Bulletin of Faculty of Science, Zagazig University (BFSZU)
e-ISSN: 1110-1555
Volume-2024, Issue-3, pp-116-130
https://bfszu.journals.ekb.eg/journal
Research Paper DOI: **10.21608/bfszu.2024.259825.1354**

==

Superiority of green synthesized nanoparticles for ameliorating salinity stress of plants

Hegazy S. Hegazy, Hanan Abdalla, Marwa H. Adarosy and Reda E. Abdelhameed
Botany and Microbiology Department, Faculty of Science, Zagazig University
Corresponding author: marwa.hassan4080@gmail.com

ABSTRACT **: Salinity stress is one of the most destructive stresses in plants that has adversely affected many agricultural lands in the world. Salinity stress causes many morphological, physiological, epigenetic and genetic changes in plants by increasing sodium and chlorine ions in the plant cells. The plants can alleviate this disorder to some extent through various mechanisms and return the cell to its original state, but if the salt dose is high, the plants may not be able to provide a proper response and can die. Nowadays, scientists have offered many solutions to this problem. Nanotechnology is one of the most emerging and efficient technologies that has been entered in this field and has recorded very brilliant results. Although some studies have confirmed the positive effects of nontechnology on plants under salinity stress, there is no complete understanding of the relationship and interaction of nanoparticles (NPs) and intracellular mechanisms in the plants. In this paper, we have tried to reach a conclusion from the latest articles that how NPs could help salt-stressed plants to recover their cells so that we can take a step towards clearing the existing ambiguities for researchers in this field.**

KEYWORDS: Salinity stress, green synthesis, nanoparticles (NPs), amelioration, plants.

Date of Submission: 03-01-2024 Date of acceptance: 20-1-2024

INTRODUCTION

Soil salinity is a major threat to crop productivity and overall crop yield. It causes osmotic, ionic and oxidative stress which leads to decline in growth and plant development **(EL Sabagh et al., 2021).** Salt-influenced soils are found on each landmass and are increasingly regular in parched or semiarid locales where yearly precipitation is low, for example, the western US, north Africa, southeast Asia, and Australia. Information from the Sustenance and Horticulture Association's Reality soil database recommends that somewhere in the range of 6 and 8% of all land meets the edge of saltiness, proportionate to between 800 million and one billion hectares **(FAO, 2008; Tanji, 2002)**.Saline soils are brought about by a high convergence of dissolvable salt particles in the dirt with sodium Na^+ and Cl^- being the most solvent and most harming to plants **(Munns and Tester, 2008).** High salinity facilitates the accumulation of free radicals and reactive oxygen species (ROS), which induces an increase in the malondialdehyde (MDA), hydrogen peroxide (H_2O_2), and proline contents, and a decrease in the antioxidant activity of enzymes, such as superoxide dismutase (SOD) and peroxidase (POD) and reducing the fodder yield (**Noura and Reda, 2021).** The ROS causes oxidation of proteins, carbohydrates, lipids,chlorophyll and nucleic acids, and this results in cell death **(Sachdev et al., 2021)**.

Causes of Saline Soils:

Salinity occurs due to problems like wrong usage of agricultural lands, lack of rain, excess evaporation, lack of drainage. Today, irrigation is being made in 17% of arid and semi-arid lands in the world and due to wrong treatments approximately 20% of these irrigated lands are being unproductive, plant presence is under negative cycle with it (**KELEŞ et al., 2023).** Soil salinity puts plants under stress with complicating ground-water flow from roots due to high concentrations of salts and causing toxicity to plants **(Munns and Tester, 2008)**. Salinity is divided to primary and secondary salinity, primary salinity occurs by natural factors like oceans, corrosion of rocks while human induced secondary salinity occurs by excessive irrigation in agricultural lands, deterioration of agricultural land structure **(Munns and Tester, 2008)**. This situation shows its effect more day by day. Being estimated that 50% of cultivated agricultural lands will be under salt stress by 2050 **(Kumar and Sharma, 2020)**. NaCl and Na_2So_4 salts are the main reasons affecting the salinity of agricultural lands **(Maryum et al., 2022).** Some factors should be considered in causing salinity such as drainage and management of irrigation resource, cultural practices and agricultural land development works are important too. The most important factor affecting salinity is lack of drainage. It causes millions of fertile agricultural lands to be destroyed **(Valipour et al. 2020).**

Effect of salinity on plants:

Salinity stress leads to a series of morphological, physiological, biochemical and molecular changes that adversely affect various physiological, biochemical and metabolic processes that are associated with plant growth and productivity **(Kumar et al., 2023)**. increasing the soil osmotic potential (osmotic stress), ionic toxicity (ionic stress), ROS, nutritional and hormonal imbalances for plants are common implications of salinity stress experienced by plants. **(Kumar et al., 2019; Munns, 2005; Yang and Guo, 2018**). These negative impacts significantly decrease plant yield under salinity stress conditions **(Parihar et al., 2015)**.

It is now clear that the responses of plants to CO_2 assimilation, osmotic regulation, ion compartmentation and/or exclusion, toxic ion uptake, chlorophyll content, chlorophyll fluorescence, ROS generation, photosynthetic electron transport and antioxidant defenses **(Munns and Tester, 2008; Tang et al., 2015)** under salt stress are quite complex and depend on manifold factors such as type and concentration of a solute, genetic potential, growth stage of the plant, type and severity of the stress **(Arif et al., 2020)**. Depending to type and dose of salt, plant cells have also different mechanisms for protecting themselves from adverse effects of salinity stress. Plants developed their defense against salinity stress at various levels by modulating molecular, biochemical and physiological pathways. Some of these mechanisms include ion hemostasis, regulation of enzymatic and non-enzymatic antioxidants, compatible solute accumulation and osmotic protection, hormonal regulation, change in expression of stress resistance genes, and regulation of nitric oxide production (**Hanin et al., 2016; Van Zelm et al., 2020).**

Negative Impacts of Salinity on Crop Physiology:

Salinity exerts its detrimental effect on plants by two mechanisms: osmotic stress and ion toxicity. The first effect is short term and occurs due to the uptake of Na^+ and Cl^- which reduce osmotic potential between root and soil solution and infiltrate water availability (**Lu et al., 2023**). Secondly, high concentrations of Na^+, Cl^-, or $(SO_2)^{-4}$ induce ion toxicity that affect nutrient uptake (**Khadiga Alharbi et al., 2022).** (NaCl) toxicity is directly related to electrical conductivity (EC), which is an indicator of plant tolerance to salt stress **(Rodríguez Coca, 2023).** Crop tolerance decreases beyond 2 dSm^{-1}, while some plants grow well even at 8 dSm^{-1}. Beyond this limit, growth and yield are negatively impacted. The adverse effects of salinity on crop morphology, physiology, biochemical and yield are listed in **Figure 1.** Seeds sown in saline conditions are poorly germinated **(Mbarki et al., 2020).** Salinity decreases the endogenous level of phytohormones and inhibits seedling establishment **(Liu et al., 2022).** If seeded in the first phase of salinity, shoot growth will be affected in later stages **(Izadi et al., 2022)**. Even if seedlings are vigorous and maintain normal growth in the second phase of salinity, yield will be affected at the end.

Salinity causes various physiological impairments in plants; due to less stomatal conductivity, Carbon-fixation capacity becomes limited, disturbing the catalytic activities of enzymes that fix Carbon and destroy photosynthetic pigments **(Omoto et al., 2012)**. A significant decrease in shoot and root biomass has been recorded in plants grown in saline **(Elgharably and Benes, 2021). El-Sayed et al. (2020)** showed that salinity (10 mM NaCl) reduced the yield of *Triticum aestivum* up to 65. Iron (Fe) is an important metal activator (co-factor) of different antioxidant enzymes **(Bhattacharya, 2022)**, which helps in regulating life sustaining processes in plants, i.e., photosynthesis and chloroplast biosynthesis**. Ullah et al. (2021)** reported that saline sodic soil is deficient in (Fe). Plants grown in such soil showed interveinal chlorosis and a declined yield**.** Chloride ion (Cl^-) is a predominant ion in saline environments and the uptake of N is indirectly correlated to it. Salinity-induced increased Cl^- uptake is often associated with decreased uptake of nitrate by crops **(Ashraf et al., 2018).**

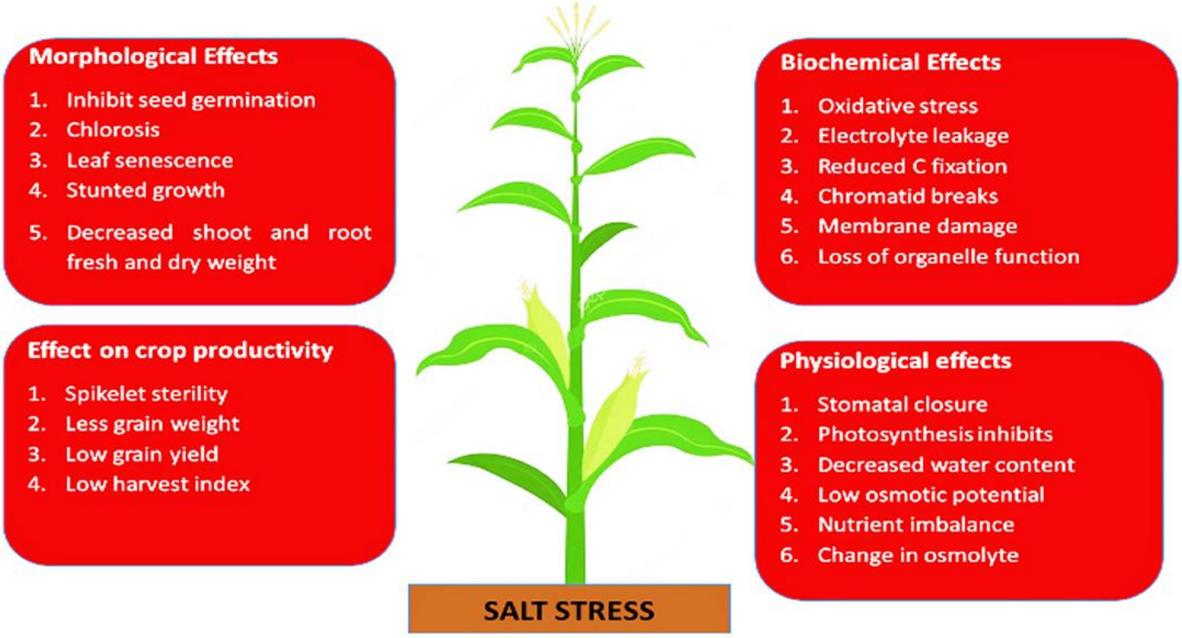


Figure 1. Effects of salt stress on crop morphology, biochemical, physiological, and yield productivity.

The effect of salinity on the plant cells:

As a toxic byproduct of aerobic metabolism, ROS are primarily found in the chloroplast, mitochondria, and peroxisome. Their enhanced production causes lipid peroxidation that affects photosynthesis and membrane permeability, damages nucleic acids, inhibits enzymes, and activates programmed cell death **(López-González et al., 2023), Figure 2. *Brassica napus* and *Triticum aestivum* grown in saline conditions experienced poor growth and yield due to elevated levels of saline water (Courbet et al., 2021).]**

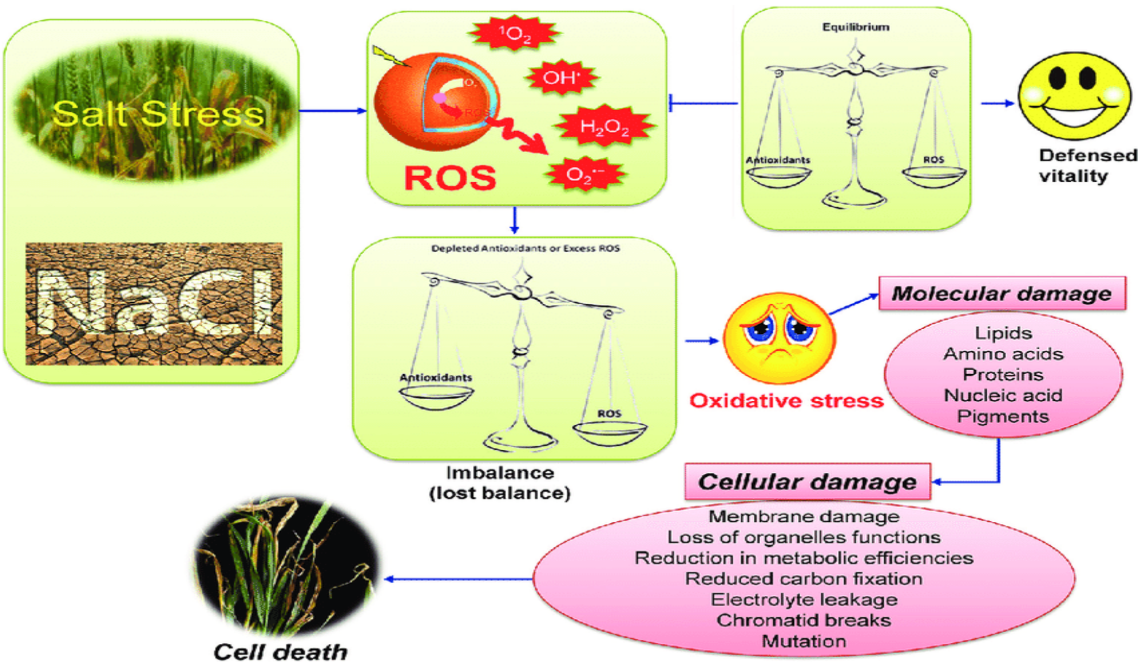


Figure 2. The effect of ROS on plant cells

Nanotechnology:

Since the nineteenth century scientists have been well aware of the ability of biological entities to reduce metal precursors but the mechanisms are still unexplored. The progress of efficient green synthesis utilizing natural reducing, capping and stabilizing agents without the use of toxic, expensive chemicals and high energy consumption have attracted researchers towards biological methods **(Mukherjee et al., 2001; Dhillon et al., 2012).** Nanotechnology is advancing day by day and opening new vista of the synthesis, characterization and applications of (NPs). Thus, nanotechnology has tremendously increased the exogenous application of NPs on plant to overcome environmental stresses like salt stress **(Rossi et al., 2016; Rajput et al., 2018)**. They possess remarkable and interesting properties owing their small sizes, large surface area with free dangling bonds and higher reactivity over their bulk cousins (**Kubik and Sugisaka 2002; Daniel and Astruc 2004; Zharov et al. 2005)**. All these special characteristics make NPs to specifically interact with plants and modulate plant morpho-physiological parameters **(Das and Das, 2019).** High surface to volume ratio, physico-chemical properties, their utilization in various industries and environmental remediation are increasing gradually **(Rajput et al., 2018).** Accumulation of treated salt induces the osmotic stress in plants **(Abdel Latef et al., 2017)** and the application of NPs further help to adjust the salt induced osmotic stress. (NPs) having one of the dimension in the range of 1–100 nm act as a bridge between bulk materials and atomic or molecular structures **(Kaushik et al., 2010).** Exogenous application of NPs enhanced the plant growth, development, biochemistry and nutrient uptake under normal and stressed conditions **(Kalteh et al., 2018; Faizan et al., 2020).** They also positively regulate plant's crucial processes like germination, photosynthesis, stomatal conductance, transpiration and lipid metabolism both under stressed or non-stressed condition **(Hashemi, 2019; Faizan et al., 2020).**

Green synthesis of NPs:

Numerous approaches have been used to synthesize (NPs) and toxic chemicals that are used in physical and chemical methods may reside in the (NPs) formed which may prove hazardous to the environment and organisms in the field of their application **(Dhandapani et al., 2014).** It is an efficient technique which includes synthesis through plants, bacteria, fungi, algae, actinomycetes etc. Green approach is an ecofriendly, cost-effective, biocompatible and safe **(Zahir et al., 2014).** NPs synthesized from this approach produce more catalytic activity and limit the use of expensive and toxic chemicals **(Kumar et al., 2017).** In recent years, the synthesis of NPs using green approach has been increased. Rapid industrialization, urbanization and population explosion are resulting in deterioration of earth atmosphere and a huge amount of hazardous and unwanted substances are being released. It is now high time to learn about the secrets that are present in nature and its natural products which lead to advancements in the synthesis processes of NPs. Furthermore, NPs are widely applied to human contact areas and there is a growing need to develop processes for synthesis that do not use harsh toxic chemicals. Therefore, green/biological synthesis of NPs -as shown in **Figure 3-** is a possible alternative to chemical and physical methods.

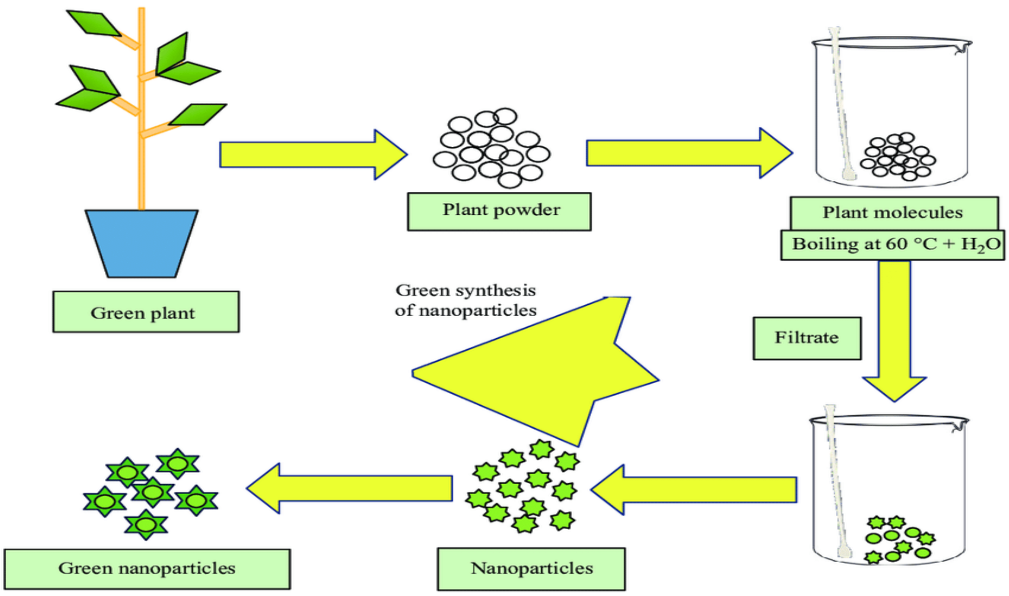


Figure 3: showing the process of green synthesis of NPs.

Applications of NPs and their uptake by plant:

The biological function of NPs depends on their physicochemical properties, concentration, and the application method (**Ali et al., 2021**). Some studies showed the positive effects of various NPs on plants under salinity stress **(Table 1).** NPs are used in different methods such as priming, irrigation, hydroponic substrate, foliar application, and direct injection **(Abou-Zeid et al., 2020; An et al., 2020).** When exposed to plants, NPs enter plant tissue through root junction and wound regions, penetrate in to the cell wall and cell membrane of root epidermis (e.g., by various mechanisms such as endocytosis, carrier proteins, plasmodesmata, or pore formation) accompanied by a complex series of events to enter plant vascular bundle (xylem) (e.g., through one of the two paths of symplast or apoplast) **(P´erez-de-Luque, 2017),** accumulate in cellular or subcellular organelles, and move to the stele symplastically, to be translocated to leaves **(P´erez-de-Luque, 2017; Tripathi et al., 2017a) (Figure 4).** NPs are also capable of penetrating through the cuticles, stomata, hydathodes, and trichrome of leaf and into the cell cytoplasm **(Sharif et al., 2013).** In the cytoplasm, the NPs may bind with different cytoplasmic organelles and interfere with the metabolic processes at that site (**Zhang and Monteiro-Riviere, 2009).**

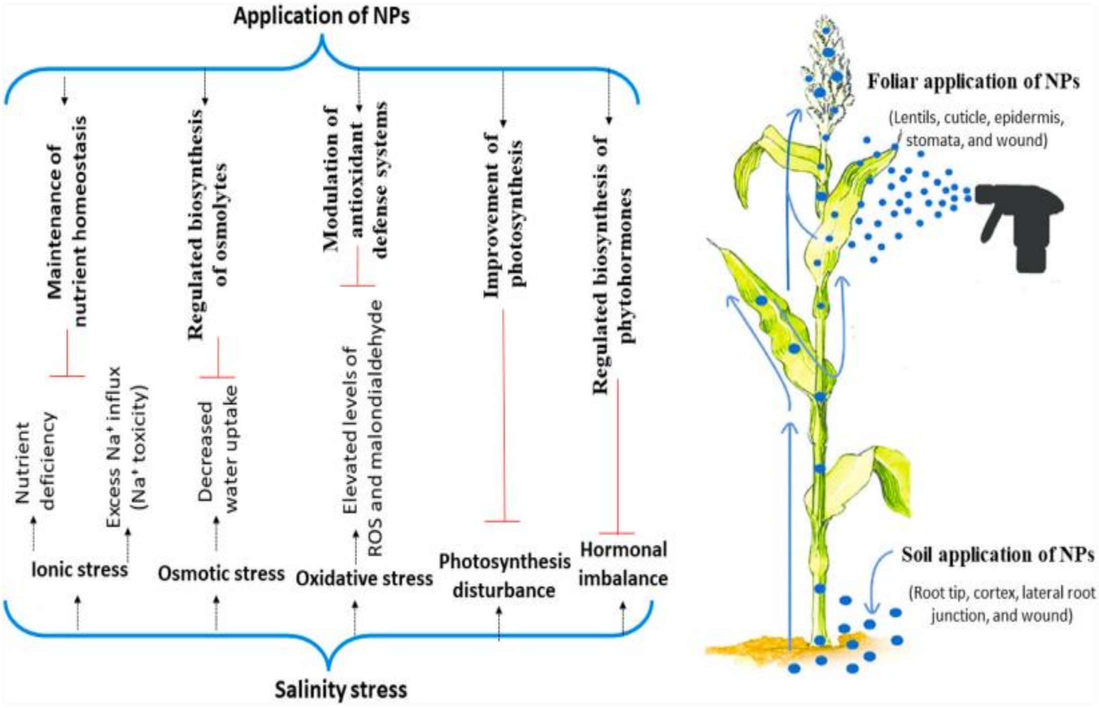


Figure 4. Some mechanisms of (NPs) induced salinity stress tolerance in plants.

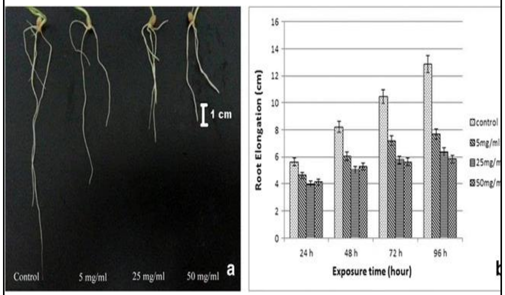
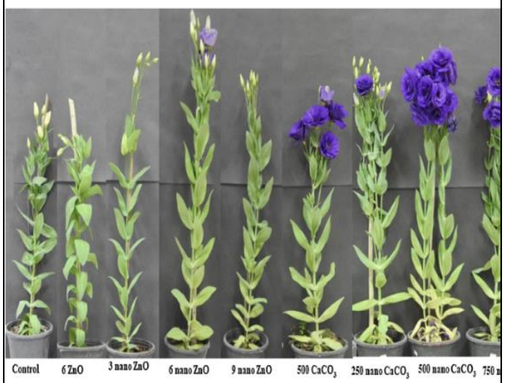
The direct absorption of NPs in seeds can also occur by entering the coat via parenchymatic intercellular spaces, accompanied by diffusion in the cotyledon **(Tripathi et al., 2017b).** In general, the mechanisms by which NPs accumulate in plants through their cell walls are still not well understood **(Ali et al., 2021).** According to these reports, the uptake, translocation, and accumulation of NPs depend on the species of plant (the plant cells' physiology and structure), the size, type, chemical composition, functionalization, and stability of the NPs, and the NPs interactions with soil (environmental conditions), root exudates (mucilage and metabolites), and root-associated microorganisms. **Ali et al. (2021)** reported that the accumulation rate of NPs by the root of plants may be impacted by environmental conditions and the properties of NPs In a previous study, the application of silver sulfide (Ag_2S) NPs in combination with potassium chloride and ammonium thiosulfate significantly enhanced the concentration of Ag-NPs in the shoot and roots of lettuce *(Lactuca sativa* L.) **(Doolette et al., 2015).**

In another study, soil organic matter decreased cerium dioxide (CeO_2) NPs through roots in maize (*Zea mays* L.) **(Zhao et al., 2012).** It has been also known that when NPs are used in soil or as foliar sprays, root and leaf-associated microorganisms can affect the mobility of NPs **(Feng et al., 2023)**. In a study, mycorrhizae could reduce the uptake of Ag-NPs into the roots of the *Trifolium repens* plant **(Feng et al., 2013).** But this was completely different in various plant species. For example, the uptake of phosphorus and selenium NPs increased in the presence of microorganisms **(Perfileva et al., 2021),** while the uptake of iron and silver NPs was decreased in legumes in the presence of microorganisms **(Feng et al., 2013; Guo and Chi, 2014)**. Mucilage is the first barrier to the entry of toxic particles and are also effective in improving the absorption of beneficial elements as well as the growth of soil microorganisms (e.g., an effect on microorganism symbiosis) **(Driouich et al., 2013; Mckenzie et al., 2013).** The mucilage can also acidify the environment of the rhizosphere (**Schaller et al., 2013**) and as a result promote dissolution of some insoluble NPs **(Schwab et al., 2016),** which in turn affect the uptake of the NPs by plants. The application methods, size, concentration, and climate are also the essential factors that determined the effective adsorption of NPs after foliar application **(Lv et al., 2022)**. Leaf morphology and its chemical composition, the presence of trichrome, and existence of leaf exudates and waxes are essential factors that affect the trapping of NPs on the surface of the leaf (**Larue et al., 2014**). For example, it has been reported that the presence of chemicals such as pesticides in foliar application affects the absorption of NPs in tomato plants **(Bueno et al., 2022).** Most studies also report that the size of the cell wall's pore is the key constraint on the entrance of NPs into the plant cell. The small NPs are reported to penetrate plant roots along with osmotic pressure, capillary forces, or passing directly through the root epidermal cells **(Ali et al., 2021; Du et al., 2011; Lin and Xing, 2008)**. However, the epidermal cells of the root cell wall are semipermeable containing small pores and restrict the large NPs. In addition, the cuticle also acts as a primary leaf barrier, restricting the entry of NPs to a size of < 5 nm **(Ali et al., 2021)**.

The basic structure of nanomaterials is complementary to the evaluation of their effect on the uptake, translocation, and accumulation of NPs in plants (**Raliya et al., 2016).** The above facts demonstrate the need to standardize laboratory experiments to assess NPs in plant tissues at various levels to determine the exact effect of NPs supported by their physical-chemical properties (**Zhang et al., 2012).** Therefore, a detailed study on the nature of the NPs is needed to understand and elucidate the absorption, translocation, and accumulation processes. To determine their movement and localization to various structures and cell organelles within the plant, monitoring and tracking NPs of high purity and stability are also important **(Ali et al., 2021).**

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

Species No.	**Figure**	**NPs and plants**	**End points**	**Reference/s**
1.		Carbon nanotubes on toma seeds (*Solanum lycopersicum*)	Enhance germination a growth rates.	**(Ma** et al., 2010)
2.		Aluminum oxide on tobac (*Nicotiana tabacum*)	Negative effect on t growth and development tobacco seedlings elongation.	(Burklew et al., 2012)

3.		Aluminum oxide NPs on whe (*Triticum aestivum)*	Significantly improved.	(Yanık et al., 2015)
4.		$AgNO_3$ NPs and GA-Ag ryegrass (*Lolium multiflorum*	Significant increase germination percentage soaking in nanopartic suspension and severe reducti on soaking and incubation copper nanoparticles.	(Farooqui et al.,2016)
5.		ZnO NPs on *Eustoma grandiflorum*	Decreased the Peroxida (POD) activity and increased t activity of both Super oxi dismutase (SOD) and Catala (CAT) enzymes.	(Youssef et al.,2020)
6.		Carbon NPs on *Trigonella foenumgraecum*	Increased the trigonelli content.	(Noohpisheh et al., 20

Effects of NPs on plants under salt stress:

In recent years, much attention has been directed toward the use of NPs, as one of the most promising methods, to improve growth and plant performance under salinity stress (**Ahmad and Akhtar, 2019**). NPs enter the plant system by several routes, mainly through roots and leaves **Figure 3.** NPs interact with plants at cellular and subcellular levels after entry, promoting changes in morphological, biochemical and physiological, and molecular states **(Khan et al., 2019b**). These interactions may be positive or negative, depending on the nature of the NPs and the plant species. The chemical nature, reactivity, size, and specifically concentration of NPs in or on the plant could determine NPs' effects on plant systems (**Paramo et al., 2020; Zulfiqar and Ashraf, 2021**). Available evidence has shown that different NPs can promote salinity-stressed plant growth and development **(Ali et al., 2021; Zulfiqar and Ashraf, 2021)** at concentrations below certain limits by various known mechanisms **Figure 3.** These studies were mostly performed under artificial treatment conditions such as plate growth medium and hydrophobic or pot conditions. To understand the impact of NPs on plant growth, we discuss the positive effects of NPs to improve plant salinity stress tolerance.

- **Effect of NPs on physiological aspect of plants:**

1. Improvement of photosynthesis

One of the most important processes affected by salinity stress, depending on the type of plant, salt dose and other conditions, is photosynthesis **(Hnilickova et al., 2021**). Several studies report that the foliar application of NPs dramatically improves the content of chlorophyll in plants, enabling plants to synthesize more complexes for light harvesting to absorb more light energy and improve photosynthesis **(Ali et al., 2021; Zulfiqar and Ashraf, 2021**). According to various studies that have examined the effect of NPs on salinity-stressed plants, most of the available NPs were able to increase photosynthesis by increasing the content of photosynthetic pigments **(Singh et al., 2021; Zulfiqar and Ashraf, 2021). Xuming et al. (2008)**, by genetic analysis of the smaller RuBisCO subunit, found that foliar application of TiO_2-NPs significantly increased the amount of this enzyme and plant photosynthesis. **Ullah et al. (2020)** have recently evaluated the effect of TiO_2-NPs on wheat growth under salinity stress. Their results showed that the application of the NPs improved wheat growth under saline stress which was ascribed to the property of absorbing light by the NPs and helping photosynthesis and better absorption of water by wheat plant. Based on three separate studies conducted on the effect of TiO_2-NPs on spinach plant, **Hong et al. (2005)** reported the ability of TiO_2 NPs to protect chloroplasts against aging due to their photocatalytic properties. It is known that the addition of silicon reduces the permeability of the plasma membrane of leaf cells and significantly improves the upper structure of chloroplasts, which greatly reduces the damage caused by stress with the disappearance of the bilayer membrane and the collapse of the grana **(Etesami et al., 2020; Zhu et al., 2004).**

The rate of photosynthesis was significantly increased by SiO_2 NP treatments due to increased activity of carbonic anhydrase and photosynthetic pigment synthesis (**Siddiqui and Al-Whaibi, 2014). Avestan et al. (2019**) have shown that nano-silicon dioxide application to strawberry plants maintained epicuticular wax structure and improved photosynthetic pigments but resulted in lower accumulation of osmolytes than that of salinity-treated plants. In tomato, the supplementation of Si-NPs under saline stress maintained the concentrations of chlorophylls and glutathione reductase, and enhanced phenylalanine ammonia lyase activity, and the levels of fruit vitamin C compared with those in the non-treated plants grown under salt stress **(Pinedo-Guerrero et al., 2020**). While examining the effect of carbon nanotubes in a potential vegetable crop broccoli, the supplementation of multi-walled carbon nanotubes under saline regimes, resulted in improved rate of photosynthesis and water uptake **(Martínez-Ballesta et al., 2016).** Recently**, Gohari et al. (2020a**) have observed that the low levels of multi-walled carbon nanotubes had salt ameliorating effect on *Ocimum basilicum* plants via increasing photosynthetic pigments. **Baz et al. (2020**) tested carbon NPs on lettuce varieties under salt stress. They found that pretreatment with carbon NPs improved seed germination under salinity stress (150 mM) and high temperature.

2. Maintenance of plant water balance

In plants under salt stress, the amount and absorption of water by the plant decreases. High concentrations of salt in soil solution result in increased osmotic stress, which limits water absorption by the plant and in turn affects leaf water content, stomatal conductance, leaf growth (acceleration of leaf senescence and leaf death) and photosynthesis (decrease in chlorophyll concentrations) and ultimately results in a reduction in plant growth **(Munns and Tester, 2008**). There are reports that show that NPs can improve water status and water use efficiency in many plant species **(Mahmoud et al., 2020b; Zulfiqar and Ashraf, 2021)**, alleviating salt-induced osmotic stress. Furthermore, several studies have reported that plants treated with NPs maintain a higher stomatal conductance and transpiration rate, stomatal conductance, leaf water content, and root and whole-plant hydraulic conductance **(Zulfiqar and Ashraf, 2021**). Aquaporins are channel proteins belonging to the major intrinsic protein superfamily that play an important role in plant water relations. The main role of aquaporins in plants is transport of water and other small neutral molecules across cellular biological membranes **(Kapilan et al., 2018).** It has been reported that NPs can increase root hydraulic conductance through increased expression of plasma-membrane intrinsic protein aquaporins, which may in part contribute to the increase in water uptake and reduce oxidative stress and membrane damage (**Ali et al., 2021; Zulfiqar and Ashraf, 2021)**. For example, NPs treatments improve seed absorption and water retention **(Ali et al., 2021**); it may be attributed to increasing seed germination **(Khodakovskaya et al., 2009**). The tomato seeds were inoculated to media with carbon nanotubes;

after 2-day incubations, the seeds' moisture content was treated with the NPs containing 19% more than untreated seeds. These findings suggested that the NPs promote the uptake and retention of water.

- **Effect of NPs on biochemical aspects of plants:**

1- Modulation of antioxidant defense systems in plant:

It is well known that ROS production is one of the responses of plants to abiotic stresses including salinity stress and plant developed antioxidant enzymes to deal with the excessive ROS in salinity stressed-plant cells **(You and Chan, 2015).** The effect of NPs on increasing the content of antioxidant enzymes has been proven in many studies **(Abdoli et al., 2020; Gonz´ alez-García et al., 2021).** The researchers stated that some NPs have the properties of certain antioxidant enzymes and thus help the plant to overcome the oxidative conditions created. For example, the NPs of cobalt, iron and cesium act similarly to the enzyme catalase (CAT) and the cesium, manganese, copper and iron NPs also act similarly to the enzymes peroxidase (POD) (**Rico et al., 2015). Khan et al. (2020)** investigated the effect of seed priming with this Ag-NPs (10, 20, and 30 mM) on pearl millet (*Pennisetum glaucum* L.) under salinity stress (0, 120, and 150 mM NaCl). Their results showed a significant increase in growth traits in this plant in the presence of this NPs, which was due to an increase in antioxidant enzymes such as SOD, CAT, and glutathione peroxidase (GPX) and a decrease in the ratio of sodium to potassium. In a study that 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 mM NaCl) was investigated, TiO_2-NPs caused an increase in antioxidant content and a decrease in H_2O_2, especially at a concentration of 100 mg L^{-1} **(Gohari et al., 2020a**). In addition, cerium-NPs were able to improve the activity of antioxidant enzymes in cotton plants to remove ROS inside the cell. The NPs also increased plant growth under salinity stress (**Liu et al., 2021).**

Recently, **Gohari et al. (2020a)** and **Gohari et al. (2020b)** have observed that low levels of multi-walled carbon nanotubes had salt ameliorating effect on *Ocimum basilicum* plants via increasing photosynthetic pigments and inducing both enzymatic (i.e. APX, CAT and GP) and non-enzymatic components (i.e. phenolic content) of the antioxidant defense system. **Moradbeygi et al. (2020)** investigated the effect of iron-NPs under salinity stress conditions on (*Dracocephalum moldavica* L). According to the results of this experiment, the NPs were able to improve the conditions for the plant growth under salinity by increasing the content of phenolic and flavonoid compounds, especially in the roots, and reducing the content of antioxidant enzyme activity. The authors believe that the non-enzymatic system is more important than the enzymatic system to neutralize the destructive effect of stress in this plant. Hence, when the non-enzymatic defense system is weakened, the enzymatic defense system is activated to help eliminate free radicals and their destructive effects on the plant. The above facts demonstrate that various NPs can alleviate the oxidative damage in plants by modulating antioxidant defense systems (both enzymatic constituents and non-enzymatic constituents).

- **Regulation the biosynthesis of phytohormones in plant:**

In a study, the application of Ag-NPs on wheat plant under stressful conditions increased the content of indole-3-butyric acid (IBA), 1-naphthalene acetic acid (NAA), and 6-benzylaminopurine (BAP) and decreased the content of ABA. These changes are likely to be one of the key mechanisms of Ag-NPs in improving the plant growth under stress **(Abou-Zeid and Ismail, 2018**). Also, improved root biomass and the maintenance of the proper osmotic state of the cells in salinity-stressed strawberry plant were attributed to selenium NPs-mediated increase in indole-3-acetic acid (IAA) and ABA levels in this plant **(Zahedi et al., 2019**). In wheat, Ag-NPs were reported to influence germination and grain yield under salt stress by modulating photosynthetic efficiency and plant hormones as the levels of 6-benzylaminopurine, 1-naphthalene acetic acid, and indole-3-butyric acid increased, whereas those of ABA decreased (**Abou-Zeid and Ismail, 2018**). In general, the research related to NPs's repercussions on growth hormones under salinity stress conditions is limited. Study of how to adjust the levels and initial adaptive responses of phytohormones by NPs can be an interesting research field in the future.

- **Regulation the biosynthesis of compatible solutes:**

Under salinity conditions, compatible solutes or osmolytes increase in plants. The compatible solutes may alleviate the limiting effect of increasing the high ion concentrations (Na^+ and Cl^-) on the activity of enzymes by stabilizing proteins and their complexes, as well as membranes under salinity stress (**Etesami and Jeong, 2018**).

There are some reports that NPs application can also increase plant tolerance to salinity stress by modifying the levels of the compatible solutes **(Zulfiqar and Ashraf, 2021**). There are many reports that NPs application can also increase plant tolerance to salinity stress by modifying the levels of solutes such amino acids (e.g., proline) and total soluble sugars **(Abdoli et al., 2020; Alabdallah and Alzahrani, 2020),** which minimize the osmotic shock created by NaCl stress due to ion toxicity (Na^+ and Cl^-). For example, **Farouk and Al-Amri (2019)** reported that Zn-NPs application to salinity-stressed canola (*Brassica napus* L.) plants alleviated the salt-induced harmful effects via osmolyte biosynthesis and ionic regulation. In another study**, Mohamed et al. (2017**) demonstrated that seed pre-sowing treatment with Ag-NPs improved the growth, proline, and soluble sugars of salt-stressed wheat seedlings. **Wan et al. (2020**) have recently evaluated the effect of carbon nanohorns on *Sophora alopecuroides* seedlings under salinity stress. Their results showed that the foliar spray of the NPs promoted the root fresh weight, leaf soluble sugar content, and leaf and root total protein contents. **Abdel Latef et al. (2017)** have recently evaluated the effect of different concentrations (0·01%, 0·02% and 0·03%) of TiO_2 NPs on bean plants under salinity stress. Their results showed that the lowest concentration (0.01%) improved the plant tolerance to salinity, which was ascribed to improvement in amino acids, soluble sugars, and proline in this plant.

Conclusions and future prospective:

Production of NPs using extracts from natural substances is emerging as an important nanotechnology. The use of natural resources for production of NPs is sustainable, eco-friendly, inexpensive and free of chemical contaminants for biological and medical applications where purity of NPs is of major concern. Useful and common nanomaterials can be produced easily on large scale. The biological methods do not need harsh or toxic chemicals. The waste products of plant extracts are non-toxic and easier to dispose off. Furthermore, NPs synthesized via green route are more stable and effective in comparison with those produced by physico–chemical methods. Greener synthetic efforts reported earlier are dedicated to Ag and Au NPs, which may be due to their importance in disinfection science. This report is devoted to several other metals and its oxides NPs viz. Fe, Pd, Ru, PbS, CdS, CuO, CeO_2, TiO_2, and ZnO NPs synthesized by biological methods which have imperative roles in human welfare. A considerable number of efforts have been taken in order to obtain secondary metabolites from the extract of natural products which may act as reducing, stabilizing and capping agents in the synthesis process of nanomaterials. Capping and stabilizing agents present in biological entities act as growth terminators and inhibits agglomeration processes and thus enhances the stability and persistence of NPs. The nature of biological entities in different concentrations with combination of organic reducing agents influences the size and shape of NPs. The most of these investigations have been carried out in research laboratories in small scale but researchers are engaged to explore the potential and application of NPs at large scale in agricultural field, environment, health science and many more to fulfill the future demands of growing population of world and to provide best service for human welfare.

References:

Abdel Latef, A. A. H., Abu Alhmad, M. F., & Abdelfattah, K. E. (2017). The possible roles of priming with ZnO nanoparticles in mitigation of salinity stress in lupine (*Lupinus termis*) plants. *Journal of plant growth regulation*, *36*, 60-70.

Abdoli, S., Ghassemi-Golezani, K., Alizadeh-Salteh, S., (2020). Responses of ajowan (*Trachyspermum ammi* L.) to exogenous salicylic acid and iron oxide nanoparticles under salt stress. Environ. Sci. Pollut. Res. 27, 36939–36953.

Abou-Zeid, H., Ismail, G., (2018). The role of priming with biosynthesized silver nanoparticles in the response of *Triticum aestivum* L to salt stress. Egypt. J. Bot. 58, 73–85.

Abou-Zeid, H.M., Ismail, G.S.M., Abdel-Latif, S.A., (2020). Influence of seed priming with ZnO nanoparticles on the salt-induced damages in wheat (*Triticum aestivum* L.) plants. J. Plant Nutr. 44, 629–643.

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

Alabdallah, N.M., Alzahrani, H.S., (2020). The potential mitigation effect of ZnO nanoparticles on nanoparticles on [Abelmoschus esculentus L. Moench] metabolism under salt stress conditions. *Saudi Journal of Biological Sciences*, *27*(11), 3132-3137.

Ali, S., Mehmood, A., Khan, N., (2021). Uptake, translocation, and consequences of nanomaterials on plant growth and stress adaptation. Journal of Nanomaterials, 2021, 1-17.

Amarnath, C.A., Nanda, S.S., Papaefthymiou, G.C., Yi, D.K., Paik, U., (2013). Nanohybridization of low-dimensional nanomaterials: synthesis, classification and application. Critic. Rev. Solid State Mater. Sci. 38, 1–56.

An, J., Hu, P., Li, F., Wu, H., Shen, Y., White, J.C., Tian, X., Li, Z., Giraldo, J.P., (2020). Emerging investigator series: molecular mechanisms of plant salinity stress tolerance improvement by seed priming with cerium oxide nanoparticles. Environ. Sci. Nano 7, 2214–2228.

Avestan, S., Ghasemnezhad, M., Esfahani, M., Byrt, C.S., (2019). Application of nanosilicon dioxide improves salt stress tolerance in strawberry plants. Agronomy 9, 246.

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

Bhattacharya, S. Protective Role of the Essential Trace Elements in the Obviation of Cadmium Toxicity(2022). Glimpses of Mechanisms. *Biol Trace Elem Res* 200, 2239–2246 (https://doi.org/10.1007/s12011-021-02827-7

Bueno, V., Gao, X., Abdul Rahim, A., Wang, P., Bayen, S., & Ghoshal, S. (2022). Uptake and translocation of a silica nanocarrier and an encapsulated organic pesticide following foliar application in tomato plants. *Environmental Science & Technology*, *56*(10), 6722-6732.

Burklew CE, Ashlock J, Winfrey WB, Zhang B., (2012). Effects of Aluminum Oxide oxide nanoparticles on the growth, development, and microRNA expression of tobacco (*Nicotiana tabacum*). *PloS one*, *7*(5), e34783.

Das, A., Das, B., (2019). Nanotechnology a Potential Tool to Mitigate Abiotic Stress in Crop Plants, Abiotic and biotic stress in plants.

Dhandapani, P., Siddarth, A.S., Kamalasekaran, S., Maruthamuthu, S., Rajagopal, G., (2014). Bio-approach: ureolytic bacteria mediated synthesis of ZnO nanocrystals on cotton fabric and evaluation of their antibacterial properties. Carbohydr. Polym. 103, 448–455.

Dhillon, G.S., Brar, S.K., Kaur, S., Valero, J.R., Verma, M., (2012). Chitinolytic and chitosanolytic activities from crude cellulase extract produced by A. niger grown on apple pomace through koji fermentation. Journal Microbiology & Biotechnology21, 1312e1321.

Doolette, C.L., McLaughlin, M.J., Kirby, J.K., Navarro, D.A., (2015). Bioavailability of silver and silver sulfide nanoparticles to lettuce (*Lactuca sativa*): effect of agricultural amendments on plant uptake. J. Hazard. Mater. 300, 788–795.

Driouich, A., Follet-Gueye, M.-L., Vicr´e-Gibouin, M., Hawes, M., (2013). Driouich, A., Follet-Gueye, M. L., Vicré-Gibouin, M., & Hawes, M. (2013). Root border cells and secretions as critical elements in plant host defense. *Current Opinion in Plant Biology*, *16*(4), 489-495.

Du, W., Sun, Y., Ji, R., Zhu, J., Wu, J., Guo, H., (2011). TiO_2 and ZnO nanoparticles negatively affect wheat growth and soil enzyme activities in agricultural soil. J. Environ. Monit. 13, 822–828.

Dur´ an, P., Acuna, ˜ J., Jorquera, M., Azcon, ´ R., Borie, F., Cornejo, P., Mora, M., (2013). Enhanced selenium content in wheat grain by co-inoculation of csvseleno bacteria and arbuscular mycorrhizal fungi: a preliminary study as a potential Se biofortification strategy. J. Cereal Sci. 57, 275–280.

EL Sabagh, A., Islam, M. S., Skalicky, M., Ali Raza, M., Singh, K., Anwar Hossain, M., ... & Arshad, A. (2021). Salinity stress in wheat (*Triticum aestivum* L.) in the changing climate: Adaptation and management strategies. *Frontiers in Agronomy*, *3*, 661932.

Elgharably, A., Benes, S. (2021). Alfalfa Biomass Yield and Nitrogen Fixation in Response to Applied Mineral Nitrogen Under Saline Soil Conditions. *J Soil Sci Plant Nutr* **21**, 744–755 https://doi.org/10.1007/s42729-020-00397-6

Etesami, H., Fatemi, H., & Rizwan, M., (2021). Interactions of nanoparticles and salinity stress at at physiological, biochemical and molecular levels in plants: A review. *Ecotoxicology and Environmental Safety*, *225*, 112769.

Etesami, H., 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. Ecotoxicol. Environ. Saf. 156, 225–246.

FAO (2008). FAO Land and Plant Nutrition Management Service. http://www.fao.org/ag/agl/agll/spush

Farooqui, A. R. E. E. B. A., Tabassum, H. E. E. N. A., Ahmad, A. S. A. D., Mabood, A. B. D. U. L., Ahmad, A. D. N. A. N., & Ahmad, I. Z., (2016). Role of nanoparticles in growth and development of plants: A review. *Int J Pharma Bio Sci*, *7*(4), 22-37.

Feng, R., Wang, H., Liu, T., Wang, F., Cai, L., Chen, X., & Zhang, S. (2023). Response of microbial communities in the phyllosphere ecosystem of tobacco exposed to the broad-spectrum copper hydroxide. *Frontiers in Microbiology*, *14*.

Feng, Y., Cui, X., He, S., Dong, G., Chen, M., Wang, J., Lin, X., (2013). The role of metal nanoparticles in influencing arbuscular mycorrhizal fungi effects on plant growth. Environ. Sci. Technol. 47, 9496–9504.

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 *Dracocephalum moldavica.* Sci. Rep. 10, 1–14.

Gohari, G., Safai, F., Panahirad, S., Akbari, A., Rasouli, F., Dadpour, M.R., Fotopoulos, V., (2020b). Modified multiwall carbon nanotubes display either phytotoxic or growth promoting and stress protecting activity in *Ocimum basilicum* L. in a concentration dependent manner. Chemosphere 249, 126-171.

Hanin, M., Ebel, C., Ngom, M., Laplaze, L., Masmoudi, K., (2016). New insights on plant salt tolerance mechanisms and their potential use for breeding. *Frontiers in plant science*, *7*, 1787.

Hashemi, S., (2019). Effect of nanoparticles on lipid peroxidation in plants. Lipid Metabolism. IntechOpen.

Hossain, Z., Mustafa, G., Komatsu, S., (2015). Plant responses to nanoparticle stress. Int. J. Mol. Sci. 16 (11), 26644–26653. https://doi.org/10.3390/ijms161125980.

Hussin, S., Geissler, N., and Koyro, H. W., (2013). Effect of NaCl salinity on *Atriplex nummularia* (L.) with special emphasis on carbon and nitrogen metabolism. Acta Physiol. Plantar. 35, 1025–1038. doi: 10.1007/s11738-012-1141-5.

Islam, M. J., Uddin, M. J., Hossain, M. A., Henry, R., Begum, M. K., Sohel, M. A. T., ... & Lim, Y. S. (2022). Exogenous putrescine attenuates the negative impact of drought stress by modulating physio-biochemical traits and gene expression in sugar beet (Beta vulgaris L.). *PloS One*, *17*(1), e0262099.

Izadi, Y., Moosavi, S. A., & Gharineh, M. H. (2022). Salinity affects eco-physiological aspects and biochemical compositions in chia (*Salvia hispanica* L.) during germination and seedling growth. *Scientia Horticulturae*, *306*, 111461.

Kalteh, M., Alipour, Z.T., Ashraf, S., Marashi Aliabadi, M., Falah Nosratabadi, A., (2018). Effect of silica nanoparticles on basil (*Ocimum basilicum*) under salinity stress. J. Chem. Health Risks 4 (3). https://doi.org/10.22034/JCHR.2018.544075.

Kapilan, R., Vaziri, M., Zwiazek, J.J., (2018). Regulation of aquaporins in plants under stress. Biol.Res. 51, 1–11.

Karunakaran G, Suriyaprabha R, Manivasakan P, Yuvakkumar R, Rajendran V, Mahmoodzadeh H,Aghili R., (2014) Effect on germination and early growth characteristics in wheat plants (*Triticum aestivum* L.) seeds exposed to TiO_2 nanoparticles. J Chem Health Risks 4(1):29–36

Kaushik N, Thakkar MS, Snehit S, Mhatre MS, Rasesh Y, Parikh MS (2010) Biological synthesis of metallic nanoparticles. Nanomed Nanotechnol Biol Med 6:257–262

KELEŞ, B., & AKBAŞ, F. (2023). Morphological, Physiological and Biochemical Responses of Safflower (*Carthamus tinctorius* L.) Exposed to Salinity Stress. *Kahramanmaraş Sütçü İmam Üniversitesi Tarım ve Doğa Dergisi*, *26*(6), 1246-1252.

Keller, A.A., Gardea-Torresdey, J.L., (2012). Effect of surface coating and organic matter on the uptake of CeO_2 NPs by corn plants grown in soil: Insight into the uptake mechanism. J. Hazard. Mater. 225, 131–138.

Kendirli B, Çakmak B, Uçar Y., (2005). Salinity in the Southeastern Anatolia Project (GAP), Turkey: issues and options. Irrigation and Drainage**.** 54(1):115-122. DOI: 10.1002/ird.157

Khadiga Alharbi, Areej Ahmed Al-Osaimi, and Budour A., (2022). Alghamdi*ACS Omega* .*7* (24), 20819-20832. DOI: 10.1021/acsomega.2c01427

Khan, I., Raza, M.A., Awan, S.A., Shah, G.A., Rizwan, M., Ali, B., Tariq, R., Hassan, M.J., Alyemeni, M.N., Brestic, M., Zhang, X., Ali, S., Huang, L., (2020). Amelioration of salt induced toxicity in pearl millet by seed priming with silver nanoparticles (Ag NPs): The oxidative damage, antioxidant enzymes and ions uptake are major determinants of salt tolerant capacity. Plant Physiol. Biochem. 156, 221–232.

Khodakovskaya, M., Dervishi, E., Mahmood, M., Xu, Y., Li, Z., Watanabe, F., Biris, A.S., (2009). Carbon nanotubes are able to penetrate plant seed coat and dramatically affect seed germination and plant growth. ACS Nano 3, 3221–3227.

Kumar P and Sharma PK (2020) Soil Salinity and Food Security in India. Front. Sustain. Food Syst. 4:533781. doi: 10.3389/fsufs.2020.533781

Kumar, M., Etesami, H., & Kumar, V. (Eds.). (2019). Saline soil-based agriculture by halotolerant microorganisms (pp. 1-253). Springer Singapore.

Kumar, R., Ghoshal, G., Jain, A., Goyal, M., (2017). Rapid green synthesis of silver nanoparticles nanoparticles (AgNPs) using (Prunus persica) plants extract: exploring its antimicrobial and catalytic activities. *J Nanomed Nanotechnol*, *8*(4), 1-8.

Kumar, R., Sagar, V., Verma, V. C., Kumari, M., Gujjar, R. S., Goswami, S. K., ... & Prasad, P. V. (2023). Drought and Salinity Stress Induced Physio-Biochemical Changes in Sugarcane: An Overview of Tolerance Mechanism and Mitigating Approaches. *Frontiers in Plant Science*, *14*, 1225234.

Larue, C., Castillo-Michel, H., Sobanska, S., C´ecillon, L., Bureau, S., Barth`es, V., Ouerdane, L.,Carri`ere, M., Sarret, G., (2014). Foliar exposure of the crop *Lactuca sativa* to silver nanoparticles: evidence for internalization and changes in Ag speciation. J. Hazard. Mater. 264, 98–106.

Liu Z, Ma C, Hou L, Wu X, Wang D, Zhang L, Liu P., (**2022**) Exogenous SA Affects Rice Seed germination under salt stress by regulating Na^+/K^+ balance and endogenous GAs and ABA homeostasis. *International Journal of Molecular Sciences*, *23*(6), 3293.

Liu, J., Li, G., Chen, L., Gu, J., Wu, H., Li, Z., (2021). Cerium oxide nanoparticles improve cotton salt tolerance by enabling better ability to maintain cytosolic K+/Na+ ratio. J. Nanobiotechnol. 19, 1–16.

López-González, D., Ferradás, Y., Araniti, F., Graña, E., Hermida-Ramón, J. M., González, M. V., ... & Sánchez-Moreiras, A. M. (2023). Trans-cinnamaldehyde-related overproduction of benzoic acid and oxidative stress on Arabidopsis thaliana. *Frontiers in Plant Science*, *14*, 1157309.

Lu, Yingying, and Wieland Fricke., (2023). "Salt Stress—Regulation of Root Water Uptake in a Whole-Plant and Diurnal Context" *International Journal of Molecular Sciences* 24, no. 9: 8070. https://doi.org/10.3390/ijms24098070

Lv, W., Geng, H., Zhou, B., Chen, H., Yuan, R., Chuanxin, M. A., ... & Wang, F., (2022). The behavior, transport, and positive regulation mechanism of ZnO nanoparticles in a plant-soil-microbe environment. *Environmental Pollution*, 120368.

Ma, X., Geiser-Lee, J., Deng, Y., & Kolmakov, A. (2010). Interactions between engineered nanoparticles (ENPs) and plants: phytotoxicity, uptake and accumulation. *Science of the total environment*, *408*(16), 3053-3061.

Mahmoud, A.W.M., Abdeldaym, E.A., Abdelaziz, S.M., El-Sawy, M.B., Mottaleb, S.A., (2020a). Synergetic effects of zinc, boron, silicon, and zeolite nanoparticles on confer tolerance in potato plants subjected to salinity. Agronomy 10, 19.

Mahmoud, A.W.M., Abdeldaym, E.A., Abdelaziz, S.M., El-Sawy, M.B.I., Mottaleb, S.A., (2020b). Synergetic effects of zinc, boron, silicon, and zeolite nanoparticles on confer tolerance in potato plants subjected to salinity. Agronomy 10, 19.

Martínez-Ballesta, M.C., Zapata, L., Chalbi, N., Carvajal, M., (2016). Multiwalled carbon nanotubes enter broccoli cells enhancing growth and water uptake of plants exposed to salinity. J. Nanobiotechnol. 14, 1–14.

Maryum, Z., Luqman, T., Nadeem, S., Khan, S. M. U. D., Wang, B., Ditta, A., & Khan, M. K. R. (2022). An overview of salinity stress, mechanism of salinity tolerance and strategies for its management in cotton. *Frontiers in Plant Science*, *13*, 907937.

Mbarki S, Skalicky M, Vachova P, Hajihashemi S, Jouini L, Zivcak M, Tlustos P, Brestic M, Hejnak V, Khelil AZ., (2020). Comparing Salt Tolerance at Seedling and Germination Stages in Local Populations of *Medicago ciliaris* L. to *Medicago intertexta* L. and *Medicago scutellata* L. Plants (Basel). Apr 19;9(4):526. doi: 10.3390/plants9040526. PMID: 32325817; PMCID: PMC7238089.

Mckenzie, B.M., Mullins, C.E., Tisdall, J.M., Bengough, A.G., (2013). Root–soil friction: quantification provides evidence for measurable benefits for manipulation of root-tip traits. Plant Cell Environ. 36, 1085–1092.

Mohamed, A.K.S.H., Qayyum, M.F., Abdel-Hadi, A.M., Rehman, R.A., Ali, S., Rizwan, M., (2017) Interactive effect of salinity and silver nanoparticles on photosynthetic and biochemical parameters of wheat. Arch. Agron. Soil Sci. 63, 1736–1747.

Munns R, Gilliham M. (2015). Salinity tolerance of crops- what is the cost? New Munns, R., & Gilliham, M. (2015). Salinity tolerance of crops–what is the cost? *New phytologist*, *208*(3), 668-673.

Munns R, Tester M. Mechanisms of salinity tolerance. (2008). The Annual of Plant Biology.651-681.

Munns, R., (2005). Genes and salt tolerance: bringing them together. N. Phytol. 167, 645–663.

Nair, R., Varghese, S.H., Nair, B.G., Maekawa, T., Yoshida, Y., Kumar, D.S., (2010). Nanoparticulate material delivery to plants. Plant Sci. 179, 154–163.

Noohpisheh, Z., Amiri, H., Mohammadi, A., Farhadi, S., (2021). Effect of the foliar application of zinc oxide nanoparticles on some biochemical and physiological parameters of Trigonella foenum-graecum under salinity stress. Plant Biosyst. - Int. J. Deal. Asp. Plant Biol. 155, 267–280.08 3053-3061], Science of The Total Environment Volume 481,2014, Page 635, ISSN 0048-9697, https://doi.org/10.1016/j.scitotenv.2014.02.044.

Omoto, E., Taniguchi, M., and Mayake, H., (2012). Adaptation responses in C4 photosynthesis of maize under salinity. *Journal of plant physiology*, *169*(5), 469-477.

P´erez-de-Luque, A., (2017). Interaction of nanomaterials with plants: what do we need for real
palladium/titanium dioxide nanoparticles and their application for the reduction of methyl orange, congo red and rhodamine B in aqueous medium. Combinat. Chem. High Throughput Screen. 20, 787–795

Parihar, P., Singh, S., Singh, R., Singh, V.P., Prasad, S.M., (2015). Effect of salinity stress on plants and its tolerance strategies: a review. Environ. Sci. Pollut. Res. 22, 4056–4075.

Perfileva, A. I., Tsivileva, O. M., Nozhkina, O. A., Karepova, M. S., Graskova, I. A., Ganenko, T. V., ... & Krutovsky, K. V. (2021). Effect of natural polysaccharide matrix-based selenium nanocomposites on Phytophthora cactorum and rhizospheric microorganisms. *Nanomaterials*, *11*(9), 2274.

Pinedo-Guerrero, Z.H., Cadenas-Pliego, G., Ortega-Ortiz, H., Gonzalez-Morales, ´ S., Benavides-Mendoza, A., Vald´es-Reyna, J., Ju´ arez-Maldonado, A., (2020). Form of silica improves yield, fruit quality and antioxidant defense system of tomato plants under salt stress. Agriculture 10, 367.

Rajput, V.D., Minkina, T.M., Behal, A., Sushkova, S.N., Mandzhieva, S., Singh, R., Gorovtsov, A.,Tsitsuashvili, V.S., Purvis, W.O., Ghazaryan, K.A., Movsesyan, H.S., (2018). Effects of zinc-oxide nanoparticles on soil, plants, animals and soil organisms: a review. Environ. Nanotechnol. Monit. Manag. 9, 76–84. https://doi.org/10.1016/j. enmm.2017.12.006

Rajput, V.D., Minkina, T.M., Behal, A., Sushkova, S.N., Mandzhieva, S., Singh, R., Gorovtsov, A., Tsitsuashvili, V.S., Purvis, W.O., Ghazaryan, K.A., Movsesyan, H.S.,(2018). Effects of zinc-oxide nanoparticles on soil, plants, animals and soil organisms: a review. Environ. Nanotechnol. Monit. Manag. 9, 76–84. https://doi.org/10.1016/j. enmm.2017.12.006.

Raliya, R., Franke, C., Chavalmane, S., Nair, R., Reed, N., Biswas, P., (2016). Quantitative understanding of nanoparticle uptake in watermelon plants. *Frontiers in Plant Science*, *7*, 1288.

Rico, C.M., Peralta-Videa, J.R., Gardea-Torresdey, J.L., (2015). Chemistry, biochemistry of

Rizwan (2018) Salinity effects on nitrogen metabolism in plants – focusing on the activities of nitrogen metabolizing enzymes: A review, Journal of Plant Nutrition, 41:8, 1065-1081, DOI: 10.1080/01904167.2018.1431670

Rodríguez Coca, L.I.; García González, M.T.; Gil Unday, Z.; Jiménez Hernández, J.; Rodríguez Jáuregui, M.M.; Fernández Cancio, Y. (**2023**). Effects of Sodium Salinity on Rice (*Oryza sativa* L.) Cultivation: A Review. *Sustainability* 15, 1804. https://doi.org/10.3390/su15031804

Rossi, L., Zhang, W., Lombardini, L., Ma, X., (2016). The impact of cerium oxide nanoparticles on the salt stress responses of *Brassica napus.* L. Environ. Pollut. 219, 28–36.

Sachdev S, Ansari SA, Ansari MI, Fujita M, Hasanuzzaman M., (2021). Abiotic Stress and Reactive Oxygen Species: Generation, Signaling, and Defense Mechanisms. Antioxidants (Basel). Feb 11;10(2):277. doi: 10.3390/antiox10020277.

Schaller, J., Brackhage, C., Paasch, S., Brunner, E., Baucker, ¨ E., Dudel, E.G., (2013). Silica uptake from nanoparticles and silica condensation state in different tissues of Phragmites australis. Sci. Total Environ. 442, 6–9.

Schwab, F., Zhai, G., Kern, M., Turner, A., Schnoor, J.L., Wiesner, M.R., (2016). Barriers, pathways and processes for uptake, translocation and accumulation of nanomaterials in plants–Critical review. Nanotoxicology 10, 257–278.

Sharif, F., Westerhoff, P., Herckes,P., (2013). Sorption of trace organics and engineered nanomaterials onto wetland plant material. *Environmental Science: Processes & Impacts*, *15*(1), 267-274.

Siddiqui, M.H., Al-Whaibi, M.H., (2014). Role of nano-SiO2 in germination of tomato (*Lycopersicum esculentum* seeds Mill.). Saudi J. Biol. Sci. 21, 13–17.

Singh, P., Arif, Y., Siddiqui, H., Sami, F., Zaidi, R., Azam, A., Alam, P., Hayat, S., (2021). Nanoparticles enhance the salinity toxicity tolerance in *Linum usitatissimum* L. by modulating the antioxidative enzymes, photosynthetic efficiency, redox status and cellular damage. Ecotoxicol. Environ. Saf. 213, 112020.

Sumer, A. (2004). Evidence of sodium toxicity for the vegetative growth of maize during the first

synthesis of silver nanoparticles and their immobilization in the mycelia matrix. A novel biological approach to nanoparticle synthesis. Nano Lett 1:515–51

Tang, X., Mu, X., Shao, H., Wang, H., Brestic, M., (2015). Global plant-responding mechanisms to salt stress: physiological and molecular levels and implications in biotechnology. Crit. Rev. Biotechnol. 35, 425–437.

Tanji, K. K., & Kielen, N. C. (2002). Agricultural drainage water management in arid and semi-arid areas (Vol. 61). Rome: FAO**.**

Tripathi, D.K., Shweta, Singh, S., Singh, S., Pandey, R., Singh, V.P., Sharma, N.C., Prasad, S.M., Dubey, N.K., Chauhan, D.K., (2017a). An overview on manufactured nanoparticles in plants: Uptake, translocation, accumulation and phytotoxicity. Plant Physiol. Biochem. 110, 2–12.

Tripathi, D.K., Singh, S., Singh, V.P., Prasad, S.M., Dubey, N.K., Chauhan, D.K., (2017b). Silicon nanoparticles more effectively alleviated UV-B stress than silicon in wheat (*Triticum aestivum*) seedlings. Plant Physiol. Biochem. 110, 70–81.

Ullah A, Bano A and Khan N., (2021). Climate change and salinity effects on crops and chemical communication between plants and plant growth-promoting microorganisms under stress. Frontiers in Sustainable Food Systems, *5*, 618092**.**

Ullah, S., Adeel, M., Zain, M., Rizwan, M., Irshad, M.K., Jilani, G., Hameed, A., Khan, A., Arshad, M., Raza, A., Baluch, M.A., Rui, Y., (2020). Physiological and biochemical response of wheat (*Triticum aestivum*) to TiO_2 nanoparticles in phosphorous amended soil: A full life cycle study. J. Environ. Manag. 263, 110365.

Valipour, M.; Krasilnikof, J.; Yannopoulos, S.; Kumar, R.; Deng, J.; Roccaro, P.; Mays, L.; Grismer, M.E.; Angelakis, A.N. (2020).The Evolution of Agricultural Drainage from the Earliest Times to the Present. *Sustainability* 12, 416. https://doi.org/10.3390/su12010416

Van Zelm, E., Zhang, Y., Testerink, C. (2020). Salt tolerance mechanisms of plants. Annu. Rev. Plant Biol. 71, 403–433.

Wan, J., Wang, R., Bai, H., Wang, Y., Xu, J., (2020). Comparative physiological and metabolomics analysis reveals that single-walled carbon nanohorns and ZnO nanoparticles affect salt tolerance in Sophora alopecuroides. Environ. Sci. Nano 7, 2968–2981.

Yang, Y., Guo, Y., (2018). Elucidating the molecular mechanisms mediating plant salt-stress responses. *New Phytologist*, *217*(2), 523-539.

Yanık, F., Vardar, F., (2015). Toxic Effects of Aluminum Oxide (Al_2O_3) Nanoparticles on Root Growth and Development in *Triticum aestivum* . Water Air Soil Pollut 226, 296. https://doi.org/10.1007/s11270-015-2566-4

Yin, L., Wang, S., Li, J., Kiyoshi, K., Oka, M., (2013). Application of silicon improves salt tolerance through ameliorating osmotic and ionic stresses in the seedling of *Sorghum bicolor*. Acta Physiol. Plant. 35 (11), 3099–3107.

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

Zahedi, S.M., Abdelrahman, M., Hosseini, M.S., Hoveizeh, N.F., Tran, L.-S.P., (2019). Alleviation of the effect of salinity on growth and yield of strawberry by foliar spray of selenium-nanoparticles. Environ. Pollut. 253, 246–258.

Zahir, A.A., Chauhan, I.S., Bagavan, A., Kamaraj, C., Elango, G., Shankar, J., Arjaria, N., Roopan, M., Rahuman, A.A., Singh, N., (2014). Synthesis of nanoparticles using (*Euphorbia prostrata)* extract reveals a shift from apoptosis to G0/G1 arrest in Leishmania donovani. J. Nanomed. Nanotechnol. 5, 1–12.

Zhang, L.W., Monteiro-Riviere, N.A., (2009). Mechanisms of quantum dot nanoparticle cellular uptake. *Toxicological Sciences*, *110*(1), 138-155.

Zhang, Z., Kong, F., Vardhanabhuti, B., Mustapha, A., Lin, M., (2012). Detection of engineered silver nanoparticle contamination in pears. J. Agric. Food Chem. 60, 10762–10767.

Zhu, Z., Wei, G., Li, J., Qian, Q., Yu, J., (2004). Silicon alleviates salt stress and increases antioxidant enzymes activity in leaves of salt-stressed cucumber (*Cucumis sativus* L.). Plant Sci. 167, 527–533.

Zulfiqar, F., Ashraf, M., (2021). Nanoparticles potentially mediate salt stress tolerance in plants. Zu*Plant Physiology and Biochemistry*, *160*, 257-268.