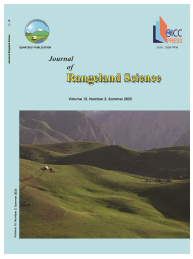

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A review on effects of facilitators in seed germination of range species in ecological zones of Iran

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Abstract:

The growth facilitators are used to improve plant germination rate, and growth can increase rangeland restoration's success in dry regions. This study reviewed articles that were published in scientific databases from 1998 to 2022 and the number of each facilitator in the ecological zones of Iran (Caspian or Hircanian, Iran-o-Tourani, Khalij-o-Omanian, and Zagros) was filtered and displayed in charts. Most publications were related to the use of all facilitators in the Iran-o-Tourani region (Organic or biological matters: 35, Hydrogel:30, Nanoparticles:24, Animal manure:15, Seed Humic acid:12, Compost:12, priming:11). This result can be considered as the need to seed planting of rangeland species in the Iran-o-Tourani region to prevent further destruction of rangelands, increase fodder for livestock, and prevent desertification and fine dust. The lowest number of publications was related to the Zagros and Khalij-o-Omanian ecological zones due to humidity and much precipitation. The results showed that nanoparticles, organic and biological materials and hydrogels have been used the most in all ecological zones due to their lowest environmental risks and the highest efficiency in increasing the yield of plants.

Keywords: Germination rate; Nanoparticles; Degraded rangelands; Organic materials; Hydrogel

Introduction

Ecological zones of Iran and their characteristics

Iran is diverse and comprehensive regarding elevation, climate, soil, and biotic factors, including flora and fauna. Thus, the elevation ranges from −24 to +5678 m asl, and the temperature varies from −30 to +50 °C. Iran's average annual precipitation is 242 mm, and the average annual evaporation potential is 2100 mm; soil encompasses clay, sand, sand-clay, humus, and limestone (Raziei, 2022). It has four main ecological zones (figure 1), including Caspian or Hircanian, Iran-o-Tourani, Khalij-o-Omanian, and Zagros (Pairanj et al., 2011; Khorshid Doust et al., 2020). These variations have caused a variation in the composition and diversity of vegetation so that there are different and diverse plant communities in Iran (Akhani, 1998; Asadi et al., 2011). About 90% of Iran embraces arid and semi-arid climates (Akbarinia et al., 2004). The above conditions have created a bridge for the intersection of the five phytogeographic regions Euro Siberian, Iran-o-Tourani, Mediterranean, Saharo Sindian, and Sudano (Khorshid Doust et al., 2020).

Caspian or Hircanian ecological zone

The Caspian or Hircanian ecological zone covers the southern margin of the Caspian Sea and the northern profile of the Alborz Mountain range from Astara in the west to Golidaghi in the east, which covers about 2,086,371 ha of forests in the country. The climate in this area is moderate and mild, with well-distributed rainfall throughout the year and almost no dry summer period (Akhani, 1998). This region is more humid in the west, and the amount of rainfall decreases gradually towards the east so that the average annual rainfall in the west is about 1500 mm, and in the east, it is 600 to 700 mm. Forest communities in the Hyrcanian forest can be seen higher from 200 – 300 m altitude. Specific forest vegetation communities, however, can be seen above 1000 m altitude. The most important species of this region are: *Fogus orientalis*, *Acer insigne*, *Acer Cappadocicum*, *Ulmus glabra*, *Fraxinus excelsior*, *Tilia begonifolia*, *Cerasus avium*, *Quercus castaneifolia*, *Zelkova carpinifolia*, *Alnus subcordata* and *Carpinus betulus*.

The Iran-o-Tourani ecological zone

Iran-o-Tourani ecological zone, which covers most of the central plateau of Iran, contains about 4,666,941 ha of the

country. Based on topography and elevation, this area is divided into two sub-regions including a mountainous region with cold climate and lowland section with dry climate based on topography and altitude from the sea level (Khorshid Doust et al., 2020). Although the region's climatic conditions have caused the trees to be scattered and far apart due to its large area, it enjoys diverse plant species, so 69% of Iran's flora is located in this area. The main species of this region are: *Astragalus* spp., *Silen Cousinia*, *Allium*, *Nepeta*, *Euphorbia*, *Centaurea acantholimon*, *Salvia* and *Onobrychis*.

This part of the central plateau of Iran covers from the Alborz highlands in the north to the slopes of the Zagros in the west, in the northeast to Azerbaijan, and from the south to the Khalij-o-Omanian regions and covers nearly 85% of the country's area. Its tree communities are mainly juniper communities at high elevations and *Amygdalus orientalis* tree communities at low elevations (Mahmoudi et al., 2019).

Zagros ecological zone

This region extends from the Sardasht of West Azerbaijan to Firouzabad in Fars province, about 5,440,494 ha. This area is under the direction of the sub-humid climate from the Black Sea and the Mediterranean Sea. Some species such as Lappula barbata, Asperugo procumbens, Campanula stevenii, and Rumex tuberosus are only in the northern slope, some species such as Verbascum orientale, Astragalus ankylotus, Turgenia latifolia, and Scabiosa persica only in the southern slope and some including Cerienthe minor, Astragalus persicus, Eryngium thyrsoideum and Cynodon dactylon with (almost) equal proportions in both north and south directions (Mahmoudi et al., 2019). However, the other main species of this ecological zone are *Q.libani* and *Q. brantii Acer Persicum*, *Amygdalus* spp. *Berberis vulgaris*, *Celtis caucasica*, *Crataequs* sp., *Cotoneaster* sp., Cupressus horizantalis, *Fraxinus* sp., *Pistacia mutica*, *Pistacia Khinguk*, *Prunus* sp. and *Pyrus* sp.

Khalij-o-Omanian ecological zone

The ecological zone of the Khalij-o-Omanian, which occupies about 2,119,000 ha of Iran area, covers a part of the southwest and all the southern coasts. Due to the ecological difference, the primary vegetation of this area is divided into two territories, the Persian Gulf and the Oman Sea (Asadi et al., 2011).

The main species of this ecological zone are *Zizyohus spina christi*, *Prosopis farcta*, *Zizyphus nomularia*, *Prosopis spicigera*, *Acacia tortilis*, and *Acacia nilotica*.

The annual precipitation is usually less than 300 mm, with scorching summers and mild winters. However, the winters in the Gulf region are colder and sometimes even freezing.

Degradation of Iran's four ecological zones

In the last three decades, a large area of these areas has been turned into agricultural land, and the amount of destruction of these areas is so high and severe that many plant species

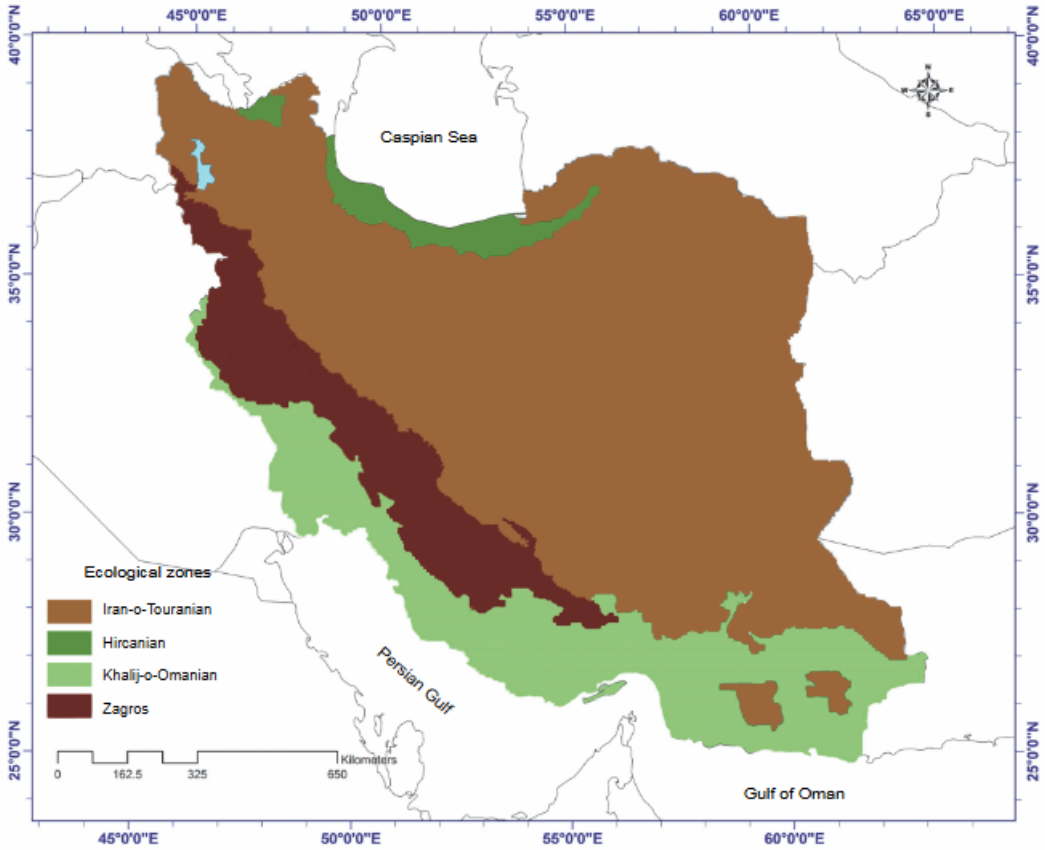

Figure 1. Iran's ecological zones (Hesami et al., 2018).

in these areas have become extinct (Abbasi Khalaki et al., 2019; Akbarinia et al., 2004). The results of the investigations illustrated that among all the ecological zones of Iran, the index of destruction in the ecological zones of the Iran-o-Tourani region increases from the semi-desert area towards the high mountains. In other words, the destruction potential is higher in areas with more rainfall (Akbarinia et al., 2004).

In such a situation, the exploitation of these ecosystems through animal grazing, land use change, development of exploitation of mines, and the impact of other construction and development programs due to the lack of attention to environmental issues provide the basis for the destruction and deterioration of these habitats leading to desertification, and the production of fine dust (Moameri et al., 2018). Therefore, it is necessary to adopt the management approaches and methods of plant restoration in rangeland improving and preventing rangeland destruction.

The importance of using facilitators

Environmental stresses are a big challenge for the growth and development of plants in degraded environments. To overcome this problem, the use of growth facilitators is in priority to improve seed germination and seedling establishment in these areas (Mahmoudi et al., 2019). Growth facilitators accelerate germination, and increase seed strength and seedling establishment (Moameri et al., 2018). We divided growth promoters into seven categories: nanoparticles, organic or biological materials, hydrogels, seed bio-priming, humic acid, compost, and animal manure. Examining the number of studies conducted in Iran's ecological zones can be beneficial for adopting management methods for vegetation restoration.

Materials and methods

Published articles related to the use of fertilizers in the ecological zones of Iran were searched in national and international journals Magiran, Scientific Information Database (SID) and Science Direct from March 2000 to July 2022. As a result, the number of articles related to facilitators in the ecological zones of Iran was collected and presented in graphs.

Results

Nanoparticles

Nanoparticles are discrete collections of atoms on the nanometer scale ($9-10$ m) that have a wide range of potential and actual applications in industry and agriculture. Nanoparticles of silver, silicon dioxide, potassium, calcium, iron, zinc, and phosphorus can have different effects on plants. According to the investigations, many studies have been conducted on nanoparticles and their impact on rangeland plants (figure 2). Most studies of nanoparticles have been on *Artemisia* spp. and *Achillea* spp. rangeland plants. The highest percentage of research activities was conducted on iron oxide, silver, silica, and copper oxide. The effect of some nanoparticles such as potassium silicate, potassium nitrate, and silver nanoparticles on the studied species

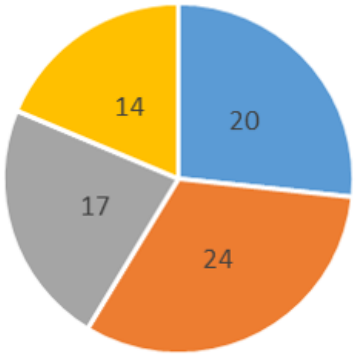

Figure 2. Nanoparticle.

encompassing *Onobrychis sativa*, *Thymus kotschyanu*, *Festuca ovina*, and *Silybum marianum* has been investigated. The results of Azimi et al. (2017) on *Bromus kopetdaghensis* demonstrated that with the increase in the concentration of nanoparticles, the organs of this species, such as height and weight parameters of the plant decreased. Using silicon nanoparticles coated with seeds in a concentration of 10 mg/Liter, the increases in 24%, 66% and 34% of shoot dry weight, root dry weight, and height were obtained compared to control, respectively. In treating foliar spraying of silicon nanoparticles with a concentration of 2 mg, the increases of 27, 68, and 35% in shoot dry weight, root dry weight, and height were obtained compared to control, respectively. According to Askary et al. (2017), the effect of nanoparticles in the alfalfa (*Medicago sativa*) illustrated that iron treatment has a positive effect on growth parameters and photosynthetic pigments and the suitable type of iron fertilizer for alfalfa plant is 25 micromolar iron oxide concentration introduced as the optimal amount.

Organic or biological materials

Beneficial microorganisms can be mentioned among other facilitators to improve the germination of rangeland plants. When beneficial microorganisms are added to soil in the form of foliar spraying or irrigation, they cause more plant growth and increase the quality and performance of the plant by increasing the level of photosynthesis efficiency and the level of nitrogen fixation.

According to figure 3, the most studied organic and biological materials in the Iran-o-Tourani and Caspian ecological zones investigations showed that the most studies in this field were conducted on *Calligonum* spp. and *Medicago* spp., and mycorrhiza, Nitrobacter, biochar, and fungi had more frequency.

Hydrogels

Hydrogels are networks made of natural or synthetic polymers with high water absorption power. Adding hydrogel to the soil causes success in establishing plants and strengthening their growth in arid and semi-arid areas. Investigations showed that most studies were conducted on mountain rangeland and desert plants in the Iran-o-Tourani region (figure 4). Zangooei Nasab et al. (2013) found that the ap-

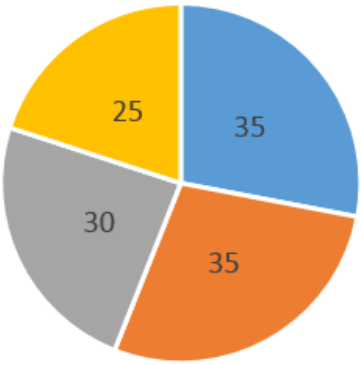

Figure 3. Organic and biological substances.

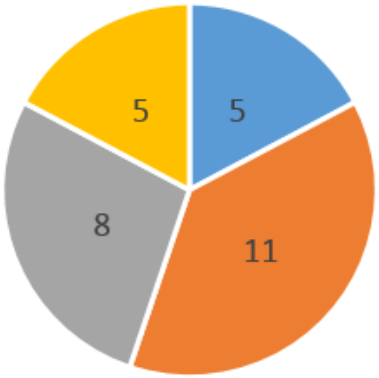

Figure 5. Priming.

plication of hydrogel on Haloxylon persicum had a positive and significant effect on the growth indicators of seedling height, fresh and dry weight of aerial parts, fresh and dry weight of roots, and root length. Khalili et al. (2021) showed that under normal irrigation conditions and the combined application of mushroom and hydrogel, the highest values of cucumber height, number of fruits per plant, final fruit yield, shoot and root dry weight, relative leaf water content and water use efficiency were obtained.

Seed bio-priming

A group of bacteria called plant growth stimulating rhizobacteria, which can accumulate on plant roots and the soil around the roots, stimulate the plant growth. One of the seed priming methods is using microorganisms in seed inoculation, known as priming. The use of these microorganisms in seed inoculation increases the performance of plants, especially if the microorganisms settle in the root zone of the plants and coexist with the plant. Priming treatments improve the performance of *Festuca arundinacea* and improve resistance to drought stress (Rouhi et al., 2011). According to figure 5, many studies in this field have been conducted in the Iran-o-Tourani region, and many seed biological priming conducted on rangeland plants of *Hordeum* spp., *Artemisia* spp., *Astragalus* spp., and *Festuca* spp. in this zone.

Humic acid

Humic acid biologically stimulates the growth of plants and the favorable proliferation of beneficial soil microorganisms and increases the natural resistance of plants against diseases and pesticides. If it is powdered fertilizer, it can be used in the form of irrigation, mixing with soil and foliar spraying. If humic acid is liquid, it is used by two methods irrigation and spraying. The study of Ahmadi et al. (2021) on the *Panicum miliaceum* showed that the combined application of humic acid and mycorrhiza improved the resistance and performance of millet plants by increasing the amount of phosphorus and the ratio of potassium to sodium and reducing the amount of sodium in the plant, reducing the adverse effects of soil and water salinity. According to figure 6, most studies in this field have been conducted in the plants grown in Iran-o-Tourani region such as *Triticum* spp., *Medicago* spp., *Artemisia* spp., and *Trachyspermum* spp.

Compost

In arid and desert areas, lack of water is one of the major environmental factors that adversely affect the growth and production of plants. The process of composting, which is prepared from agricultural waste, can make plants resistant

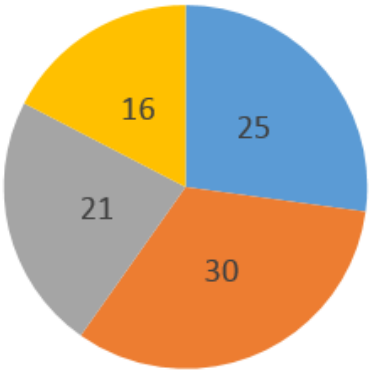

Figure 4. Hydrogel.

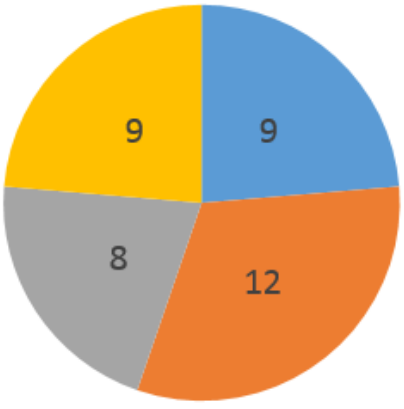

Figure 6. Humic acid.

to drought. Compost increases plant growth by improving soil structure, and plant nutrition and increasing soil storage capacity. The results of Sadeghi and Khani (2013) on species of salsola and Artemisia Aucheri illustrated that the application of compost up to 40 m^3/ha increased plant height (1.25%), canopy diameter (5.1%), weight wet and dry plant (0.7% and 9.5%, respectively) compared to control. Furthermore, the apparent specific mass, electrical conductivity, and organic carbon content of soil increased with compost application in plots of both species. In total, 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 in desert conditions. Figure 7 shows the results of the investigation in the ecological zones of Iran in the field of compost studies.

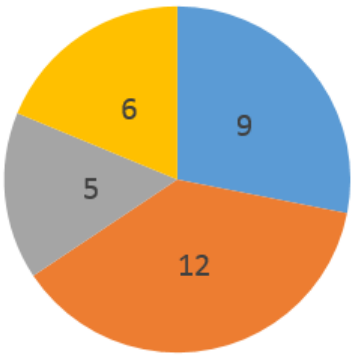

Figure 7. Compost.

Animal manure

Animal manure contains nitrogen, one of the soil's most valuable nutrients. Animal manure is usually incorporated into the soil as much nitrogen as is volatilized into the atmosphere (if is left in the upper soil) rather than mixing in the soil. Animal manure is a soil amendment (Parsafar et al., 2022). Nowrooz Nejad et al. (2010) illustrated that animal manure can increase productivity and fix nitrogen by nodules produced on *alfalfa* roots. Animal manure can assist plant growth due to its long-term decomposition and activation of other nitrogen-fixing bacteria.

Investigations illustrated that most studies in this field had been conducted on the range plants *Artemisia* spp., *Agropyron* spp., and *Bromus* spp. The results of figure 8 showed that most studies are conducted in the Iran-o-Tourani ecological zones, and the minor studies were conducted in the Zagros region.

Comparison of published data of facilitators

A review of the studies has been conducted using growth facilitators in the vegetative areas of Iran. Figure 9 shows that most of the studies conducted on the use of facilitators are related to organic and biological materials, followed by nanoparticles and hydrogel.

More use of these three items in the ecological zones of Iran, especially the Iran-o-Tourani zones, is due to their great influence on plant physiology and increasing germination

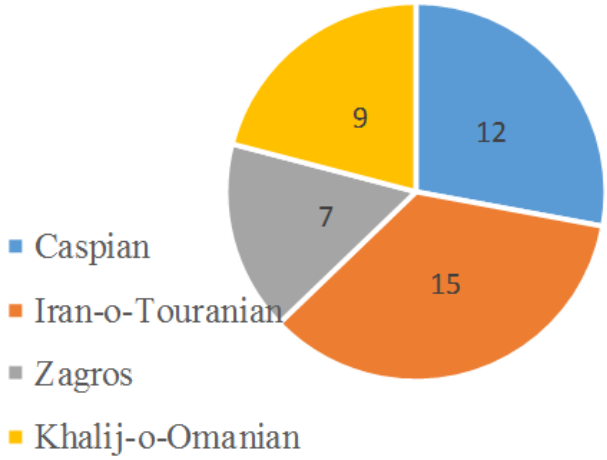

Figure 8. Animal manure.

rate and growth and more water absorption (Oladosu et al., 2022; Delshadi et al., 2017) (Table 1). Despite the great effect of seed priming on plant germination, the use of biological materials in seed priming has been neglected and little research has been done on it.

Discussion

In general, the results of the investigations showed that 100 scientific studies had been conducted on the rangeland species of *Artemisia sieberi*, *Agropyron* spp., *Bromus* spp., *Trachyspermum* spp., as well as desert species such as *Haloxylon* spp. and *Calligonum* spp. Most nanoparticle studies were on the rangeland plants *Artemisia* spp. and *Achillea* spp., with 30 scientific articles. The nanoparticles of iron oxide, silver, silica, and copper oxide with 40 articles had the most studies done on plants and the most in the ecological zones of Iran-o-Tourani with 24 articles.

The most studies on the use of organic and biological substances on rangeland plants *Calligonum* spp. and *Medicago sativa*, with 125 articles. Investigations showed that most studies with 92 articles used hydrogels on plants. The most application of hydrogels in the vegetative regions of Iran-o-Tourani with 30 articles, and the minor study in the Caspian region with 12 articles. Using hydrogels in Iran-o-Tourani

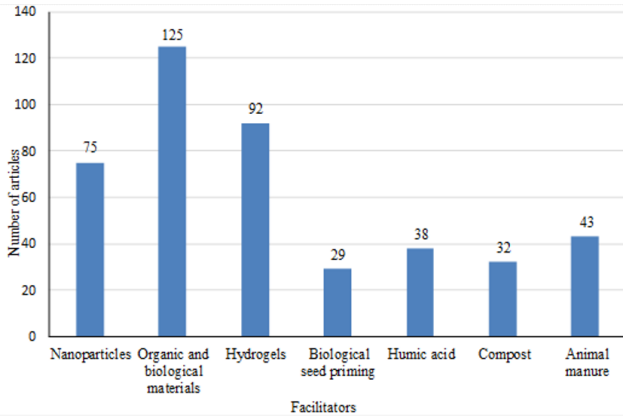

Figure 9. The total number of articles published in the field of studies of growth facilitators in Iran's ecological zones from 2000 to 2022.

Table 1. Growth facilitators used by different studies in Iran's ecological zones.

Genus	Type of facilitators	Amount of used facilitators	References
Bromus kopetdaghensis	Silicon nanoparticles	10 mg/Liter	Azimi et al. (2017)
Medicago sativa	Iron oxide	25 micromolar	Askary et al. (2017)
Haloxylon persicum	Hydrogel	0.4%	Zangooei Nasab et al. (2013)
Cucumis sativus	Hydrogel and fungi	-	Khalili et al. (2021)
Hibiscus sabdariffa	Hydrogel	-	Sajjadi et al. (2021)
Festuca arundinacea	Polyethyleneglycol seed priming	-	Rouhi et al. (2011)
Panicum miliaceum	Humic acid and mycorrhiza	10 Kg/ha	Ahmadi et al. (2021)
salsola and Artemisia Aucheri	compost	40 m^3/ha	Sadeghi and Khani (2013)
Medicago sativa	Animal manure	3%	Nowrooz Nejad et al. (2010)
Festuca ovina	Silver nanoparticles	25, 50, 75%	Abbasi Khalaki et al. (2021)
Onobrychis sativa	Beneficial microorganisms	2%	Moameri et al. (2018)
Onobrychis sativa	Beneficial microorganisms	1 – 2%	Abbasi Khalaki et al. (2021)
Onobrychis sativa	Potassium nanosilicate	1000 mg/Liter	Moameri et al. (2018)
Ferula assafoetida	GA3	1000, 2000, 3000 mg/Liter	Rajabian et al. (2007)
Solidago virgaurea	GA3	125,505, 250 ppm	Parsafar et al. (2022)
Ferula assafoetida	GA3	-	Zare et al. (2011)
Dorema ammoniacum	cooling	-	Naseri et al. (2019)
Thymus kotschyanus	AgNPs-Si NPs	-	Abbasi Khalaki et al. (2016)

regions can be related to water retention to restore pastures and prevent the spread of desertification.

Most studies with 11 articles have been conducted in the biological priming in the Iran-o-Tourani region, in the rangeland plants *Hordeum* spp., *Artemisia* spp., *Astragalus* spp., and *Festuca* spp. Most studies in the field of humic acid have been conducted in the Iran-o-Tourani region with 22 articles and the plants *Triticum* spp., *Medicago* spp., *Artemisia* spp., and *Trachyspermum* spp. The results of the investigation in the vegetative regions of Iran-o-Tourani in the field of compost studies illustrated that the Iran-o-Tourani region has the highest level of studies with 12 articles, and the Caspian vegetative region has the least number of studies with three articles. Most studies on the application of animal manure are related to rangeland plants *Artemisia* spp., *Agropyron* spp., and *Bromus* spp., with 28 scientific articles. In general, the results of studies in four ecological zones of Iran demonstrated that in the Iran-o-Tourani region, compared to other vegetation regions, most studies have been conducted with 139 scientific articles. This result can be attributed to the need to plant rangeland plants to prevent the further destruction of rangelands and the increase of fodder for livestock and Hempen to prevent the increase of desertification and fine dust. The lowest studies were related to the ecological zones of Zagros and Khalij-o-Omanian, and due to the presence of precipitation and the lack of plants' need for growth-facilitating substances, the rangeland plants of this area have been less studied.

Conclusion

The research results showed that the use of facilitators can increase the success rate of plant germination in arid and semi-arid climates. The three facilitators include nanoparticles, organic and biological materials and hydrogel can improve plant productivity in arid and semi-arid climates by increasing soil water holding capacity and supplying plant nutrients. Therefore, their high use in the ecological region of Iran and Turani indicates their good performance in arid and semi-arid environments.

Authors Contributions
All authors have contributed equally to prepare the paper.

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.

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