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RESEARCH ARTICLE

Morphological and Germination Characteristics of *Alhagi maurorum* Boiss. and *Salsola richteri* Kar. Seeds Distributed in the Karakum Desert of Turkmenistan

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ABSTRACT

The Karakum Desert is the largest desert in Turkmenistan and covers a significant part of Central Asia. This desert is home to plant species that can adapt to hot, dry, and barren conditions. During the summer months, the Karakum Desert can get extremely hot, with temperatures reaching up to 50 °C, while in winter, it can drop to -20 °C. Therefore, the desert conditions significant seasonal temperature differences. In winter, rainfall is very low, snow rarely falls, and quickly melts. Afghan winds have an impact on the desert vegetation. The desert vegetation mainly consists of short grasses and woody shrubs. Despite the scarcity of rainfall and high temperatures during the summer months, steppe plants have generally been able to adapt to the harsh conditions of the desert. There are also species that have adapted to the desert climate, such as *Alhagi maurorum* Boiss., *Haloxylon persicum* Bunge, *Haloxylon aphyllum* (Minkw.) Iljin), *Solanum nigrum* L., and *Salsola richteri* Kar. These plants are highly valuable in terms of nutrition for animals and are used as winter animal feed in rural areas. In this study, the seed and germination characteristics of *Alhagi maurorum* Boiss. and *Salsola richteri* Kar, which are tree and shrub-like plants that can adapt to Karakum Desert conditions, were examined. In laboratory study, the morphological characteristics of the seeds were determined, and vitality and germination tests were conducted. Information was obtained about the germination adaptation of these plants in desert ecosystems. As a result of the study, it was determined that *S. richteri* had a very low rate of viable seeds and no germination, while the germination process of *Alhagi maurorum* could take a considerably long time.

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1. Introduction

Turkmenistan is located in the center of the Asian continent and is bordered by Kazakhstan, Uzbekistan, Afghanistan, and Iran. The Caspian Sea is located to the west. Its physical geography is influenced by extremely low humidity and high summer temperatures, resulting in a harsh continental climate (Rustamov, 1994). Approximately 80% of Turkmenistan's territory consists of deserts (Rustamov, 1994), with the largest being the Karakum Desert, covering an area of 349648 square kilometers (Monier, 2017). The Karakum Desert stretches across a wide area between Uzboy in the west, the Amu Darya River in the east, the Kopet Dag and Paropamisus Mountains in the south, and the Kwarazm (Khiva) oasis in the north. Along the eastern edge of the desert, there is a belt of sand dunes

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ranging from 10 to 50 kilometers wide, with some dune hills (barhan) reaching heights of up to 25 meters (Rustamov, 1994).

In the Karakum Desert, the average annual temperature is 15.8°C. The absolute maximum temperature reaches up to 45°C in the north and 50°C in the south. The absolute minimum temperature is -33°C in the north and -28°C in the south. The frost-free period lasts for approximately 230 days. Precipitation sharply decreases during the summer months. The average annual rainfall is 115 mm in the north and 130 mm in the south. In Southeast Karakum, there is almost no rainfall from June to September, while in Central Karakum, 4% of the annual rainfall occurs in July and August. The rainfall regime exhibits large fluctuations in both annual and monthly averages. Rainfall is generally observed from October to May, with the maximum monthly rainfall occurring in March and April. Due to the arid and hot climate, surface temperatures can sometimes reach 76-78°C in July. The average annual surface temperature ranges from 14 to 15°C in the northern Karakum and from 18 to 20°C in the Central and Southeast Karakum. During the driest period from June to September, the relative humidity ranges from 20% to 30% (Rustamov, 1994), and the average annual sunshine duration ranges from 2800 to 3095 hours (Babayev & Gurbandurdyev, 2002).

1.1. Vegetation of Turkmenistan and the Karakum Desert

The causes of desertification in Turkmenistan are the degradation of vegetation, water erosion, the conversion of pastures into swamps, the salinization of irrigated areas, and the formation of salt marshes due to the closure of the Kara Boğazgöl Bay in the Caspian Sea (Rustamov, 1994). In these deserts, there are plant species that adapt to extreme climatic conditions, such as drought, high temperatures, and soil salinity (D. E. Smith, 2010). These adaptations enable desert plants to survive. In the summer months, stomata shrink to minimize water loss, leaves are shed, or waxy substances are produced to cover the leaf surface. In addition, their root systems are well developed to absorb water and can reach the groundwater level (Rustamov, 1994).

The desert vegetation in Turkmenistan mainly consists of halophytic and psammophytic shrub communities, with the dominant formations being *Haloxyleta, Salsoleta, Calligoneta*, and *Artemiseta* (Rustamov, 1994). Steppes dominate in the Karakum Desert. Gandım (*Calligonum triste*) is found in the desert's hilltop areas, while shrubs called borjak (*Sambucus nigra*) are found in the lower regions. Additionally, desert plants such as sazak (*Haloxylon persicum, Haloxylon aphyllum*) and patlak (*Solanum nigrum*) are widespread in this region (Khan et al., 2013). The main tree and shrub species in the desert regions, along with *Haloxylon persicum* and *Haloxylon aphillum*, are various species of *S. richteri*, *Calligonum*, *Ephedra*, *Halothamnus, Ammodendron*, and *Astragalus* (United Nations, 2012). The vegetation in the Karakum Desert consists of an herbaceous cover composed of sand sedge (*Carex physodes*) and annual plants, as well as shrub species such as saksaul (*Haloxylon aphyllum*), cerkez (*S. richteri*), and gandım (*Calligonum triste*) (Rustamov, 1994). The vegetation in the desert includes trees, shrubs, and herbaceous plant species such as *Ammodendron conollyi*, *Haloxylon* spp., *Calligonum* spp., *Ephedra strobilacea*, *S. richteri*, *Stipagrostis* spp., and *Carex physodes*, which spread in sandy areas. The richest vegetation is found in the eastern Karakum region, where the massifs of *Haloxylon aphyllum* and *H. persicum* are located (Rustamov, 1994). Despite low productivity of 200 to 300 kg/ha, the vegetation in the desert is highly nutritious and widely used for grazing thousands of animals such as sheep, goats and camels (Walker, 1979). The vegetation in Turkmenistan deserts is a valuable source of fodder for the livestock sector. The desert areas are used for sheep and camel grazing throughout the year. The vegetation in the desert plays an important ecological role by stabilizing the dunes (Rustamov, 1994).

1.1.1. Yandak (Alhagi maurorum Boiss.*)*

Alhagi maurorum Boiss. (Yandak) is generally found in hot-dry climate regions and is resistant to saline soils. It typically grows and blooms actively during spring and summer months. It can adapt well to challenging environmental conditions such as drought and salinity. Due to its thorny nature, it can hinder grazing of animals in pastures (Mandaville, 2011; Sharma, 2013). The success of adapting to salty and dry soils increases the economic and ecological significance of this species (Jones & Brown, 2015). The spread of this species, especially in agricultural fields, meadows, and pastures, can contribute to ecosystem services such as soil stabilization and erosion control (Brown & Green, 2016). It is an important resource in terms of agricultural and industrial uses (Almenova, 2021). It can be used as animal feed and can also be evaluated as a biomass source in bioethanol production (Sharma, 2013). It is also used as fuel (Khan et al., 2013).

In addition to its valuable ecological characteristics, *A. maurorum* also has medicinal properties. Its roots are widely used in traditional medicine practices (Jones & Brown, 2015). The plant has wound-healing properties (Dastyar & Lysiuk, 2023). *A. maurorum*'s antioxidant, anti-inflammatory, and antidiabetic properties have been demonstrated in various studies (Mazandarani et al., 2017; Sharifi-Rad et al., 2019). It has been used in folk medicine as a laxative, diaphoretic, expectorant, and diuretic. Its oil is used in the treatment of rheumatism, while its flowers are used in the treatment of hemorrhoids, migraines, and warts. Topically, root water extract is used to relax the kidneys and help pass kidney stones (Dafni & Lev, 2002; Mandaville, 2011; Said et al., 2014; Singh et al., 1990). Recently, extracts have been shown to be beneficial against skin hyperpigmentation (Titova et al., 2021). All *Alhagi* species are plants with nectar that are of great importance for beekeeping. Due to its antibacterial property, its water and infusions are used in folk medicine for the treatment of colitis, dysentery, inflammation of the colon and duodenum, stomach ulcers, and gallbladder inflammation (Teshaevna et al., 2022). It is used in traditional medicine to treat constipation and rheumatic pains (El-Sayed et al., 1993). *A. maurorum*'s seed coat is small, hard, and durable. It has a brownish color and typically resembles a small kidney bean in shape. This feature protects the seeds against external factors and enables them to maintain their germination abilities in different ecological conditions.

1.1.2. Çerkez (*Salsola richteri* Kar.)

Salsola richteri Kar, which spreads in the Karakum Desert, is classified as a halophyte due to its ability to grow in saline soils and its tolerance to high salt concentrations (Abideh, 2015). Its flowers are pale green or yellowish green in color and usually bloom between August and September (Brown & Green, 2016; J. K. Smith, 2018). Its spread is limited because it grows in drifting sand, making it highly valuable as a sand stabilizer (Kaul, 1970). This plant species plays an important role in desert ecosystems due to its ability to grow in saline soils. Additionally, it is widely used in agricultural lands due to its ability to prevent soil erosion. Due to its tolerance to high salt concentrations, it has the potential to be used in areas affected by soil salinization. *S. richteri*, a large shrub, can grow to 1.5-2 m and live for 25 to 30 years. It has a deep root system, allowing the plant to access water sources more effectively (Abideh, 2015). The main root, which grows vertically and horizontally, can reach 120 cm, while the lateral roots can extend up to 7-9 m and reach depths of 3-4 m, reaching the groundwater level (Petrov, 1935). In the *S. richteri* formation, 12 to 20 different plant species have been recorded, all of which have adapted to living in unstabilized sand (Rodin, 1963). *Salsola* roots generally grow horizontally in sands where the groundwater level is deep (20-25 m), while they primarily develop vertically in sands close to the water level (8-10 m). Like many other shrubs, *S. richteri* forms new roots from its sand-covered stems (Nechayeva et al, 1973). *Salsola* is a pioneer species for grassland regeneration, notable for its features such as sexual reproduction, seed dormancy, and seed bank formation (K. Toderich, 2008). It is a promising plant for halting the movement of sand dunes due to its ability to thrive in infertile sands, high seed yield, ability to propagate through seeds and cuttings, tolerance to salinity, and strong root system (Sarigul, 2021). It is commonly found in arid and semi-arid regions. It is a potential forage crop for semi-arid and arid environments due to its high nutritional value, abundant seed production, tolerance to extreme climatic conditions and resilience to prolonged drought conditions (Hanif et al., 2018). Its vegetation period extends from the end of March to October or November, it blooms from May to July, and produces seeds from September to October. It produces 30 to 50 kg/ha of green biomass annually (Nechayeva et al., 1973). *S. richteri* and *S. paletzkiana* are used in sand stabilization in the desert region of Central Asia. They restrict the movement of sand layers by stopping their natural shifting (Koşak, 2009). They prevent erosion in pastures and their young shoots, leaves, and seeds are consumed by animals as fodder (Pirasteh-Anosheh et al., 2021). Plants in desert pastures are highly valuable food sources for sheep, camels and cattle. They have important ecological characteristics that indicate their suitability for growth in desert areas, such as high drought resistance, salt tolerance and good forage quality (Shamsutdinova & Shamsutdinov, 2021).

The leaves of *S. richteri* contain an alkaloid called salsolinol at a rate of 0.3%, which can lower high blood pressure. It is also recommended for headache and dizziness (Glushchenko et al., 2018). It is used in the treatment of heart and skin diseases, cough, flu and in cosmetic products (Hanif et al., 2018). Its roots contain flavonoids and tannins with diuretic effects. Its seeds, which have high fat and protein content, can be used in human nutrition. It also plays an important role in desert ecosystems and preventing soil erosion (Niknam, 2017).

The seeds of *S. richteri* stand out with their round shape, hard shell, and aesthetic edges resembling butterfly wings. This plant species living in salty habitats has the ability to adapt to the environment with its unique morphological features of seeds. Grazing, agricultural use, and mining activities cause destruction of vegetation cover and increase sand mobility. Disturbance of plant cover in the desert, particularly the decline of shrub species like *Salsola*, results in imbalance. Decrease in shrub species that can adapt to arid and saline soils negatively affects the desert ecosystem (K. H. Toderich, 2009). Therefore, preservation and restoration of vegetation cover in desert regions are necessary for sustainable environmental management. Examining the seed bank in the soil and determining the germination, seedling formation, and development characteristics of species contribute significantly to the development of management strategies for the conservation of desert ecosystems. Understanding the adaptation mechanisms of plants growing in Karakum Desert and natural areas can be achieved through laboratory studies. The obtained results can contribute to the creation of comprehensive information about the germination characteristics of plant species in this special desert ecosystem of Central Asia, as well as the development of sustainable natural resource management strategies and the conservation and restoration of the desert ecosystem.

2. Materials and Methods

2.1. Materials

The seed materials of the study were collected from the Karakum Desert in order to determine the seed and germination characteristics of the yandak (*A. maurorum*) and çerkez (*S. richteri*) shrubs that grow in and around the desert. This desert is one of the unique ecosystems of Central Asia.

The seeds were collected from the vicinity of Zahmet Village, located in Sakarçage town in the Mary province of Turkmenistan, in 2022 and 2023. The collection point is an area approximately 24 kilometers away from the village (Figure 1). This region is significant in terms of hosting the unique plant flora of the Karakum Desert ecosystem. The collected seeds were wrapped in paper and placed in a bag, then brought to the laboratory.

Figure 1. Seed collection areas of the Karakum Desert plants.

Both species of seeds were brought to the laboratory of the Department of Silviculture, Faculty of Forestry, Bursa Technical University for studies. The focus of the research is on the morphological and germination characteristics of the seeds.

2.1.1. Seed cleaning and storage

The collected seeds were separated from their shells in the laboratory (Figure 2) and then stored in a refrigerator until the germination tests.

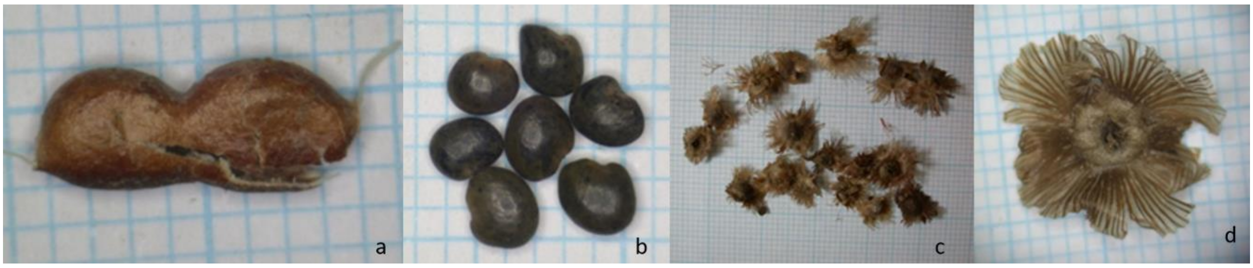

Figure 2. (*A. maurorum*) seed (a, b) and Çerkez (*S. richteri*) seed (c, d).

Lovibond germination cabinet, precision balance, stereo microscope, digital caliper, sealed plastic bags, leak-proof plastic containers of different sizes, filter papers, nitrile gloves, Petri dishes, Maxim XL fungicide, and Tetrazolium chloride (TTC).

2.2. Method

2.2.1. Determination of seed characteristics

The weight of 1000 seeds and morphological characteristics were determined in seeds. Seed weights were determined in accordance with ISTA (1999) rules using 100 seeds and 4 replicates. For morphological characteristics, the length, width, and thickness were measured using a digital caliper in 100 seeds, then averages were taken.

2.2.2. Tetrazolium chloride (TTC) test in seeds

To determine seed viability, the Tetrazolium chloride (TTC) test was conducted. TTC solution is commonly used to reveal metabolic activity in seeds and determine their germination capacity. For the viability test, a 1% TTC solution was prepared and kept in light for 10 minutes. Then, 60 seeds of *A. maurorum* and *S. richteri* were wrapped in filter paper, dipped into the solution, and incubated at 40°C. To check if the seeds were stained after 24 hours of incubation, a cutting process was applied. The seeds that were not cut and remained firm were crushed by applying pressure. The stained and unstained seeds were counted to determine the viability rates.

2.2.3. Germination tests

Plastic Petri dishes with a diameter of 9 mm were preferred for seed germination. To prevent fungal infections, drying papers placed in the Petri dishes were sterilized by keeping them in an oven at 105 °C for one hour. Germination tests were conducted with 4 replicates, each consisting of 100 seeds. To prevent possible fungal infections, a 0.1% Maxim XL fungicide solution was prepared and added to the Petri dishes. The Petri dishes were wrapped in cling film and incubated in a dark environment at 24°C for 200 days for germination. Germinated seeds were counted on days 3, 7, 10, 14, 21 and 28 and then for 200 days by increasing the periods, and germination rates were determined. Germination speed was determined by dividing the number of seeds germinated on day 10 by the total number of seeds. Regular observations and counts were made and recorded in a table. Each stage of germination and development was photographed.

3. Results and Discussion

3.1. Some Morphological Characteristics of Seeds

Determination of 1000-grain weight was done according to ISTA rules. 100 seeds were weighed in 4 replicates, and the 1000-grain weight was determined by proportioning. Thirty seeds were measured for wide, length, and thickness to determine the morphological characteristics of the seeds, and the averages are provided in Table 1.

Table 1. Average wide, length, and thickness of seeds (mm).

Seeds	Length (mm)	Wide (mm)	Thickness (mm)	1000 sed weight (g)
A. maurorum	2.6	2.1	1.1	5.7
S. richteri	10.2	10.0	1.9	9.6

3.2. Results of Viability Testing in Seeds

TTC tests were conducted to determine the viability of the seeds. This test is a method used to assess the biological activity and viability of seeds. These data provide important information for interpreting the germination process and determining seed quality. The TTC test conducted on *A. maurorum* and *S. richteri* seeds provided information about seed viability. The test results showed that some seeds of *A. maurorum* cracked and turned red after 24 hours. However, some seeds did not show any cracking or coloring (Figure 3).

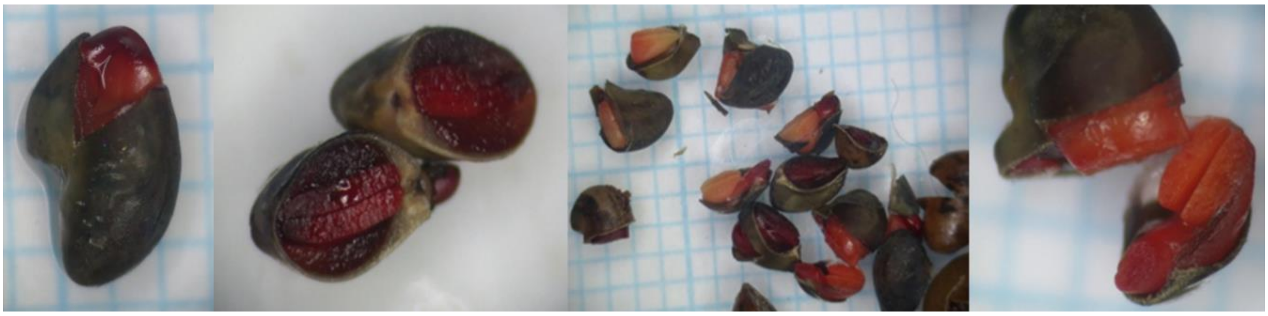

Figure 3. Live seeds stained in the TTC test in *A. maurorum*.

Out of a totaly of 60 *A. maurorum* seeds, 25% cracked and turned red within 24 hours, 5% is empty and the remaining 70% were determined to be live and too hard when crushed. The endosperm and embryo were observed to be yellow and not stained. This may be due to impermeability of the seed coat in seeds with different coat thickness, which prevents staining and cracking. In the germination process of *A. maurorum*, the different coat structure of the seeds may lead to an extended germination period of 200 days. This demonstrates that the plant has developed a unique germination strategy to sustain its existence and adapt to desert environments (Figure 4).

Figure 4. Non-stained, firm and live seeds in the TTC test in *A. maurorum*

A total of 30 seeds of *S. richteri* were used in the TTC test. 13% of these seeds turned red while 87% were found to be empty (Figure 5). This indicates that *S. richteri* seeds have a lower potential for maintaining viability in their natural environment. It suggests that environmental factors in desert habitats negatively affect the germination ability of the seeds. The formation of empty seeds can also be caused by different biotic or abiotic factors. Scientific studies have observed low seed germination in *S. richteri*. Pollination and fertilization in *Salsola*, as well as embryological findings related to embryo and fruit development are a subject of debate. The embryo of *Salsoloideae* species is curved in a spiral shape and the perisperm is almost absent. In these species, seed yield and quality are mostly dependent on the meteorological conditions of the year. Studies have shown that rainy years promote seed maturation in desert plants, while seed formation rapidly declines in dry years, and many plants do not produce seeds at all (K. Toderich, 2008).

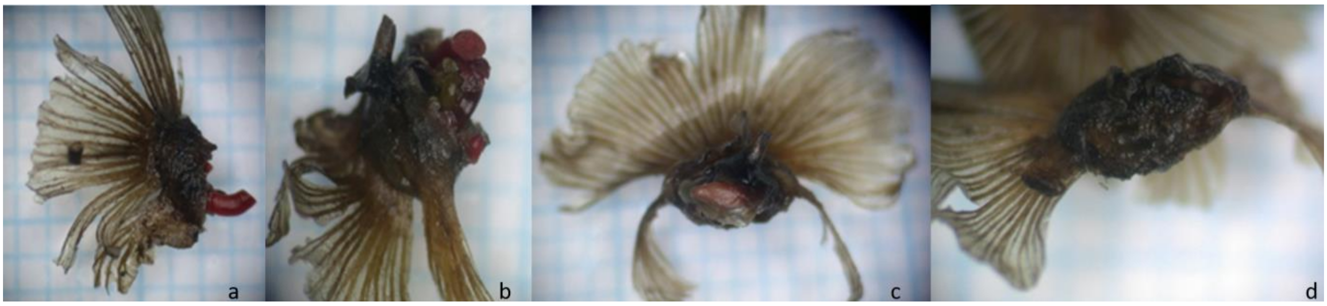

Figure 5. Seeds stained in the TTC test in *S. richteri* (a, b, c) and empty and rotten seeds (d).

The lack of any signs of germination in the germination test of *S. richteri* and the low viability rates in the TTC test indicate problems in pollination, embryo, and endosperm formation. This situation may be due to the environmental factors created by the desert or excessive animal grazing pressure.

3.3. Germination Characteristics and Rates

Counts and observations were made at specific intervals to determine the germination abilities of the seeds in the study.

3.3.1. Alhagi maurorum

In the study, it was determined that *A. maurorum* seeds began to germinate from the 2nd day. However, germination did not continue at the same rate, and it was observed that germination continued for a long period after the first germinating seeds. It was determined that there was only a small loss of around 7% in the germination rates of seeds from 2022. At the end of the 200-day period, a total germination rate of 24.2% was observed in *A. maurorum* seeds. It was observed that the seeds developed a long root structure (Figure 6) (Table 2).

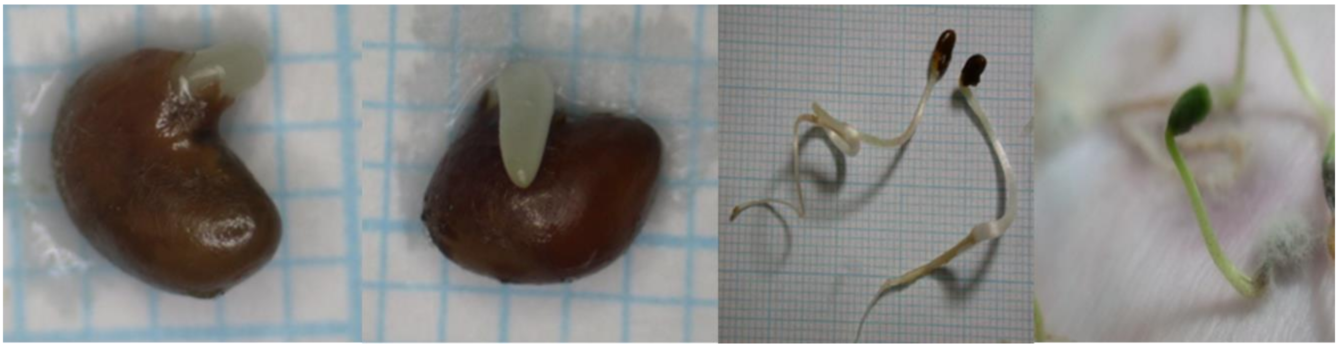

Figure 6. Germinated seeds of *A. maurorum*.

Desert species have many adaptation mechanisms that ensure germination at the right place and time. Rapid germination strategy is the most important adaptation mechanism for reproduction in desert ecosystems where rainfall is minimal. In arid ecosystems, plants need to rapidly develop a root system after their storage reserves are depleted (Prado-Tarango et al., 2018). Rapidly germinating species in arid and semi-arid environments need to withstand prolonged periods of drought. While fast-germinating plants germinate with the first rainfall, slow-germinating ones require long periods of wetting (Gutterman, 1993). The germination period of seeds in desert plants is quite flexible. Mechanisms such as rapid and nonsynchronous germination have developed through a long process of adaptation in the challenging desert environment (Lu et al., 2022). The prolonged germination period in *A. maurorum* seeds indicates that the plant has developed an adaptation to adverse desert conditions. Some seeds germinate immediately, while others prolong their germination periods due to their hard shells, suggesting the production of seeds with different germination characteristics in the same environment. Similar germination characteristics can also be observed in *Arctomecon californica*, where it has been found that dormancy is broken in approximately 5% of seeds each year, allowing them to have a long-lasting seed bank (Van-Buren et al., 2021). It is believed that the same characteristic is likely present in *A. maurorum* as well.

Table 2. Germination rates of *A. maurorum* seeds based on the year of collection.

Days	Germination (%)	
	2022 seed	**2023 seed**
3	1.25	3.2
7	1	2.8
10	0.75	1.2
14	0.75	1
21	0.75	1
28	0.75	1
35	1.25	1
40	1.25	1
50	0.75	1.6
60	0.75	1.2
70	0.75	1
80	1.25	1.4
110	1.5	1.8
130	1.75	2
170	1.8	1.8
200	1	1.2
Total (%)	17.3	24.2

The seeds of *A. maurorum* collected in 2022 and 2023 showed germination rates of 17.3% and 24.2%, respectively. The germination rates slowed down and decreased over the course of 200 days (Figure 7). 10 days after incubation of seeds, the germination rate was determined as 3% in 2022 seeds and 7.2% in 2023 seeds.

Similar results obtained a study conducted by Pirasteh-Anosheh (2020) that *A. maurorum* seeds continue to germinate at certain intervals. The dormancy condition in these seeds contributes to the spread of seeds to distant distances and the survival of seedlings. In addition, it was stated that *A. maurorum* has a hard shell and does not germinate easily, and chemical processes such as sulfuric acid should be used to break dormancy and increase germination rate. A study by Pirasteh-Anosheh (2020) showed that germination potential continues depending on the salinity level. According to the study by Aguado et al. (2012), rains that overlap with seed dispersal in some desert species can trigger suitable conditions for germination. In deserts with winter and summer rains, temperature determines the germination time of annual plants. Photoperiodism and thermoperiodism are important adaptation mechanisms that regulate the germination of seeds at the right time of year and season. However, there is limited information about the germination and survival mechanisms of desert plants. Therefore, more research is needed to understand how seeds determine the right time for germination (Gutterman, 1993). Desert plants have developed special adaptation abilities to reproduce. The ability to complete the life cycle in desert conditions is accomplished through the structural, physiological, and biological adaptations of halophytes in the form of half-shrubs (Shamsutdinova & Shamsutdinov, 2021). The seeds of desert plants show diversity according to the temperature requirements for germination. In extremely arid desert conditions, seeds do not germinate until there is enough water source for the survival of seedlings (Hassan et al., 2022). Long-lived plants in deserts have the characteristic of irregular flowering and fruiting to tolerate irregular rainfall. However, germination can fail in many desert plants when there is insufficient moisture. The seeds of desert plants maintain their viability in the soil for many years and ensure successful germination and seed production until the next rain (Goodin & Northington, 1985). The seeds of desert plants have adaptations such as a hard and mucilage-coated cuticle layer, specialized dormancy, and very rapid root growth (Cervantes et al., 2019). Studies have shown that some seeds can withstand surprisingly high temperatures (Ooi et al., 2009) and maintain their viability despite severe drought (Copete et al., 2021). These and similar adaptations enable desert plants to survive and reproduce in extreme conditions. One of these adaptations is seed banks in the soil, and dormancy plays an important role in this adaptation. Long-lived seed banks provide protection against unpredictable environmental changes or harsh climatic conditions, which are considered risk-aversion strategies of desert plants (Hassan et al., 2022). Residual seed banks in the soil or on the plant provide a seed source for germination and the continuation of the generation in plants in subsequent years. These seed banks are seen as an adaptation mechanism in desert ecosystems when suitable conditions for germination and seedling formation cannot be predicted (Koontz & Simpson, 2010; Meyer & Pendleton, 2005). In desert environments, most species have persistent aerial seed banks (Gunster, 1992; Hegazy et al., 2013). These seed banks allow only a portion of the seeds to germinate and maintain the populations with each rainfall (Hegazy et al., 2013). The germination rate is quite low in A. maurorum. In *Salsola richteri*, although 13% of the seeds are still viable, no germination occurs, indicating a dormant state that can be considered as a mechanism for adaptation to drought in these two desert plants. This adaptation strategy has also been observed in *A. maurorum*. Although some seeds start to germinate two days later, it was determined that the germination process is quite long.

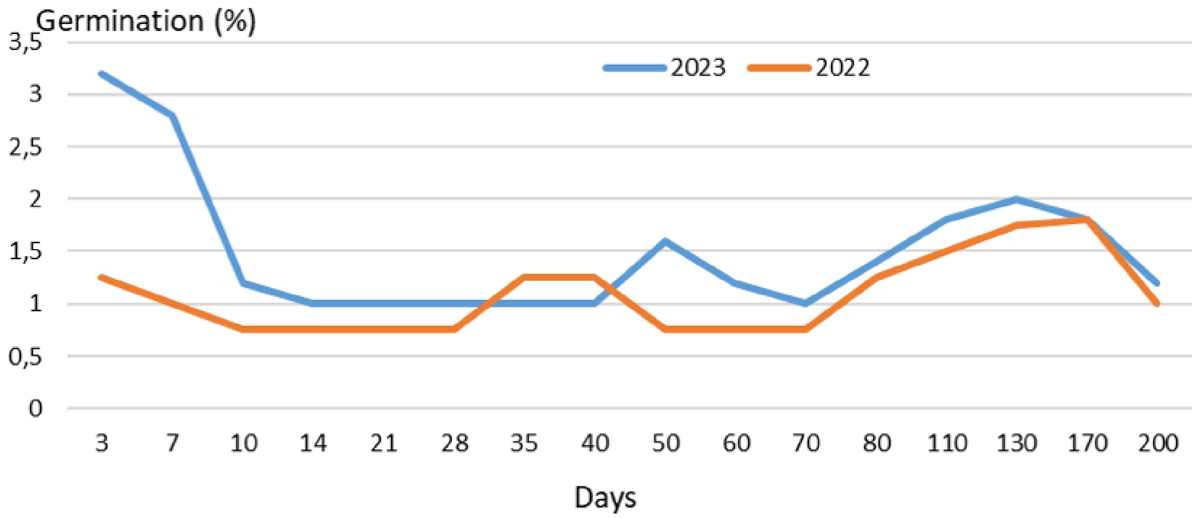

Figure 7. Germination rates of *A. maurorum* seeds collected in 2022 and 2023.

The thickness and permeability of the seed coat affect the germination rate and duration. Different thicknesses of seed coat structures allow the plant to adapt to changing conditions in natural environment and germinate at various times. In the SEM images, it was determined that the seed coat of late germinating seeds is 1/3 thicker at the same point compared to early germinating seeds (Figure 8).

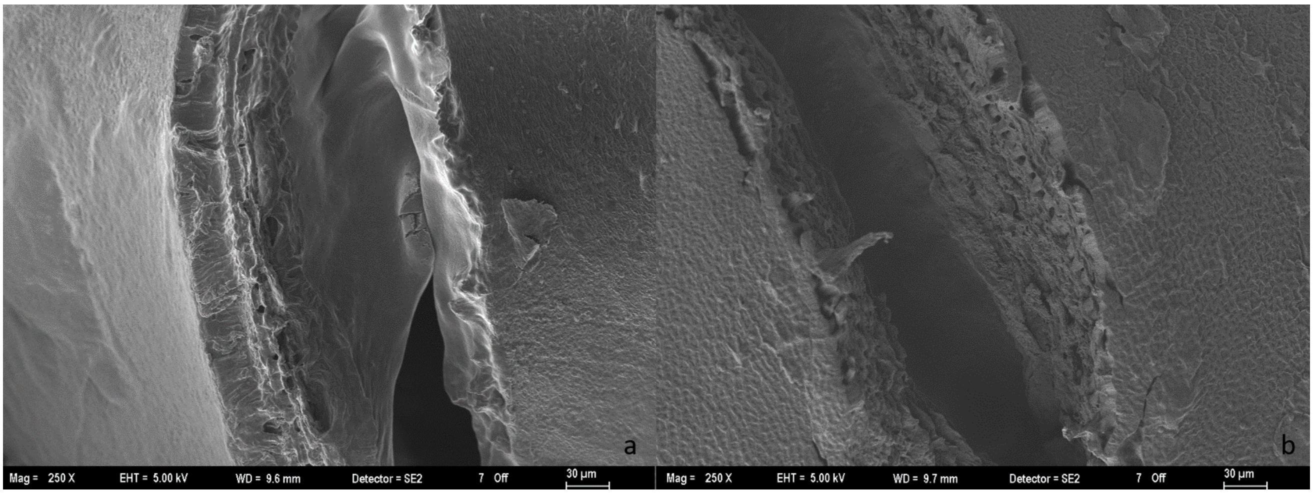

Figure 8. SEM images of early (a) and late (b) germinated seed coats of *A. maurorum*.

3.3.2. Salsola richteri

In viability tests, it was determined that only a small portion of the seeds (13%) were viable and no germination occurred. It is believed that this is due to the possibility of seeds having multiple dormancies. Studies have shown that removing the seed coat is effective in increasing seed germination rate in *Salsola* plants. Depending on storage conditions, it has been determined that woody *Salsola* species enter a short dormancy period (8-10 months, rarely one to five years). Mechanical damage or chemical treatments can be used to overcome dormancy and increase germination of *Salsola* seeds (K. Toderich, 2008). For example, in *Salsola kali*, germination is faster and it was observed that some seeds started germinating after only 29 minutes of water absorption (Gutterman, 1993). Germination in Kızılkum Desert varies between 4-51% in *Salsola orientalis*, 4-50% in *S. arbuscula*, and 6-65% in *S. gemmascens* during different years (K. Toderich, 2008). Male and/or female infertility, bud and flower shedding, and lack of embryo development are considered to be the main reasons for the formation of empty seeds in desert plants. The low reproductive capacity of *S. richteri* and the difficulty of seed germination may contribute to the decrease of vegetation cover in the desert and the increase in desertification. The arid climate of the Karakum Desert has been noted to threaten the extinction of many plant and shrub species. In addition, it is stated that the unconscious habits of the local population such as animal grazing and wood stockpiling accelerate desertification (K. N. Toderich, 2001).

4. Conclusions and Recommendations

In this study, the germination and morphological characteristics of *A. maurorum* and *S. richteri* desert plant species were examined. The results obtained show that the viability and germination rates of both species' seeds vary greatly. While *A. maurorum* showed germination success, the germination process lasted for a long time. On the other hand, germination did not occur in *S. richteri*. Viability tests revealed that 95% of *A. maurorum* seeds and 13% of *S. richteri* seeds were viable. Desert ecosystems are sensitive ecosystems characterized by low and irregular rainfall, extreme dryness and heat, infertile soils, and poor water retention capacities. The plant species growing in these ecosystems have developed different characteristics to adapt to extreme conditions. In particular, the long germination process of *A. maurorum* seeds is an example of this adaptation and is important for restoration efforts in desert ecosystems. The ability of an aerial seed bank to remain in the soil for a long time, the long germination period, the continuation of the plant population, and the fact that only a portion of the seeds germinate under suitable ecological conditions are all signs of good adaptation. This seed characteristic and the richness of the seed bank are important factors to consider in restoration efforts. The low viability and germination rates of some plant species' seeds indicate the sensitivity of desert ecosystems. Plants growing in the Karakum Desert and its surroundings are being indiscriminately exploited by the local population, causing harm to nature and the ecosystem. Uncontrolled grazing, irregular and excessive cutting for fuel use rapidly destroy the vegetation in the desert. As a result of this destruction, vegetation rapidly decreases, soil erosion increases in sensitive areas, ecosystem balance is disrupted, and some plant species become extinct or endangered. The results obtained from this study will provide practical benefits for the conservation and restoration of these species' habitats.

Conflict of Interest

The authors declare that they have no conflict of interest.

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