



Nanoparticles For Stress Resilience Of Crop Plants

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Abstract: Nano-particles are newly emerging chemical tools which mitigate biotic and abiotic stresses in plants by counteracting different oxidants produced in stressed plants. Because of their small size, it is very easy for these molecules to enter into plants and regulate different mechanisms. They regulate different stresses by having different mechanisms like, closing of stomata during drought stress, regulation of ions and enhancement in expression of aquaporin genes during salinity stress, and also overcome heavy metals toxicity by reducing their accumulation in tissues. Nanoparticles also have capacity of regulating biotic stress. In this article, we discuss the roles of nanoparticles in mitigating stress factors and their probable potential in rendering stress resilience in plants.

Keywords: Nanoparticles (NPs), stress, oxidants, antioxidants, BnPT1-1 & BnPT1-2, total soluble sugar (TSS), proline content (PC), membrane electrolyte leakage (MEL), pathogenesis-related (PR) protein.

1. Introduction

Plants face various types of biotic and abiotic stresses during different stages of their life cycle (Wang et al., 2022). In the present time, abiotic stresses such as drought, flood, temperature, heavy metals, salinity, cold, heat etc. as well as biotic stresses such as bacterial, fungal, nematodes, herbivores, insects etc. are different types of stresses to which plants face (Ejaz et al., 2018; Seleim et al., 2021). Plants in stress condition produce reactive oxygen species (ROS) such as superoxide anion ($O_2^{\cdot-}$), hydrogen peroxide (H_2O_2), and hydroxyl radical ($HO\cdot$) which cause changes in gene expression and metabolic activity. Different researches had been performed which show that ROS are mostly hazardous in nature, but in recent years its advantageous impacts as signalling molecules have also been reported in plants depending on their concentration (Nabi et al., 2019). Nanoparticles (NPs) are small in size with range of 1-100 nm (nanometer) in at least one dimension. They have distinct physiochemical features such as high surface to volume ratio, high reactivity, tuneable pore size and the overall morphology (Siddiqui et al., 2015). As per latest researches, NPs have been found as a reasonable chemical species that help in countering both types of stresses i.e., biotic and abiotic. With the help of their application, plants become capable of keeping the deficiency of nutrients away. They also enhance crop production, change organic system and increase the survival of plants in stress environment. Examples of nanoparticles that support survival of plants in stress conditions such as NPs of phosphorus, calcium, magnesium, zinc, iron, copper, etc. (Tripathi et al., 2017). Nowadays, NPs have become an effective technology for increasing plant yield. Their use in agricultural field has been associated with the cutback use of other fertilizers (Barzana et al., 2022). NPs act as stimulants for plant growth factors, increased nutrients uptake, triggering plant growth promoting phytohormones, activation and expression of antioxidant enzymes, minerals absorption, increased photosynthetic pigments and lowered oxidative stresses (Mauricio et al., 2018; Manzoor et al., 2022). Overall, we can call them 'Magic bullets' as they can serve as a complete package of

nutrients, herbicide, pesticide, and gene delivery agents (Siddique et al., 2015). Hereby, in this article, we are summarizing the role of NPs in various abiotic and biotic stress regulations in plants.

2. Role of NPs in mitigating abiotic stresses

Due to continuous increase in anthropogenic activity, natural factors such as temperature, humidity, rainfall, atmospheric gases, and other edaphic factors have been affected a lot in various ways, which further appear as a serious threat for life of organisms. Since, these factors has a direct relation with plant biology, their impact on crop productivity can be seen in a negative way. These factors are also shown in co-relation with each other, such as occurrence of high temperature in a continuous manner, causes the drought to develop, which further related to development of high saline condition in the soil that ended-up with changing edaphic factors. All these factors are accounted for the abiotic stress to develop, which may appear in the form of high temperature, drought, salinity, heavy metal toxicity, cold, heat, etc. which severely affect crop productivity (figure 1).

NPs could play an effective role in mitigating the impact of these abiotic stresses on crop plants. Since these NPs are considered as 'Magic bullets', they can be used during unfavourable circumstances of crop production, as they are capable of modifying the plant physiochemical factors to perform better in different stressful conditions. One of the most impactful roles of NPs is the activation of aquaporins expression, independent of the type of NPs being used. Researchers work under abiotic stress has proved them a potential tool that could reduce stress symptoms and agricultural losses (Barzana et al., 2022). Many researches have already done that helps us to understand the role NPs in different aspect of plant physiology.

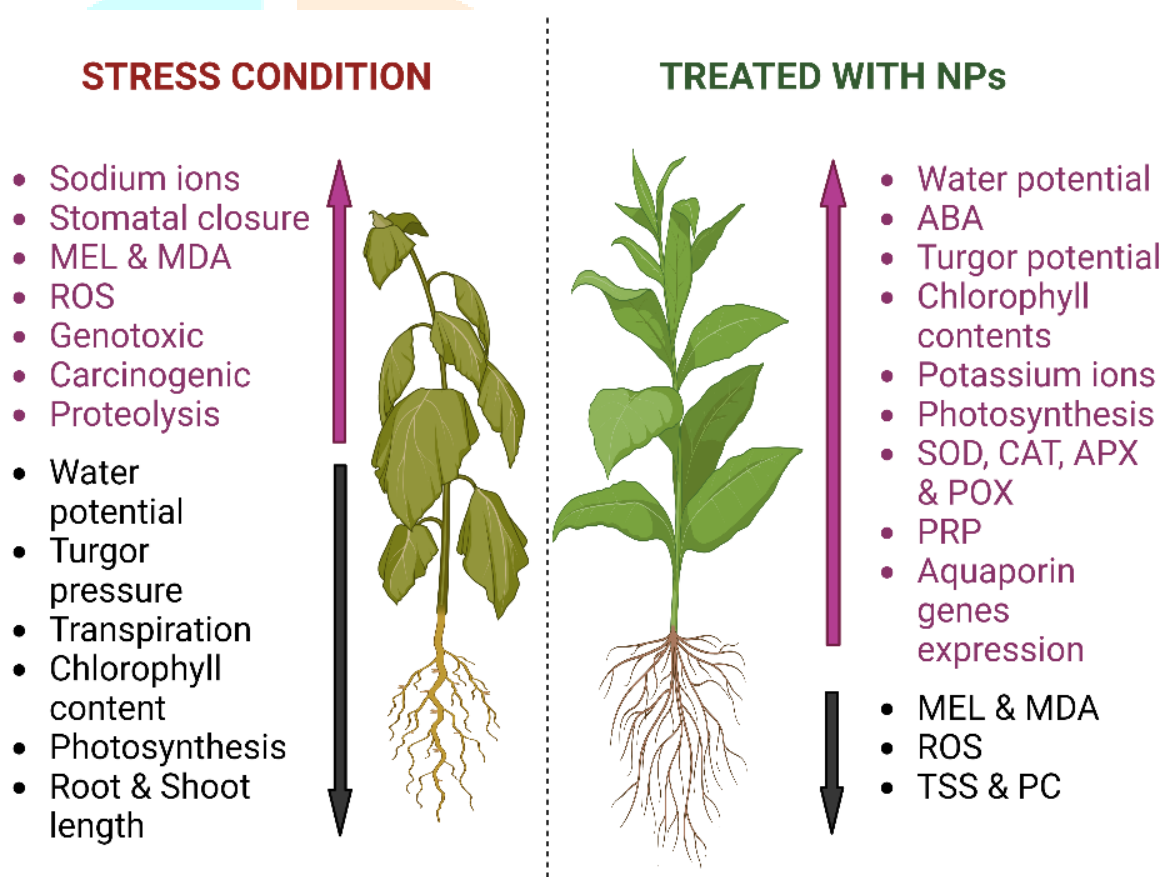


Figure 1: Regulation of various plant responses by NPs under stressed conditions. (MEL; membrane electrolyte leakage, MDA; malondialdehyde, ROS; reactive oxygen species, ABA; Abscissic acid, SOD; superoxide dismutase, CAT; catalase, APX; ascorbate peroxidase, POX; peroxidases, PRP; Pathogenesis-related (PR) proteins, TSS; total soluble sugar, PC; proline content).

To better understand the role of NPs in regulating abiotic stresses in crop production, a brief explanation has given up below:

(a) The role of NPs in alleviating drought stress

Plant contains water as a main component of their fresh weight, and is very crucial for plant's growth and development. Continuous increase in global temperature causes more evaporation, which leads to the reduction of soil and surface water availability, whose impact can be seen in the form of drought. Drought is a condition of prolonged dryness in the natural climate cycle, which can occur anywhere in the world. It is mainly characterized by having high temperature, lack of precipitation, and a complete shortage of water. Drought could have serious impact on lives of people as it could affect health, agriculture, economy, energy availability and development. Plants show complete dehydration and, sometimes they die if dehydration continued for the longer duration. Due to drought stress about 45% of the world's agricultural lands are affected as it reduces the water content of plants and, hence water potential and turgor pressure of plant cells also decreases which results into stomatal closure. Closing of stomata reduces the gaseous exchange between plant cell and surrounding environment that further leads to negative impact on process of photosynthesis (Ahmad et al., 2020). Shreelakshmi et al. (2021) studied effects of uncapped FeNPs and capped FeNPs by simultaneous application and found that when *Setaria italica* seedlings treated with citrate capped FeNPs they showed better result as compared to uncapped FeNPs in reference seedling's length and weight. Further, it was demonstrated that plants showed better absorbance and activity of capped FeNPs in comparison to uncapped FeNPs during drought stress. According to Linh et al. (2020) an experiment of nanoparticles treated soybean plants demonstrated healthier shoot development in drought stress at their somatic stage. According to the Kolbert et al. (2021) exogenous application of NO and TiO₂ NPs, causes plants to become capable of protecting the wheat seedlings against oxidative stress induced by drought. Application of SiNPs raises the contents of chlorophyll and alleviates oxidative stress by reducing amount of malondialdehyde (MDA), H₂O₂ and membrane electrolyte leakage in maize (Tripathi et al., 2016). Uptake of macro and micro nutrients by *Solanum melongena* L. after treatment with ZnO₂ shows better results and maintains the water contents of the plants during drought stress (Semida et al., 2021). Addition of ZnO-NPs to soil enhances the drought tolerance of wheat and sorghum spp. by increasing nutrient utilization and fortification of these crop plants (White et al., 2022). Taran et al. (2017) experimentally proved that in drought stress steppe ecotype variety (*Stolichna*) has more superoxide dismutase (SOD) and catalase (CAT) activity after treatment with Zn-NPs. Nano-Cu^o increases closure of stomata to reduce the water loss and increases activity of SOD and ascorbate peroxidase (APX) to reduce the ROS level (Van Nguyen et al., 2022).

(b) The role of NPs in mitigating salinity stress

The term 'salinity' refers to the dissolved salts in soil or water. It could become a major problem when its concentration rises above the tolerance level. Different salt like sodium chloride, magnesium & calcium sulphate, & bicarbonate etc. are present in soil and water (El-Badri et al., 2022). Sodic soil could be formed naturally as well as by the human activities. Natural sodic soil is mostly found near seashore, whereas the anthropogenic condition could be developed due to excessive discharge of effluents containing dissolved salts in the soil as well the use of excessive fertilizers in the crop fields. Plants which grow normally on sodic soil are called halophytes. When non- halophytes grow in sodic soil then they show abnormal physiology and also problematic life-cycle due to salt stress. These plants cannot absorb water because of the presence of high amount of salt (physiological dryness) (Hoang et al., 2016). Salinity stress causes reduction in the chlorophyll contents, osmotic potential and turgor pressure. It also causes imbalance of Na⁺/K⁺ ratio, increased ROS production, shortening of root & shoot lengths and the formation of deformed structure (Aazami et al., 2021). Aazami et al., 2020 and Faizan et al., 2021 concluded that by application of Fe & ZnO₂ NPs in tomato during salinity stress helps in production SOD, CAT and APX which counteracts ROS level (oxidative damage) in cell. Selenium NPs accommodate in salinity stressed plants and show improvement in the physiological as well as the antioxidant properties. Selenium NPs promotes water uptake & expression level of two aquaporin genes (BnPT1-1 and BnPT1-2) at the time of seed germination. It reduces the total soluble sugars and proline content (TSS and PC) about 15-20% in salinity stressed plants. By the application of selenium NPs, MDA and PC were reduced by 19-38% respectively. Treatment of TiO₂NPs significantly reduced the (MEL) and phenolics compounds and increase the relative water content (RWC) and K⁺/Na⁺ ratio in saline stressed plants. These NPs also enhances the activity of SOD, CAT and Phenylalanine ammonia-lyase (PAL) under salinity stressed (El-Badri et al., 2022). When *Trigonella foenumgraecum* grown in NaCl salinity stress condition with

ZnO₂ NPs, then it shows improvement in the activity of plant peroxidase (POD), polyphenol oxidase (PPO), lipoxygenase (LOX) and PAL in comparison to simply salinity stressed condition (Noohpishes et al., 2020).

(c) Alleviation of Heavy metal stress in Plants by NPs

Plant confronts various unfavourable conditions in their life. Besides all other stresses heavy metal toxicity is one of the main problems for the plants to have normal metabolic rates and good productivity (Zhang et al., 2020). HMs are usually defined as metals with relatively high density and high atomic weight which at certain higher concentrations, shows its toxic nature. Industrialisation & urbanization culture are affectively increasing heavy metals in soil, water & atmosphere. Such HMs are Cd, Hg, Pb, Ni, Cu, Ag, Mn, Zn, Cr, As, Cs, B, Se and Al (Gill et al., 2014). HMs involves in genotoxic, carcinogenic and mutagenic activities. HMs remarkably interferes with the beneficial microorganisms in phyllosphere and rhizosphere, retardation of growth and development, reduces the water absorption and translocation, lowering the synthesis and performance of chlorophyll, induces membrane electrolyte leakage, risk to proteolysis and peptide chain formation, increases the production of free radicals which damage the general metabolic activity (Zhou et al., 2020). Many researches demonstrate that NPs are positively involved in plants with heavy metal stress. NPs have potential to overcome HMs accumulation in plants (Ahmad et al., 2019). Hussain et al. (2019) showed by their research that wheat seed priming SiNPs promotes the photosynthesis by increasing chlorophyll *a* and *b* contents, decreased the MEL, MDA & H₂O₂ and increased the concentration of antioxidants enzymes such as SOD, CAT and POD with 38%, 63% & 56% respectively in Cd stress. El-Saadony et al. (2021) done their research and explain that *Phaseolus vulgaris* L. after treated with SiNPs showed that the plant improves the HMs stress tolerance with decreasing Na⁺, MEL, and MDA contents and ROS are scavenging by SOD, CAT, APX and peroxidase (POX) (Ahmad et al., 2019). Application of sulfure NPs to the Hg stressed *Brassica napus*, suppresses the metals absorption, accumulation, oxidative stress and enhancing the seedlings growth & minerals uptake (Yuan et al., 2021). According to Xin et al., 2020 polysuccinimide nanoparticles (PSI-NPs) when treated with Cu stressed corn (*Zea mays*) seedlings then it encourages their growth and development by increasing the SOD and CAT activity. Cd stressed tomato seedlings shows increased tolerance by having boosted up in chlorophyll content and decreases in soluble sugars after treatment with Fe₃O₄ -NPs (Rahmatizadeh et al., 2019).

(d) Alleviation of UV-B stress in plants by NPs

Plants depend on the sunlight for the process of photosynthesis. They mainly use the wavelength of visible range (400-700 nm) for performing the process of photosynthesis. UV radiation ranges between 100-400 nm have nothing to do with the process of photosynthesis. UV radiation has mainly classified into three types, these are UV-A, UV-B, UV-C ranges from 315-400 nm, 280-315 nm, 100-280 nm, respectively. Out of all these, UV-C is most harmful in nature but fortunately it is absorbed by the atmospheric layer, and does not fall to biospheric region. Whereas, UV-B is harmful, as well as it is also falls to biospheric region.

Crop plants employ the best measures to reduce the impact of UV-B radiation, but all these measures, not respond in a better way on having high stress conditions. And hence, impactful measures are essential for mitigating the effect of UV-B radiation on crop plants. Nano-particle is one such measure that work efficiently in combating the effect of these UV radiations. Certain recent researches on TiO₂, Ag, Si- NPs have shown fruitful results in combating the effect of UV-B in crop plants. These NPs shows mitigation in UV-B stress by enhancing the photosynthesis in crop plants, by enhancing the accumulation of flavanoids, and by reducing the oxidative stress as they could improve or mimic many antioxidative enzyme activities (Soni et al., 2022).

3. Role of NPs in the regulation of biotic stress

Human population is augmenting day by day, and to achieve zero hunger rate at world-level, plants are required to protect from both biotic and abiotic stresses (Tripathi et al., 2022). Biotic stresses want high attention because it simply disseminates from one location to another and reduces crop production heavily (Abdelaziz et al., 2021). NPs play a vital role by reducing the growth of biotic stresses, without damaging microbiome ecosystem. Biotic Stresses are mainly bacterial, fungal, oomycetes, nematodes, herbivores, insects etc. Inoculum of these pathogens enters into plant organic system by active or passive methods through stomata, cuticle surface, and injured portions or by vectors (Zohra et al., 2021).

The inoculum can be easily disseminated by natural (winds, water, or animal etc.) or by human activity (germplasm exchange, etc.) (Gull et al., 2019). After entering into plant, pathogens produce degradative

enzymes (cellulase, pectinase etc.), harmful secondary metabolites and arrest/controlled the host metabolic machinery (Wu et al., 2022). By the attack of pathogens plant produces ROS, which start the damaging cell organelles & interferences with metabolic reactions/cycles (Kumari et al., 2020).

Plant protection from these pathogens could become easy if nano-technology based tools involve. Micro-needle patches, nanopore sequencing, nano-barcoding, nano-biosensors, mi-RNA based nano diagnosis are certain examples of nano- technology based prorection of plants (Shivashakarappa et al., 2022).

According to Robledo et al., (2022) Cu-based nanoparticle has been proved to be a better fungicidal and bactericidal in comparison to any traditional fungicide. *In a vitro* experiment, performed by using nCu and nCuO along with seven different fungi species that are responsible for foliar and soil-borne diseases, Cu-NPs has been shown a better fungicide to almost all the seven different species. However, CuO shows no impact on the fungal species. It was demonstrated clearly that metallic Cu-NPs sounds better as fungicidal and bactericidal activity as they also show protection to stored grains from fungi. A work of Azim et al., (2022) focuses on a metal oxide NPs i.e., ZnO-NPs and shows that these metal oxides possess distinctive photochemical properties, fungicidal properties, antibacterial properties, catalytic property, as they have been used since years in medicinal industries as well.

Nano-hydroxyapatite (nano-HA) is a new phosphorus based nano-fertilizer that could be used in agricultural fields. With the proper understanding of surrounding environment, their application in the fields could be a safe and sustainable. Use of nano-HA in maize field shows increased fresh biomass, increased chlorophyll content of crop plants and the bioavailability of phosphorus in the soil, which indicate the positive impact of these nano-HA on plant growth and development (Jia et al., 2022).

From Satti et al. (2022) it was proved that TiO₂ NPs trigger biochemical & proteome modifications to enhance the activity of SOD & CAT in *Triticum aestivum* L. under stress of *P. striiformis*. The mortality of *Meloidogony incognita* increased when eggplant treated with SiNPs which interference with hatching of eggs (El-Ashry et al., 2021). Chitosan-NPs cause inhibition of growth of *Fusarium andiyazi* on tomato plants as compared to chitson. It alters the gene expression of pathogenesis-related (PR) proteins and antimicrobial peptides (AMPs), glucanase & chitinase, and SOD & CAT activity many folds (Chun et al., 2019 and Kumari et al., 2020). Another study cleared that SeNPs suppress the growth, spore viability, sporulation & proliferation of *Sclerospora graminicola* in millets & maize plants (Zohra et al., 2021).

Conclusion and future perspectives

Plants face many types of biotic and abiotic stresses in their life cycle. These stresses conclusively reduce the crop yields & imbalance the ecosystem homeostasis. Nanotechnology is a newly emerging branch which deals with NPs. This review summarised about the researches, which proved that the application of different types of NPs through foliar spray, seed priming and root surfaces, enhances the stress tolerating rates in crops. NPs reduce water loss in drought stress, suppress HMs accumulation, balance of Na⁺/K⁺ ratio during salinity stress and induce expression of defensive genes during biotic stress. NPs also stimulate production and efficiency of antioxidant enzymes such as SOD, CAT, APX, etc. Conclusively, it is found that, NPs would be a boon for human lives, if further researches supposed to be conducted in this field. As their size, shape, and less toxic nature are favourable for crops which are facing abiotic and biotic stresses. It would be great to work with NPs in near future to have enough crop production for feeding increasing global population.

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