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Seed Priming: A Key to Sustainability in Drought Stress

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Authors' contributions

This work was carried out in collaboration among all authors. Author SA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SC and VH managed the analyses of the study. Author SL managed the literature searches and correspond the article. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Abiotic stresses spot lights the field crops at all growth phases and results in significant yield losses in important crops, endangering the safety of the world's food supply. Numerous physiological, biochemical, and molecular tactics have been examined by crop researchers to battle drought stress/water limiting stress, but in the current environment, these measures are meager. It is so claimed that plants can be primed by various organic and inorganic stimulants for exceptional toughness under stressful circumstances. In order to confer tolerance, novel seed priming techniques are promising field of research in stress biology and crop stress management. Seed priming is the process of carefully hydrating seeds with germination stimulants so that pre-germinative metabolic activity can continue while the radicle's emergence is halted. The terms "hydro-priming," "osmo-priming," "halo-priming," "solid matrix priming," "bio-priming," and "hormonal priming" refer to various priming techniques. It will speed up and synchronize germination, improve plant growth and stand establishment, raise stress tolerance, improve fertilizer and water use

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efficiency, and have superior weed suppression effects. This review paper covers the physiological and biochemical changes through several seed priming techniques, Nano-priming and its significance in sustainable agriculture.

Keywords: Seed priming; water limited stress; seed priming techniques; nano priming.

1. INTRODUCTION

For the vast majority of India's poor and vegetarian people, pulses are a staple food and a significant source of protein. Pulses offer the ideal combination of high biological value vegetarian protein when combined with cereals. According to the findings of household consumption surveys, there has been a fall in pulse consumption, which has increased malnutrition and decreased protein intake [1]. About 24% of the world's undernourished population still live in India [2]. According to GOI report (2016), a plunge in the country's per capita net availability of pulses from 70.3 to 29.1 g/day/capita was observed in years 1959 to 2003. With the production of pulses in the recent decades, an improvement in availability of pulses in vegetarian population in India. According to projections from the Indian Institute of Pulses Research, Kanpur, the nation's pulses demand will reach 39 million tonnes by 2050, necessitating a 2.2 percent annual growth in production [3]. According to GOI report (2016), a plunge in the country's per capita net availability of pulses from 70.3 to 29.1 g/day/capita was observed in years 1959 to 2003. With the production of pulses in the recent decades, an improvement in availability of pulses in India has noticed which was mainly due to pulse related initiatives (policies and programmes) which works in the direction of boosting the domestic production and increased imports, and is currently at 47.2 g/day/capita [4]. Pulses, as an important source of protein, constitute a basic ingredient in the diet of vast majority of poor and vegetarian population in India. According to projections from the Indian Institute of Pulses Research, Kanpur, the nation's pulses demand will reach 39 million tonnes by 2050, necessitating a 2.2 percent annual growth in production [3]. The Economics times 2020 reported the total production of pulses for 2019–2020 was 23.02 million tones which was shown as increase of 2.76 million tonnes from the five-year average production of 20.26 million tonnes [7]. India accounts for about 29% of the global area and 19% of the global production of pulses making it the largest producer and consumer in the world. More significantly, India is the world's largest importer and processor of pulses. In comparison to the global average of 1023 kg/ha the country's average production is roughly 841 kg/ha [5]. Agriculture is the most vulnerable sector to water constraint and is experiencing a large (40 to 60 percent) loss in output potential in rain-fed areas [6]. By 2050, it is anticipated that there will be an additional 2 billion people on the planet, which will increase the need for food to feed the expanding population [8]. However, the main problems impeding efforts to meet the world's food needs are global warming, climate change, and an ever-increasing population [9]. Abiotic stress are the atrocious challenges that come forward mainly due to unfavorable climatic change scenario, such challenges are heavy metal toxicity, drought, heat, and high soil salinity, which ultimately decreased crop output across the globe [10].

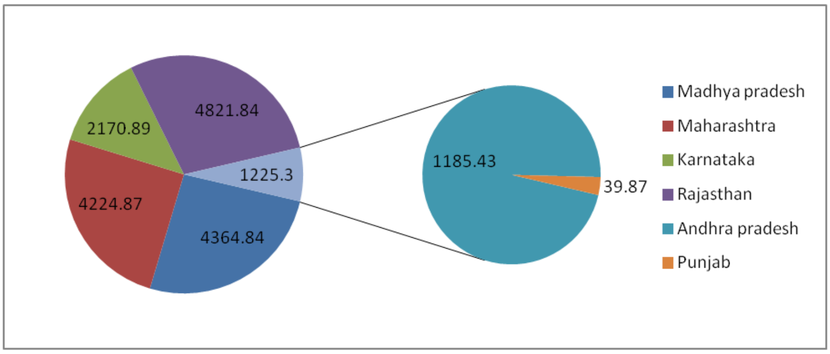

Fig. 1. State wise production of pulses (in tonnes) during 2020-21, Ministry of Agriculture & Farmers Welfare, (2021) https://pib.gov.in/Press

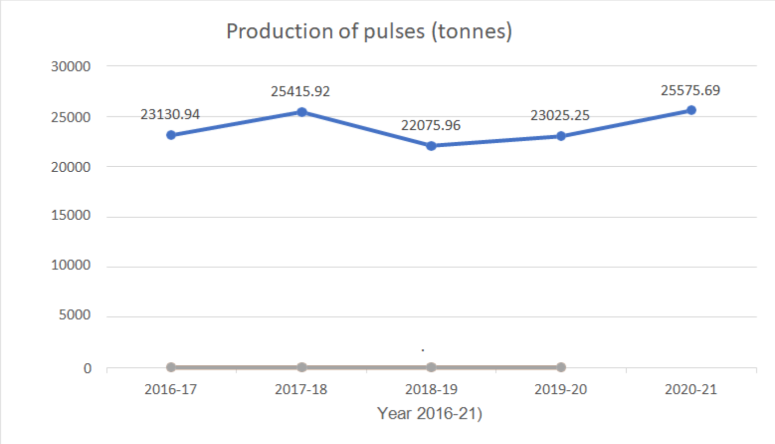

Fig. 2. State wise production of pulses (in tonnes) during 2016-21, Ministry of Agriculture & Farmers Welfare, (2021) https://pib.gov.in/Press

2. EFFECT OF DROUGHT STRESS ON GROWTH AND DEVELOPMENT OF PLANT

The main issues impacting seed germination, emergence, seedling vigour, and ultimately crop output are abiotic stresses. These unfavorable circumstances significantly affect many agricultural areas in dry and semi-arid countries. Drought can interfere with a plant's natural functioning at various phases of growth, which lowers the plant's overall production [11]. Plants adjust physiologically, biochemically, and molecularly to these conditions to some extent, but these natural adaptation techniques are insufficient to produce the desired results [12,13]. Low germination percentage and less stand establishment reduces overall growth of seedlings by affecting their morphological (seedling length and biomass), physiological (relative water content), biochemical (amylase, protease, and lipase activities), and molecular (stress proteins, aquaporins, and dehydrins) characteristics [14,15]. Additionally, it generates reactive oxygen species (ROS) and affects the cell in two ways firstly, disrupts cell membranes which results in electrolytes leakages secondly limitation in electron transfer, quenching of excitation energy which produces O_2 in PSII, reduction in O_2 to O_2 [16]. Reproductive phase the sensitive growth phase of plant determines yield in most crops is also affected by drought stress [17,18]. Drought stress during the reproductive period affects grain development, grain number, grain weight, and many other yields and yield-attributing features, which leads to a significant decrease in productivity and quality of final production [19,20]. Being an agricultural nation, India needed simple, efficient, and manageable technologies to improve crop establishment under all environmental circumstances. Seed priming is a straightforward and effective way to synchronize seed germination, promote emergence, and establish in the farm, among other methods for increasing crop yield. By synchronizing seed germination, the seed priming approach can help farmers reduce the losses by drought stress, increase crop production, and create systemic resilience to drought stress in plants.

2.1 Seed Priming

Simple and efficient hydration strategy to promote seed germination is seed priming. Seeds undergo a physiological process known as regulated hydration and drying during priming, which results in an improved and increased pre-germinative metabolic process for quick germination [21]. Prior to germination, seed treatments cause a physiological state known as the "primed state," which enhances a number of cellular reactions [22]. The prepared seeds produce seedlings that have early, uniform germination and an overall improvement in its lifetime different growth characteristics might be seen [23,24]. It improves crop production, nutrient uptake, water use effectiveness, release of photo- and thermos-dormancy and activating genes/ proteins that respond to stress [25], such as late embryogenesis abundant (LEAs), which may result in the development of drought stress resistance [26,27].

2.2 Techniques of Priming

Every crop needs a unique, optimized priming procedure. Optimization takes into account a number of factors, including the amount of time needed for treatment, the priming or coating material, the vigour of the seeds, and the storage circumstances (temperature, moisture, oxygen requirement etc.)

2.2.1 Nano priming: A realistic seed priming technique

The rapidly expanding area of nanotechnology has several industrial applications in the fields of pharmaceuticals, food, cosmetics, electronics, textiles, energy, environmental bio-remediation etc. [28]. Currently, agriculture sector is also interested and performing wonders in applications of nanotechnology in field of seed biology [29]. Numerous researchers have been conducted extensive research on the use of nano particles for crop protection and yield enhancement against a variety of biotic and abiotic challenges [30]. To comprehend how Nanoparticles (NPs) and plants interact, many studies have been conducted and presented significant data on various research platforms. However, due to the association of NPs differing from species to species, a variety of results based on the physiological and molecular parameters of crops have been seen. In addition, NPs respond differently depending on their size, shape, manufacturing method and chemicals used [31]. Plant growth is altered when NPs penetrate the cell wall and cause a variety of morphological and physiological alterations.

2.2.2 Nano technology in sustainable agriculture

Nanotechnology offers enormous promise in agriculture, such as minimizing the effects of climate change and enhancing abiotic stress management measures [44]. Nano-enabled technologies have been developed to promote plant growth, such as the application of nano fertilizers through various irrigation methods (such as soil irrigation, foliar spray, and seed coating), nano-sensors to monitor real-time plant health, and genetic engineering of plants to increase defense-related phytohormones and photosynthetic efficiency. Application of nano fertilizers may have high surface area-to-volume ratio, high pollutant removal effectiveness, and efficient provision of critical nutrients for soil health over conventional fertilizers [45]. Several research have reported on the use of NPs as nano fertilizers to boost crop yield under stress circumstances [46,47]. Nutrient retention capacity (high surface area) of NPs reduces nutrient losses and provides potential benefits to plants [48,49]. NPs as nano fertilizers improved abiotic stress tolerance in plants by enhancing plant growth, nutritional content, phytohormones, antioxidant enzymes, and photosynthetic efficiency while decreasing cellular oxidative stress. Recently, iron oxide (Fe_3O_4) NPs have been employed to boost crop development in both high mechanical stress-contaminated soil and drought-stressed circumstances [50,51]. Furthermore, [52] demonstrated that FeO NPs improved wheat seedling growth by reducing oxidative stress caused by Cd and Pb contamination [53]. The use of nanoparticles effectively alleviates salt stress by lowering salt content and the harmful effects associated with it. Furthermore, nano-silicon (Si) has been shown to greatly improve salt stress, seed germination, the antioxidant defence system, leaf turgor, and the carbon-assimilation process [54]. [55] recently showed that the application of cerium oxide (CeO) NPs maintained quantum yield of photosystem II and CO_2 assimilation via ROS scavenging, particularly hydrogen peroxide, produced by abiotic stress [56]. Titania (TiO_2) nanoparticles increased catalase (CAT), glutathione peroxidase (GPOX), and superoxide dismutase (SOD) activities and reduced oxidative stress in Duckweed (*Lemna mino*r) plants [57].

2.2.3 Nano Priming under drought stress

Drought is a major environmental condition that has piqued the interest of both environmental and agricultural specialists. Limited moisture content diminishes cell size, disrupts membrane integrity, induces oxidative stress, and causes leaf senescence, all of which reduce crop output [58]. Previous research has shown that Si NPs improve plant drought tolerance. Drought resistance, for example, improved in hawthorn plants treated with SiNPs, but defense-related physiological indicators varied according to drought levels and SiNPs concentrations applied [59]. Similarly, Si NPs revealed a high potential for post-drought plant recovery in barley plants through modifying morphophysiological characteristics [60,61] discovered that Si NPs improved cucumber growth and yield under water-stressed and saline situations [85].

Under drought conditions, chitosan NPs enhanced the relative water content, photosynthetic rate, CAT, SOD activities, yield, and biomass of wheat plants [62]. Foliar application of Fe NPs has been shown to alleviate drought stress effects on safflower cultivars [63], whereas soil application of CeO NPs improved plant growth at 100mg/kg and increased photosynthetic rate by regulating water use efficiency in soybean (*Glycine max*) plants [64]. The application of silver nanoparticles minimized the harmful effects of drought stress on lentils (*Lens culinaris* Medic.) plants [65]. [66] Identified Si NPs-assisted Abscissic acid administration as an efficient drought resistance management approach in Arabidopsis thaliana.

2.2.4 Nano-priming stimulates seed germination and seedling growth

Seed germination is a key and sensitive stage of plant life that involves a variety of metabolic activities; overcoming environmental challenges at this point of the life cycle is critical for later growth stages [67]. In comparison to unprimed seeds, priming can synchronize seed germination and increase seedling vigour under stress circumstances [68,69]. The effects of nano-priming on seed germination have been studied, and NPs such as zinc and zinc oxide, iron, titanium oxide, and silver NPs have been widely used in this regard [70,71]. Nano-priming improved photosynthetic parameters, maintained biochemical balance, and increased biomass production in the wheat seedlings as compared to the untreated seeds. Additionally, compared to unprimed seedlings, seed-priming wheat seeds with ZnONPs increased shoot height and root-shoot biomass in seedlings under saline stress [72].

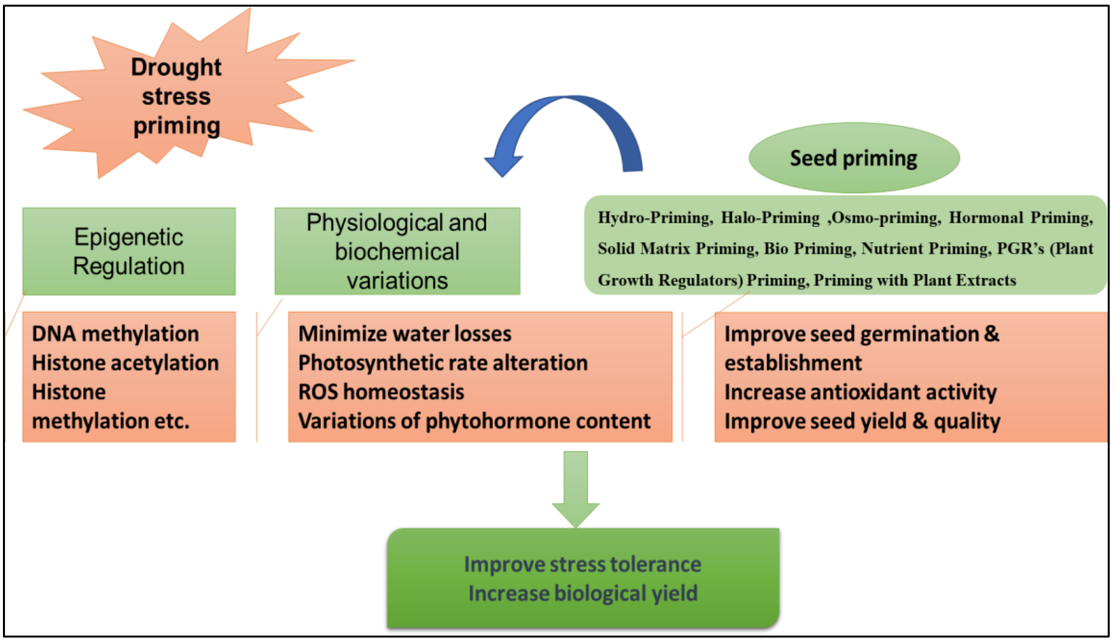

Fig. 3. A Seed priming effects under drought stress

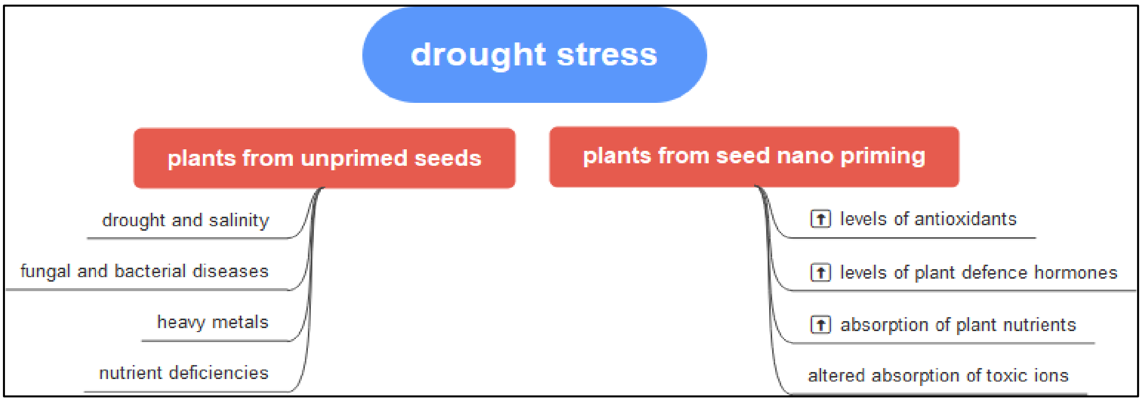

Fig. 4. Difference between primed and unprimed seeds under drought stress

Table 1. Effects of Nano-priming agents on crops yield

S. No.	NPs agents used in studies	Effects on different crops	References
1.	Iron-oxide nanoparticles	Crop: Sorghum (*Sorghum bicolor* (L.) Effects: increase Seed and seedlings vigor, Biochemical activity, Biomass, and water content in leaves.	[32]
2.	Zinc oxide and iron oxide nanoparticles	Crop: Wheat (*Triticum aestivum* L.). Effects: increase Plant morphology, Biomass, Biochemical activity, Cadmium uptake, and Biofortification.	[33]
3.	Silicon nanoparticles	Crop: Wheat (*Triticum aestivum* L.). Effects: increase Biomass, Biochemical activity, ROS levels, and Cadmium uptake.	[34]
4.	Manganese (III) oxide nanoparticles	Crop: Jalapeño (*Capsicum annuum* L.). Effects: increase Salinity resistance, Antioxidant enzymes.	[35]
5.	Iron (II) sulfide aqua nanoparticles	Crop: Rice (*Oryza sativa* L.). Effects: increase Seed and seedlings vigor, Plant morphology, Anti-microbial activity.	[36]
6.	Platinum nanoparticles stabilized with poly (vinylpyrroli done)	Crop: Pea (*Pisum sativum* L.). Effects: increase Seed and seedlings vigor, Plant morphology, and decrease micro-organisms colonization (Arbuscular Mycorrhizal fungi (AMF) and rhizobia	[37]
7.	Iron nanoparticles	Crop: Wheat (*Triticum aestivum* L.), types WL711 (low-iron genotype) and IITR26 (high- iron genotype). Effects: increase Seed and seedlings vigor, Plant morphology, and Harvest.	[38]
8.	Copper and Iron nano particles	Crop: Wheat (*Triticum aestivum* L.) seeds of varieties galaxy-13, Pakistan-13, and NARC- 11. Effects: increase Enzymatic activity, Biochemical activity, Anti-oxidant activity, Abiotic stress resistance, and Harvest.	[39]
9.	Cobalt and Molybdenum oxide nanoparticles	Crop: Soybean seeds (*Glycine max* (L). Merr.). Effects: increase Seed and seedlings vigor, Plant morphology, Biomass, and Enzymatic activity.	[40]
10.	Molybdenum Nanoparticles Combined with the bacteria Meso rhizobiu cicero ST-282 And Bacillus-subtilis Ch13	Crop: Chickpea (*Cicer arietinum* L.). Effects: increase Seed and seedlings vigor, Plant morphology, Antioxidant enzymes, and Harvest.	[41]
11.	Nanoparticles of zinc, titanium, and silver	Crop: Chilli (*Capsicum annuum* L.). Effects: increase Seed and seedlings vigor, Plant morphology, Anti-microbial activity.	[42]
12.	Copper nanoparticles	Crop: Common bean (*Phaseolus vulgaris* L.). Effects: increase Seed and seedlings vigor, (High concentrations inhibited seed germination, independent of nanoparticle size), and Biomass.	[43]

Additionally, nano-priming with ZnO, the damaging effects of salt stress on overall growth, photosynthetic pigments, and ultra-structure of leaves were reduced. Similar to this, the use of ZnONPs as a priming factor in the Brassica napus cultivars significantly improved seedling growth under salt stress and showed an increase in the length of shoots (9.60% and 25.63%) and roots (41.64% and 48.17%), respectively, as well as increased biomass [73].

Festuca ovina seeds exposed to drought stress showed increased vigour after being supplemented with AgNPs (25, 50, and 75%);

length of root and shoot, their corresponding wet and dry weights, vigour index, and coefficient of the seedlings increased after nano-priming, with maximum values reported at 75% concentration of AgNPs [74]. Additionally, the addition of titanium oxide nanoparticles (TiO_2NPs) to maize seeds increased the length of the seedlings' roots and their fresh and dry weights under both normal and salinity-stress circumstances [75]. In this study, it was discovered that nano-priming with TiO_2 was more successful at encouraging seedling growth than hydro-priming. Following TiO_2NPs treatment, increased relative water content, K+ concentration, total proline content, and phenolic contents enhanced seedling growth. In a recent experiment, [76] primed rapeseeds under salt stress with cerium oxide nanoparticles (nano-ceria), which improved K+ retention and decreased Na+ accumulation, changing the Na+/K+ ratio to handle salt stress as compared to control seedlings. Some nanoparticles can be poisonous and have negative effects on many growth parameters in addition to being helpful for seedling growth, which calls for diligent research in the field of nano-priming [77]. For example, priming pearl millet (*Pennisetum glaucum*) seeds with 5 ml of 20 and 50 mg L^{-1} of AgNP solutions slowed the growth of the seedlings in terms of the length of their roots and shoots [78]. Additionally, French bean (*Phaseolus vulgaris* cv. Contender) seeds primed with two engineered nanomaterials-nano chitosan (Cs, 10%) or carbon nanotubes (CNTs, 20 g L^{-1}) either alone or combined with NPK—displayed reduction in all seedling growth parameters as compared to the control, including the root and shoot length, fresh and dry weight, leaf area, and water content [79]. However, foliar treatment of these nanomaterials at the same dose demonstrated a different effect than seed priming.

2.2.5 Nano-priming under ROS equilibrium

Nano-primed plant seeds and seedlings have an ordered reactive oxygen species (ROS) homeostasis and antioxidant system that protects seeds from oxidative damage and ensures seed longevity [80]. Under normal conditions, the use of nano-scale zero-valent iron (G-nZVI) increased ROS generation, which aided in the germination of (*Oryza sativa* L. cv. Gobindobhog) seeds [81]. Similarly, 25 mg L^{-1} of nanoscale micronutrient iron (Fe_2O_3) increased ROS generation in Oryza sativa and Zea mays seeds to accelerate seed germination when compared to hydro-primed seeds [82]. Under stress conditions, nano-priming establishes a balance between ROS generation and scavenging in seeds. In manganese (Mn)-stressed *Helianthus annuus* (L.), for example, 12.5- 200 M Sulphur nanoparticles (SNPs)-priming caused a decrease in total ROS content-superoxide radical (O_2) and hydrogen peroxide (H_2O_2), as well as increased catalase (CAT) and superoxide dismutase (SOD) antioxidant activity [83]. In another experiment, TiO_2 nano-priming (60 ppm) of salt-stressed maize seedlings increased SOD and CAT activities while decreasing malondialdehyde (MDA-another oxidative stress marker) content and membrane electrolyte leakage (MEL) [84]. When 0.05% chitosan nanoparticles (CsNPs) were employed for priming treatment of broad bean seeds, the activities of ROS scavenging antioxidant enzymes- CAT, peroxidase (POX), and ascorbate peroxidase (APX) increased. In contrast, 0.1% of CsNPs had a negative effect on these antioxidant enzymes [83].

These findings support the use of nanoparticles as a priming agent for purposeful priming; nevertheless, the type of nanoparticles, plant species, and growing circumstances should all be considered.

3. CONCLUSION

A technology known as seed priming increases germination, promotes early flowering and maturity, increases crop resistance to abiotic challenges, and is both safe and effective for the environment. The discussion above makes it clear that various priming techniques have been researched on a variety of crops and have been found to be beneficial in terms of crop yield. It is also suggested that seed priming is a better solution against germination issues when seeds are grown in unfavorable conditions. However, there are still a number of restrictions on seed priming techniques. Not every priming technique will result in considerable germination and growth. In this aspect, choosing a certain priming technique is crucial to getting greater germination and eventual yield. Therefore, more thorough research is needed to choose appropriate priming techniques for certain crops in order to ensure a higher yield.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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