivum L.) plants. *Journal of Plant Nutrition*, *44*(5), pp.629-643.

[18] Mahdy, A.M., Sherif, F.K., Elkhatib, E.A., Fathi, N.O. and Ahmed, M.H., 2020. Seed priming in nanoparticles of water treatment residual can increase the germination and growth of cucumber seedling under salinity stress. *Journal of Plant Nutrition*, *43*(12), pp.1862-1874.

[19] Pérez-de-Luque, A., 2017. Interaction of nanomaterials with plants: what do we need for real applications in agriculture?. *Frontiers in Environmental Science*, *5*, p.12.

[20] Tripathi, D.K., Singh, S., Singh, S., Pandey, R., Singh, V.P., Sharma, N.C., Prasad, S.M., Dubey, N.K. and Chauhan, D.K., (2017a). An overview on manufactured nanoparticles in plants: uptake, translocation, accumulation and phytotoxicity. *Plant physiology and biochemistry*, *110*, pp.2-12.

[21] Shafiq, F., Iqbal, M., Ali, M. and Ashraf, M.A., 2019. Seed pre-treatment with polyhydroxy fullerene nanoparticles confer salt tolerance in wheat through upregulation of H 2 O 2 neutralizing enzymes and phosphorus uptake. *Journal of Soil Science and Plant Nutrition*, *19*, pp.734-742.

[22] Tripathi, D.K., Singh, S., Singh, V.P., Prasad, S.M., Dubey, N.K. and Chauhan, D.K., (2017b). Silicon nanoparticles more effectively alleviated UV-B stress than silicon in wheat (Triticumaestivum) seedlings. *Plant Physiology and Biochemistry*, *110*, pp.70-81.

[23] Durán, P., Acuña, J.J., Jorquera, M.A., Azcón, R., Borie, F., Cornejo, P. and Mora, M.L., 2013. Enhanced selenium content in wheat grain by co-inoculation of selenobacteria and arbuscularmycorrhizal fungi: A preliminary study as a potential Se biofortification strategy. *Journal of Cereal Science*, *57*(3), pp.275-280.

[24] Guo, J. and Chi, J., 2014. Effect of Cd-tolerant plant growth-promoting rhizobium on plant growth and Cd uptake by Loliummultiflorum Lam. and Glycine max (L.) Merr. in Cd-

contaminated soil. *Plant and soil*, *375*, pp.205-214.

[25] Wang, W.N., Tarafdar, J.C. and Biswas, P., 2013. Nanoparticle synthesis and delivery by an aerosol route for watermelon plant foliar uptake. *Journal of nanoparticle research*, *15*, pp.1-13.

[26] Larue, C., Castillo-Michel, H., Sobanska, S., Cécillon, L., Bureau, S., Barthès, V., Ouerdane, L., Carrière, M. and Sarret, G., 2014. Foliar exposure of the crop Lactucasativa to silver nanoparticles: evidence for internalization and changes in Ag speciation. *Journal of hazardous materials*, *264*, pp.98-106.

[27] Lin, D. and Xing, B., 2008. Root uptake and phytotoxicity of ZnO nanoparticles. *Environmental science & technology*, *42*(15), pp.5580-5585.

[28] Tolaymat, T., Genaidy, A., Abdelraheem, W., Dionysiou, D. and Andersen, C., 2017. The effects of metallic engineered nanoparticles upon plant systems: An analytic examination of scientific evidence. *Science of the total environment*, *579*, pp.93-106.

[29] Hezaveh, T.A., Pourakbar, L., Rahmani, F. and Alipour, H., 2019. Interactive effects of salinity and ZnO nanoparticles on physiological and molecular parameters of rapeseed (Brassica napus L.). *Communications in Soil Science and Plant Analysis*, *50*(6), pp.698-715.

[30] Ye, Y., Cota-Ruiz, K., Hernández-Viezcas, J.A., Valdes, C., Medina-Velo, I.A., Turley, R.S., Peralta-Videa, J.R. and Gardea-Torresdey, J.L., 2020. Manganese nanoparticles control salinity-modulated molecular responses in Capsicum annuum L. through priming: A sustainable approach for agriculture. *ACS Sustainable Chemistry & Engineering*, *8*(3), pp.1427-1436.

[31] Zhao, G., Zhao, Y., Lou, W., Su, J., Wei, S., Yang, X., Wang, R., Guan, R., Pu, H. and Shen, W., 2019. Nitrate reductase-dependent nitric oxide is crucial for multi-walled carbon nanotube-induced plant tolerance against salinity. *Nanoscale*, *11*(21), pp.10511-10523.

[32] Muneer, S., Park, Y.G., Manivannan, A., Soundararajan, P. and Jeong, B.R., 2014. Physiological and proteomic analysis in chloroplasts of Solanumlycopersicum L. under silicon efficiency and salinity stress. *International Journal of Molecular Sciences*, *15*(12), pp.21803-21824.

[33] Hernández-Hernández, H., Juárez-Maldonado, A., Benavides-Mendoza, A., Ortega-Ortiz, H., Cadenas-Pliego, G., Sánchez-Aspeytia, D. and González-Morales, S., 2018. Chitosan-PVA and copper nanoparticles improve growth and overexpress the SOD and JA genes in tomato plants under salt stress. *Agronomy*, *8*(9), p.175.

[34] You, J. and Chan, Z., 2015. ROS regulation during abiotic stress responses in crop plants. *Frontiers in plant science*, *6*, p.165102.

[35] Rico, C.M., Peralta-Videa, J.R. and Gardea-Torresdey, J.L., 2015. Chemistry, biochemistry of nanoparticles, and their role in antioxidant defense system in plants. *Nanotechnology and plant sciences: nanoparticles and their impact on plants*, pp.1-17.

[36] Gohari, G., Mohammadi, A., Akbari, A., Panahirad, S., Dadpour, M.R., Fotopoulos, V., Kimura, S., 2020a. Titanium dioxide nanoparticles (TiO 2 NPs) promote growth and ameliorate salinity stress effects on essential oil profile and biochemical attributes of Dracocephalummoldavica. Sci. Rep. 10, 1–14.

[37] Gohari, G., Safai, F., Panahirad, S., Akbari, A., Rasouli, F., Dadpour, M.R. and Fotopoulos, V., 2020b. Modified multiwall carbon nanotubes display either phytotoxic or growth promoting and stress protecting activity in Ocimumbasilicum L. in a concentration-dependent manner. *Chemosphere*, *249*, p.126171.

[38] Fahad, S., Hussain, S., Matloob, A., Khan, F.A., Khaliq, A., Saud, S., Hassan, S., Shan, D., Khan, F., Ullah, N. and Faiq, M., 2015. Phytohormones and plant responses to salinity stress: a review. *Plant growth regulation*, *75*, pp.391-404.

[39] Manickavasagam, M., Pavan, G. and Vasudevan, V., 2019. A comprehensive study of the hormetic influence of biosynthesized AgNPs on regenerating rice calli of indica cv. IR64. *Scientific Reports*, *9*(1), p.8821.

[40] Zahedi, S.M., Abdelrahman, M., Hosseini, M.S., Hoveizeh, N.F. and Tran, L.S.P., 2019. Alleviation of the effect of salinity on growth and yield of strawberry by foliar spray of selenium-nanoparticles. *Environmental Pollution*, *253*, pp.246-258.

[41] Abou-Zeid, H. and Ismail, G., 2018. The role of priming with biosynthesized silver nanoparticles in the response of

Triticumaestivum L to salt stress. *Egyptian Journal of Botany*, *58*(1), pp.73-85.

[42] Abdoli, S., Ghassemi-Golezani, K. and Alizadeh-Salteh, S., 2020. Responses of ajowan (Trachyspermumammi L.) to exogenous salicylic acid and iron oxide nanoparticles under salt stress. *Environmental Science and Pollution Research*, *27*, pp.36939-36953.

[43] Avestan, S., Ghasemnezhad, M., Esfahani, M. and Byrt, C.S., 2019. Application of nano-silicon dioxide improves salt stress tolerance in strawberry plants. *Agronomy*, *9*(5), p.246.

[44] Farouk, S. and Al-Amri, S.M., 2019. Exogenous zinc forms counteract NaCl-induced damage by regulating the antioxidant system, osmotic adjustment substances, and ions in canola (Brassica napus L. cv. Pactol) plants. *Journal of Soil Science and Plant Nutrition*, *19*(4), pp.887-899.

[45] Wan, J., Wang, R., Bai, H., Wang, Y. and Xu, J., 2020. Comparative physiological and metabolomics analysis reveals that single-walled carbon nanohorns and ZnO nanoparticles affect salt tolerance in Sophoraalopecuroides. *Environmental Science: Nano*, *7*(10), pp.2968-2981.

[46] Hnilickova, H., Kraus, K., Vachova, P. and Hnilicka, F., 2021. Salinity stress affects photosynthesis, malondialdehyde formation, and proline content in Portulacaoleracea L. *Plants*, *10*(5), p.845.

[47] Singh, P., Arif, Y., Siddiqui, H., Sami, F., Zaidi, R., Azam, A., Alam, P. and Hayat, S., 2021. Nanoparticles enhances the salinity toxicity tolerance in Linumusitatissimum L. by modulating the antioxidative enzymes, photosynthetic efficiency, redox status and cellular damage. *Ecotoxicology and Environmental Safety*, *213*, p.112020.

[48] Pradhan, S., Patra, P., Das, S., Chandra, S., Mitra, S., Dey, K.K., Akbar, S., Palit, P. and Goswami, A., 2013. Photochemical modulation of biosafe manganese nanoparticles on Vignaradiata: a detailed molecular, biochemical, and biophysical study. *Environmental Science & Technology*, *47*(22), pp.13122-13131.

[49] Shahi, S. and Srivastava, M., 2018. Influence of foliar application of manganese on growth, pigment content, and nitrate reductase activity of Vignaradiata (L.) R. Wilczek under salinity. *Journal of plant nutrition*, *41*(11), pp.1397-1404.

[50] Iqbal, M.N., Rasheed, R., Ashraf, M.Y., Ashraf, M.A. and Hussain, I., 2018. Exogenously applied zinc and copper mitigate salinity effect in maize (Zea mays L.) by improving key physiological and biochemical attributes. *Environmental Science and Pollution Research*, *25*, pp.23883-23896.

[51] Xuming, W., Fengqing, G., Linglan, M., Jie, L., Sitao, Y., Ping, Y. and Fashui, H., 2008. Effects of nano-anatase on ribulose-1, 5-bisphosphate carboxylase/oxygenase mRNA expression in spinach. *Biological trace element research*, *126*, pp.280-289.

[52] Siddiqui, M.H. and Al-Whaibi, M.H., 2014. Role of nano-SiO2 in germination of tomato (Lycopersicumesculentum seeds Mill.). *Saudi journal of biological sciences*, *21*(1), pp.13-17.

[53] Baz, H., Creech, M., Chen, J., Gong, H., Bradford, K. and Huo, H., 2020. Water-soluble carbon nanoparticles improve seed germination and post-germination growth of lettuce under salinity stress. *Agronomy*, *10*(8), p.1192.

[54] Wu, H., Shabala, L., Shabala, S. and Giraldo, J.P., 2018. Hydroxyl radical scavenging by cerium oxide nanoparticles improves Arabidopsis salinity tolerance by enhancing leaf mesophyll potassium retention. *Environmental Science: Nano*, *5*(7), pp.1567-1583.

[55] Prasad, T.N.V.K.V., Sudhakar, P., Sreenivasulu, Y., Latha, P., Munaswamy, V., Reddy, K.R., Sreeprasad, T.S., Sajanlal, P.R. and Pradeep, T., 2012. Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanut. *Journal of plant nutrition*, *35*(6), pp.905-927.

[56] Faizan, M., Bhat, J.A., Chen, C., Alyemeni, M.N., Wijaya, L., Ahmad, P. and Yu, F., 2021. Zinc oxide nanoparticles (ZnO-NPs) induce salt tolerance by improving the antioxidant system and photosynthetic machinery in tomato. *Plant Physiology and Biochemistry*, *161*, pp.122-130.

[57] Rawat, M., Nayan, R., Negi, B., Zaidi, M.G.H. and Arora, S., 2017. Physio-biochemical basis of iron-sulfide nanoparticle induced growth and seed yield enhancement in B. juncea. *Plant physiology and biochemistry*, *118*, pp.274-284.

[58] Kim, S.A. and Guerinot, M.L., 2007. Mining iron: iron uptake and transport in plants. *FEBS letters*, *581*(12), pp.2273-2280.

[59] Sami, F., Siddiqui, H. and Hayat, S., 2020. Impact of silver nanoparticles on plant physiology: a critical review. *Sustainable Agriculture Reviews 41: Nanotechnology for Plant Growth and Development*, pp.111-127.

[60] Etesami, H. and Maheshwari, D.K., 2018. Use of plant growth promoting rhizobacteria (PGPRs) with multiple plant growth promoting traits in stress agriculture: Action mechanisms and future prospects. *Ecotoxicology and environmental safety*, *156*, pp.225-246.

[61] Kopittke, P.M., Lombi, E., Wang, P., Schjoerring, J.K. and Husted, S., 2019. Nanomaterials as fertilizers for improving plant mineral nutrition and environmental outcomes. *Environmental Science: Nano*, *6*(12), pp.3513-3524.

[62] Sytar, O., Kumari, P., Yadav, S., Brestic, M. and Rastogi, A., 2019. Phytohormone priming: regulator for heavy metal stress in plants. *Journal of Plant Growth Regulation*, *38*, pp.739-752.

[63] Farhangi-Abriz, S. and Torabian, S., 2018. Nano-silicon alters antioxidant activities of soybean seedlings under salt toxicity. *Protoplasma*, *255*, pp.953-962.

[64] Pérez-Labrada, F., López-Vargas, E.R., Ortega-Ortiz, H., Cadenas-Pliego, G., Benavides-Mendoza, A. and Juárez-Maldonado, A., 2019. Responses of tomato plants under saline stress to foliar application of copper nanoparticles. *Plants*, *8*(6), p.151.

[65] Munns, R. and Tester, M., 2008. Mechanisms of salinity tolerance. *Annu. Rev. Plant Biol.*, *59*, pp.651-681.

[66] Kapilan, R., Vaziri, M. and Zwiazek, J.J., 2018. Regulation of aquaporins in plants under stress. *Biological research*, *51*, pp.1-11.

[67] Martínez-Ballesta, M.C., Zapata, L., Chalbi, N. and Carvajal, M., 2016. Multiwalled carbon nanotubes enter broccoli cells enhancing growth and water uptake of plants exposed to salinity. *Journal of Nanobiotechnology*, *14*, pp.1-14.

[68] Rios, J.J., Martínez-Ballesta, M.C., Ruiz, J.M., Blasco, B. and Carvajal, M., 2017. Silicon-mediated improvement in plant salinity tolerance: the role of aquaporins. *Frontiers in plant science*, *8*, p.254076.

[69] Karimi, S., Tavallali, V., Ferguson, L. and Mirzaei, S., 2020. Developing a nano-Fe complex to supply iron and improve salinity tolerance of pistachio under calcium bicarbonate stress. *Communications in Soil Science and Plant Analysis*, *51*(14), pp.1835-1851.

[70] Moradbeygi, H., Jamei, R., Heidari, R. and Darvishzadeh, R., 2020. Investigating the enzymatic and non-enzymatic antioxidant defense by applying iron oxide nanoparticles in Dracocephalummoldavica L. plant under salinity stress. *ScientiaHorticulturae*, *272*, p.109537.

[71] Noohpisheh, Z., Amiri, H., Mohammadi, A. and Farhadi, S., 2021. Effect of the foliar application of zinc oxide nanoparticles on some biochemical and physiological parameters of Trigonellafoenum-graecum under salinity stress. *Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology*, *155*(2), pp.267-280.

[72] Sen, S.K., Chouhan, D., Das, D., Ghosh, R. and Mandal, P., 2020. Improvisation of salinity stress response in mung bean through solid matrix priming with normal and nano-sized chitosan. *International journal of biological macromolecules*, *145*, pp.108-123.

[73] Nejatzadeh, F., 2021. Effect of silver nanoparticles on salt tolerance of Saturejahortensis l. during in vitro and in vivo germination tests. *Heliyon*, *7*(2).

[74] Youssef, N.M., Ghareeb, Z.F., Ali, A.I. and Taha, L.S., 2020. Mitigation of salinity stress on in vitro growth of Eustoma grandiflorum using zinc nanoparticles. *Plant Arch*, *2*, pp.4547-4554.

[75] Ye, Y., Cota-Ruiz, K., Hernández-Viezcas, J.A., Valdes, C., Medina-Velo, I.A., Turley, R.S., Peralta-Videa, J.R. and Gardea-Torresdey, J.L., 2020. Manganese nanoparticles control salinity-modulated molecular responses in Capsicum annuum L. through priming: A sustainable approach for agriculture. *ACS Sustainable Chemistry & Engineering*, *8*(3), pp.1427-1436.

[76] Shah, T., Latif, S., Saeed, F., Ali, I., Ullah, S., Alsahli, A.A., Jan, S. and Ahmad, P., 2021. Seed priming with titanium dioxide nanoparticles enhances seed vigor, leaf water

status, and antioxidant enzyme activities in maize (Zea mays L.) under salinity stress. *Journal of King Saud University-Science*, *33*(1), p.101207.

[77] Mahmoud, A.W.M., Abdeldaym, E.A., Abdelaziz, S.M., El-Sawy, M.B. and Mottaleb, S.A., 2019. Synergetic effects of zinc, boron, silicon, and zeolite nanoparticles on confer tolerance in potato plants subjected to salinity. *Agronomy*, *10*(1), p.19.

[78] Pinedo-Guerrero, Z.H., Cadenas-Pliego, G., Ortega-Ortiz, H., González-Morales, S., Benavides-Mendoza, A., Valdés-Reyna, J. and Juárez-Maldonado, A., 2020. Form of silica improves yield, fruit quality and antioxidant defense system of tomato plants under salt stress. *Agriculture*, *10*(9), p.367.

[79] González-García, Y., Cárdenas-Álvarez, C., Cadenas-Pliego, G., Benavides-Mendoza, A., Cabrera-De-La-Fuente, M., Sandoval-Rangel, A., Valdés-Reyna, J. and Juárez-Maldonado, A., 2021. Effect of three nanoparticles (Se, Si and Cu) on the bioactive compounds of bell pepper fruits under saline stress. *Plants*, *10*(2), p.217.

[80] Mahmoud, L.M., Dutt, M., Shalan, A.M., El-Kady, M.E., El-Boray, M.S., Shabana, Y.M. and Grosser, J.W., 2020. Silicon nanoparticles mitigate oxidative stress of in vitro-derived banana (Musa acuminata 'Grand Nain') under simulated water deficit or salinity stress. *South African Journal of Botany*, *132*, pp.155-163.