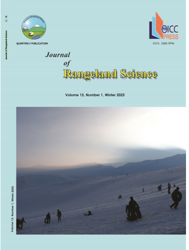

Volume 15, Issue 1, 152508 (1-10)

Journal of Rangeland Science (JRS)

https://dx.doi.org/10.57647/j.jrs.2025.1501.08

Effect of facilitators on enhancement of seed germination, seedling growth and establishment in some plant species

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Original Research

Received:
29 March 2023
Revised:
20 May 2024
Accepted:
4 June 2024
Published online:
20 January 2025

Abstract:

Improper Seed Germination (SG) of plants is an undesirable factor in agriculture, pasture and rangeland restoration operations. Therefore, researchers are trying to examine different techniques to facilitate germination and improve seedling establishment. Facilitators play an important role in managing and improving growth processes, through accelerating SG. In this regard, the key aim of this study is to review different types of facilitators and their effects on the germination, growth, and establishment of plants. Results showed that: firstly, the most used method by various facilitators was seed pretreatment and secondly, most of the germination tests for nanoparticles have been done in laboratory environments. It is necessary to examine these facilitators in the field and natural environments to determine their real efficiency and effectiveness. Thirdly, it seems that the use of effective microorganisms is much more cost-effective than nanoparticles due to the ease of use in large areas, cheaper price and higher efficiency. The general positive effects of facilitators include improving environmental stress resistance, plant growth, surface coverage, root depth, root length, the fresh and dry weight of root, SG, crop quality, and yield. Their adverse effects also differ depending on the various characteristics of both facilitators and plants.

Keywords: Germination; Facilitator; Nanoparticles; Microorganisms

Introduction

Seed germination provides a suitable platform for plant growth, development, and performance. Wide-range factors have been threatening the seedling survival of different species, especially in arid and semi-arid lands. Since plants growth begins from SG, success in this stage has a critical role in life survival, succession, and final density per unit area, and preservation of the PS. Weak germination and establishment of plants are significant problems in these regions (Allen, 2019). Thus, it is essential to use techniques to improve the germination and establishment of plant seedlings in arid land.

One of the most important ways to improve this is to use seed facilitators (Moameri and Abbasi Khalaki, 2019). Using nanoparticle-type facilitators improves plant performance to absorb nutrients, germination and plant production, repel pests and diseases, and to create a substrate for planting plants (Eskandarinasab et al., 2019).

The reason for the increase in germination speed in seeds treated with facilitators can be due to the increase in the activity of regulatory enzymes such as alpha-amylase, increase in ATP production, increase in RNA and DNA synthesis, and increase in mitochondrial function (Mosavi et al., 2021). Different studies are trying to find appropriate methods to increase the percentage of SG. Seed pretreatment with facilitators is recognized as an economical, simple, and recommended technique. The general results of facilitator experiments under different soil, climate, and ecological conditions for various plants showed improvements in the SG, seedling growth, seedling emergence vigor, plant establishment, and plant forage quality and production (Moameri et al., 2018).

Therefore, this review was conducted to 1) introduce the most used types of facilitators regarding their influential role in the growth and establishment of plants; 2) summarize the positive and negative impacts of selected facilitators on plant germination, growth, and establishment.

Types of facilitators and their effects on growth and establishment Nano-particles

Nano-particles are three-dimensional materials with a size of 1 to 100 nm. Although there are different ways to synthesize nano-particles, biological production is considered due to advantages such as environmental compatibility and low energy consumption. These particles are characterized by high thermal conductivity, catalytic reactivity, nonlinear optical performance and chemical stability due to their large surface area-to-volume ratio (Agarwal et al., 2017). Furthermore, some nano-particle characteristics (e.g., their adsorption, transport, and accumulation) differ in various PS depending on the PS type and the nano-particle's size, chemical combination, structure, and strength (Arora et al., 2012).

Plant responses to nano-particles vary depending on the type of plant species, their vegetative stage, age, and the nature of the nano-particles (Abbasi Khalaki et al., 2022). Through penetrating the seeds, the nano-particles increase germination by increasing the water uptake via the seed (Azarnivand et al., 2011). The large surface area of nano-particles results in adsorption molecules and thus becomes more effective. Using nano-particles as a facilitator is a considerable opportunity to enhance plant production and minimize environmental hazards.

Although nano-particles have high positive effects, their application in large-scale fields is expensive. Nano-particles of trace elements also damage the cell in high concentrations and cause oxidant action. Like other abiotic stresses, they induce the production and accumulation of active oxygen species (Anjitha et al., 2021). Different types of nano-particles have been applied to PS improvement of physiochemical properties.

Nano-silicon is also considered as an excellent growth-promoting agent, increasing plant growth and stimulating or strengthening plant biomass, height, and productivity under stressful situations (Siddiqui et al., 2014). It could amend the saline stress depression on various PS and transfer DNA and chemicals into plants and organs of living organisms (Torney et al., 2007).

Silver nanoparticles (AgNPs) have lately been applied in the endowment of new formulations like pesticides. It vastly improves silver's bactericidal and fungicidal efficiency against furthermost significant plant pathogenic fungi and protects seeds (Lamsal et al., 2011). Effects of Titanium dioxide (TiO_2) nano-particles on germination and growth of *Eurotia ceratoides*, *Nitraria schoberi*, *Halothamnus glaucus*, *Salsola rigida*, *Kochia prostrata* showed that in most of these plants, low concentrations of nano-titanium dioxide had no critical impact on germination and seedling growth. However, high concentrations (1500 mg/L) reduced germination and seedling growth by causing toxicity. High condensation of nano-magnetite (Fe_3O_4) reduced the SG and seedling growth of *Agropyron desertorum* and *Agropyron elongatum* (Kamali et al., 2017). Most studies conducted on nano-particles of iron oxide, silver and silica oxide. The effect of some nano-particles including potassium silicate, potassium nitrate, and silver nano-particles, on the studied species including *Onobrychis sativa*, *Thymus kotschyanu*, *Festuca ovina*, and *Silybum marianum*, has been investigated (Mosavi et al., 2021). Also, these studies have been limited to Iranian and Turanian vegetation areas including high mountains, dry forests, and cold semi-steppe areas (Fazeli-Nasab et al., 2018). Abbasi Khalaki et al. (2022) summarized the effects of nano-particles on biological activity and plant growth parameters in figure 1.

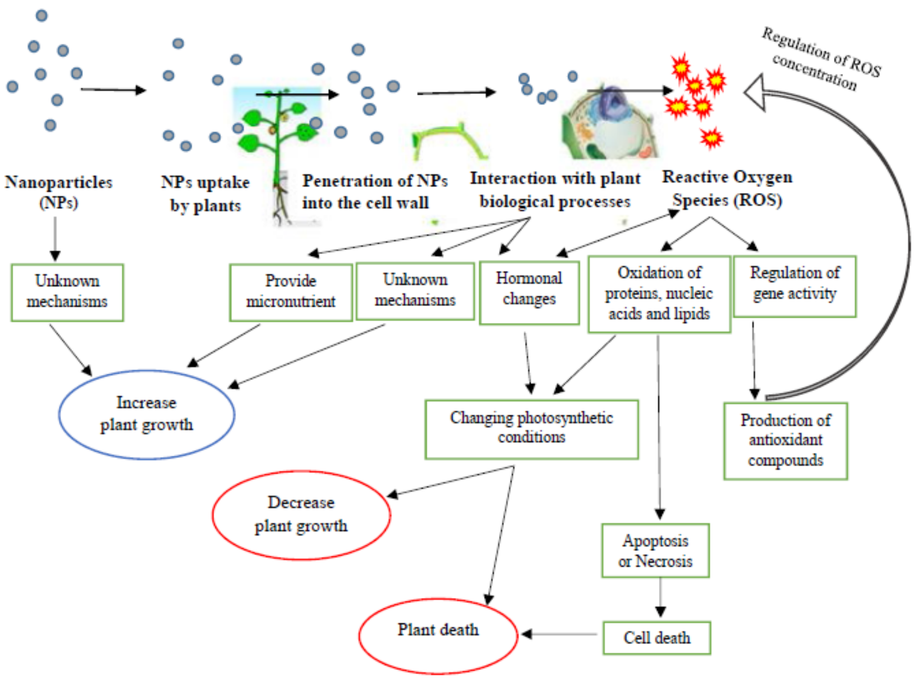

Figure 1. The effects of nanoparticles on biological activity and plant growth parameters (Abbasi Khalaki et al., 2022).

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Hydrogels

Lack of water and its low quality are two dangers to natural resources in most tropical, temperate, arid, and semi-arid lands. Moreover, rainfall is usually low in arid and semi-arid regions, and its circulation and distribution are irregular. Therefore, water shortage and drought pressures are restrictive features for plant production and control of the plant's existence. Vegetation restoration and recovery with the help of hydrophilic hydrogels such as hydrogels are effective during ecosystem restoration programs. Hydrogels with three-dimensional hydrophilic polymer networks could absorb water or aqueous solutions in their network structures without losing structural integrity (Zhang et al., 2022).
Hydrogels can improve germination by solving the dehydration difficulty and improving the product's quantity and quality. Hydrogels are a set of hydrophilic molecules and polymers that can store high amounts of water, which lead to an increase in water-holding valence, reduce the soil water and nutrients leaching, decrease evaporation rate from the soil surface and increase soil aeration, improvement growth and thus increasing yield under normal and stressed conditions. Hydrogel polymers enable to increase their initial weight a hundred times within a short period and release the absorbed water gradually under stressed conditions. Koladosu et al. (2022) reported that hydrogel polymers increase soil aeration and cause better plant growth and thus, yield. The use of hydrogel polymers due to the water supply required by the plant can also be a significant factor in increasing plant resistance to heavy metal stress (figure 2). In addition to the benefit of increasing available water, hydrogels can improve soil physical, chemical, and biological properties, especially in arid and semi-arid areas where rainfall is scant and irregular long dry spells and evaporation are high (Guo et al., 2020; Albalasmeh et al., 2022).
Several studies in arid and semi-arid lands stated that hydrophilic polymers enhanced water-holding capability in sandy soils and reduced water losses over leakage. For example, Wu et al. (2008) and Nezami et al. (2010) obtained about 11 and 50% reduction in water usage due to polymer treatment compared with control. Bal et al. (2008) verified the sound performance of hydrogels in increasing soil moisture content and decreasing bulk density and electrical conductivity of sandy soil. The germination and growth experiments showed that CMC-g-PAA/HC was retained with 78.3% germination vigor (GV) and 80.0% germination (GR) ratio, dramatically improving plant growth to 28 days. The results indicated that as-prepared eco-friendly CMC-g-PAA/HC could be a water retention agent and nutrient carrier in arid and semi-arid regions (Zhang et al., 2022). Moreover, the cost of CMC-g-PAA/HC raw materials in this study is potentially competitive with other products in the market. The effect of various physical and chemical stimuli on hydrogels is briefly shown in figure 3.

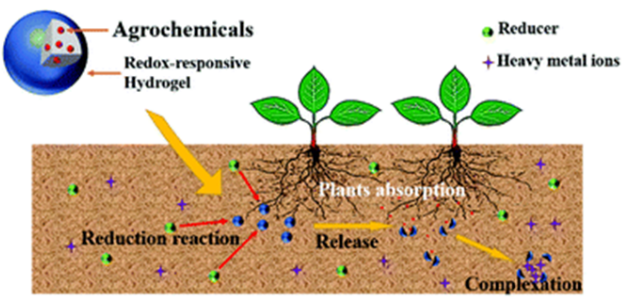

Figure 2. Vegetation restoration with the help of hydrogels (Saha et al., 2020).

Organic or biotic matters

Organic or biotic matters (bio-fertilizers) are a marketable mixture of microbes including yeasts, fungi, bacteria, and actinomycetes. Photosynthetic bacteria could work synergistically with other microorganisms to decrease the pathogenic prevalence. Studies have shown that effective micro-organisms can positively affect the physiological characteristics of plants, such as photosynthesis, soil biological activity, and plant disease, thus leading to increased plant yields (Nayak et al., 2020).
When effective micro-organisms are used with soil or as a foliar spray on plants, they increase the photosynthetic and nitrogen-fixing bacteria and then cause more plant growth and higher yield and quality by increasing photosynthetic efficiency, increasing surface area, and stabilizing nitrogen (Sairam and Srivastava, 2002).
The increase in stem length by effective microorganisms is due to the production of some growth-promoting hormones, especially axing gibberellins and cytokines (Olle and Williams, 2015). Zydlik and Zydlik (2008) pointed to the positive effects of effective micro-organisms in the soil and reported an increase in the root volume of plants. The results showed the increased phosphorus, nitrogen, and potassium in the plant culture medium. Mowa and Maass (2012) designed an experiment to investigate the influence of the effective micro-organisms on SG of *Harpagophytum procumbens*. The results showed that germination increased by 32% in the treatment of effective microorganisms. The effective micro-organisms increase soil and plant resistance to dehydration, carbon mineralization, and root penetration in the soil (Anon, 1995). The effect of organic matter on soil properties is depicted in figure 4.

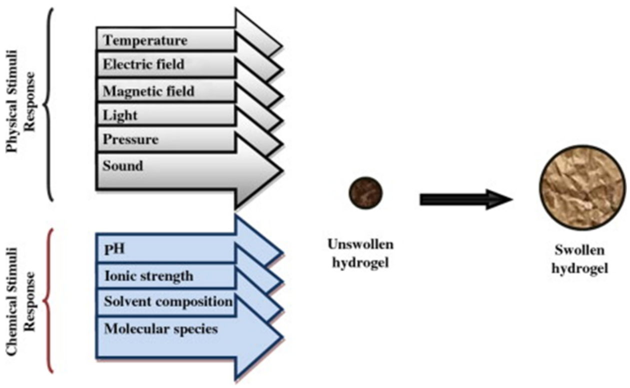

Figure 3. Stimuli response swelling hydrogel (Ahmed, 2015).

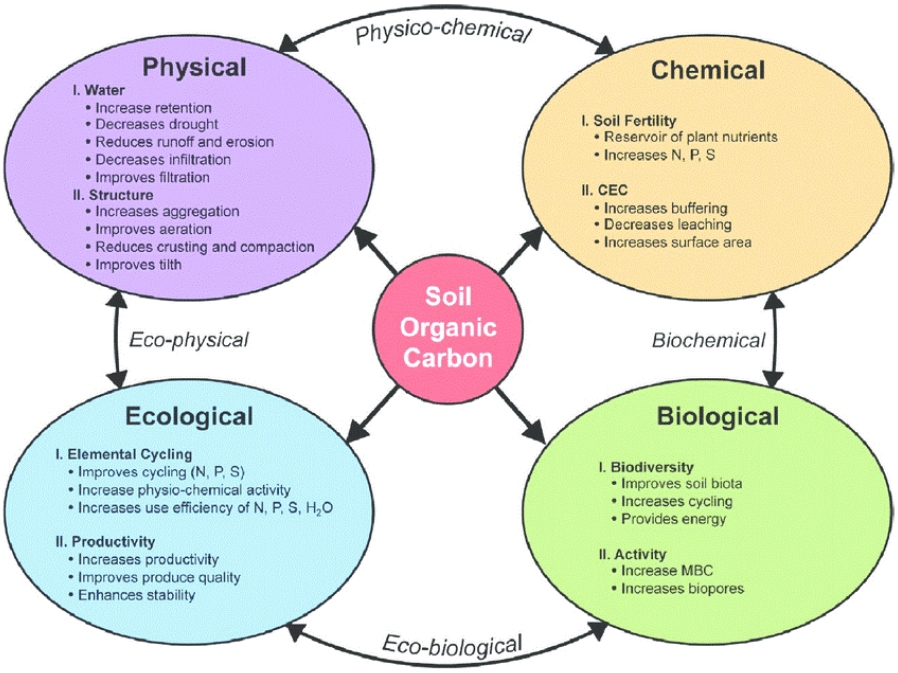

Figure 4. Effect of organic matter on soil properties (Lal, 2016).
(Abbreviation: MBC: microbial biomass C, CEC: Cation exchange capacity)

Seed bio-priming

Seed bio-priming involves covering the seed with some helpful bacteria and hydrating it for a certain period without cracking the seed coat's root. Seed priming is a novel yet simple technique that involves using beneficial and eco-friendly biological agents to improve the physiological functioning of seeds. This technique also plays a vital role in restoring agroecological balances through the improvement of soil fertility or by decreasing soil and water pollution (Chakraborti et al., 2022). It is a technique for enhancing seed germination, stress management, plant growth regulation, and acting as a bio-control agent/inoculum by inducing plant immunity (Mitra et al., 2021; Sarkar et al., 2021). One of the seed priming methods is using micro-organisms in seed inoculation, known as priming. Using these micro-organisms in seed inoculation increases the yield of plants, especially if the micro-organisms settle in the root zone of plants and coexist with the plant. Priming treatments improve the yield of *Festuca arundinacea* and increase stress resistance. Two genera of *Azospirillium* sp. and *Azotobacter* sp. are nitrogen-fixing free bacteria that can fix nitrogen without forming nodules on the roots. In addition to stabilizing atmospheric nitrogen and increasing the absorption of high-consumption nutrients such as phosphorus and minerals, these bacteria can also metabolize carbon, which is very important as an energy source for the plant. Using these micro-organisms in seed inoculation increases plant harvest, primarily if the micro-organisms used in seed insemination are located in the root zone of the seed and coexist with the plant (Bennett and Whipps, 2008). These bacteria have increased plant growth, effective nutrient uptake, root growth and development, competitiveness with other plants, and resistance to various stresses (Bothe et al., 1992). Figure 5 shows the physiological, biochemical and molecular basis of the prime seed and its effect on germination.

Humic matters

Humic matters are categorized into three subtypes humic acid, fulvic acid, and humic (Muscolo et al., 2013). Humic acid is a dominant component of humic matter and an excellent natural resource generated during organic material's decay. It is active in interacting with organic and inorganic contaminants and is used to increase plant production, growth, and ion binding. Its primary resources are peat and lignites. Colorful organic polymers with irregular molecular formulas are the main form of humic matter. Humic matter lacks nitrogen, phosphorus, or potassium (NPK). While their organic structures motivate plants to form multiple proteins related to germination, secondary metabolites, and abiotic stress stability (García et al., 2016).

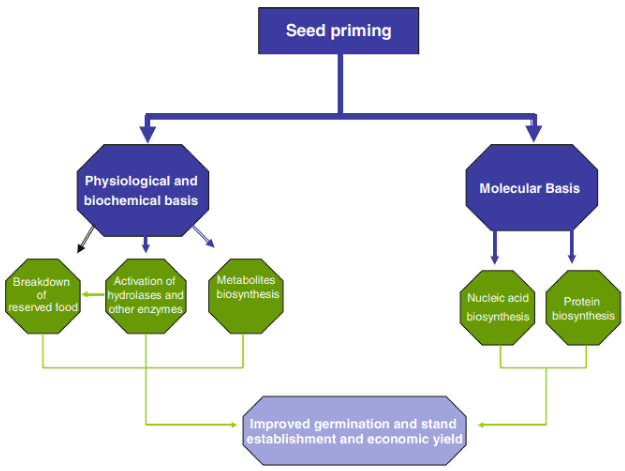

Figure 5. Plant seeds priming mechanism (Farooq et al., 2010).

Humic acids increase the yield of alfalfa and Italian ryegrass, in which their root masses are intensely enlarged (Khaleda et al., 2017). In general, humic matters promote the mitotic spaces in roots, activating lateral root development linked to enhanced root density. This result is attributed to the strengthened absorption of soil nutrients (Zandonadi et al., 2007). Atiyeh et al. (2002) showed that the indoleacetic acid, gibberellins, and cytokinins extracted from the humic acid of vermicompost had critical impacts on plant growth. Humic acid has cytokinin, auxin and gibberellin like activity (Zhang et al., 2006).

Composts

Composts are enriched organic matter produced during an aerobic process of recycling organic matter. Composting has low operating costs and greater social and environmental values (Abdellah et al., 2022). For instance, conventional mushroom compost is generated from a mix of wheat straw ($40-45\%$ dry weight), stable bedding ($20-25\%$), poultry manure ($10-15\%$), and gypsum ($5-10\%$) with varying amounts ($10-15\%$) of other potential substances wastes.
Applying compost as organic fertilizer can reduce fertilizer dependence and improve crop quality. Composts contain high amounts of nitrogen, phosphorous, potassium, and micro-nutrients. Composting can maximize the material cycle and carbon capture. They could increase soil carbon storage plant productivity (Meyer and Monsen, 2004), soil water-holding capability, and nutrient emissions from micro-organisms (Ryals et al., 2015).
The results of the experiment by Sadeghi and Khani (2013) on two species of *Salsola tomentosa* and *Artemisia aucheri* showed that the application of compost up to a concentration of 40 m^3/ha increased the height of the plant (1.25%), canopy diameter (5.1%), The fresh and dry weight of the plant (respectively 0.7% and 9.5%) more than the control treatment (without compost application). Also, the apparent specific mass, electrical conductivity, and organic carbon content of soil increased with compost application in both species.
The results of this experiment showed that the concentration of 30 m^3/ha was the best concentration to increase the growth of both species of *Salsola tomentosa* and *Artemisia aucheri* in dry desert conditions. The composting process is described in figure 6.

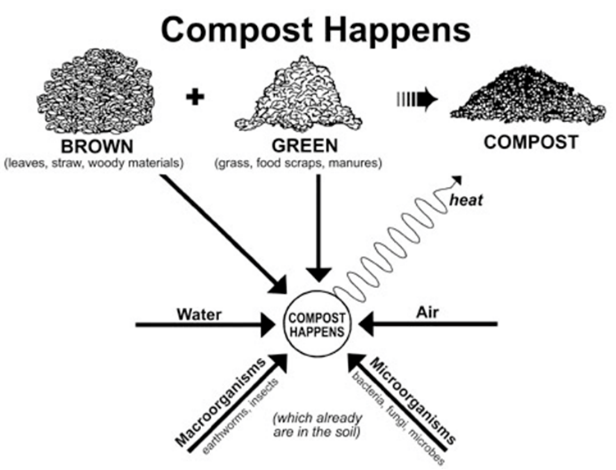

Figure 6. The process of composting (Risse and Faucette, 2009).

Animal manure

Animal manure has been broadly used today due to the sustainable cultivation of plants. It can also be selected as a facilitator because in addition to modulating soil temperature fluctuations, it decreases runoff, increases permeability, and improves soil structure, micro-organism activity, and plant yield with high allopathic properties can reduce weeds (Bilalis et al., 2003). Livestock manure is used not only to meet the nutritional needs of the plant but also to improve the physical structure of the soil so that it can retain moisture during drought and lack rainfall and organic matter, several times as many mineral particles in the soil (Rayne and Aula, 2020). However, inorganic fertilizers have a notable effect on food production increasing worldwide; their high costs, poor distribution systems, and privation of manufacturing capacity are some of the preventing factors to their accessibility for users. Besides its ability to add nutrients to the soil, Kraal manure (ordinary livestock manure in rural areas) also significantly improves the soil structure. The addition of kraal manure to the soil increase the ratio of large to small pore spaces so that they increase a gaseous exchange between the soil and the atmosphere, and this also improves the soil's water-holding capacity. Animal manure contains nitrogen, one of the soil's most valuable nutrients. Animal manure can help plant growth due to its long-term decomposition and activation of other nitrogen-fixing bacteria.

Karrikin matters

Karrikins are a newly discovered group of plant growth regulators. They are Effective for removing seed eco-dormancy and successfully germinating many plant species. One of the priming techniques is a smoke extract, which has been reported to improve SG in various plants (Ghebrehiwot et al., 2013). This stimulatory effect of smoke on germination has been attributed to karrikinolide activity. Karrikinolide is an active chemical compound of butenolide or 3-methyl-2H-furo [2, 3-c] pyran-2-one formula, which is named karrikins (Nair et al., 2013). Karrikins (KARs) have been identified as molecules derived from plant material smoke (Antala et al., 2019), which play a crucial role in various biological processes including seed dormancy release, germination regulation, and seedling establishment. The karrikins regulate seed germination differently in different species (Meng et al., 2017). One possible means of KARs application to agricultural and pasture soils is indirectly through biochar, where KARs have recently been identified (Antala et al., 2019). Sunmonu et al. (2016) revealed that karrikins benefit seed growth by effective mobilization of starch accumulation from cotyledons/endosperms to various seedling tissues, and the likely type of action by which this is facilitated could be by helping hydrolytic enzyme activities, mostly amylase.
Moreover, it has been shown that karrikins decrease lipid

Table 1. Positive effects of facilitators on germination, growth, and establishment of plant species.

Facilitators	Concentration	Stage	Plant species	Test type	Positive effects on plant parameters	References
Nanoparticles	1 mM	Seed	*Sorghum bicolor*	Laboratory	Basis height; leaf height; chlorophyll amount	(Namasivayam and Chitrakala, 2011)
	50 ppm	Seed	*Brassica juncea*	Laboratory	Root height; shoot height; chlorophyll content	(Sharma et al., 2012)
	60%	Seed	*Thymus kotschyanus*	Laboratory	Seed germination; seedling size; fresh and dry weight; medium germination period	(Abbasi Khalaki et al., 2016)
Silicon/silicon dioxide (Si–SiO_2)	40 mg/L	seed	*Agropyron elongatum*	Laboratory	Seed germination; root and shoot size; fresh and dry weight	(Azimi et al., 2014)
	40 mg/L	seed	*Astragalus squarrosus*	Laboratory	Seed germination	(Azimi et al., 2016)
	30 mg/L	Seedling	*Medicago sativa*	Field	Plant growth; yield; plant fresh and dry mass	(Zmeeva et al., 2017)
	1000 mg/L	Seed	*Onobrychis sativa*	Laboratory	Algometric coefficient; shoot height	(Moameri et al., 2018)
	1000 mg/L	Seed	*Alopecurus textilis*	Field	Canopy cover; amount of florescence; survival rate	(Abbasi Khalaki and Moameri, 2019)
	1000 mg/L	Seed	*Medicago sativa*	Field	Plant height; basal space; canopy cover; branch number; depth of rooting	(Abbasi Khalaki et al., 2021)
Zinc/zinc oxide (Zn–ZnO)	10 ppm	seed	*Cyamopsis tetragonoloba*	Laboratory	Plant biomass; shoot and root height; root capacity; chlorophyll content	(Raliya and Tarafdar, 2013)
	15 mg/kg	Seed	*Hordeum vulgare*	Laboratory	Root elongation; biomass	(Najaf Disfani et al., 2016)
	500 ppm	Seed	*Capsicum annuum*	Laboratory	Plant development	(García-López et al., 2018)
Silver (Ag)	40 & 80 ppm	Seedling	*Crocus sativus*	Field	Stem size; humid and desiccated weight of root	(Rezvani and Sorooshzadeh, 2014)
Titanium dioxide (TiO_2)	30 mg/mL	Seed	*Petroselinum crispum*	Laboratory	Shoot and root height; weight; chlorophyll content	(Dehkourdi and Mosavi, 2013)
	40 &60 ppm	Seed	*Foeniculum vulgare*	Laboratory	Germination speed; average germination time; shoot arid weight; vigor index	(Feizi et al., 2013)
	150 mg/L	Seed	*Mentha piperita*	Field	Essential oil content; active ingredient amount	(Ahmad et al., 2018)
	5 ha/kg	Seed	*Ocimum Basilicum*	Field	Photosynthesis speed; chlorophyll content; seedling fresh and dry shoot and root size	(Parande and Mirza, 2011)
Iron/Iron oxide (Fe–FeO)	0.05 mM/L	Seed	*Capsicum annuum*	Laboratory	Plant development	(Yuan et al., 2018)
Gold (Au)	10 μg/mL	Seed	*Arabidopsis thaliana*	Laboratory	SG; seed function; vegetative development	(Kumar et al., 2013)
Superabsorbent	0.4%	Seedling	*Haloxylon persicum*	Field	Weight, root fresh and dry weight and root size	(Zangooei Nasab et al., 2013)
	20 & 30 mg/Kg	Seedling	*Vigna radiata*	Pot		(Javaid and Bajwa, 2011)
Effective microorganisms	1 & 2%	Seedling	*Harpagophytum procumbens*	Field	Germination	(Mowa and Maass, 2012)
	20 mg/L	Seedling	*Cucumis sativus*	Pot	Plant quality; pests and diseases reduction; development	(Olle and Williams, 2015)
Humic acid	86 mg/L	Seedling	Alfalfa *Italian ryegrass*	Pot	Productivity; root density	(Khaleda et al., 2017)

Table 2. Negative effects of facilitators on germination, growth, and establishment of RPS.

Facilitators	Concentration	Stage	Plant species	Type test	Negative effects on plant parameters	References
Silver (Ag)	10 mg/L	Seed	*Linum usitatissimum* *Lolium perenne* *Hordeum vulgare*	Laboratory	Shoot and root height	(El-Temsah and Joiner, 2010)
	40 mg/L	Seed	*Medicago sativa*	Laboratory	Shoot height	(Ramezani et al., 2014)
	800−1600 mg/L	Seed	*Brassica nigra*	Laboratory	Seed germination	(Amooaghaie et al., 2015)
Titanium dioxide (TiO_2)	4%	Seed	*Vicia*	Laboratory	Seed germination	(Castiglione et al., 2011)
	1000 mg/L	Seed	*Nitraria schoberi*, *Salsola rigida*, *Halothamnus glaucus*, *Kochia prostrata*	Laboratory	Germination and seedling development; toxicity	(Dietz and Herth, 2011)
	2.5 mg/L	Seed	*Panicum virgatum*	Laboratory	Plant development; root growth	(Boykov et al., 2018)
Iron oxide (Fe_3O_4)	400 μg/mL	Seed	*Agropyron elongatum* *Agropyron desertorum*	Laboratory	Percentage and seedling development, reduced germination	(Kamali et al., 2017)
Iron/ Iron oxide (Fe- FeO)	750−1500 mg/L	Seed	*Linum usitatissimum*	Laboratory	Shoot and root size	(El-Temsah and Joiner, 2010)
	3.2 mg/Kg	Seed	*Trifolium repens*	Field	Mycorrhizal biomass	(Feng et al., 2013)

peroxidation and oxidative enzyme activity, thereby motivating seedling growth. Levesque (2013) described that exogenous strigolactone treatment had a positive regulatory role in *Arabidopsis* and enhanced the drought stability of the plants. In addition, genetic regulation of karrikin content/response could be responsible for a novel way to develop a crop with high drought tolerance. Generally, karrikins have been presented as generally efficient stimulants that raise SG of more than 1200 species; however, various species are stimulated differently by this plant growth regulator according to their genetic potentials (Dixon et al., 2009).

The most widely used types of facilitators are summarized in the following figure according to their effective role in the growth and establishment of plants (figure 7).

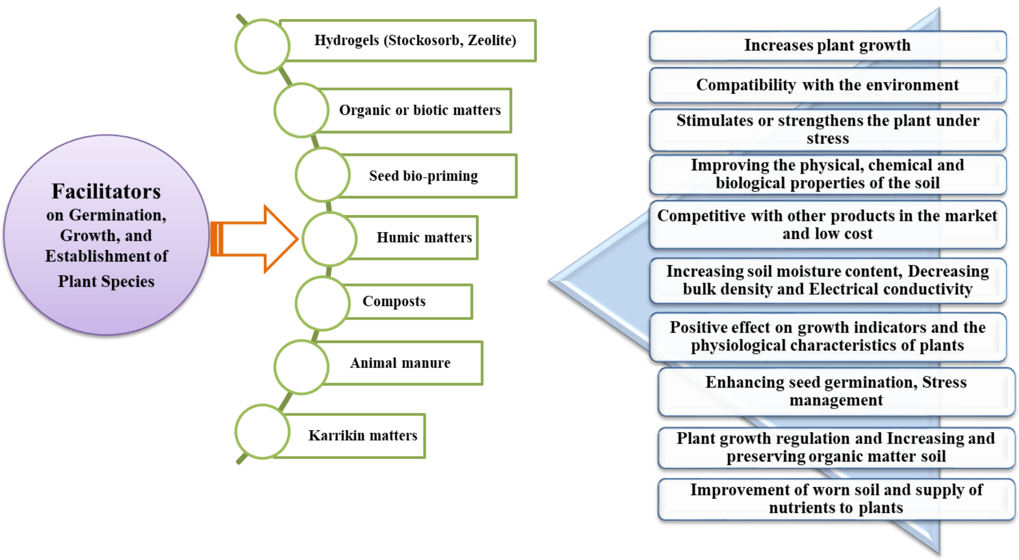

Figure 7. A view of the most used types of facilitators regarding their effective role in the growth and establishment of plants (Brooker et al., 2008).

Positive and negative effects of facilitators

Depending on the type of plant, different concentrations of facilitators can cause different positive and negative effects in the plant. The most use of facilitators is in the seed and seedling stage. Tables 1 and 2 summarize the positive and negative effects of various facilitators examined in this article.

Conclusions and prospects

Seed germination (SG) depends on the potential of embryo growth, hormones, and environmental factors. The results of a review of 85 articles showed that the characteristics of germination and seedling growth, in most cases, have a significant and positive effect on improving germination and growth plants. Facilitators can improve the SG partly by changing soil metals' behavior, their accessibility to plants, toxicity, and leaching potential. Applying facilitators including nanoparticles, hydrogels and organic or biotic maters has significantly enhanced the SG potential. Different concentrations of facilitators have different positive and negative effects on the SG characteristics of PS. Therefore, it seems that facilitators in the appropriate concentrations can improve the seed germination characteristics, growth, and establishment of plants (Tables 1 and 2). While sometimes high concentrations of facilitators had reduced the components of germination, growth, and establishment of plants (Table 2). According to the review of articles, the most used method of facilitators were seed pretreatment and their use in the initial stages of germination. Therefore, the use of various facilitators in order to improve germination and rapid seedling growth in the early stages can increase germination success.

It should be noted that although nano-particles had high positive effects, their application in large-scale fields is expensive and most of the research has been done in a laboratory. Therefore, it is suggested to use nanoparticles to improve plant parameters, their performance in natural habitat and field to determine their real efficiency and effectiveness. According to the review of the articles, the use of effective microorganisms is much more economical than nanoparticles due to the ease of use in wide areas, cheaper price and higher efficiency. Most current methods employ an environmentally sustainable and cost-effective seed pre-treatment process. More effective treatments can be used for each species to promote better establishment, growth, and yield of the species and restore the arid and semi-arid lands.

Authors contributions
Authors have contributed equally in preparing and writing the manuscript.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author, upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Abbasi Khalaki M., Ghorbani A., Esmali Ouri A., Shokouhian A.A., Jafari A. (2021) Some facilitators effects on Alfalfa and sainfoin growth in restoration of dry-farming lands (study area: Balekhlichay Watershed, Ardabil, Iran). *ECOPERSIA* 9 (1): 43–51.

Abbasi Khalaki M., Ghorbani A., Moameri M. (2016) Effects of silica and silver nanoparticles on seed germination traits of *Thymus kotschyanus* in laboratory conditions. *Journal of Rangeland Science* 6 (3): 221–231.

Abbasi Khalaki M., Moameri M. (2019) The use of effective microorganisms and potassium silicate nanoparticles facilitators in the development of Alopecurus textilis species growth traits. *The first international conference and the fourth national conference on the protection of natural resources and environment. University of Mohaghegh Ardabili*

Abbasi Khalaki M., Moameri M., Ghorbani A., Alagoz S.M., Dolatabadi N., Lajayer B.A., Hullebusch E.D. van (2022) Effects, uptake and translocation of Ag-based nanoparticles in plants. In Toxicity of Nanoparticles in Plants. *Academic Press,* 171–192.

Abdellah Y.A.Y., Shi Z.J., Sun S.S., Luo Y.S., Yang X., Hou W.T., Wang R.L. (2022) An assessment of composting conditions, humic matters formation and product maturity in response to different additives: A meta-analysis. *Journal of Cleaner Production* 366:132953.

Agarwal H., Kumar S.V., Rajeshkumar S. (2017) A review on green synthesis of zinc oxide nanoparticles–An eco-friendly approach. *Resource-Efficient Technologies* 3 (4): 406–413.

Ahmad B., Shabbir A., Jaleel H., Masroor M., Khan A., Sadiq Y. (2018) Efficacy of titanium dioxide nanoparticles in modulating photosynthesis, peltate glandular trichomes and essential oil production and quality in *Mentha piperita*. *Current Plant Biology* 13 (1): 6–15.

Ahmed E.M. (2015) Hydrogel: Preparation, characterization, and applications: A review. *Journal of Advanced Research* 6 (2): 105–121.

Albalasmeh A.A., Mohawesh O., Gharaibeh M.A., Alghamdi A.G., Alajlouni M.A., Alqudah A.M. (2022) Effect of hydrogel on corn growth, water use efficiency, and soil properties in a semi-arid region. *Journal of the Saudi Society of Agricultural Sciences* 21 (8): 518–524.

Allen M.F. (2019) Belowground structure: a key to reconstructing a productive arid ecosystem. In The reconstruction of disturbed arid lands. *Routledge,* 113–135.

Amooaghaie R., Tabatabaei F., Ahadi A.M. (2015) Role of hematin and sodium nitroprusside in regulating *Brassica nigra* seed germination under nano silver and silver nitrate stresses. *Journal of Water and Soil Science* 113:259–270.

Anjitha K.S., Sameena P.P., Puthur J.T. (2021) Functional aspects of plant secondary metabolites in metal stress tolerance and their importance in pharmacology. *Plant Stress* 2:100038.

Anon A. (1995) Effective microorganisms and their influence on vegetable production – a review. *Journal of Horticultural Science and Biotechnology* 88 (4): 380–386.

Antala M., Sytar O., Rastogi A., Brestic M. (2019) Potential of karrikins as novel plant growth regulators in agriculture. *Plants* 9 (1): 43.

Arora S., Sharma P., Kumar S., Nayan R., Khanna P.K., Zaidi M.G.H. (2012) Gold-nanoparticle induced enhancement in growth and seed yield of *Brassica juncea*. *Plant Growth Regulation* 66:303–310.

Atiyeh R.M., Lee S., Edwards C.A., Arancon N.Q., Metzger J.D. (2002) The influence of humic acids derived from earthworm-processed organic wastes on plant growth. *Bioresource Technology* 84 (1): 7–14.

Azarnivand H., Sourib M., Etemad V. (2011) Effect of water stress on seed germination of *Artemisia spicier* and *Artemisia fragrant*. *Desert* 12 (1): 17–21.

Azimi R., Heshmati G.A., Kavandi Habib R. (2016) Evaluation of SiO_2 nanoparticle effects on seed germination in *Astragalus squarrosus*. *Journal Rangeland Science* 6 (2): 135–143.

Azimi R., Jankju Borzelabad M., Feizi H., Azimi A. (2014) Interaction of SiO_2 nanoparticles with seed prechilling on germination and early seedling growth of tall wheatgrass (*Agropyron elongatum*). *Polish Journal Chemical Technology* 16 (3): 25–29.

Bal P.M., De Lange A.H., Jansen P.G., Van Der Velde M.E. (2008) Psychological contract breach and job attitudes: A meta-analysis of age as a moderator. *Journal of Vocational Behavior* 72 (1): 143–158.

Bennett A.J., Whipps J.M. (2008) Dual application of beneficial microorganisms to seed during drum priming. *Applied Soil Ecology* 38 (1): 83–89.

Bilalis D., Sidiras N., Economou G., Vakali C. (2003) Effect of different levels of wheat straw soil surface coverage on weed flora in *Vicia faba* crops. *Journal of Agronomy and Crop Science* 189 (4): 233–241.

Bothe H., Körsgen H., Lehmacher T., Hundeshagen T. (1992) Differential effects of *Azospirillum*, auxin and combined nitrogen on growth of the roots of wheat. *Symbiosis* 13:167–179.

Boykov I.N., Shuford E., Zhang B. (2018) Nanoparticle titanium dioxide affects the growth and micro RNA expression of switchgrass (*Panicum virgatum*). *Ecology* 111 (3): 450–456.

Brooker R.W., Maestre F.T., Callaway R.M., Lortie C.L., Cavieres L.A., Kunstler G., Liancourt P., et al. (2008) Facilitation in plant communities: the past, the present, and the future. *Journal of Ecology* 96 (1): 18–34.

Castiglione M.R., Giorgetti L., Geri C., Cremonini R. (2011) The effects of nano-TiO_2 on seed germination, development and mitosis of root tip cells of *Vicia narbonensis* and *Zea mays*. *Journal of Nanoparticle Research* 13 (6): 2443–2449.

Chakraborti S., Bera K., Sadhukhan S., Dutta P. (2022) Bio-priming of seeds: Plant stress management and its underlying cellular, biochemical and molecular mechanisms. *Plant Stress* 3:100052.

Dehkourdi E.H., Mosavi M. (2013) Effect of anatine nanoparticles (TiO2) on parsley seed germination (*Petroselinum crispum*) in vitro. *Biological Trace Element Research* 155 (2): 283–286.

Dietz K.J., Herth S. (2011) Plant nano toxicology. *Trends in Plant Science* 16 (11): 582–589.

Dixon K.W., Merritt D.J., Flematti G.R., Ghisalberti E.L. (2009) Karrikinolide-a phytoreactive compound derived from smoke with applications in horticulture, ecological restoration and agriculture. *Acta Horticulturae* 81 (3): 155–170.

El-Temsah Y.S., Joiner E.J. (2010) Impact of Fe and Ag nanoparticles on seed germination and differences in bioavailability during exposure in aqueous suspension and soil. *Environmental Toxicology* 27 (5): 42–49.

Eskandarinasab M., Rafeiolhossaini M., Roshandel P., Tadayon M.R. (2019) Investigation of seed germination indices and anthocyanin content of Niger (*Guizotia abyssinica*) seedling under the effect of three nanoparticles. *Iranian Journal of Seed Research* 5 (2): 73–89.

Farooq M., Basra S.M.A., Wahid A., Khaliq A., Kobayashi N. (2010) Rice seed invigoration: a review. . *Organic Farming, Pest Control and Remediation of Soil Pollutants* 1 (1): 137–175.

Fazeli-Nasab B., Sirousmehr A.R., Azad H. (2018) Effect of titanium dioxide nanoparticles on essential oil quantity and quality in *Thymus vulgaris* under water deficit. *Journal of Medicinal plants and By-product* 7 (2): 125–133.

Feizi H., Kamali M., Jafari L., Moghaddam P.R. (2013) Phytotoxicity and stimulatory impacts of nanosized and bulk titanium dioxide on fennel (*Foeniculum vulgare*). *Chemosphere* 91 (4): 506–511.

Feng Y., Cui X., He S., Dong G., Chen M., Wang J., Lin X. (2013) The role of metal nanoparticles in influencing *arbuscular mycorrhizal* fungi effects on plant growth. *Environmental Science and Technology* 147 (16): 9496–9504.

García A.C., Souza L.G. de, Pereira M.G., Castro R.N., Garcia-Mina J.M., Zonta E., Lisboa F.J., Berbara R.L. (2016) Structure-property-function relationship in humic substances to explain the biological activity in plants. *Scientific Report* 6 (1): 87–98.

García-López J.I., Zavala-García F., Olivares-Sáenz E., Lira-Saldívar R.H., Díaz Barriga-Castro E., Ruiz-Torres N.A., Ramos-Cortez E., Vázquez-Alvarado R., Niño-Medina G. (2018) Zinc oxide nanoparticles boosts phenolic compounds and antioxidant activity of *Capsicum annuum* L. during germination. *Agronomy* 8 (10): 215.

Ghebrehiwot H.M., Kulkarni M.G., Szalai G., Soós V., Balázs E., Van Staden J. (2013) Karrikinolide residues in grassland soils following fire: Implications on germination activity. *South African Journal of Botany* 88:419–424.

Guo J., Shi W., Wen L., Shi X., Li J. (2020) Effects of a super-absorbent polymer derived from poly-γ-glutamic acid on water infiltration, field water capacity, soil evaporation, and soil water-stable aggregates. *Archives of Agronomy and Soil Science* 66 (12): 1627–1638.

Javaid A., Bajwa R. (2011) Effect of Effective microorganism application on crop growth, yield, and nutrition in *Vigna radiata*(L.) Wilczek in different soil amendment systems. *Communications in Soil Science and Plant Analysis* 42 (17): 2112–2121.

Kamali N., Sadeghipour A., Soori M. (2017) Investigating the toxicity effects of nano Fe_3O_4 on germination and early growth of *Agropyron desertorum* and *Agropyron elongatum*. *Journal of Rangeland* 11 (3): 321–330.

Khaleda L., Kim M.G., Kim W.Y., Jeon J.R., Cha J.Y. (2017) Humic acid and synthesized humic mimic promote the growth of *Italian ryegrass*. *Journal of the Korean Society of Grassland and Forage Science* 37 (3): 242–247.

Koladosu Y., Rafii M.Y., Arolu F., Chukwu S.C., Salisu M.A., Fagbohun I.K., Muftaudeen T.K., Swaray S., Haliru B.S. (2022) Superabsorbent polymer hydrogels for sustainable agriculture: A review. *Horticulturae* 8 (7): 605.

Kumar V., Guleria P., Kumar V., Yadav S.K. (2013) Gold nanoparticle exposure induces growth and yield enhancement in Arabidopsis thaliana. *Environmental Science Articles - Science Research* 461:462–468.

Lal R. (2016) Feeding 11 billion on 0.5 billion hectare of area under cereal crops. *Food and Energy Security* 5 (4): 239–251.

Lamsal K., Kim S-W., Jung J.H., Kim Y.S., Kim K.S., Lee Y.S. (2011) Inhibition effects of silver nanoparticles against powdery mildews on cucumber and pumpkin. *Microbiology Journal* 39:26–32.

Levesque J. (2013) Managing diversity in Pakistan: Nationalism, ethnic politics and cultural resistance [review essay]. *South Asia Multidisciplinary Academic Journal* 1:1–18.

Meng Y., Shuai H., Luo X., Chen F., Zhou W., Yang W., Shu K. (2017) Karrikins: regulators involved in phytohormone signaling networks during seed germination and seedling development. *Frontiers in Plant Science* 7:2021.

Meyer S.E., Monsen S.B. (2004) Habitat-correlated variation in mountain big sagebrush (*Artemisia tridentate*) seed germination patterns. *Journal of Ecology* 72:739–742.

Mitra D., Mondal R., Khoshru B., Shadangi S., Mohapatra P.K.D., Panneerselvam P. (2021) Rhizobacteria mediated seed bio-priming triggers the resistance and plant growth for sustainable crop production. *Current Research in Microbial Sciences* 2:100071.

Moameri M., Abbasi Khalaki M. (2019) Capability of *Secale montanum* trusted for phytoremediation of lead and cadmium in soils amended with nano-silica and municipal solid waste compost. *Environmental Science and Pollution Research* 26 (1): 24315–24322.

Moameri M., Alijafari E., Abbasi Khalaki M., Ghorbani A. (2018) Effects of Nan priming and bio priming on growth characteristics of *Onobrychis sativa* under laboratory conditions. *Journal of Rangeland* 12 (1): 101–111.

Mosavi S.E., Omidi H., Latifi S.A. (2021) Effect of seed pretreatment with auxin on germination, growth and pigmentation indices of radish seedling (*Raphanus sativus*) under salinity stress. *Journal of Seed Research* 11 (38): 1–9.

Mowa E., Maass E. (2012) The effect of sulphuric acid and effective microorganisms on the seed germination of *Harpagophytum procumbens* South African. *Journal of Botany* 83:193–199.

Muscolo A., Sidari M., Nardi S. (2013) Humic substance: Relationship between structure and activity. Deeper information suggests univocal findings. *Journal of Geochemical Exploration* 129:57–63.

Nair J.J., Munro O.Q., Pošta M., Papenfus H.B., Beier P., Van Staden J. (2013) X-ray crystallographic structure determination of the smoke-derived karrikin KAR3. *South African Journal of Botany* 88:107–109.

Najaf Disfani M., Mikhak A., Kassaeec M.Z., Magharid A.H. (2016) Effects of nano Fe/SiO_2 fertilizers on germination and growth of barley and maize. *Archives of Agronomy and Soil Science* 63 (6): 817–826.

Namasivayam S.K.R., Chitrakala K. (2011) Ecotoxicological effect of *Lecanicillium lecanii* (Ascomycota: Hypocreales) based silver nanoparticles on growth parameters of economically important plants. *Journal of Biopesticides* 4 (1): 97–101.

Nayak N., Sar K., Sahoo B.K., Mahapatra P. (2020) Beneficial effect of effective microorganism on crop and soil-a review. *Journal of Pharmacognosy and Phytochemistry* 9 (4): 3070–3074.

Nezami H., Khazaei R., Boroumand Rezazadeh Z., Hosseini A. (2010) Effect of drought stress and defoliation on sunflower (*Helianthus annuus*) in controlled conditions. *Desert* 12 (2): 99–104.

Olle M., Williams I. (2015) The influence of effective microorganisms on the growth and nitrate content of vegetable transplants. *Journal of Advanced Agricultural Technologies* 2 (1): 25–28.

Parande H., Mirza M. (2011) Comparison of nano Fe chelate with Fe chelate effect on growth parameters and antioxidant enzymes activity of *Ocimum basilicum*. *New Cellular and Molecular Biotechnology Journal* 1 (4): 89–98.

Raliya R., Tarafdar J.C. (2013) ZnO nanoparticle biosynthesis and its effect on phosphorous-mobilizing enzyme secretion and gum contents in cluster bean (*Cyamopsis tetragonoloba*). *Agricultural Research* 2 (1): 48–57.

Ramezani F., Shayanfar A., Tavakkol Afshari R., Rezaee K. (2014) Effect of silver, nickel, zinc and zinc–copper nanoparticles on germination, seedling establishment and enzyme activity of alfalfa (*Medicago sativa*) seed. *Iranian Journal of Field Crop Science* 45 (1): 107.

Rayne N., Aula L. (2020) Livestock manure and the impacts on soil health: A review. *Soil Systems* 4 (4): 64.

Rezvani N., Sorooshzadeh A. (2014) Effect of nano-silver on root and bud growth of saffron in flooding stress condition. *Saffron Agronomy and Technology* 2 (1): 91–104.

Risse L.M., Faucette B. (2009) Food waste composting: Institutional and industrial applications. *Bulletin. University of Georgia* 1189:1–8.

Ryals A.J., Cleary A.M., Seger C.A. (2015) Recall versus familiarity when recall fails for words and scenes: The differential roles of the hippocampus, perirhinal cortex, and category-specific cortical regions. *Brain Research Bulletin* 14 (92): 72–91.

Sadeghi H., Khani K. (2013) Determining the best concentration of tea compost as a potential method to maximize the growth of two species of *Salsola tomentosa* and *Artemisia aucher* in dry areas. *Journal of Iranian Agricultural Research* 31 (2): 1–12.

Saha A., Sekharan S., Manna U. (2020) Superabsorbent hydrogel (SAH) as a soil amendment for drought management: A review. *Soil and Tillage Research* 204:104736.

Sairam R.K., Srivastava G.C. (2002) Changes in antioxidant activity in sub-cellular fractions of tolerant and susceptible wheat genotypes in response to long term salt stress. *Plant Science* 162 (6): 897–904.

Sarkar D., Rakshit A., Al-Turki A.I., Sayyed R.Z., Datta R. (2021) Connecting bio-priming approach with integrated nutrient management for improved nutrient use efficiency in crop species. *Agriculture* 11 (4): 372.

Sharma P., Bhatt D., Zaidi M.G.H., Saradhi P.P., Khanna P.K., Arora S. (2012) Silver nanoparticle-mediated enhancement in growth and antioxidant status of *Brassica juncea*. *Applied Biochemistry and Biotechnology* 167:2225–2233.

Siddiqui M.H., Al-Whaibi M.H., Faisal M., Al Sahli A.A. (2014) Nano-silicon dioxide mitigates the adverse effects of salt stress on *Cucurbita pepo*. *Environmental Toxicology and Chemistry* 33 (11): 2429–2437.

Sunmonu T.O., Kulkarni M.G., Van Staden J. (2016) Smoke-water, karrikinolide and gibberellic acid stimulate growth in bean and maize seedlings by efficient starch mobilization and suppression of oxidative stress. *South African Journal of Botany* 102:4–11.

Torney F., Trewyn B.G., Lin V.S.Y., Wang K. (2007) Mesoporous silica nanoparticles deliver DNA and chemicals into plants. *Nature Nanotechnology* 2 (5): 295–300.

Wu L., Liu M., Liang R. (2008) Preparation and properties of a double-coated slow-release NPK compound fertilizer with superabsorbent and water-retention. *Bioresource Technology* 99 (3): 547–554.

Yuan J., Chen Y., Li H., Lu J., Zhao H., Liu M., Nechitaylo G.S., Glushchenko N.N. (2018) New insights into the cellular responses to iron nanoparticles in *Capsicum annuum*. *International Journal of Scientific Reports* 8 (1): 1–9.

Zandonadi D.B., Canellas L.P., Façanha A.R. (2007) Indolacetic and humic acids induce lateral root development through a concerted plasmalemma and tonoplast H^+ pumps activation. *Planta* 225:1583–1595.

Zangooei Nasab S.h., Emami H., Astaraei A.R., Yari A.R. (2013) Effects of stockosorb hydrogel and irrigation intervals on some soil physical properties and growth of *Haloxylon* seedling. *Journal of Soil Management and Sustainable Production* 3 (1): 167–182.

Zhang X., Ervin E.H., LaBranche A.J. (2006) Metabolic defense responses of seeded bermudagrass during acclimation to freezing stress. *Crop Science* 46 (6): 2598–2605.

Zhang Y., Tian X., Zhang Q., Xie H., Wang B., Feng Y. (2022) Hydrochar-embedded carboxymethyl cellulose-g-poly (acrylic acid) hydrogel as stable soil water retention and nutrient release agent for plant growth. *Journal of Bioresources and Bioproducts* 7 (2): 116–127.

Zmeeva O.N., Daibova E.B., Proskurina L.D., Petrova L.V., Kolomiets N.E., Svetlichnyi V.A., Lapin I.N., Kosova N.I. (2017) Effects of silicon dioxide nanoparticles on biological and physiological characteristics of *Medicago sativa* notho subsp. Varia (Martyn) in natural agroclimatic conditions of the subtaiga zone in Western Siberia. *Bio NanoScience* 7 (1): 672–679.

Zydlik P., Zydlik Z. (2008) Impact of biological effective microorganisms preparations on some physico-chemical properties of soil and the vegetative growth of apple-tree rootstocks. *Nauka Przyroda Technologies* 2 (1): 1–8.