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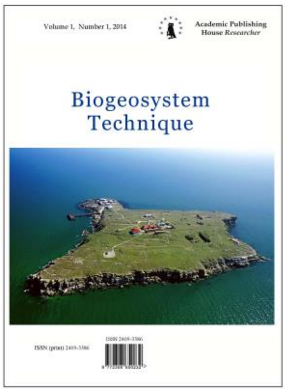

Nano-Priming Technology for Sustainable Agriculture

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Abstract

Climate change affected crop growth and development which reduced crop production. Decreasing crop production can create food security-related problems. Nanotechnology is a new era of technology for the solution of climate change-related problems in agriculture we can say the "NanoTech-Agril" era that helps the farmer to produce a larger number of crops without any problem related to climate change problems like salinity, drought, flood etc. Nanoparticle-based seed priming can enhance the seed metabolism and signalling pathways, that not only enhanced seed germination but also help in the establishment of plants for the entire lifecycle. Nano-seed priming also enhanced the metabolic, biochemical, antioxidant and phytohormone pathways resulting in the promotion of abiotic and biotic stresses that cut off the need for pesticides and fertilizers. The present review provides an overview of the nanoparticle application for sustainable agriculture.

Keywords: Climate change, food security, nano seed priming, antioxidant, pesticides, fertilizers

1. Introduction

Several difficulties are being expressed by agriculture, including pest-related productivity losses, natural resources depletion, and the consequences of global climate change (De La Torre-Roche et al., 2020; Kah et al., 2019). Another issue is that conventional farming techniques depend on the constant use of fertilizers and pesticides, which pollutes the environment (Rajput et al., 2018). By 2050, the global population is predicted to reach 9-10 billion, suggesting that food production would need to expand by 25-70 % from present levels (Scott et al., 2018). As a result, new agricultural technology must be used in order to assure sustainability and boost production (Fraceto et al., 2016; Panpatte et al., 2016). Seed germination is the beginning of a plant's life, and

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good germination is critical for the survival of plant species and its conservation, especially in some ecosystems like rangeland and agricultural land (Manjaiah et al., 2018). Furthermore, in terms of drought and salt stress, the germination stage is one of the most vulnerable. If a plant can endure these challenges, it will go to the next stage of development (Akter et al., 2018). Plant development and production are determined by the rate and homogeneity of seedlings, which protect buds from damage caused by adverse environmental factors (Rajput et al., 2015). These include drought, salinity, temperature, moisture, which have significant impact on seed germination and subsequent seedling growth (Friedrichs et al., 2019; Maity et al., 2018; Zahedifar, Zohrabi, 2016).

Crop protection can benefit from nanomaterials, particularly nanoparticles (Scott et al., 2018). This is a significant area of study that has piqued the interest of a number of agricultural firms, culminating in the use of nanoparticles in formulations (Chau et al., 2019). Pest control, plant nutrition, and environmentally friendly production methods can all benefit from the use of nanopesticides and nanofertlizers (Acharya et al., 2020; Rajput et al., 2021c). Nanoparticles have been demonstrated to have varied impacts on seeds and plants in recent research (Acharya et al., 2020; Pérez-de-Luque, 2017). Some negative side effects such as phytotoxicity or germination suppression may be caused due to nanoparticles (Rajput et al., 2020a). On the other hand, some nanoparticles can function as stimulants in cellular signaling pathways, enhancing seed metabolism, seedling vigor and plant development (Abbasi Khalaki et al., 2020). The physical and chemical features of nanoparticles, such as size, zeta potential, and concentration, are the determinants that ultimately dictate biological responses (Abbasi Khalaki et al., 2020; Acharya et al., 2019; Singh et al., 2021). These features are important in the absorption and transport of nanoparticles in plants. Smaller nanoparticles, for example, are more effective at crossing biological barriers (Bombo et al., 2019; Hu et al., 2020; Palocci et al., 2017; Rajput et al., 2022; Valletta et al., 2014). The nanoparticles' surface charge is also important. The leaves may pick up both positively and negatively charged nanoparticles and transport them to roots. But only negatively charged nanoparticles are immediately absorbed by the roots. Formation of mucilage occurs due to positive charges which checks the plants from absorbing them (Avellan et al., 2017; Spielman-Sun et al., 2019). To protect seeds during storage, promote germination and its synchronization, boost crop tolerance to abiotic and biotic stress, and plant development, nanopriming may be applied to seeds which will also assist in minimizing the amounts of pesticides and fertilizers required (Malik et al., 2020; Marina Voloshina, 2020). It has been suggested by new research that a variety of genes can be activated during germination such as those involved in plant stress tolerance by seed nanopriming. Although studies have already demonstrated encouraging results (Hussain et al., 2019; Ye et al., 2020), the use of nanotechnology for seed priming is a new field of research. Because many nanoparticles contain antimicrobial properties and may thus load antimicrobial compounds, seed nano-priming can also be employed for seed protection (Hussain et al., 2019; Pirzada et al., 2020). Furthermore, nano-priming may be employed to target seed biofortification in order to improve food quality and production (Hussain et al., 2019; Pirzada et al., 2020).

2. Results and discussion

Nanoparticles and nano-enabled products

Nanotechnology is an emerging technology that have the potential solution for most agriculture problems (Singh et al., 2022). Nanoparticles have many unique properties due to their tiny size in nanometers 1-100 nm with a large surface area which increase their physical and chemical importance (Rajput et al., 2021b; Singh et al., 2022). These favorable features of nanoparticles help to formation in various nano-enabled products e.g., nanofertilizer, nanoinsecticide, nanopesticides etc. for sustainable agriculture (Table 1). Four basic kinds of NPs are defined based on their chemical composition: Carbon-based such as nanofibers and nanotubes of carbon; Metal-oxide-based such as Ag, Cu, etc.; Bio-organic-based such as micelles and liposomes; Composite based (Lowry et al., 2019). Organic and inorganic types of NPs is another classification.

Organic NPs, such as polymeric NPs, liposomes, carbon-based nanomaterials, lipid-based nanocarriers, and solid lipid NPs, are biodegradable. Inorganic NPs are made of inorganic materials such as metals and metal oxides, such as silver oxide and zinc oxide. Silver NPs (Ag-NPs) are the most commonly used of all the synthesized NPs, with a dominance of more than 25 % in diverse consumer items (Scott et al., 2018). Antifungal, antiviral, and antibacterial medicines are the most common uses of Ag-NPs.

Table 1. Nano-enabled agriculture products (Rajput et al., 2021b)

Nano-enabled products	Company	Country	Applications
AZterknot fungicide	Vive Crop Protection	Canada	Use as fungicide
Nanosulf Drenching	Alert Biotech	India	Use as antifungal
Natural Pesticide Nano-5-011	Organic Fertilizing	Taiwan	Use as pesticide
NeuDelta-2.5EC	Neufarm GmbH	Germany	Use as pesticide
Groagro 4: Super Kalium Catalyst + T. E	Bonding Technology Resources SdnBhd	Malaysia	Potassium nanofertilizer
PADI 3 (17: 3 : 25 : 2) + GROAGRO 4	Bonding Technology Resources SdnBhd	Malaysia	Use as NPK fertilizer
Nano-urea	Indian Farmers Fertilizer Cooperative Limited (IFFCO)	India	Nano-urea replacement of traditional urea fertilizer

New kinds of NPs with a wide range of applications in numerous industries are generated each year employing state of art technology. Two ways are there for synthesis of NPs: i) top-down method and ii) bottom-up method (Fraceto et al., 2016; Panpatte et al., 2016). In addition, NPs are also synthesized using three distinct methods: physical, chemical and biological. The variance in stabilizing and lowering the potential of biomolecules present in the plant results n the synthesis of green NPs for seed priming accumulated NPs. Camerel et al., 2002 reported the creation of gold NPs inside the live plant alfalfa when the plants were cultivated in an $AuCl_4$ rich environment. Bali and Harris discovered *Medicago sativa* and *Brassica juncea* plants' capacity to collect Au NPs from aqueous $KAuCl_4$ solutions in a comparable study. The majority of the NPs were found in the xylem parenchyma cells, although some were also found in the epidermis, vascular bundles, and cortex. Throughout the last several years, the majority of research has concentrated on synthesis of NPs utilizing the inactive component of the plants, either in powder form or as an extract (Mohamad et al., 2014). Metallic NPs may be made from a variety of plant components, including leaves, stems, flowers, fruits, roots, seed coats, seeds, and latex.

NPs are made at a certain temperature and pH by combining plant biomass/extract and a salt solution of metal. The colour change of the solution serves the major conformation of NPs synthesis (Mohamad et al., 2014). Plant extracts are made using a variety of techniques including Soxhlet apparatus, cold treatment, and hot treatment, which are then used to make NPs. Because of it is of scale-up and downstream processing, this technique of NP synthesis is more suited than intracellular approach. This approach is also environment friendly, non-toxic, biocompatible and renewable (Camerel et al., 2002; Dikshit et al., 2021; Mittal et al., 2013; Mohamad et al., 2014). These NPs are recognized to have a variety of biological uses due to their biocompatibility. The production of metal NPs begins with the addition of plant extract to a metal precursor solution containing metal salts. For the production of Ag, Au, Pt, Cu, Fe, Se, Ni, NPs, metal precursor solutions such as $AgNO_3$, $HAuCl_4$, $PdCl_2$, $H2PtCl_6$, $Cu(NO_3)23H_2O$, $FeCl_36H_2O$, Na_2SeO_3, and $(NiNO_3)26H_2O$ are often utilized (Dikshit et al., 2021). Metal NPs are synthesized primarily in three phases utilizing plant extract. The reduction of metal ions (M^+ or M_2^+) to metal atoms (M^o) and subsequent nucleation of the reduced metal atoms happens in the first step (Dikshit et al., 2021). The convergence of tiny nearby NPs into bigger particles happens in the second stage, which is accompanied by rise in thermodynamic stability. The procedure is completed at the last stage by giving the NPs their final form (Makarov et al., 2014; Si, Mandal, 2007). Various functional biomolecules are present in the plant extract which help in reduction and stabilization of metal ions in the solutions. But, identifying the exact reducing and stabilizing molecules in NP production is challenging because the plant extract contains large variety of phytochemicals.

Germination and Principles of Seed Priming

For crop quality and plant development in agriculture, germination is a critical phase (Abbasi Khalaki et al., 2020). Seedling growth is rapid, resulting in rapid expansion of the leaves and elongation of the roots, which favors nutrient intake, biomass production, and translocation through transpiration flow (Mahakham et al., 2016). Slow germination exposes the early seedling, which is one of the most sensitive phases of the plant life cycle, to a variety of environmental stress conditions or diseases, resulting in reduced vigor and crop output, as well as financial losses for farmers (Acharya et al., 2019). There are three phases of seed germination (Nonogaki et al., 2010). Phase I is imbibition which begins with quick water absorption, basal metabolism of seed, mitochondrial activity, transcription and protein synthesis in the seed. The metabolism becomes hyperactive in phase II (lag phase or activation), with the generation of enzymes essential for reserve mobilization and embryo growth, including as amylases, endoxylanase, and phytase. The seeds show rapid water intake in phase III, and embryo expansion culminates in radicle protrusion (Nonogaki, 2014). Auxins are responsible for seed germination or dormancy (Wu et al., 2020). To govern cellular activities associated to seed germination, ROS modulate gene expression and phytohormone signaling, as well as the homeostasis of abscisic acid, gibberellins, auxins, and ethylene (Wu et al., 2020). When ROS levels are too high, however, substantial oxidative damage occurs, causing seed germination to be hampered (Bailly, 2019). To be encompassed in the so-called oxidative window, which allows appropriate germination completion, ROS level must be spatiotemporally managed (Bailly, 2019).

To increase seed germination and plant development, seed priming is a classical agricultural practice based on seed preparation prior to planting (Carrillo-Reche et al., 2018). Its commonly a water-based approach in which seeds are soaked in water and then dried or physically by UV priming (Lemmens et al., 2019). To initiate pre-germination metabolic pathways (phases I and II), water absorption must be sufficient without causing radicle emergence. Seed metabolism is altered by this process at the molecular and cellular levels such as increased reverse mobilization capacity, transcriptomic reprogramming, loosening of cell wall, higher tendency for translation and post-translation modifications. It generates a specific physiological state on absorption that increases and strengthens the germination and vitality of primed seeds (Carrillo-Reche et al., 2018). Antioxidant mechanisms, heat shock proteins and other stress related responses are induced due to soaking and subsequent drying due to which cross resistance to additional stressors develops. Furthermore, rapid germination reduces the time that germinating seeds are exposed to unfavorable soil conditions. To promote seedling vigour, make plants more tolerant to stress conditions, and increase and coordinate germination, seed priming has therefore been used and thus improving quality of food and increasing yield as a result (Carrillo-Reche et al., 2018; Lemmens et al., 2019).

Seed priming can be done in a variety of ways, such as hydro-priming or hydro-thermopriming, in which water treatment is given to seeds, typically for 7-14 hours to keep them hydrated, allowing germination phase II to proceed (Carrillo-Reche et al., 2018). Temperature alteration (cold and hot) can be used with this approach (Noorhosseini et al., 2017). To manage hydration (about 10-20 %), and modify seed metabolism via an abiotic stress, low water potential solutions are utilized in osmo-priming. Other pre-sowing treatments include using microorganisms (Lemmens et al., 2019), solutions containing salts (Saddiq et al., 2019), and plant growth regulators (Sytar et al., 2018) for bio-priming, halopriming and hormo-priming respectively.

For seed priming, a novel approach would be seed nano-priming in which nanomaterials, primarily nanoparticles are used (Table 2).

Table 2. Use of nanomaterial for seed priming and coating

Nanoparticle	Characteristics	Crops	Application	References
Fe-NPs	Particle size <50nm	*Sorghum bicolor*	Enhances germination, seeding growth and salinity tolerance of *S. bicolor*	(Maswada et al., 2018)
Biogenic Fe-NPs	Particle size of 19–30 nm	*Citrullus lanatus*	Modulate Antioxidant Potential and Defense-Linked Hormones in *C. lanatus* Seedlings	(Kasote et al., 2019)
Biogenic Ag-NPs	Particle size of 6-26 nm	*Oryza sativa*	Enhancing germination and starch metabolism of aged *O. sativa* seeds	(Mahakham et al., 2017)
ZnO-NPs and Fe_2O_4-NPs	ZnO-NPs 20–30 nm Fe_2O_4-NPs 50-100 nm	*Triticum aestivum*	Improved the plant growth and reduced the oxidative stress and cadmium concentration in *T.aestivum*	(Rizwan et al., 2019)
Si-NPs	Si-NPs 90nm	*T.aestivum*	Improved the biomass and yield while reduced the oxidative stress and cadmium concentration in *T.aestivum* grains	(Hussain et al., 2019)
Au-NPs	Au-NPs 10-30nm	*Zea mays L.*	promoting *Z. mays* seed germination	(Mahakham et al., 2016)
Nano-pyrite (FeS_2)	FeS_2-NPs10-30nm	*O. sativa*	Use as NPK fertilizer *O. sativa* production	(Das et al., 2018)

Seed priming and seed nano priming are not the same thing, because traditional seed priming mostly include hydropriming using water or solutions from which the chemicals are adsorbed on the seed and seed coating is formed with these nutrients, biopolymers or hormones. Suspensions and nanoformulations are utilized in seed nano-priming, and the nanoparticles may or may not be taken up by the seeds (Acharya et al., 2019). Even when nanoparticles are taken up, the majority of them remain as coating on the seed surface (Acharya et al., 2019; Montanha et al., 2020). To defend against diseases while storage or in the fields, fungicides or bactericides are combined with such seed coatings (Gross et al., 2020). Khodakovskaya et al. (2009) published one of the first studies demonstrating the ability of nanomaterials to alter seed germination. Despite the lack of seed priming, these researchers revealed that tomato seeds can absorb carbon nanotubes. The water intake was boosted by these nanotubes, leading to 2-fold more blooms on tomato plants. Carbon nanotubes have also been shown to improve the gene expression of various types of channel proteins for water and alter seed metabolism in plants like barley, soybean, and maize (Villagarcia et al., 2012). For seed nano-priming, distinct nanomaterials have been shown to have potency such as metallic, biogenic metallic, and polymeric nanoparticles (Siddaiah et al., 2018). This leads to alteration of gene expression that can change the metabolic processes like production of hormones, and cause rapid development of shoot and root. After seed priming, high resistance to pests and other biotic and biotic factors in the field develops in the plants due to rise in the antioxidant activity and enzymatic activities in the defense system (Itroutwar et al., 2019; Siddaiah et al., 2018).

Application of different Nanoparticlesin seed priming

Silver nanoparticles (Ag-NPs)

After carbon nanotubes, Ag-NPs are now one of the most frequently utilized nanoparticles. Antimicrobial properties of these NPs are widely employed in a variety of fields, including detergents, textiles, and polymers (Awasthi et al., 2017). For their distinct properties such as preferred optical, electrical and magnetic properties, Ag-NPs are highly prized. Thus, they can be mixed in cryogenic superconducting components, electronic materials, biosensor materials, cosmetics, composite fibers, checking the action of ethylene, and antimicrobial applications in plants. They are also suggested to be beneficial in gardening and other agricultural operations because of Ag-NPs capacity to prevent seeds from bacterial and fungal attack (Parveen, Rao, 2015).

Silica nanoparticles (Si-NPs)

Following oxygen, Silicon (Si) is the most prevalent element on earth contributing around 31% of earth's crust (Dietz, Herth, 2011). Nanosilica is a valuable substance with applications in variety of disciplines of research and technology, biology and electronics. According to some experts, Si might help plants cope with salt stress (Wang et al., 2011). Si helps to enhance the light absorption of leaves, photosynthetic activity, plant resistance to biotic or abiotic stress, organ longevity, evapotranspiration reduction, and the mechanical strength of leaves. The epidermal tissue of the secretory organs of plant contains Si (Rastogi et al., 2019). Improvement in crop quantity and quality has been proven by using silicon fertilizers in a variety of climates and soil in different plants. Silicon NPs are able to influence plant metabolism because of their unique physiological features(Rastogi et al., 2019). Furthermore, DNA and other chemicals may also be transported into animal and plant cells by silica NPs (Wang et al., 2011). Germination characteristics like speed of germination, dry weight, and radicle height of plant are all improved by nanosilica (Rastogi et al., 2019; Wang et al., 2011).

Copper nanoparticles (Cu-NPs)

For proper growth and reaction involved in photosynthesis, copper (Cu) is a necessary component. It participates in exchange of proteins and hydrocarbons. Various oxidizing enzymes, such as ascorbic acid oxidase and polyphenol oxidase, include copper (Leng et al., 2015). For plant metabolism and development of plant, Cu is essential. Excess amount of copper can cause toxicity but its deficiency is indicated by curled leaves (Leng et al., 2015). Cu-NPs released from a variety of goods have the potential to harm individuals and ecological systems (Chen et al., 2012). Copper oxide (CuO) NPs have been found to be hazardous to aquatic creatures like crustaceans, algae, zebra fish, and protozoa in recent researches (Chen et al., 2012). On the other hand, for *Vigna radiata (L.) R. Wiclczek* seedling development, metabolism and germination, less CuO concentrations were shown to be preferable (Singh et al., 2017). However, some past findings are unclear becausethe impact of Cu-NPs on plants is still to be examined thoroughly (Leng et al., 2015).

Iron nanoparticles (Fe-NPs)

In the earth's crust, iron (Fe) is the fourth most abundant element and is considered non-toxic (Li et al., 2006). All organisms require iron as a micronutrient. It is essential for formation of chlorophyll, process of photosynthesis, and respiration (Najafi Disfani et al., 2017). Fe-NPs are one of the many nanoparticles employed in restoration of wastewater (Fu et al., 2014) and environmental applications (Najafi Disfani et al., 2017). In plant germination, proper development, and increased output, iron oxide (FeO) NPs play a critical role. Because iron is the most abundant component of chlorophyl, elevating FeO-NPs decreases iron insufficiency and boosts levels of chlorophyll a and chlorophyll b (Ghafariyan et al., 2013). As a result, iron oxide NPs have a significant impact on the advancement of agriculture and other disciplines due to their vital role in plants (Li et al., 2006). To improve iron availability to the plants, increase height, biomass and root length, and influence the action of hormones and antioxidant enzymes, FeO-NPs are also used as nano-fertilizers.

Zinc oxide nanoparticles (ZnO-NPs)

Because of its function in formation of chlorophyll and carbohydrates production, zinc is a necessary element for plant development. The absorption of harmful heavy metals is reduced when zinc levels in plants are increased and thus their toxic effects are reduced. Nanoparticles are utilized in a variety of industries including biosensors, electrodes, health and home products. While in agriculture, Zinc nanoparticles are mainly used because f their major functions in physiological responses and anatomy of plants (Awasthi et al., 2017). ZnO is required for regulating the metabolism of phytohormones and numerous enzyme functions, including superoxide dismutase and dehydrogenases (Rajput et al., 2021a). Because of their wide surface area, photodegradation, low toxicity, extended life duration, high pore volume, nanoparticles of zinc oxide can be employed as catalysts, polymer additives, chemical absorbents, and antibacterial. The effect of ZnO-NPs on seed germination in a variety of plant species has become the focus of past few researches (Awasthi et al., 2017; Gaafar et al., 2020; Sharma et al., 2021). However, due to the biological activity of metal-based NPs, the use of ZnO-NPs nano-fertilizer has been observed to have harmful impacts on plants (Itroutwar et al., 2020). According to several studies, nano-ZnO is so poisonous that it can halt plant root development.

Impact of nano-priming in abiotic stress

Pollution and salinity of soil can substantially reduce quantity of harvests (Maswada et al., 2018). Owing to direct ionic impacts on metabolism of plants as well as nutrient and water shortages, plant development is slowed down due to high salt content (Abdel Latef et al., 2017). Anthropogenic causes of heavy metal accumulation include waste disposal and burning, discharges from sludge and sewage, industrial operations, and use of fertilizers while natural or geogenic causes includesome local geological events or accumulation from air (Qayyum et al., 2017).

Under high salinity, roots were elongated and germination was enhanced on priming of manganese nanoparticles n jalapeno pepper seeds (*Capsicum annuum L.*). Moreover, on properly modifying sodium distribution between shoots and roots, salt stress was reduced via oxidative stress control (Ye et al., 2020). Priming of zinc NPs on lupin seeds increased their tendency to withstand the effects of salt stress along with the maintenance of pigments involved in photosynthesis and growth metrics like fresh and dry weight and root and shoot length. Because of higher amounts of organic compounds, antioxidant enzymes, phenols and photosynthetic pigments, Zn NPs primed lupin seeds showed promoted plant growth in high salt levels (Figure 1).

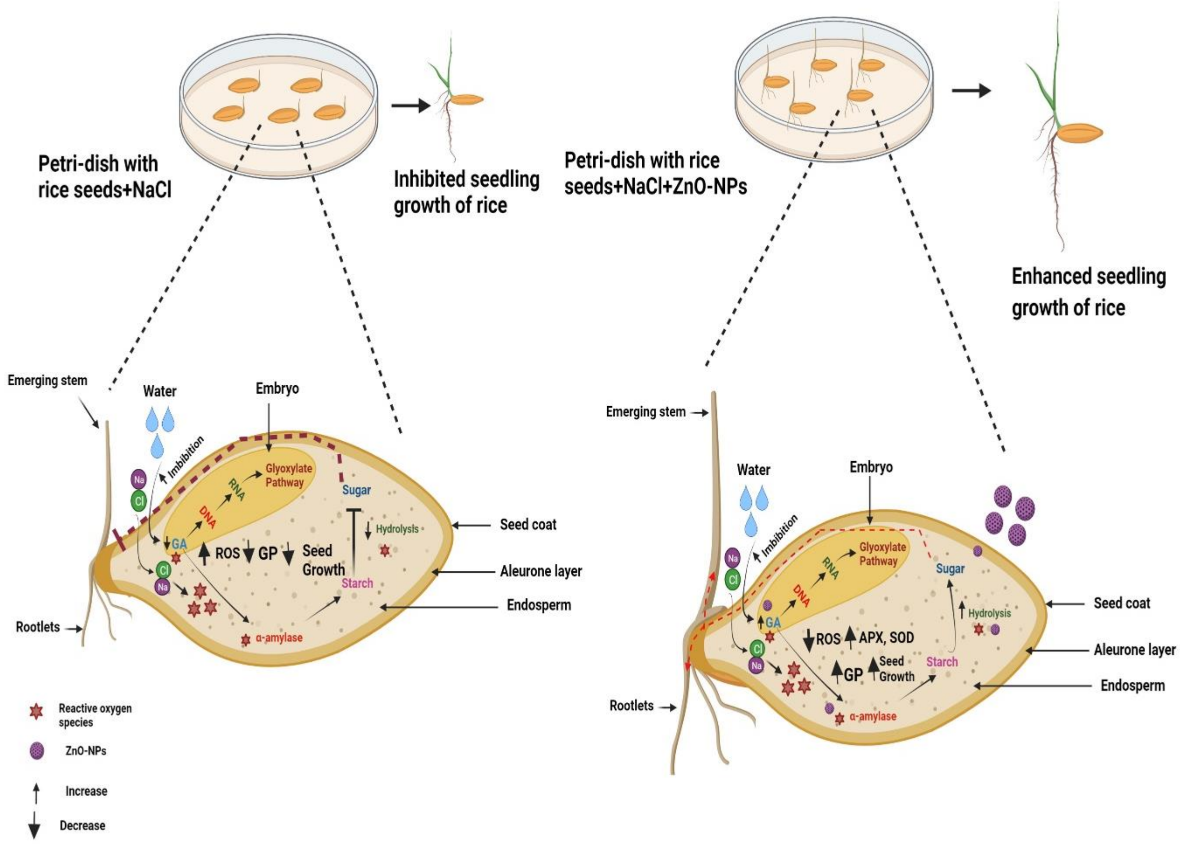

Fig. 1. Diagrammatic representation of NPs base seed priming and mitigation of abiotic stress (Salinity stress) at germination stage of rice plant

Enhanced germination, higher levels of chlorophyll, and better development in salty circumstances were demonstrated by nano-iron treated sorghum seeds (Maswada et al., 2018). Such findings suggest that not only to promote germination of seeds but also to prevent stress, this technique may be utilized. Rizwan et al. (2019) demonstrated that when wheat seeds were primed with zinc and iron nanoparticles in an instance of heavy metal accumulation, cadmium concentration was reduced in the grains due to inhibition of cadmium absorption. In shoots, roots, and grains, cadmium amounts were decreased by 38 %, 55 %, and 83 % respectively using zinc nanoparticles where as it was decreased by 54 %, 56 %, and 84 % in the shoots, roots and grains respectively by using iron nanoparticles. After priming of seeds, amount of zinc and iron was increased in plants (Rajput et al., 2020b). It was found that when seeds were primed with silicon nanoparticles, cadmium absorption was reduced, production of carotenoids and chlorophyll a and chlorophyll b increased, photosynthetic rate and biomass of plant was increased while function of antioxidative enzymes and generation of reactive oxygen species was decreased in cadmium contaminated soil (Rajput et al., 2020a). The synthesis of phytohormones like jasmonic acid and salicylic acid which are produced during plant defense responses might be altered due to deficiencies in minerals like zinc and iron (Khan et al., 2017). Onion extracts were used to prime watermelon seeds with biogenic iron nanoparticles (Kasote et al., 2019). In the early stage of seedling, stress tolerance was boosted in the plants with higher amounts of jasmonic acid and cis-(+)-12-oxo-phytodienic acid (its precursor). Using copper nanoparticles for seed priming of maize can improve drought resilience in plants. Decreased oxidative stress with increased amounts of chlorophyll, anthocyanin, and carotenoids were maintained in the leaves (Nguyen et al., 2020). All this suggests that nano-priming of seeds might help plants cope with stress induced by contamination of heavy metals, drought, nutritional deprivation, or salty environments. Moreover, metabolism is also regulated to increase plant development and resistance to stress. For preventing the negative consequences of the climatic crisis and reducing yield losses due to man made as well as natural impacts on the globe, nano-priming of seeds can be a viable option to induce resistance to abiotic stress in plants.

Concerns

Nanomaterials should be applied with prudence though they have the capacity to be used for coating and priming of seeds. not just in agricultural field, but also in other industrial fields, the proper use of these technologies necessitates the adoption of suitable laws based on reliable research (Kah et al., 2018). Assessment of the outcomes of nanoparticles in the ecosystem taking into account their potential of toxicity in the surroundings and lawful guidelines are necessary for the commercial production of nanoparticles, their applications in the agriculture, and disposal of the industrial discharge.

Many habitats are linked to agricultural operations, and nanoparticles can have a significant influence on them (Lowry et al., 2019). As a result, to produce nanomaterials which are safe for land as well as the larger surroundings, it is critical to comprehend their method of action. Prior to the treatment of seeds, it is important to assess the conditions for priming including size and quantity of nanoparticle, and the time span of treatment. Inhibition of germination, harmful changes in metabolism and structure of cell, alteration in interaction between microbiota and roots, and decrease in plant growth are some negative impacts which can occur due to improper priming conditions (Rahman et al., 2020). To create nanomaterials which are efficient as well as having minimum harmful consequences, it is critical to comprehend the influence of chemical and physical features of nanoparticles on seeds and related organisms (Camara et al., 2019). Polymeric, metallic, and biogenic metallic nanoparticles, all types of nanoparticles discussed above are different from one another in their physical, chemical and biological properties. Seed nano-priming can be designed for a variety of techniques including developing tolerance in plants to biotic and abiotic stressors, biofortification, protection of seeds, or a combination of all factors.

Significant benefits can be attained by using nanoparticles for seed priming. In comparison to applications in soil and foliar, seed treatments decrease the nanoparticle exposure. For seed priming, low amounts of nanoparticles are required which is another plus point. It may be delivered in a regulated manner by manufacturers, to prevent excessive material discharge into the environment. Although, research is needed to figure out how various nanoparticles like polymeric, metallic and biogenic metallic behave and interact with the growth of plant, the quantity of nanoparticles left in the plant will most likely be negligible, extremely little or perhaps zero.

3. Conclusion

For modulation in agriculture, nanotechnology is a potential field. One of the techniques that may be used to improve sustainability is seed nano-priming. These techniques can enhance plant growth and protect them from various stress conditions, leading to improved quality and quantity of food. Thus, seed treatment by nanotechnology has the tendency to shift conventional methods like using agrochemicals in agriculture to a highly sustainable agriculture. Such features combined can lead to a system that ensure reduced environmental damage caused by traditional methods and gives a better and secure product for farmers and consumers.

Many concerns such as priming conditions for seed, scaling up, harmful impacts on plants and associated organisms must be evaluated during the formation of these technological materials in the industries and their field applications. But implementing such techniques of nanoparticles can change the complete management of crops with safer practices for environment, farmers and consumers by reducing pesticide application amounts and their negative impact threats.

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