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Nanoformulation for the Development of Heat and Drought Tolerance in Plants

Ashutosh Singh¹, Sharwan Kumar Shukla¹, Girija Choudhary¹, Sajan Kumar¹, Sangeeta Singh², Vikram Singh Gaur³, Chander Mohan⁴, *Rahul Chandrakant Kaldate¹

¹R L B Central Agricultural University, Jhansi, Uttar Pradesh, India

²ICAR–Indian Grassland and Fodder Research Institute, Jhansi, Uttar Pradesh, India

³College of Agriculture, Balaghat, JNKVV, Jabalpur, Madhya Pradesh, India

⁴ICAR – IIMR Regional Station, Begusarai, Bihar, India

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Abstract

The atmospheric temperature above the optimal and water deficit condition of soil is the major cause that affects proper plant growth and significantly reduces economic yield. Nanoformulation such as ZnO, SiO₂, and TiO₂ plays key role in the development of tolerance in plants against heat and drought stress. These metallic nanoformulations are used in seed nanoprimer and foliar spray to regulate the photosynthetic mechanism and hormonal balance to develop tolerance against heat and drought stress. Proper application of these nanoformulations ensures the growth and development of plants with significant increase in economic yield.

Keywords: Nanoformulation, Heat, Drought, Tolerance, Stress, Chitosan, Chlorophyll. Photosynthesis

1. Introduction:

Continuous increase in the atmospheric temperature and reduction in soil moisture is the major threat of crop production and sustainable development. Human induced activities such as deforestation, industrialization and urbanization are the identified cause of increase in atmospheric temperature. Destruction of water bodies, natural habitat and grasslands causes environmental imbalance (Yin, et al., 2023). Due to environmental imbalance, irregular rainfalls in most of the global region have been observed and exist as water deficit conditions. Moisture deficiency in the soil affects seeds germination, establishment and proper growth of plants. Water and nutrient absorption machinery of the plants have failed due to lack of moisture in the soil therefore improvement of plants in context of development of tolerance against heat and drought stress boosts the plant mechanism through proper water and nutrient uptake can be helpful in mitigating oxidative stresses (Zhao, et al., 2017).

Nanoformulation is one of the potential approaches to mitigate the effect of high temperature and water deficit condition by boosting the plant antioxidant system. Several metallic carbon-based polymers have been developed for enhancing the effect of high temperature and drought (Zhao, et al., 2023). Some nanoformulation like ZnO₂ SiO₂, TiO₂ have been successfully demonstrated by researchers as chitosan to improve plant tolerance against high temperature and drought by enhancing water uptake, accelerating antioxidative system and mitigating the acute effect of oxidative stresses (Li, et al., 2021). The standard nanoformulation (chitosan) and method of their application involves seed nanopriming, foliar application, floral application etc. regulates hormonal balance and photosynthesis system for maintaining balance under heat and drought and other stressed conditions (Zhang, et al., 2022).

2. Role of Key nanoformulation under heat and drought stress:

Nanoparticles and formulations including silicon dioxide, copper oxide, zinc oxide, iron oxide, titanium dioxide etc play crucial role in improvement of water use efficiency system, chlorophyll content, SOD, POD and CAT enzyme activities scavenging reactive oxygen species to destroy the effect of high atmospheric temperature and water deficit conditions (Wang, et al., 2019). The brief role of nanoparticles and formulations practiced in the significant reduction of effect of heat and drought to properly regulate the plant system is represented in Figure 1.

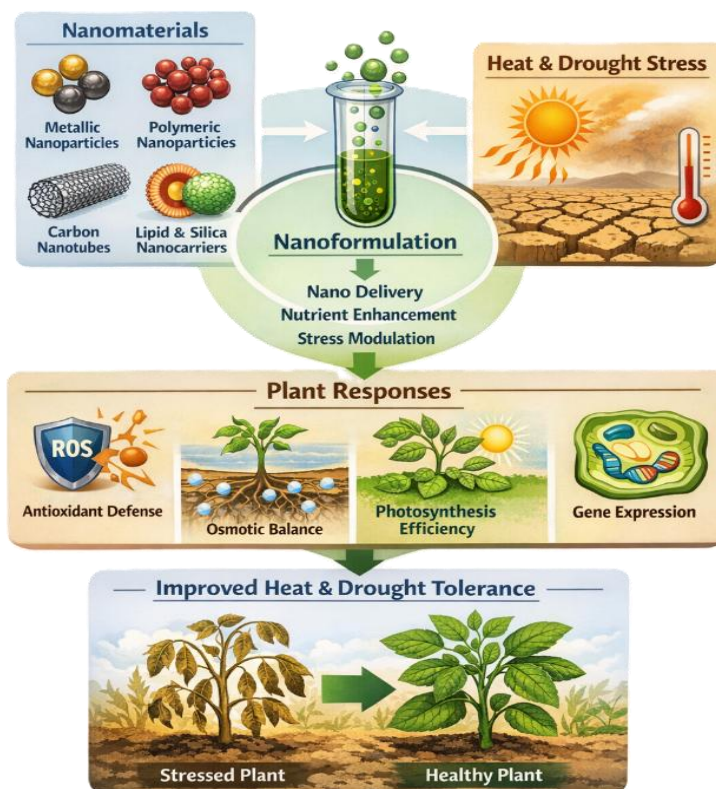


Fig.1: Nanoformulation mediated enhancement of plant tolerance to heat and drought stress.

2.1. Chitosan nanoparticles: This is one of the potent nanoformulations to resist the plant against drought and acute water deficit conditions in the soil. The chitosan nanoparticles stimulate plant natural defense system when subjected to water deficit conditions (Kareem, et al., 2022). The defense mechanism involves over production of antioxidant enzymes (SOD, POD, CAT) and excess amount of nitric oxide.

2.2. Iron oxide (Fe₂O₃) nanoformulation: This nanoformulation is generally used as nano fertilizer in crop production. The active nanoparticles of the iron oxide present in the formulation enhance the photosynthetic mechanism by increasing the plasticity of photosynthetic pigment. The active gradient of iron oxide in the nanoformulation may also enhance plant growth under heat and drought conditions (Li, et al., 2021).

2.3. Copper and Zinc oxide (ZnO): The standardized combinations of zinc oxide and copper have been experimented as robust nanoformulation when plant subjected to heat and water deficit condition. Water use efficiency is the important physiological parameter of plants under heat and drought conditions is enhanced after the application of copper and zinc oxide formulations (Guo, et al., 2020). Further zinc oxide and copper nanoparticles significantly increase the chlorophyll content and reduces pigment cell membrane damage for reducing the effect of drought and high atmospheric temperature.

2.4. Silicon Dioxide (SiO₂) nanoformulation: The active formulation of silicon dioxide plays important role in the development of tolerance against drought and heat stress by increasing the activity of antioxidant enzyme SOD, POD and CAT. In several studies SiO₂ formulation have been observed as very crucial for the scavenging reductive oxygen species (ROS) to reduce the effect of heat and drought stress (Zhang, et al., 2022).

2.5. Titanium Dioxide (TiO₂) nanoformulation: Titanium dioxide nanoformulation is one of the potent regulatorsto enhance photosynthetic efficiency of plants under stressed conditions. Foliar application of titanium dioxide mitigates heat and light stress by enhancing photosynthetic activity and strengthening physical barriers.

3. Action mechanism of nanoformulation under heat and drought stress:

Antioxidant defense, photosynthetic efficiency, osmoregulation, water management and hormonal modulation are the key plant physiological features that exist for the development of tolerance under heat drought and other abiotic stresses. Some of the important mechanisms associated with nanoformulation and plant defense system are briefly explored here:

3.1. Osmoregulation and water management: Relative water content and osmolytes accumulation have been found to increase in stressed plants after application of nanoformulation. Management of osmotic stress due to stimulation and accumulation of

osmolytes like proline are involved in the development of elasticity in plant physiological mechanism (especially osmotic adjustment and water update) (Sohag, et al., 2020). Furthermore, nanoformulation also improves relative water content in the plant tissue to prevent the damage of cell membrane under stressed conditions.

3.2. Photosynthetic efficiency improvement: Silicon based nanoformulations have been found as one of the potent formulations to enhance the photosynthetic efficiency in plants under stressed conditions. Foliar application of silicon based nanoformulation on stressed plant protect photosynthetic apparatus (particularly chlorophyll) under water deficit condition and high temperature stress (Wang, et al., 2022).

3.3. Antioxidant defense enhancement: Growth and development stages of the plant including seedlings, tillering/branching, flowering, fruiting are directly affected due to high atmospheric temperature and limited soil moisture. Acceleration of enzymatic antioxidants inside the plant system may increase after application of ZnO, SiO₂ and TiO₂. Application of these nanoformulations may combat with reactive oxygen species (ROS) caused by heat and drought conditions (Guo, et al., 2020).

3.4. Hormonal modulation: Most of the stress responsive plant hormones like proline, abscisic acid and cytokinin's are responsible for proper growth and development of plants. Application of these plant hormones may ensure the enhancement of proline, ABA and cytokinin in plant tissue to combat with heat and drought conditions (Wang, et al., 2022).

4. Mode of nanoformulation application:

Pre and post treatments (seed coating before sowing and foliar application) significantly reduce the effect of heat and drought stress in plants. The pre-treating of seeds to enhance seed germination provides strength to the seedling's vigor under stressed conditions. Further the foliar application of nanoformulation to the leaves and aerial organs of the plant enhances antioxidant level and reduce heat stress by promoting stomatal regulation under high atmospheric temperature and water deficit conditions (Li, et al., 2022).

5. Conclusion:

High atmospheric temperature and low level of soil moisture are the main constraints for the growth and development of plants. These threats are affecting global food productivity by reducing economic crop yield. Nanoscience and technology are the emerging techniques to reduce the effect of drought and heat stress up to a certain level. Dozens of nanoformulation using metallic carbon-based polymers have been artificially synthesized with potential to reduce the effect of heat and drought on plants. These nanoformulations strengthen the osmolytes, photosynthetic pigment, hormonal balancing, antioxidant activity, reductive oxygen species, water use efficiency etc. for saving crop plants under heat and drought stress.

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