Review Article

THE SIGNIFICANCE OF NANOPARTICLES IN PLANT TOLERANCE TO ABIOTIC STRESS IN HORTICULTURE CROPS: A REVIEW

ABSTRACT:

Horticultural crops are not only essential for human nutrition but also add visual beauty to our surroundings. They provide a rich source of vital nutrients and aesthetic appeal. However, these crops frequently face many challenges from abiotic stressors like drought, nutrient deficiencies, heat, and heavy metal stress, which significantly hinder their growth and productivity. To address these challenges, various strategies have been employed, including genetic modifications to boost stress resilience.Applications spanning multiple sectors, including agriculture. In the realm of agriculture, nanotechnology offers innovative solutions, encompassing soil and water remediation, nanoscale plant protection, and the delivery of nano-nutrition to crops. These applications are crucial for ensuring sustainable progress in horticultural crops contending with a variety of environmental challenges. However, despite the increasing utilization of nanoparticles in various applications, there is still much to be understood about their precise interactions with plants. This presents a sustainable and effective path forward for agriculture.

***Keywords**:* Horticultural crops,aesthetic appeal,Nano-nutrition

INTRODUCTION:

Abiotic stresses, such as heavy metals (HMs), drought, salinity and water logging, are the foremost limiting factors that adversely affect the plant growth and crop productivity worldwide. The plants respond to such stresses by activating a series of intricate mechanisms that subsequently alter the morpho-physiological and biochemical processes. Over the past few decades, abiotic stresses in plants have been managed through marker-assisted breeding, conventional breeding, and genetic engineering approaches. With technological advancement, efficient strategies are required to cope with the harmful effects of abiotic environmental constraints to develop sustainable agriculture systems of crop production (Manzoor et al., 2022).NPs can increase crop yields in sustainable agriculture by strengthening plant resistance to abiotic stress, addressing present and future production challenges. Various efficient and eco-friendly techniques, including exogenously applied chemicals, have been deployed to reduce the detrimental impacts of abiotic stress on plants and increase their ability to adapt to adverse conditions (Hayat et al., 2023).

1. ABIOTIC STRESSES:

Plants encounter a wide range of challenges throughout their life cycles, broadly categorized as biotic stresses caused by living organisms like bacteria, viruses, and nematodes, and abiotic stresses resulting from environmental factors. Abiotic stress, particularly, is a major concern that has a significant impact on the productivity and quality of horticultural crops. These stressors, which encompass soil salinity, flooding, and extreme temperatures (both high and low), disrupt various stages of crop growth and development (AK, 2016). They divert their energy away from growth and reproduction to adapt to the stress, ultimately leading to reduced crop yields (Mushtaq et al., 2020; Rai et al., 2011). In fact, unfavorable conditions can slash crop yields by as much as 70% (Robert & Hughes, 2007). These ROS can inflict damage on lipids, proteins, and DNA, leading to cellular harm and even plant death (Nouman et al., 2014). To counteract the excessive production of ROS and the associated oxidative stress, plants have developed an effective antioxidative defense system. This system comprises both enzymatic and non-enzymatic components. Besides generating which serve as osmolytes to maintain cellular stability (Abbasi et al., 2007; Hussain et al., 2018; Kao, 2017). The combined impact of these stresses, including interactions between biotic and abiotic factors. This is a pressing concern for horticultural crops, which not only have higher market value but also require more resources and provide essential nutrients in our diets. A significant portion of the essential vitamins and minerals we need comes from vegetables and fruits, and a deficiency in these can lead to nutritional diseases and, in severe cases, even death (Rouphael& Colla, 2018). Abiotic stresses don't just decrease crop yields; they also affect the quality of the produce, leading to changes in appearance and nutritional value (Khan et al., 2017). Often involving changes in gene expression (Zhuang et al., 2014). However, these adaptive strategies come at a cost, diverting energy and nutrients away from normal growth processes.These practices include selecting appropriate cultivars, timing planting, adjusting planting density, and optimizing water and fertilizer use (Wang et al., 2003). Additionally, strategies such as protected cultivation, soilless farming, and grafting are used to protect plants from adverse conditions. Grafting, in particular, is a crucial method for maintaining the resistance of vegetable crops, especially high-yield varieties like cucurbits and solanaceous plants. It enhances their ability to withstand challenges like saline soil, nutrient or water deficiencies, and the harmful effects of heavy metals or pollutants (AlHarbi et al., 2018; Schwarz et al., 2010; Kumar et al., 2017). Genetic improvement stands out as another pathway to bolster crop tolerance to abiotic stresses by transferring genes associated with stress responses. Scientists have placed particular emphasis on regulatory genes, such as transcription factors, which have the ability to govern multiple stress-related genes simultaneously. Nevertheless, genetic improvement encounters challenge due to the intricate nature of plant responses, genetic diversity, and the protracted breeding process (Zhuang et al., 2014; Wang et al., 2016; Singhal et al., 2016). In vitro selection emerges as a valuable tool for developing stress-tolerant plant lines, especially with regard to salt and drought tolerance. This method involves inducing genetic variation in plant cells, exposing them to stressors, and subsequently regenerating the entire plant from the surviving cells. While this approach is less time-consuming and costly than traditional genetic engineering, it does have its limitations concerning trait stability and potential epigenetic changes (Perez-Clemente & Gómez-Cadenas, 2011; Rai et al., 2011). In summary, abiotic stresses represent a substantial threat to agriculture, especially for high-value horticultural crops. Dealing with these challenges requires a multifaceted approach, which includes a combination of agronomic practices, genetic enhancement, in vitro selection, and the creative utilization of biostimulants and bioactive compounds to guarantee both crop yield and quality (Oosten et al., 2017).

2. INTRODUCTION TO NANOPARTICLES:

Nanotechnology is a field that focuses on the manipulation of matter, whether it's living or non-living, at incredibly small scales, involving individual atoms and molecules (Diab et al., 2020b; Kumar et al., 2022). Its applications have gained significant recognition, to the extent (Gallocchio et al., 2015). Within the field of nanotechnology, structures and devices measuring less than 100 nanometers are modified in at least one dimension to produce nanomaterials with distinctive characteristics. These nanomaterials are tailored for use across various industries (Pérez-Labrada et al., 2020). Nanotechnology encompasses the processing, synthesis, manipulation, and utilization of nanomaterials, typically measuring 100 nanometers or less in size. These materials exhibit remarkable optical characteristics, size-dependent properties, and a significant surface area, making them highly valuable for applications in areas like nutrition and plant protection (Abd Elkodous et al., 2021; Nair et al., 2010).In agriculture, the incorporation of nanoparticles into crops has demonstrated its effectiveness. This practice bolsters plant growth, development, quality, and yield, while also enhancing the plants' ability to withstand unfavorable environmental conditions. Furthermore, it's worth noting that, in certain conditions, plants themselves can naturally produce nanomaterials. The field of nanotechnology holds the promise of offering farmers and consumers environmentally friendly and health-conscious options, ultimately driving economic growth without adverse impacts on the environment and human well-being (Alves et al., 2018; Hong &Dobrovolskaia, 2019; Saxena et al., 2016).

3. TRANSLOCATION AND UPTAKE OF NANOPARTICLES IN PLANTS:

Various techniques are commonly employed to introduce nanoparticles (NPs) into plants, including methods like seed coating, soil saturation, and foliar spray applications. Given the pivotal role of plants in the soil ecosystem, they serve as a potential pathway for NPs to be taken up, transported, and integrated into the food chain (Wang et al., 2013; Dang et al., 2019). It's crucial to comprehend how plants absorb NPs. A previous study conducted by Zhu, Han, Xiao, & Jin in 2008 demonstrated that FeO NPs could be absorbed, transported, and accumulated in pumpkin plants without causing harm. A noteworthy finding was that a substantial portion of the accumulated iron content, specifically 67.4%, was detected within the root tissues, with 45.4% distributed both internally and externally across the root surface. In contrast, only a minute fraction, just 0.6%, was identified within the leaf tissue. Moreover, copper oxide nanoparticles were found to exhibit mobility within maize plants through the xylem and phloem conduits, as reported by Wang in 2012. Additionally, research conducted by Lin et al. in 2009 revealed the capability of Fullerene (C70) nanoparticles to traverse the vascular system of rice plants, potentially being passed on to subsequent generations.

The entry of nanoparticles (NPs) into plant roots and leaves, as well as their subsequent movement within the plant, occurs through two distinct pathways: the apoplastic and symplastic routes (Huang et al., 2022). In a separate study carried out by Cui et al. in 2020, SiO2 NPs were observed within rice cells under conditions of arsenic contamination. Advanced microscopy techniques revealed that these NPs disperse within the interstitial spaces between cell walls and plasma membranes after their initial passage through the cell walls. Osmotic pressure and capillary forces may influence their further movement (Lin et al., 2009). While various mechanisms, such as ion channels, carrier proteins, and aquaporins, offer potential pathways for NPs to enter plant cells, the precise mechanisms are not yet fully understood (Rico et al., 2011).

4. IMPACTS OF NANOPARTICLES ON PLANTS EXPERIENCING HEAVY METAL STRESS:

Including atmospheric deposition, industrialization, waste disposal, and industrial processes (Ali et al., 2019; Mohammad et al., 2018; Irshad et al., 2021a). The persistent presence of heavy metals (HMs) in polluted soils gives rise to significant environmental concerns. This situation has far-reaching consequences, affecting not only plants but also posing threats to humans and animals through exposure to harmful compounds (Noman et al., 2020a; Khan et al., 2020). The accumulation of these substances in plants can result in oxidative damage, disrupt photosynthesis, disturb ion regulation, and hinder nutrient absorption, ultimately impeding plant growth (Rizwan et al., 2019a; Li et al., 2020).

Researchers have been actively investigating the potential of nanoparticles (NPs) in addressing the challenges posed by heavy metal (HM)-contaminated soil, with recent studies demonstrating promising outcomes (Tripathi et al., 2015; Hussain et al., 2018a). For example, FeO NPs have shown their ability to mitigate the harmful effects of cadmium (Cd) toxicity in wheat plants, leading to enhanced plant growth, increased chlorophyll levels, and improved antioxidant enzyme activity. NPs have proven effective in curbing the accumulation of toxic ions within plant cells, thereby shielding them from the stress resulting from excessive ions. Furthermore, the beneficial effects of silicon (Si) NPs in counteracting phytotoxicity induced by HMs have been observed (Adrees et al., 2020). These findings underscore the significance of further research in the development of innovative nano-remediation strategies, effectively combatting the detrimental effects of HMs on plant growth and development.

5. THE IMPACT OF NANOPARTICLES ON PLANTS EXPERIENCING DROUGHT STRESS:

Drought stands as a prominent environmental challenge that has garnered considerable attention from both environmental and agricultural experts. It presents a substantial threat to global agriculture, significantly impeding plant growth and diminishing crop yields. Drought stress impacts various facets of plant development, ultimately jeopardizing the economic viability of the agricultural sector (Kumar and Verma, 2018). Drought stress is marked by the scarcity of moisture, leading to reduced cell size, cell membrane damage, the initiation of oxidative stress, and premature leaf aging. All these factors contribute to a decline in crop yield (Timari et al., 2016).

For example, hawthorn plants exhibited increased resilience to drought when treated with Si NPs (Ashkavand et al., 2018). Similarly, Si NPs have played a significant role in aiding the recovery of barley plants following drought stress, exerting their influence on a range of morphophysiological traits (Ghorbanpour et al., 2020). Chitosan NPs have also proven advantageous by enhancing relative water content, the rate of photosynthesis, and the activities of catalase (CAT) and superoxide dismutase (SOD) (Behboudi et al., 2019).

6. THE INFLUENCE OF NANOPARTICLES ON PLANTS FACING SALT STRESS:

Soil salinity represents a prominent global issue that exerts a substantial impact on crop yields. It introduces ionic toxicity and disrupts the ionic balance within plants (Parihar et al., 2015). Consequently, sodium (Na+) and chloride (Cl-) ions accumulate within plant cells, causing toxicity that severely impairs plant health (Shabala and Cuin, 2008; Khan et al., 2021). Salt stress leads to a significant depletion of potassium ions (K+) in leaf mesophyll cells, while the concentration of sodium ions (Na+) within the cell's cytosols rises. This disrupts the plant's ability to assimilate carbon dioxide (CO2) in saline environments. The reduction in CO2 assimilation directly impacts crop growth rates and overall production (Parida and Das, 2005).Manganese NPs, employed for seed priming, have proven effective in managing salinity stress by influencing molecular responses in pepper crops (Sabaghnia and Janmohammadi, 2015; Ye et al., 2020).

7. CONCLUSION:

The review highlights the vital role that horticultural crops play in meeting our dietary and aesthetic preferences. However, these crops encounter substantial challenges from various abiotic stressors, necessitating innovative approaches to enhance their resilience and productivity. The expanding field of nanotechnology presents promising solutions in agriculture, encompassing areas like soil and water remediation, nanoscale plant protection, and nutrition. While guidelines have been established to ensure the responsible use of nanoparticles, there exists a knowledge gap regarding their interactions with plants. Looking ahead, it's evident that nanomaterials hold significant potential for mitigating abiotic stress in horticultural crops. Continuous research into the specific roles and impacts of nanoparticles in plant interactions is imperative. This research has the potential to enrich our understanding of how nanotechnology can be effectively harnessed to bolster crop resilience against environmental challenges, thereby making a substantial contribution to the sustainability of agriculture.

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