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Effect of nanoparticles on Wheat to combat drought and Salinity Stress: Review

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ABSTRACT

A significant obstacle to maintaining global crop productivity and food security is drought stress (DS). With the current rapid climate change and intensifying drought, nanoparticles (NPs) have become a fantastic instrument to increase crop productivity. DS interferes with cellular membranes, nutrient and water uptake, the photosynthetic system, and antioxidant activities, which have a negative impact on plant development and physiological and metabolic processes. When NPs are applied, the membranes are protected, the water relationship is maintained, and the nutrient and water intake is improved, which significantly increases plant development under DS. NPs shield the photosynthetic machinery and enhance photosynthetic efficiency, osmolyte, hormone, and phenolic accumulation, antioxidant activities, and gene expression, giving plants more tolerance to DS. Due to the ability to be applied by both seed soaking and seedling foliar application at various growth stages of the plant, chemical treatment is one of the encouraging methods to improve the drought tolerance of wheat. In this study, the effects of different chemical treatments on wheat physiology and drought production were assessed. Continuous climate change has a negative impact on crop productivity, especially wheat farming. It has been determined that chemical treatment can stabilise the effects of drought on wheat by enhancing the activity of hormones and enzymes that are responsive to drought, as well as by increasing the production of stress proteins and antioxidant enzymes to prevent the generation of reactive oxygen species. In order to maintain wheat's typical physiology in response to changing climates, drought resistance has been improved by the application of various chemicals with pre- and post-emergence treatment. For a successful treatment strategy, it is also important to explore potential priming chemicals and assess molecules with various development phases, chemical combinations, and treatment modalities.

Key words: Nano- Particles, Drought Stress, Photosynthesis, Salinity

Introduction

It is anticipated that the world's population would increase to 9.8 billion people by the middle of this century. In addition, a severe food scarcity could result from drought, which will only get worse as a result of climate change (Kah et al., 2019). According to (Lambers et al. 2008), drought is the most severe abiotic stress that restricts plant growth and results in greater losses in crop output. The plant's morphological, physiological, biochemical, and molecular characteristics are adversely affected, which lowers crop yield and quality (Farooq et al., 2009). Therefore, it is crucial to use practical, safe methods to build and enhance plants' capacity to withstand drought.

The use of nanomaterials (NMs) has been shown to be one of many successful ways for dealing with drought-induced plant death (Khan et al., 2017). Numerous NMs have reportedly increased crop output while engaging in sustainable agriculture to satisfy the rising global need for food, feed, and fuel (Kah et al., 2019). Research findings from the previous two decades have demonstrated the significance of NMs in a variety of life aspects, including agriculture and the food sector.

Due to their high surface-to-volume ratio, NMs with particle sizes between 1 and 100 nm are of particular interest in this respect and may play a significant role in the advancement of sustainable agriculture (Chen & Yada, 2011). Numerous application techniques can be used to apply them to plants (Mohamed & Kumar, 2016). Recent research reveals that some metallic NPs, including silver and titanium dioxide, can have considerable harmful effects in animal cell culture and animal models

(Cox et al., 2017). According on type, size, and concentration of nanoparticles (NPs), application method, and plant species, NPs can have either beneficial or negative impacts on plant growth, development, and productivity (Du et al., 2017; Tripathi et al., 2017). For instance, Ag-NPs at 50-2500 mg/L hindered root elongation in maize, whereas the same concentrations had a favourable impact on the growth of watermelon and zucchini seedlings (Almutairi & Alharbi, 2015). According to (Thiruvengadam et al., 2015), turnip (Brassica rapa L.) treated with 5 and 10 mg/L of Ag-NPs demonstrated an increase in ROS production and DNA damages, which were linked to up-regulation of genes involved in the biosynthesis of glucosinolates and phenolic compounds. Additionally, (Tiwari et al.,2017) reported that tomato plants treated with TiO_2-NPs have a twofold reaction on growth and photosynthetic performance depending on their concentration, with these attributes being positively impacted by low concentrations (0.5-2 g/L) and negatively impacted by high concentrations (4 g/L). There has not yet been a thorough analysis of how NMs can help crop plants recover from the oxidative and osmotic damages brought on by drought. This review will clarify this issue as a result.

This review first gives a brief overview of the negative effects of drought stress on physiological and biochemical plant processes before highlighting recent research on the potential use of NMs in reducing the negative effects of drought on various field and horticultural crops. Considering available literature, the NMs that are used to mitigate the drought-induced damage in either field or horticultural crops include carbon-based NMs (carbon nanotubes and fullerene), metallic/metallic oxide (CeO_2, Fe and Fe-oxides, K, Ag, TiO_2 and ZnO), metalloids (Si and SiO_2), non-metallic (P) NPs, in addition to nano-size polymers and composites (nano-chitosan, hydroxyapatite, nano-clay, analcite and micronutrient nano-composites.

By the end of 2050, the world's population is predicted to reach 9.6 billion, necessitating a 70–100% increase in food yield to accommodate the growing population (Rodrigues et al., 2017; Alabdallah et al., 2021). Significant yield losses are nevertheless caused by factors such as escalating global warming and climate change, a decline in arable land, excessive fertiliser and pesticide usage, and an increase in the severity of abiotic stresses (Hasan et al., 2021a; Hasan et al., 2021b). As a result, there is a grave threat to global food security from the decline in crop output. To secure global food security, it is essential to take the necessary steps to reduce the harmful effects of abiotic stressors on crops (Genc et al., 2019; Hasan et al., 2021a). Globally, crop growth and production are significantly impacted by drought stress (DS), a severe abiotic stress (Seleiman et al., 2021).

Wheat is sometimes referred to as a salt excluder, which implies it reduces salinity stress by removing Na^+ as much as possible from the shoot. (Genc, Y. et al., 2016) Compared to durum wheat genotypes, bread wheat has a substantially greater ability to reject Na^+. Furthermore, salt tolerance is a polygenic trait, and genetic, environmental, and physiological factors can all affect how it manifests. In fact, it is possible to choose a genotype within the same species that is salt-tolerant, indicating that this potential may be enhanced by traditional breeding techniques. Additionally, there hasn't been much research done on the physiological variations between spring and winter genotypes under salt stress. (Genc, Y.et al.,2007) In the current study, we tested the various responses and adaptations to salt stress using five distinct spring wheat and five different durum wheat genotypes. Some of species, like S-24, were chosen as the reference one because of their well-known salt tolerance. (W.M. Bhutta and M. Hanif, 2010) The impact of salinity on certain important physiological and morphological parameters was assessed for the genotypes employed. (M. Ashraf, 2010) In order to improve plant tolerance to salt stress and boost agricultural production on salinized soils irrigated with brackish water, the identified genotypes may be significant resources for genetic improvement programmes (Saddiq, M.S., 2010).

Drought stress

Drought severity and frequency will rise under continuing global climate change scenarios (Walter et al., 2011). According to (Trenberth et al. 2014), drought-induced damage to plants is often caused by reduced water uptake by roots and higher water loss from plant leaves and soil evaporation. More crop output losses are caused by drought stress (inadequate water supply) than by other stressors. Because of this, it is regarded as the main factor restricting crop plants' growth, development, and productivity (Lambers et al., 2008). Accordingly, the greatest danger to food security is drought stress (Farooq et al., 2009).

Drought stress: adverse effects on crop plants

Inadequate water availability for plants has a number of negative consequences on plant growth and productivity, ranging from cellular to whole-plant levels. Numerous physiological and biochemical processes are impacted by drought stress. According to (Reddy et al.,2004), it has a negative impact on the water status of plants as evidenced by a decline in leaf water content, relative water content (RWC), water potential, stomatal conductance, and transpiration rate with rising canopy and leaf temperature that linearly correlates with increasing drought severity. Due to a lack of water, decreased transpiration, and poor enzyme activity involved in nutrient assimilation, drought restricts the availability, uptake, translocation, and metabolism of mineral nutrients (Farooq et al., 2009). According to (Osakabe et al.,2014), under drought stress, abscisic acid (ABA) builds up in plants and activates a signalling cascade that impacts anion and K^+ efflux from guard cells, leading to loss of turgor and ultimately stomatal closure. Due to reduced light-harvesting pigments and obstruction of the photosynthetic machinery, reduced photosynthesis in drought-stressed plants is primarily caused by stomatal closure, which limits CO^2 influx, increased leaf temperature, which damages the thylakoid membrane, and disturbed activity of various enzymes, including RuBisCO and other Calvin cycle and ATP synthesis-related enzymes.

In drought-stressed plants, decreased photosynthesis and respiration and increased photo-respiration cause reactive oxygen species (ROS) to be produced and accumulated in the chloroplasts, mitochondria, and peroxisomes, respectively. This causes oxidative stress damage to the cell compartments, including lipid peroxidation, protein denaturation, and nucleic acid obstruction (Das & Roychoudhury, 2014). Last but not least, drought-induced osmotic and oxidative stressors, as well as decreased cell division and elongation, have a negative impact on crop plants' growth, development, and productivity.

Inducing drought stress tolerance in crop plants

Plants have evolved a number of strategies for drought resistance (drought avoidance and tolerance). Osmotic and oxidative stressors brought on by drought are primarily responsible for the detrimental effects of drought stress on plants. Plants produce and store neutral and nontoxic compounds (also known as suitable solutes or osmolytes) in the cytoplasm as well as specific inorganic ions in vacuoles to help them deal with osmotic stress (Abid et al., 2018). According to (Hoekstra et al., 2001), the build-up of suitable solutes stabilises the structure and functions of macromolecules while also maintaining the hydrated state of cells and the structural integrity of their membranes. Proline, glycine betaine, and soluble sugars are only a few of the several substances that make up these suitable solutes. Proline is essential for osmotic adjustment as well as cell redox regulation, free radical scavenging, cytosolic pH buffering, and reducing photo-damage to thylakoid membranes (Lawlor & Cornic, 2002).

According to Schieber and Chandel (2014), drought causes oxidative stress by producing ROS such as superoxide radicals ($O_2^{\bullet}$), hydrogen peroxides (H_2O_2), and hydroxyl radicals ($OH^{\bullet}$), which damage lipids, proteins, and DNA. Antioxidants, both enzymatic and non-enzymatic, participate in cellular defence mechanisms for ROS detoxification. Through the dismutation process of O_2 and H_2O_2, superoxide dismutase (SOD) transforms $O_2^{\bullet}$ stress (Schieber & Chandel, 2014). Catalase (CAT) and particular peroxidases (POX) can thereby convert H_2O_2 into H_2O and O_2 (Roychoudhury et al., 2012). Ascorbate (AsA), flavonoids, glutathione (GSH), and carotenoids are the principal non-enzymatic antioxidants (Foyer & Noctor, 2012). Overall, the coordinated antioxidant activity linked to elevated SOD and CAT activity, along with a modification of the AsA-GSH cycle, lessens the oxidative damage caused by drought stress in crops (Zandalinas et al., 2017). Three well-known plant breeding techniques conventionalbreeding,markerassistedbreeding, and genetic engineering have been used to increase agricultural drought tolerance (Ashraf, 2010). Plant hormones are active participants in the signal chemicals that trigger the stress reactions in plants. For crop breeding and management, including exogenous application of plant growth regulators, many studies have been conducted in the past ten years to understand how plant hormones mediate abiotic stress tolerance (De Ollas et al., 2015; Muoz-Espinoza et al., 2015; De Ollas et al., 2018). In addition to phytohormones, several substances have been used to increase drought tolerance in crop plants, including seaweed extracts, biochar, osmoprotectants, plant growth promoting rhizobacteria (PGPR), and nanoparticles (Ali et al., 2017). Use of NMs has proven to be one of the most effective techniques for preventing drought-related damage to plants (Khan et al., 2017).

Nanomaterials and agricultural crops

General overview

As stated by the European Commission, "*Nanomaterial means a natural, incidental or manufactured material containing particles, in an unbound state, as an aggregate or as an agglomerate, and where, for 50% or more of the particles in the number size distribution, one or more external dimensions is in the size range 1-100 nm*" (Rai et al., 2018). The properties of manufactured or engineered NMs, such as their high surface-to-volume ratio, high stability and adsorption capacity, extraordinary electrical and optical properties, and diverse and simple functionalities, among others, have led to their widespread use in a variety of spheres of our lives, including the agricultural sector (Ghormade et al., 2011; Rai et al., 2018). In the most recent technological revolution, NMs have shown to have a tremendous promise for offering unique and improved solutions to the many problems affecting agriculture around the world (Chen & Yada, 2011; Huang et al., 2015). Overall, the use of nanotechnology in agriculture is still in its infancy, but with a thorough understanding of the interactions between manufactured NMs and plants, it will advance quickly in the near future (Pulizzi, 2019). The manipulation of seeds and other contemporary technologies that necessitate the use of in vitro plant tissue culture are only a few examples of how NMs are used to plants (Mohamed & Kumar 2016). Plants absorb NMs by an active-transport process through the xylem when plant roots draw NMs from the soil (Tripathi et al., 2017). NMs can undergo structural changes inside of plants and either stay as NMs or create ions-form complexes with other molecules or nutrients (Dimkpa & Bindraban, 2018). According to (Montes et al.,2017), NMs can activate the plant defence system since they appear to alter the activity of the enzymes involved in oxidative stress in plant tissues. At the cellular level, NMs can cause the production of ROS, which releases secondary signalling messengers and controls secondary metabolism transcriptionally (Marslin et al., 2017). On the other hand, NMs can have either positive or negative impacts on plant development, growth, and production. The types of NMs and their physicochemical characteristics, including size and concentration, manner of application, soil conditions, and plant species, all affect the opposite effect (Du et al., 2017). For instance, ZnO-NPs enhanced bean growth while inhibiting wheat growth (Dimkpa & Bindraban, 2018). According to (Agathokleous et al.,2019), the majority of NMs have an effect on plants that is often characterised by a biphasic dose response called "hormesis" with low dose stimulation and high dose inhibition.

Role of nanoparticles against drought stress

Induce biochemical, morphological, molecular, and physiological changes in the crops once NPs penetrate the plant body through the roots and leaves (Khan et al., 2019). Depending on the concentration, size, and application technique of the NPs, these modifications have a considerable impact on plant growth. Additionally, the size, composition, and reactivity of NPs can have a significant effect on plants. According to the available data, NPs significantly enhance plant growth and development while reducing the negative impacts of DS (Ahmed et al., 2021).

Nanoparticles improve membrane stability and plant–water relationships to confer drought stress

Plant growth is significantly decreased by DS due to its detrimental effects on cellular membranes and the interactions between plants and water (Hassan et al., 2020). According to (Das and Roychoudhury 2014), DS-induced ROS generation disrupts cell membranes, results in lipid peroxidation, and increases MDA buildup. According to several studies (Mohamed et al., 2017; Sun et al., 2020; El-Zohri et al., 2021), the application of NPs (ZnO) greatly reduced the buildup of MDA and H_2O_2 and preserved membrane integrity. This lowered the loss of vital osmolytes. Water shortage significantly decreased chlorophyll concentrations, PS-II efficiency, and membrane stability (Semida et al., 2021). However, exogenous NPs (ZnO) administration preserved membrane stability and cell water status under DS, enhancing PS-II and metabolic process effectiveness (Yan et al., 2016; Zhao et al., 2017; Semida et al., 2021).

By maintaining membrane and cell stability and improving the anatomical properties of plants, the application of NPs increased water uptake (Yan et al., 2016; Hafez et al., 2020). In order to improve water uptake and maintain better water status under DS, the application of NPs (ZnO) induces changes in root morphology and increases the formation of lateral roots and root biomass (Ahmad et al., 2017; Behboudi et al., 2018; Alsaeedi et al., 2019; Dimkpa et al., 2019; Zahedi et al., 2020a). SiO_2 NPs were also found to considerably increase photosynthesis, transpiration, relative water content (RWC), and water intake in another study, which was published (Sutulien et al.,2021). Additionally, NPs boost gene expression, stress and hormone signalling, and root hydraulic conductivity, which improves water uptake and provides better plant-water status under DS (Das and Das, 2019). Additionally, NPs increase the expression of aquaporins, maintain hydraulic pressure, lengthen roots, and improve root penetration, which improves plant water uptake (Faraji and Sepehri, 2020).

In summary, NP-based management of membrane stability and the connection between plants and water can lessen the negative impacts of DS. However, more research is required to fully understand how NPs affect membrane compositions, osmolyte accumulation, and the movement of various solutes across the membrane. In drought-stressed environments, nanoparticles increase nutrient absorption. According to (Hassan et al. ,2020), DS causes nutrient shortage and dramatically affects nutritional homeostasis, both of which are detrimental to plant growth. According to (Kopittke et al.,2019), NPs have a considerable impact on nutrient homeostasis and considerably enhance nutrient uptake, translocation, and allocation to various plant sections. Due to decreased nutrient absorption, transpiration flow, and membrane stability caused by a water shortage, plants' concentrations of nitrogen (N), potassium (K), manganese (Mn), and zinc (Zn) decreased (Semida et al., 2021). The application of NPs (ZnO) through soil and applied by foliar spray significantly enhanced the uptake of N, phosphorous (P), potassium (K), and zinc (Zn), and attenuated the negative effects of DS (Mangena, 2018; Dimkpa et al., 2019; Fatollahpour Grangah et al., 2020; Mustafa et al., 2021; Semida et al.,2021)

Nanoparticles protect photosynthetic apparatus and improve photosynthesis under drought stress

Lack of water lowers electron flow rate, PS-II efficiency, and chlorophyll synthesis, all of which have an adverse impact on the overall photosynthetic efficiency of plants (Semida et al., 2021). The efficiency of photosynthetic activity under DS was increased by applying NPs (ZnO), which also boosted the synthesis of chlorophyll, chlorophyll fluorescence, and the activity of chlorophyll synthesis enzymes (chlorophyllase) (El-Mageed et al., 2021; Semida et al., 2021). In addition to stabilising the ultra-structure of mitochondria and chloroplasts, the exogenous application of NPs aids plants in maintaining their photosynthetic efficiency under DS (Rahmatpour et al., 2018). In order to ensure that electrons and protons enter the electron transport chain and result in a significant increase in plant photosynthetic efficiency, NPs (TiO_2) are used to increase light-induced water hydrolysis into oxygen, electrons, and protons (Silva et al., 2022). Additionally, NPs (TiO_2) enhance the expression of LHCII-b genes in the thylakoid membrane, which encourages light absorption in cell chloroplasts (Ze et al., 2011). Additionally, RuBisCO activity, nitrogen assimilation, and nitrate reductase activity are all enhanced by NPs (TiO_2), which ensures better photosynthetic performance under DS and boosts photosynthetic efficiency in plants under DS (Yuan et al., 2013; Ali et al., 2021a).

According to Suzuki et al. (2013), stomata regulate the exchange of CO_2 and water vapours between the atmosphere and the internal surface of leaves. However, administration of NPs down-regulated the H_2O_2-mediated stomata closing and maintained better CO_2 uptake (Djanaguiraman et al., 2018). DS also activates the ABA signalling pathway that produces stomata closure (Sierla et al., 2016; Faraji and Sepehri, 2020). By enhancing the activities of enzymes in CO_2 fixation and chlorophyll synthesis, the application of NPs (TiO_2) enhances photosynthetic pigments and gas exchange properties (Mohammadi et al., 2016; Faraji and Sepehri, 2020). According to (Shafea et al., 2017), NPs also increase chloroplast light absorption, electron transport, PS-II efficiency, O_2 evolution, and photophosphorylation, which increases plant photosynthetic efficiency under DS. Additionally, NPs improved gas exchange properties and boosted the uptake of Ca, Mg, N, K, and iron (Fe), resulting in greater photosynthesis under DS (Faraji and Sepehri, 2020).

Under stressful circumstances, carotenoid functions as an antioxidant to guard against oxidative damage to chlorophyll (Emiliani et al., 2018). By protecting chlorophyll from deterioration and increasing chlorophyll concentration, NPs (CuO) application considerably increases carotenoid contents, which boosts photosynthetic efficiency under DS (Van Nguyen et al., 2022). In conclusion, the use of NPs is a practical method that enhances photosynthesis by enhancing nutrient absorption, chlorophyll synthesis, and PS-II efficiency.

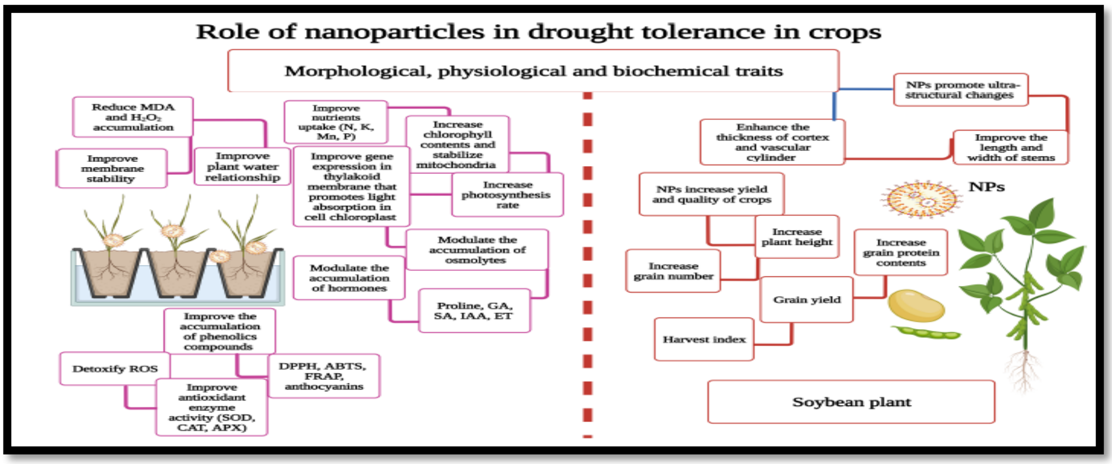

Fig: 1 Nanoparticles (NPs) play a key role in enhancing drought stress (DS) tolerance in plants. NPs reduce MDA accumulation, maintain membrane stability, induce the expression of stress-related proteins, improve nutrient and water uptake, increase photosynthesis, and increase grain yield and harvest index. This Figure is created with BioRender.com. (Mangena, P. 2018).

Soil salinity

One of the most significant abiotic factors that lowers crop productivity globally is soil salinity (Taha et al., 2021). This issue is significantly more prevalent in dry and semi-arid locations as well as tropical climates due to low rainfall and insufficient soil washing of salt (Bijanzadeh and Egan 2018; Sattar et al. 2018; Sienkiewicz-Cholewa et al. 2018). According to research, 20% of cultivated lands and 50% of agricultural irrigated land worldwide are affected by soil salinity (Zia et al., 2021), and it is anticipated that by 2050, 50% of all cultivated lands will be affected, posing a serious threat to future food security (Sienkiewicz-Cholewa et al., 2018). Natural processes or human activities such as improper fertilization, intensive irrigation, using degraded waters, and ignoring the principles of proper drainage can result in soil salinity (Zia et al. 2021; Bijanzadeh and Egan 2018; Sienkiewicz-

Cholewa et al. 2018; Soliman et al. 2019), which is caused by the accumulation of salts, especially sodium chloride (NaCl), on the soil substrate or near the soil surface (SienkiewiczCholewa et al. 2018).

According to Sattar et al. (2018) and Tester and Davenport (2003), salinity can have a negative impact on several of the morphological, biological, physiological, and biochemical processes that plants go through. Additionally, by impairing plant growth, salinity can significantly lower the amount of food that plants produce. Finding appropriate ways to lessen the negative effects of salinity stress is crucial for preserving human food security because wheat is a significant crop that is badly harmed by it (Zia et al. 2021; Javaid et al. 2019). Sodium (Na^+) is not listed as an essential nutrient for plants, although under some situations, its presence promotes plant growth (Javaid et al. 2019). Negro et al. claimed that despite high Na^+ concentrations impairing plant growth, low Na^+ concentration in soil benefits most plant species (excluding halophytes).

Conclusions and future perspectives

One of the biggest current and upcoming problems for crop production and food security is drought stress. The current analysis demonstrates that NMs regulate the expression of various genes involved in reducing the effects of drought stress on a variety of field and horticultural crops. Along with modifications to a number of physiological and biochemical processes, drought resistance genes including LEA and aquaporins are also affected as follows: (1) reducing oxidative stress damage by strengthening the antioxidant defence system; (2) reducing osmotic stress by accumulating compatible solutes and maintaining ionic homeostasis; (3) enhancing photosynthesis by increasing the content of photosynthetic pigments and RuBisCO activity; (4) enhancing water and nutrient uptake and translocation because of their role in promoting root growth, conductive tissue components, and up-regulation of aquaporins; and (5) reducing water loss. More research is required to fully understand the impact of NMs as triggers to promote drought tolerance in diverse field and horticultural crop plants, including phenological, anatomical, ecological, cytological, and molecular mechanisms in addition to physio-biochemical mechanisms. Additionally, it takes a lot of work to apply NMs to boost crop production under normal or stressful field circumstances in a way that has no detrimental effects on the environment or human health. Thus, it is important to consider the optimal concentration and application technique. Further research is needed to determine the potential impact of NM-treated feed and food plants on both human and animal health.

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