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Mediterranean Saltbush (*Atriplex halimus* L.): A promising Halophyte for Combating Desertification in Jordan

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ABSTRACT

Mediterranean saltbush (Atriplex halimus L.) belongs to the family Amaranthaceae. It is a halophyte and perennial shrub, which is a resilient and versatile plant species native to the Mediterranean basin. It has remarkable adaptation to arid and semi-arid environments. Jordan is considered one of the poorest countries in the world in terms of natural water resources, and the desert areas occupy more than three-quarters of the country. Considering the conditions of global warming, desertification, lack of rainfall, and scarcity of pastures and green fodder, A. halimus is promising to confront these challenges. This review presents the scientific classification of A. halimus, its geographical distribution, its presence in Jordan, its uses, and its anatomical and phenotypic characteristics. The study sheds light on its most important characteristics that make it an adapted plant to a desert environment. It can be concluded that by leveraging the unique properties of A. *halimus*, Jordan can address critical environmental challenges while supporting sustainable practices. This aligns with the nation's long-term goals of water conservation, land reclamation, and food security.

Keywords: Atriplex halimus, Drought, Salinity, Water Stress, Desertification, Halophytes, Xerophytes.

INTRODUCTION

Plant growth and development are extremely affected by environmental stress that limits the survival and productivity in all growth stages (Lamers et al., 2020). Stress includes biotic stress caused by damaging organisms and abiotic stress caused by unsuitable physical or chemical conditions surrounding the plant (Buchanan et al., 2015). The plant is exposed to several types of abiotic stresses, including water stress, drought, salinity, elevated temperature, low temperature, freezing, excessive light, heavy metals, and insufficient nutrients in the soil (Roeber et al., 2021).

Desert environments present some of the most challenging conditions for plant survival. These arid ecosystems are characterized by extreme temperatures, limited water availability, high solar radiation, and nutrient-poor soils (Noy-Meir, 1973). Plants that thrive in deserts have developed a variety of physiological, morphological, and biochemical adaptations to cope with these harsh environmental conditions.

The Jordanian desert, part of the vast Arabian Desert, is a unique and ecologically diverse region. Covering an area of approximately 72600 km^2, which constitutes 81% of the total area (89400 km^2) of Jordan's land area, the desert spans a variety of landscapes, including rocky plateaus, gravel plains, and sand dunes (Khresat et al.,2004). These harsh environments are home to a wide range of specialized plant species, including *Atriplex halimus*, a halophytic shrub that is highly adapted to the region's challenging conditions (Musallam et al., 2023).

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Scientific classification of *Atriplex* species illustrates that the genus *Atriplex* belongs to the family *Amaranthaceae* (*Atripliceae*, *Chenopodiaceae*) (Calasan et al., 2022; Kadereit et al., 2010). This family has more than 300 species globally. *Atriplex halimus*, commonly known as the Mediterranean saltbush, is a halophytic shrub belonging to the family Amaranthaceae (Walker et al., 2014).

Atriplex halimus (Mediterranean saltbush) is a resilient and versatile plant species native to the Mediterranean region, known for its remarkable adaptation to arid and semi-arid environments (Walker et al., 2014). It contains two subspecies: diploid halimus (2n =2x= 18) that adapted to less saline semi-arid regions, and tetraploid (schweinfurthii) (2n=4x=36) that adapted to saline, arid regions (Walker et al., 2014; Kheiria Hcini et al., 2007). *Atriplex halimus* is found naturally in several regions of the world, including Southern Europe, North Africa, the Middle East, and Western Asia (Walker et al., 2014; Dora et al., 2005). Although it is naturally widespread in several countries in the Mediterranean region, such as Jordan, Saudi Arabia, and Egypt, it has been introduced to other countries, such as Iraq, Iran, and Oman, as livestock forage (Walker et al., 2014). *Atriplex halimus* typically grows as a perennial, dense, woody shrub, reaching heights of 1-3 meters with branching that begins from the base, so this increases the ground area in which the plant grows horizontally, which may reach three meters (Dorda et al., 2005; Walker et al., 2014). *Atriplex halimus* is widely utilized for various environmental, agricultural, and nutritional purposes. It is commonly planted to combat desertification and stabilize degraded soils. Its deep-root system prevents soil erosion, while its ability to thrive in saline soils helps reclaim marginal lands (Le Houérou, 2000; Walker and Lutts, 2014).

This review describes the scientific classification of *Atriplex halimus*, its geographical distribution, its spread in Jordan, and the habitats in which it occurs. After that, in the following sections, we discuss its botanical and anatomical characteristics and some of its important uses.

Then we discuss the desert environmental conditions, Jordanian Badia (desert), *Atriplex halimus*, and desert conditions, responses of *Atriplex halimus* to water stress, adaptive features of *Atriplex halimus* to water stress, and genes related to water stress.

***Atriplex halimus* species**

Scientific classification of *Atriplex halimus*

The genus *Atriplex*, commonly known as saltbush, belongs to the family *Amaranthaceae (Atripliceae, Chenopodiaceae)* (Calasan et al., 2022; Kadereit et al., 2010) (table 1). It consists of more than 300 species globally. It is a diverse group of halophytic (salt-tolerant) shrubs, herbs, and small trees, primarily found in arid and semi-arid environments (El-Amier and El-Hayyany,2020; Kadereit et al.,2010). The genus is widely distributed across the globe, particularly in regions with saline or alkaline soils, such as deserts, coastal areas, and salt flats (Brignone et al., 2019). The ability of *Atriplex* species to thrive in harsh, saline conditions makes them ecologically significant and valuable for soil stabilization, land reclamation, and as forage for livestock (Kadereit et al., 2010; El-Amier and El-Hayyany, 2020; Bouda et al.,2006). Below is a comprehensive list of notable species within the genus *Atriplex*, including their common names, habitat preferences, and regional distributions.

Table 1: Notable species within the genus *Atriplex*, including their common names, habitat preferences, and regional distributions. (Mandak et al., 2006; Keil & Taylor, 2018; Calsan et al., 2022).

Scientific Name	**Common Name**	**Habitat**	**Distribution**
Atriplex halimus	Mediterranean Saltbush	Coastal, saline soils	Mediterranean region, North Africa
Atriplex canescens	Four-wing Saltbush	Arid deserts, alkaline soils	Western North America
Atriplex nummularia	Old Man Saltbush	Dry, saline soils	Australia

Atriplex hortensis	Garden Orache	Cultivated fields, disturbed sites	Europe, Asia, North America
Atriplex patula	Common Orache	Wetlands, disturbed areas	Worldwide (temperate zones)
Atriplex leucoclada	White-stemmed Saltbush	Arid and semi-arid lands	Middle East, Central Asia
Atriplex lentiformis	Big Saltbush	Riverbanks, saline soils	Southwestern United States
Atriplex portulacoides	Sea Purslane	Coastal salt marshes	Coastal Europe, Africa
Atriplex confertifolia	Shadscale Saltbush	Desert shrublands	Western United States
Atriplex suberecta	Sprawling Saltbush	Disturbed saline habitats	Southern Australia, New Zealand
Atriplex vesicaria	Bladder Saltbush	Semi-arid, saline soils	Australia
Atriplex semibaccata	Creeping Saltbush	Saline, disturbed areas	Australia, introduced in South Africa
Atriplex triangularis	Triangle Orache	Coastal and disturbed sites	North America, Eurasia
Atriplex laciniata	Frosted Orache	Sandy and coastal habitats	Europe, Northern Africa
Atriplex tatarica	Tatarian Orache	Steppes, saline soils	Eastern Europe, Central Asia
Atriplex coronata	Crownscale	Alkaline flats, desert areas	California, Nevada, Mexico

Atriplex halimus, commonly known as the Mediterranean saltbush, is a halophytic shrub belonging to the family Amaranthaceae. This perennial plant is native to arid and semi-arid regions around the Mediterranean Basin, extending to parts of the Middle East and North Africa (Walker et al., 2014). Its exceptional salt tolerance and drought resistance make it a vital species for soil stabilization, combating desertification, and forage in saline or degraded lands (Walker et al., 2014). The *Atriplex halimus* contains two sub-species: diploid halimus (2n =2x= 18) that adapted to less saline semi-arid regions, and tetraploid (schweinfurthii) (2n=4x=36) that adapted to saline, arid regions (Walker et al., 2014; Kheiria Hcini et al., 2007). *Atriplex halimus* was first classified by Carl Linnaeus in 1753 and is part of the subfamily *Chenopodioideae*, which includes other halophytes adapted to saline and arid conditions (Kadereit et al., 2010). The following table shows the taxonomic hierarchy of *Atriplex halimus* (table 2)

Table 2: The taxonomic hierarchy of the *Atriplex halimus* (Kadereit et al., 2010).

Taxonomic Rank	Classification
Kingdom	Plantae
Clade	Angiosperms
Clade	Eudicots
Order	Caryophyllales
Family	*Amaranthaceae*
Subfamily	*Chenopodioideae*
Genus	*Atriplex L.*
Species	*Atriplex halimus* L.

Geographical distribution of *Atriplex halimus*

Atriplex halimus is a perennial shrub widely distributed across the Mediterranean Basin and neighboring arid and semi-arid regions (Walker et al., 2014). *Atriplex halimus* is highly valued for its adaptability to extreme environmental conditions, including high salinity and drought (Musallam et al., 2023). Its distribution is influenced by ecological factors such as soil type, salinity, and climate, making it a key species in combating desertification and supporting sustainable land management (Gharibeh et al., 2023). The species is typically found in saline soils, coastal regions, and arid landscapes, thriving in loamy and clay soils and sometimes near temporary water tables (Dorda et al., 2005; Walker et al., 2014; Le Houérou, 1992). It can exist in high sodic soils (25–30 dS m^{-1}) (Le Houérou 1992).

And it grows in open lands with alkaline soils (pH 7.0-11.0) (Walker et al., 2014).

The natural range of *Atriplex halimus* includes Southern Europe, North Africa, the Middle East, and Western Asia (Walker et al., 2014; Dora et al., 2005). The following table shows some examples of the countries where this plant is widespread (table 3).

Table 3: The geographical distribution of *Atriplex halimus* (Walker et al., 2014).

Region	Countries
Southern Europe	Spain, France, Italy, Greece, Cyprus, Portugal, Malta
North Africa	Morocco, Algeria, Tunisia, Libya, Egypt
Middle East	Turkey, Jordan, Lebanon, Syria
Western Asia	Saudi Arabia, Iraq

Atriplex halimus is widespread in areas with rainfall between 100- 400 mm in arid regions and 400-600 mm in semi-arid regions (Walker et al., 2014; Dorda et al., 2005). *Atriplex halimus* is influenced by altitude and grows in areas less than 1,200 meters above sea level, as altitude reduces temperatures, which limits its growth (Walker et al., 2014) (fig. 1)

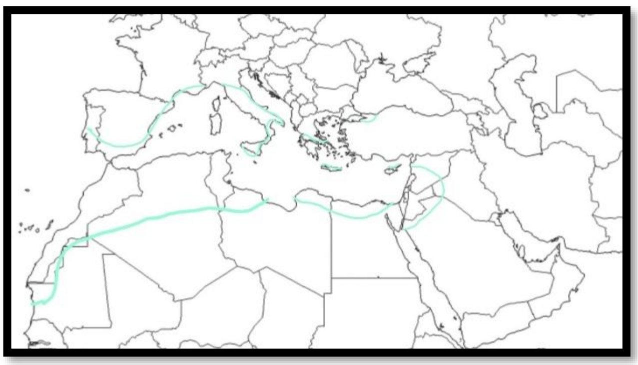

Figure 1: Map of the distribution of *Atriplex halimus* in the Mediterranean basin, modified after (Dorda et al., 2005).

Atriplex halimus in Jordan

Atriplex halimus is found in the arid areas of the Jordanian desert and is considered an excellent pastoral plant. It is exposed to the pressures of overgrazing and needs good management to give sustainable production (Tadros et al.,2000). *Atriplex halimus* achieved second place in a study conducted by the National Center for Agricultural Research and Technology Transfer in Jordan (NCARTT) in 1990 included five Atriplex species: *Atriplex undulata, Atriplex lentiformis, Atriplex amnicola, Atriplex canescens, and Atriplex halimus*, on the adaptability and palatability of these species of drought-tolerant forage plants in the Jordanian desert (Tadros et al.,2000). Drought is one of the most important obstacles to the rehabilitation of arid and semi-arid lands in Jordan. Successful experiments were conducted to rehabilitate pastures in dry desert areas in Jordan using Atriplex halimus seedlings planted in soil mixed with tuff, where the tuff replaced supplementary water, and the experiments showed its ability to improve the growth and survival of the seedlings (Alhamad et al., 2021). Atriplex halimus was used to restore pastures that had been severely degraded due to drought, human misuse, and overgrazing in northern Jordan in the areas of Al-Khanasri, Buraiqa, and Manshiet Bani Hassan, where the plant effectively contributed to improving pasture productivity(AL-Satari et al.,2014). Atriplex halimus is used to reclaim pastures in drought areas in the Mediterranean, and it was used to reclaim pastures in drought areas in Jordan and provided high-value fodder for livestock in the arid lands of the Jordanian desert. The crude protein content in the plant's leaves and branches reached its maximum levels in April (El-Shatnawi et al., 2002). According to a study of the chemical composition of Atriplex halimus was conducted on the campus of the Jordan University of Science and Technology in the period from 1995 to 1997, the percentage of crude protein in the leaves was higher than in the stems in all agricultural seasons, and it also contained a higher percentage of phosphorus and crude calcium. The study confirmed that the plant is a good source of protein during the dry season (El-Shatnawi et al., 2000). *Atriplex halimus* seedlings were planted in the Jordanian desert within reserves to increase the production of plant biomass in 2000 for grazing (Damhoureyeh, 2017). The

Jordanian Desert constitutes large areas of the country and is of a harsh nature. It is characterized by Low rainfall rate, high temperatures in the summer, and low temperatures in the winter, although these environmental conditions are not the best for plant growth, more than 300 species of plants have been identified in the Jordanian desert (Khresat et al.,2004). In a study conducted in the Zarqa region in the Jordanian desert, 17 plant families were identified, containing 46 species of plants, including the family *Chenopodiaceæ* with 9% (Al-Kofahi et al.,2024). Atriplex halimus is found in large areas of the country, such as Azraq, Mafraq, and the Jordan Valley (Taifour et al.,2014). The most widespread area of *Atriplex halimus* in Jordan is the area closest to the Mediterranean basin from the western side (fig. 2+3).

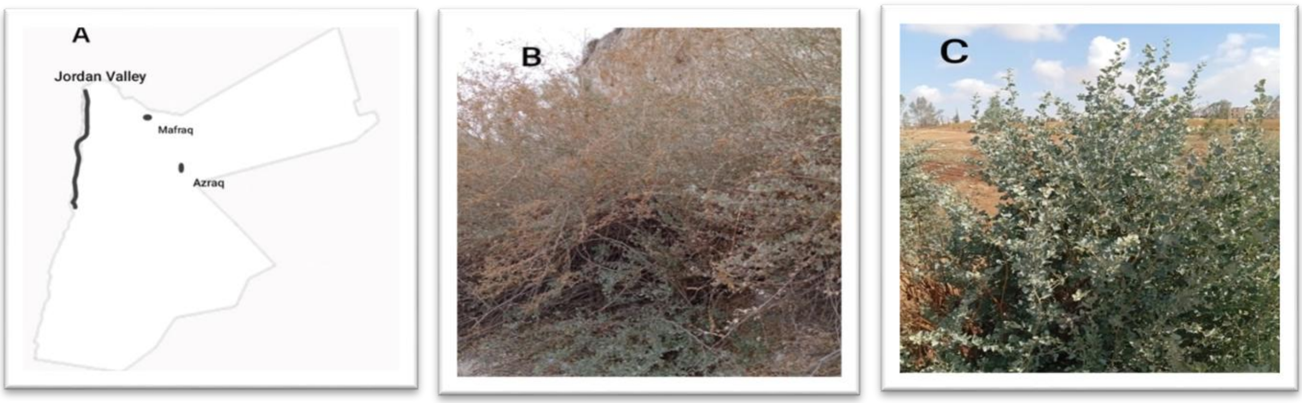

Figure 2: (A) A map of Jordan showing the regions of Jordan Valley, Mafraq, and Azraq sequentially from left to right. (B) *Atriplex halimus* growing in nature (Jordan Valley) under dry and saline conditions; picture taken at the end of November 2024. (C) *Atriplex halimus* growing in Al-Khalidiya Agricultural Research Station in Mafraq; pictures taken on the first of May 2024. The pictures are courtesy of Malik Mahmoud.

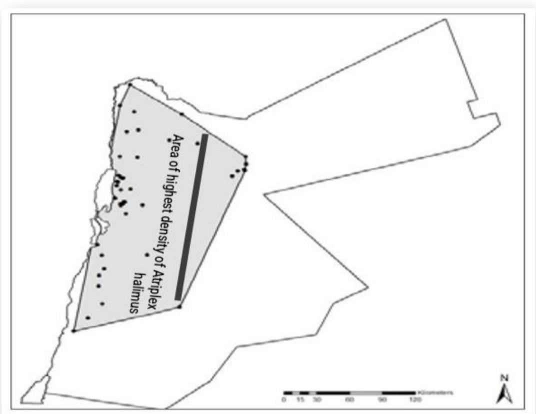

Figure 3: Map illustrating the distribution of *Atriplex halimus* in Jordan, modified after (Taifour et al., 2014).

Atriplex halimus was planted as a forage shrub with two other species, *Atriplex nummularia and Salsola vermiculata*, at Tal Rimah (N32°17′E36°53′), North-eastern Badia of Jordan in an experiment that was aimed to investigate the effect of three water harvesting techniques on the establishment of those forage shrubs and the productivity of natural vegetation in Jordan Badia (Saoub et al., 2011). Seedlings of *Atriplex halimus* that were 4, 5, and 10 months old were transplanted to the Khanasri Range Reserve in an experiment that was aimed at studying the impact of seedling age on the survival and productivity of Atriplex halimus shrubs in drought-affected rangelands of Jordan throughout the 2013, 2014, and 2015 growing seasons. The study suggested that 4–5-month-old seedlings of *Atriplex halimus* are more appropriate for transplanting than 10-month-old seedlings because of the cost–effective establishment of seedlings in the nursery (Al-Satari et al., 2018). One-year-old seedlings of *Atriplex halimus* and *Atriplex nummularia* were grown in containers in the field at the University of Jordan, Jubeiha station, in a study to investigate the variation in water deficit stress tolerance in terms of biomass production and water uptake of these two species. The results revealed that reducing the water level below 75% reduced biomass production, leaf area, and root length density but increased Water use efficiency (WUE) and root-to-shoot ratio in *Atriplex halimus* more than *Atriplex nummularia*. (Ayad et al., 2010).

Botany of *Atriplex Halimus*

Atriplex halimus typically grows as a perennial, dense, woody shrub, reaching heights of 1-3 meters. In this plant, branching begins from the base, so this increases the ground area in which the plant grows horizontally, which may reach three meters (Dorda et al., 2005; Walker et al., 2014). *Atriplex halimus* is considered native to the Mediterranean region, and its stems are stiff with bark that tends to be greyish white in color, so it is an ideal example of plants that tolerate salinity and drought (Dorda et al., 2005; Walker et al., 2014). The color of the leaves tends to be silvery white, and it has different sizes, ranging from 1-3 centimeters in length and 0.5-2 centimeters in width and distributed alternately on all parts of the stems in different and varied forms ranging between deltoid-orbicular and lanceolate with short petiole at the base (Gharibeh et al., 2023; Walker et al; 2014). Its growth habit makes it ideal for windbreaks and erosion control, and the leaves have a waxy coating covered with trichomes (hair-like structures) that help in reducing water loss and protect against excess solar radiation and provide protection against salinity (Imene and Khouloud 2024). Although the plant is evergreen, some leaves fall in the summer cause to heat and dryness (Walker et al.,2014). *Atriplex halimus* has a deep root system to exploit water in arid areas (Walker et al., 2014; Imene and Khouloud, 2024). It reproduces vegetatively or through seeds (Guerrero-Campo et al., 2006). This plant blooms between May and December (Dora et al., 2005; Walker et al., 2014). In general, *Atriplex halimus* is a monoecious species (Dorda et al.,2005; Walker et al.,2014), but Talamali et al. (2001) described it as trimonoecious. They found in Tunisia some individuals with both male and female unisexual flowers, as well as some bisexual flowers. The female flowers are greenish with two opposite bracteoles, and the male flowers are bractless with five yellowish tepals (Imene and Khouloud 2024; Walker et al., 2014). The inflorescences are tapered, compact, and paniculiform, measuring from 20 to 50 cm, and are in compound clusters or in dense spikes. Male flowers are at the top of the spike, and female flowers are at the base. (Imene and Khouloud 2024; Walker et al.,2014; Dorda et al., 2005). The fruits of *Atriplex halimus* are small and inconspicuous, typically enclosed within the bracts (6 mm in diameter) of female flowers. They are referred to as utricles—single-seeded, indehiscent structures that serve as protective coverings for the seeds. These bracts often become hardened as the fruit matures, aiding in seed dispersal and protection. Seeds are small and rounded, measuring about 1–2 mm in diameter (Imene and Khouloud, 2024).

Anatomy of *Atriplex halimus*

The anatomical features of *Atriplex halimus* are integral to its adaptation to extreme environmental conditions, such as high salinity, drought, and poor soil fertility. *Atriplex Halimus* is considered a perennial C4 species (Calone et al., 2021). C4 plants are a group of plants that utilize a specialized photosynthetic pathway known as the C4 pathway or C4 carbon fixation. This pathway is distinct from the more common C3 photosynthetic pathway, which is used by most plants. The C4 pathway is characterized by a more efficient way of capturing carbon dioxide (CO_2), which allows C4 plants to thrive in environments that are hot, dry, and have high light intensity, conditions that can lead to photorespiration in C3 plants (Buchanan et al.,2015).

In C4 plants, carbon fixation occurs in two distinct stages and involves a specialized anatomy called Kranz anatomy, which is crucial for the efficiency of the process. The first step in C4 photosynthesis occurs in mesophyll cells, where CO_2 is initially captured by an enzyme called phosphoenolpyruvate carboxylase (PEP carboxylase). This enzyme has a higher affinity for CO_2 than the enzyme used in C3 plants, RuBisCO, and does not catalyze the wasteful process of photorespiration. PEP carboxylase fixes CO_2 into a 4-carbon compound (hence the name "C4"), typically oxaloacetate, which is then converted into malate or aspartate (Buchanan et al., 2015).

The leaf structure of *Atriplex halimus* is highly specialized for water conservation and salt tolerance. The leaf cuticle is thick and waxy, helping to minimize water loss through evaporation (Walker et al., 2014). This is crucial in arid and saline environments. The epidermis is characterized by a high density of glandular trichomes, which secrete salt (Shabala et al., 2014). These trichomes play a role in excreting excess salts absorbed by the plant from the soil, thus preventing salt buildup within the tissues. The mesophyll consists of two distinct layers: a palisade layer and a spongy layer. The palisade cells are tightly packed to reduce water loss, while the spongy cells contain air spaces, which aid in gas exchange. The presence of salt glands is a distinctive feature of *Atriplex halimus*. These glands actively excrete excess sodium chloride, helping the plant to maintain osmotic balance in saline environments (Munns & Tester, 2008).

The following pictures were taken by a dissecting microscope to illustrate the presence of salt in different parts of *Atriplex Halimus* (fig. 4). The pictures show the presence of salt vesicles, their growth, and accumulation in an old leaf and a young leaf on the upper and lower surfaces of the leaves. The pictures also compare the presence of salt vesicles in a fresh, wet stem and an old, dry one. When looking at the white color in the pictures as an indicator of the presence of salt vesicles and the green color as an indicator of their absence, it becomes clear from the ratio of the two colors that the percentage of salt vesicles on the lower surface of the new leaf is greater than on the upper surface of the same leaf. This is also clear in the old leaf with the same two surfaces. The reason for this may be due to the process of photosynthesis, as the upper surface of the leaf is facing direct sunlight. If a comparison is made between the new leaf and the old leaf, the rate of growth of salt glands and their accumulation in the form of crystals in the old leaf is greater. This may be due to the size and area of the old leaf, as it has a larger size and area than the young leaf. The photosynthesis process in the young leaf may also be more efficient and active. The pictures also confirmed that the ratio of white to green was the highest among all in the pictures of the old dry stem when compared to pictures of the young wet stem and old and young leaves, as it confirmed the presence of salt vesicles in the form of growing crystals in parts of the stems. This may indicate the presence of large areas in the stems suitable for storing excess amounts of salt.

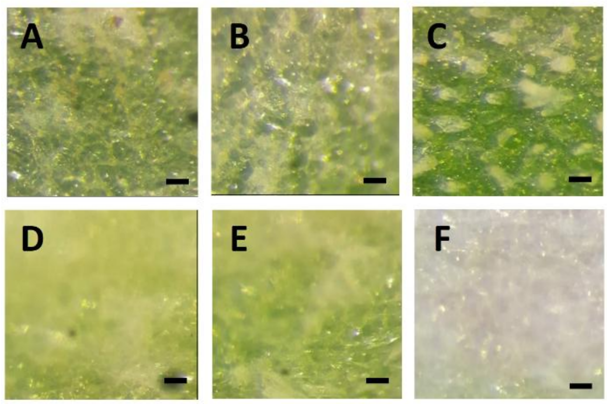

Figure 4: *Atriplex halimus* salt glands. (A) Salt glands on the adaxial surface of a young leaf. (B) Salt glands on the abaxial surface of a young leaf. (C) The salt glands are on the adaxial surface of the old leaf. (D) Salt glands are on the abaxial surface of the old leaf. (E). Salt glands are on the surface of the young stem. (F) Salt glands are on the surface of the old stem. Scale bar represents 100 µm. Courtesy of Malik Mahmoud.

The root anatomy of *Atriplex halimus* reveals a prominent cortex and central cylinder, with adaptations like thickened endodermal walls to manage water uptake in saline soils (Mahiz et al., 2015). The stems of *Atriplex halimus* are woody and exhibit a typical dicot structure with secondary growth (Mahiz et al., 2015). The vascular tissue is well-developed and consists of xylem and phloem arranged in a cylinder (0unaissia et al.,2019). The xylem is crucial for water transport, especially in dry conditions, while the phloem is responsible for the transport of nutrients. The stem cortex is often thick and contains chloroplasts, enabling photosynthesis even in the stem. This feature is advantageous when water availability is limited, and the plant relies on photosynthesis from both leaves and stems. The xylem tissue is specialized for the transport of water under drought conditions. The xylem vessels are wider compared to other species, which facilitates water movement even when the plant is subjected to water stress (Mahiz et al., 2015).

Uses of *Atriplex halimus*

Atriplex halimus, a versatile halophytic shrub, is widely utilized for various environmental, agricultural, and nutritional purposes. Its unique adaptations to arid and saline environments make it valuable for ecological restoration and sustainable development. *Atriplex halimus* is commonly planted to combat desertification and stabilize degraded soils. Its deep-root system prevents soil erosion, while its ability to thrive in saline soils helps reclaim marginal lands (Le Houérou, 2000; Walker and Lutts, 2014). The plant can absorb and tolerate heavy metals, making it a candidate for phytoremediation of contaminated soils. Walker and Lutts (2014). The foliage of *Atriplex halimus* serves as nutritious forage for livestock, particularly in arid regions. It provides a source of protein and minerals during dry seasons when conventional forage is scarce (Walker et al., 2014). The leaves are edible and occasionally used as a vegetable or herb in traditional diets, particularly in regions where the plant is native. The high mineral content makes it a functional food source (Le Houérou, 2000). *Atriplex halimus* has been used in traditional medicine to treat various ailments, such as digestive issues and skin conditions. Its antioxidant and antimicrobial properties are being explored for pharmacological applications. (Walker et al., 2014).

Desert Environment

Desert Environmental Conditions

Desert environments present some of the most challenging conditions for plant survival. These arid ecosystems are characterized by extreme temperatures, limited water availability, high solar radiation, and nutrient-poor soils. Plants that thrive in deserts have developed a variety of physiological, morphological, and biochemical adaptations to cope with these harsh environmental conditions.

Water Scarcity and Drought Stress

Water scarcity is the most defining feature of desert ecosystems. Deserts receive less than 250 mm of rainfall annually, and precipitation is often highly unpredictable and irregular (Noy-Meir, 1973). This chronic water deficit poses significant challenges for plant water uptake and retention. Drought stress leads to reduced cell turgor, impaired photosynthesis, and decreased growth rates (Chaves et al., 2009). Desert plants have evolved strategies such as deep root systems, water-storing tissues, and reduced leaf surface area to minimize water loss and maximize water use efficiency (Schwinning & Ehleringer, 2001).

Extreme Temperatures

Desert plants are exposed to extreme temperature fluctuations, both daily and seasonally. The cactus, as a desert plant, can survive at 55° C, and some Atriplex species have the capacity for photosynthetic adjustment to changing temperatures. Daytime temperatures can exceed 50°C through summer days, while nighttime temperatures can plummet to freezing in winter in Death Valley, CA (Mojave Desert) (Downton et al., 1984). These temperature extremes can disrupt cellular functions, damage proteins and membranes, and impair photosynthesis. Many desert plants possess heat shock proteins and other protective mechanisms to maintain cellular integrity under high heat stress (Wahid et al., 2007). Additionally, some species have adapted to nocturnal activity, performing key physiological processes during cooler nighttime hours to avoid daytime heat stress.

High Solar Radiation and UV Stress

Deserts receive intense solar radiation, including high levels of ultraviolet (UV) light, due to low atmospheric moisture and cloud cover. The high light intensity can cause photoinhibition and oxidative damage, affecting plant growth and productivity (Fayyaz et al., 2014). UV radiation can also damage DNA, proteins, and lipids, necessitating the need for protective pigments such as flavonoids and anthocyanins, which absorb and dissipate harmful UV rays (Jordan, 2002).

Nutrient-Poor Soils

Soil fertility in desert regions is generally low, with limited organic matter and essential nutrients such as nitrogen, phosphorus, and potassium (Barger et al., 2005). High soil salinity is also a common issue in many desert areas, further stressing plant roots and impairing water uptake (Flowers and Colmer, 2008). Desert plants often rely on symbiotic relationships with soil microbes, including mycorrhizal fungi, to enhance nutrient acquisition and improve stress tolerance (Allen, 2007).

Wind and Sandstorms

Wind is another significant environmental factor in deserts, contributing to sand movement and erosion. Strong winds can damage plant tissues, bury young seedlings, and erode the soil surface, reducing soil stability and plant establishment (Maun, 1998). Some desert plants have adapted by developing low, compact growth forms or specialized structures like spines to reduce wind damage and sand abrasion.

Plants in desert environments face a suite of extreme and often concurrent stressors, including water scarcity, extreme temperatures, high solar radiation, nutrient-poor soils, and abrasive winds. Their ability to survive and thrive under such conditions is a testament to their remarkable adaptations, which include physiological, morphological, and biochemical strategies aimed at minimizing stress and maximizing resource efficiency. Understanding these adaptations provides insight into the resilience of desert flora and offers valuable lessons for managing plant stress in increasingly arid landscapes globally.

Effects of Desert Conditions on Plants

Water regulates all biochemical processes in the plant tissues and makes up about 85-95% of its weight. Therefore, water stress has received a wide range of scientific studies. Many environmental events can lead to water stress, for example, drought, high salt concentrations, and high or freezing temperatures (Buchanan et al., 2015). Water stress inhibits plant growth and photosynthesis; it increases reactive oxygen species (ROS), plasma membrane permeability, enzymatic antioxidants, and non-enzymatic antioxidants (Sun et al., 2020). Transpiration and evaporation are two processes leading to water loss from plants.

Drought negatively affects plant productivity, growth, health, and geographical distribution. Approximately 50% of crop yields are lost due to drought, and this occurs in various parts of the world (Khalid et al., 2019). Drought is an environmental event associated with a lack of rainfall in plant-growing areas.

Salt stress is one of the most influential factors on plant growth and productivity. It greatly reduces the yield of agricultural crops. Inorganic salt is accumulated in arid regions because of excessive evaporation, leading to disruptions in plant metabolism. High concentration of Na^+ in the root zone disrupts the plant's from absorb water (Chaudhry et al., 2021). Anthropogenic activities such as irrigation, improper land use, and overfertilization lead to the accumulation of salts in the soil above the normal level, which affects plant growth. There are many mechanisms that plants have developed to cope with salt stress, which include modulating ion homeostasis, ion compartmentalization and export, and the biosynthesis of osmoprotectants (Balasubramaniam et al., 2023).

Temperature plays a critical role in plant growth and development. Elevated temperatures increase plant respiration rates, leading to a higher consumption of sugars and energy reserves. This can outpace photosynthesis, especially under prolonged heat stress, resulting in an overall energy deficit that impairs growth and reduces yield (Taiz & Zeiger, 2002). Proteins and cell membranes are sensitive to heat. High temperatures can cause protein denaturation and lipid peroxidation, which disrupts cellular functions. Plants respond by producing heat shock proteins to mitigate damage, but prolonged exposure can overwhelm these protective mechanisms (Bita & Gerats, 2013).

Low temperatures, though not freezing, can also stress plants, particularly those not adapted to cold climates. The key impacts include reduced Enzyme Activity, chlorophyll degradation, and altered membrane fluidity. Low temperatures slow down enzymatic reactions, impairing photosynthesis, respiration, and other metabolic processes. This reduction in metabolic activity can stifle growth and delay development (Sung et al., 2003).

Freezing temperatures are particularly damaging to plants, as ice formation within plant tissues can cause extensive physical and physiological damage. Freezing temperatures cause ice crystals to form in the intercellular spaces, drawing water out of cells and leading to dehydration. This results in cell shrinkage, membrane rupture, and tissue death, commonly seen as frost damage (Pearce, 2001).

Excessive light exposure, particularly high-intensity sunlight, can have detrimental effects on plants, even though light is essential for photosynthesis. When light intensity exceeds the optimal levels that a plant can use, it can cause photodamage and stress, impairing the plant's physiological functions and overall health. This condition is often referred to as light stress or photoinhibition. The impacts of excessive light on plants are complex and involve a variety of biochemical and physiological changes. Excessive light intensity can damage Photosystem II, a critical component of photosynthetic machinery. The high energy from intense light leads to the overexcitation of chlorophyll molecules, producing reactive oxygen species (ROS) that can damage proteins, lipids, and DNA within the chloroplast (Nishiyama et al., 2006). This process disrupts the electron transport chain, reducing the plant's ability to convert light into chemical energy effectively. Plants respond to excessive light by downregulating photosynthesis to prevent damage. This downregulation, known as photoprotection, involves non-photochemical quenching (NPQ), where excess light energy is dissipated as heat rather than used in photosynthesis (Demmig-Adams & Adams, 2006). Excessive light exposure can increase the rate of transpiration, leading to water loss and potential dehydration. This condition is particularly problematic in arid environments or during drought conditions, where water availability is already limited (Chaves et al., 2009). Excessive light exposure can significantly impair plant health through mechanisms such as photoinhibition, oxidative stress, and heat damage. While plants have developed protective adaptations to manage light stress, prolonged or extreme conditions can overwhelm these systems, reducing growth and productivity. Understanding these effects is essential for managing plant health, particularly in agricultural settings where light intensity can be managed through shading or selective breeding for light-tolerant varieties.

Drought and lack of rainfall lead to soil salinization. Many plant species have demonstrated the ability to survive in the arid desert environment. Despite the harsh conditions in the desert, it is considered a suitable environment for the growth and prosperity of the *Atriplex halimus*.

Jordanian Badia (Desert)

Jordanian Badia Regions

Three main topographic features that exist in Jordan: Badia(desert), mountains, and Jordan rift regions (MWI, 2009). Jordanian Badia is a harsh environment, it is arid to semi-arid, with high temperatures, poor soils, and fragile environmental ecosystems (Sada et al.,2015). More than 80% of Jordanian territories are either Badia or Desert (Sada et al.,2015). However, it is home to a remarkable array of plant species that have adapted to survive under such conditions. The *Atriplex halimus* stands out as one of the most important desert plants, contributing to both ecological stability and human livelihoods in the region (Abu-Zanat et al., 2020). Through a combination of drought tolerance, salinity resistance, and the ability to stabilize soils, this species exemplifies the resilience of desert flora.

Geographical Location and Climate of Jordanian Badia.

Jordanian Badia extends from northeast to south and east to west up until the highland areas of the western mountains; therefore, it is considered the largest area of land in Jordan (Haddad et al.,2022). Jordanian Badia is divided into three main regions: the North Badia, the Middle Badia, and the South Badia. (Sada et al.,2015; Haddad et al.,2022). (fig. 5)

Figure 4: Map of Jordan's Badia (Sada et al.,2015; Haddad et al., 2022).

Eastern Badia: This region includes both North and Middle Badia(Freiwan and Kadioglub,2008) and consists of expansive gravel plains and rocky outcrops. The climate is arid, with minimal rainfall (less than 150 mm annually), and extreme temperature fluctuations between hot summers and cold winters (Al-Eisawi, 1996).

Southern Badia: This area is famous for its sandstone mountains, towering cliffs, and vast sand dunes. The climate is arid, and rainfall is scarce, often below 50 mm annually (Sada et al.,2015), and temperatures can soar above 40°C in summer, dropping to near freezing in winter (Al-Qinna et al.,2011). Despite these conditions, several hardy plant species have adapted to survive here.

Soil Characteristics and Water Availability.

Desert soils in Jordan are typically poor in organic matter and nutrients, with a high percentage of gravel and sand. These soils often experience salinization due to limited rainfall and high evaporation rates, which concentrate salts at the surface (Salahat and Al-Qinna,2015). Water is the most limiting factor for plant life, with rainfall patterns being unpredictable and often coming in short bursts that create temporary runoff channels. Plants must adapt to long periods of drought interspersed with brief periods of water availability.

Vegetation of the Jordanian Badia.

The Jordanian Badia is characterized by sparse vegetation, with plants that exhibit various adaptations to arid conditions. Many species are drought-tolerant or salt-tolerant (halophytic), with mechanisms to minimize water loss and maximize water uptake. Some of the most important plant species in the Jordanian desert include:

Atriplex halimus (Saltbush): This halophytic shrub is one of the most common and ecologically important species in the Jordanian desert. It thrives in saline soils and arid environments, often growing in areas with limited water resources. The *Atriplex halimus* has the ability to sequester salts in its leaves and can photosynthesize efficiently even under saline and drought conditions (Walker and Lutts, 2014). It plays a crucial role in stabilizing soils, preventing erosion, and providing forage for livestock, and it is used as traditional medicine (Walker et al., 2014).

Retama raetam (White Broom): A drought-tolerant leguminous shrub that is well adapted to desert environments. Its deep root system enables it to access water from deeper soil layers, and it contributes to nitrogen fixation, enriching the soil. This plant, which is found in the Jordanian desert, gives aesthetic value to the ecosystem with its white flowers that bloom at the beginning of spring in the region. (Nawash and Al-Horani, 2011).

Anastatica hierochuntica (Rose of Jericho): A resurrection plant that can survive long periods of drought by curling into a dry ball and reviving when exposed to moisture. This plant is symbolic of desert resilience and adaptation (Rostan and Manshoor, 20024).

***Tamarix* spp.** (Tamarisk): A salt-tolerant tree that grows along wadi beds and saline soils. It is known for its ability to thrive in highly saline environments and helps in stabilizing desert ecosystems by preventing soil erosion (Neef, 1998).

Atriplex halimus and Desert Conditions

Halophytes and Xerophytes

Halophytes are plants that thrive in saline environments where the salt concentration is around 200 mM NaCl or more. They constitute about 1% of the world's flora (Flowers & Colmer,2008). It evolved to tolerate high levels of soil salinity, typically exceeding the tolerance thresholds of most terrestrial plants, and it can be used to restore vegetation (Grigore et al., 2014). Halophytes are distributed in different areas on the surface of the earth. Some of them live in shallow waters and estuaries near the shore, others are found in coastal salt marshes or even in salt desert lands (Flowers & Colmer,2015). Increasing desertification leads to reveals the extreme importance of the ecological and economic value of this highly stress-tolerant xerophytic genus(Calasan et al., 2022). The continent of Asia is considered the original homeland of the *Atriplex* plant, where it originated in the Miocene era, and from there the lineage spread to dry lands all over the world (Calasan et al., 2022). *Atriplex halimus* L. (*Amaranthaceae*) (Mediterranean saltbush) is a halophytic shrub. This plant has a wide distribution in arid and semi-arid areas in the Mediterranean basin, whose altitude is less than 900 meters(Walker et al., 2014).In the Mediterranean region, about 50 species of *Atriplex* plants have been identified, but the continents contain more than 400 species of this plant (Dorda et al., 2005).In arid desert areas, there is a type of plant called xerophytes that has a high ability to adapt to dry environments through unusual physiological mechanisms (Xi, Jie-Jun, et al., 2018). Drought-tolerant plants, xerophytes, contain many genes, proteins, and metabolites that respond quickly to severe drought stress, allowing these plants to survive in arid and semi-arid desert conditions (Bechtold and Ulrike, 2018). *Atriplex halimus* is a xerophytic C4 species that adapts to desert areas with dry climates through the effective use of water (Le Houérou, 1992).

Responses of *Atriplex halimus* to Water Stress

Water stress on *Atriplex halimus* by withholding water for 22 days leads to a significant decrease in growth, but the plant remains alive. The assimilation of carbon dioxide decreases, as a result of the influence of the dark phase on the photosynthesis process, and this is accompanied by a decrease in the rate of stomatal conduction in the leaves. An increase and improvement in optimal water utilization under conditions of water stress and drought leads to an increase in the concentration of sodium ions (Martinez et al., 2003). These parameters were affected by drought to varying degrees: photosynthetic rate, stomatal conductance, and transpiration rate in *Atriplex halimus*. Drought for three to six days did not affect the growing shoot, fresh weight, dry weight, or height, which are considered measures of growth, but they were affected by drought after 10 days had passed on 40-day-old seedlings of the picking plant. Also, the drought did not affect the Rubisco hormone or phosphoenolpyruvate carboxylase (PEPC) protein (Nemat Alla et al 2011). In *Atriplex halimus,* the biomass dry matter (BDM) production was significantly reduced when water was limited in the T50 treatment at a high level of water stress, T50 (50% moisture at field capacity) (Essafi et al., 2006). Water stress at *Atriplex halimus* leads to a reduction in CO_2 net assimilation rates quantified in the presence of high CO_2 and low O_2 levels, stomatal conductance, and transpiration. NaCl improved the water use efficiency of Polyethylene glycol PEG)-treated plants in young leaves. The internal concentration of sodium ions is increased by PEG (Martınez et al., 2005). Fresh and dry weights of shoots were significantly increased by 50 mM NaCl, but the drought by PEG after 10 days induced a reduction in the growth of forty-day-old Atriplex halimus seedlings. The metabolite profiles showed up-regulation of amino acids proline, isoleucine, valine, and methionine. Sucrose increased significantly up to three-fold and five-fold by 300 and 550 mM NaCl and up to 2.5-fold by drought for 10 days. High NaCl concentrations and the long-term drought by PEG increase the concentration of proline. NaCl affects the metabolite profiles more than PEG, and these metabolites might contribute to osmotic adjustments to act as osmoprotectants rather than osmolytes (Nemat Alla et al., 2012). In *Atriplex halimus,* water deprivation led to declines in shoot Ψw and Ψs, leaf relative water content (RWC), transpiration and CO2 assimilation, and increases in leaf K^+ and Na^+ (Walker et al.,2014). In *Atriplex halimus*, glycine betaine protects the photosynthetic apparatus against permanent soil salinity (Ben Hassine and Lutts, 2010).

Adaptive Features of *Atriplex halimus* to Water Stress

When exposed to water stress, one of the changes that occurred in *Atriplex halimus* was a noticeable increase in both the root system and crude fiber, and the surface area of the leaves became small (Essafi et al., 2006). The height and the fresh weight of *Atriplex halimus* are increased at 360 mM NaCl vs. 0 mM NaCl. *Atriplex halimus* thrived under salinity due to reduced stomatal conductance and transpiration rate, enabling the species to preserve moisture and improve water use efficiency (Calone et al., 2021). Two root systems exist in the *Atriplex halimus*. The fine roots can collect water and nutrients after rainfall, and the long main roots can collect water from the depth up to 5 m (Guerrero-Campo et al., 2006). The water Ψw and solute Ψs potentials in the *Atriplex halimus* are very low (-4.20 and -6.57) MPa, respectively. This is due to a water depression (Bajji et al., 1998). In *Atriplex halimus*, the below-ground and above-ground biomass decreased at 513 mM NaCl related to photosynthetic limitations and specific stem conductivity (Romero et al., 2020). The optimum temperature for photosynthesis in *Atriplex halimus* is relatively high, approximately 35 °C or above, so it is suitable for arid and semi-arid regions. The explanation behind this, that the plant has a C4 carboxylation pathway (Zervoudakis et al.,1998). Shoot growth was decreased by PEG in *Atriplex halimus,* and a combination of Cu, NaCl, and PEG led to further decreased in growth parameters, but the expression of glutathione, proline, or non-protein thiol did not decrease (Orrego et al, 2020). *Atriplex halimus* is a halophytic plant species able to take up toxic elements from the soil and sequester them in vacuoles, salt glands, or trichomes to decrease their toxic effects (Ishtiyaq et al, 2023). The chlorophyll and relative water content in Mediterranean saltbush were reduced in the summer months, and the leaf Na, K, Cl, and proline were increased, to achieve an osmotic adjustment in the leaf's tissues. The Mediterranean saltbush plants regulate the proline levels as well as some ions like Na, K, and Cl (Alotibi et al., 2023). In halophytes, there are many protective mechanisms for survival, including sequestration of salt via Na^+/H^+ antiporters, synthesis and accumulation of osmolytes, and activation of protective mechanisms against reactive oxygen species (ROS). A higher induction of Na^+ /H+ antiporter gene expression leads to increased Na^+ and K^+ concentration (Hamdani et al.,2017). In the study of comparative effects of $CaCl_2$ and NaCl salinity on growth and ion partitioning of *Atriplex halimus,* it turns out that NaCl and $CaCl_2$ salinity caused a significant reduction in both leaf water content and relative water content. Photosynthetic pigments were also reduced, ranging from 23 to 58% for chlorophyll a and b and 45% for carotenoids at 300mM salinity. Treated *atriplex halimus* with 300 mM NaCl was more affected than treated with 300mM $CaCl_2$ on leaves, stems, and roots. Dry weight and total biomass were reduced from (35% to 49%) by $CaCl_2$ and from (55-69%) by NaCl (Ayad, 2010). The levels of Ca, Na, Cl, and K that accumulated in leaves were higher than in stems and roots. When treated with 300mM $CaCl_2$, the content of Ca was increased by fourfold in leaves and stems and twofold in roots. The accumulated Na and Cl were in leaves and stems but not in roots (Ayad, 2010).

Genes Related to Water Stress

Several salinity-responsive genes have been identified in the Mediterranean saltbush (Sadder et al., 2013). BZIP (basic leucine zipper) transcription factors (ABI3, ABI5, and ABF-like) have an essential role in ABA stress responses (Hossain et al., 2010). In the well-watered expanded leaves compared to the expanding ones in *Atriplex halimus* at the times 9:00 and 13:00, the ABI3, ABI5, and ABF were highly expressed, showing that the sensitivity of the expanded leaves to ABA is higher (Nada et al, 2018). ABI3 is involved in stomatal closure during drought stress (Parcy and Giraudat., 1997). ABI5 and ABF act as positive regulators of ABA signaling (Finkelstein et al., 2002).The transcript levels of ABI3, ABI5 and ABF were stimulated by drought in *Atriplex halimus* leaves (Nada et al., 2018).Osmotic and high salinity stress induce DREBs dehydration responsive element binding genes (Reis et al., 2014).The regulation of DREB1 and DREB2 by water stress was inconsistent in *Atriplex halimus* expanding and expanded leaves, the expected redundant role of DREBs during drought stress may be time dependent and may have a cumulative role at 17:00 (Nada et al ., 2018).Hardy (HRD),is a transcription factor that belongs to AP2/ERF (Nakano et al., 2006). In the Arabidopsis inflorescence parts, the expression of HRD was identified (Zimmermann et al. 2004). The expression of HRD in *Atriplex halimus* showed significant decreases with increasing external NaCl concentrations (Nada and Abogadallah., 2015). Dehydrin genes (DHNs) are considered major elements to mitigate extremely harsh environmental stresses such as salinity and drought (. The AhaDHN1 is a dehydrin gene that was detected in *Atriplex halimus* and may have a role to enable saltbush plants to survive in the desert (Musallam et al., 2023), where it was shown to be more up-regulated in roots than shoots under stress (Sadder and Al-Doss, 2014). Transporters on the plasma membrane (SOS gene network)—potassium transporters and cation/proton antiporters on the vacuolar membrane (NHX) including H+-ATPases and vacuolar H+-pyrophosphatase they are consider the major halophytic genes responsible for salt tolerance (Mann et al ., 2023). A lot of genes involved in regulation of ionic uptake and transport in halophytes governing the salt exclusion and compartmentalization (SOS1, SOS2, SOS3), ion transporters, ROS system, osmoregulation (NHX, V-type and P-type H+-ATPases, H+-pyrophosphatase), and photosynthesis (Mann et al.,2021a).The SOS1 gene encodes the plasma membrane Na+ /H+ antiporters, which are responsible for sodium exclusion from the apoplast. The SOS2 gene encodes the serine / threonine type protein kinase, and the SOS3 genes encode an EF-hand-type calcium-binding protein, which regulates Na+ and K+ transport (Mann et al., 2023). WRKY transcription factors that regulate many processes in plants such as the responses to abiotic stresses (Rushton et al., 2010). WRKY transcription factors have an active role in drought stress tolerance (Banerjee and Roychoudhury, 2015).

Discussion

In Jordan Badia, where water scarcity and desertification are significant challenges, *Atriplex halimus* plays a crucial role in the restoration of degraded arid rangelands, soil stabilization, and biodiversity conservation (Al-Satari et al., 2018; Abu-Zanat et al., 2020). This shrub is important in desert ecosystems because it helps prevent soil erosion, particularly in areas prone to wind erosion and sand movement. It also serves as a source of food for livestock, making it a valuable species for pastoral communities in Jordan (El Shaer and Attia, 2002). Jordan’s climate ranges from Mediterranean in the west to arid and hyper-arid in much of the east and south, with hot, dry summers, cool, wet winters, large spatial variation in annual precipitation (from >400 mm in some highlands to <50 mm in desert areas), and increasing climate risk from warming and precipitation decline. In such a context, species that tolerate low rainfall, high evaporative demand, and soil salinity are particularly valuable for rehabilitation and pastoral systems. *Atriplex halimus's* combination of salt/drought tolerance, capacity for osmotic adjustment, and usefulness as forage and for soil amelioration makes it well suited to many Jordanian rangeland and reclamation objectives.

Considering the harsh climatic conditions prevailing in the Jordanian desert and the deterioration of pastures, there is an urgent need for studies on *Atriplex halimus* this is to answer many questions that are considered important in this stage. Is it possible to make feed suitable for cows, sheep, and goats in the Jordanian environment? Can silage be made from it, and what is its impact on milk and meat production and livestock health? Since most of Jordan's area is desert, there is a need for a comprehensive study of its presence in Jordanian regions to determine which areas are most suitable for its propagation as a pasture crop. Are the previous studies complete, or are there any shortcomings? There is a need to determine the productivity of Atriplex halimus per acre in the Jordanian desert under the prevailing climatic conditions. Future studies should also investigate the possibility of transporting it from its production sites to distant cow farms, for example, and its suitability for storage, and whether it loses its nutritional value if it is stored or provided as dry fodder for livestock in Jordan.

Since the use of Atriplex halimus is multifaceted, future studies may provide an answer to its use as a basic feed for many different types of livestock, not only cows, sheep, and goats, but also fish and poultry. This depends on several aspects, including whether it is served dry or wet, or whether it is given as a single feed or combined with another type of feed. Since Atriplex halimus can absorb heavy elements from the soil, there must be studies to show the number of materials it absorbs and whether it can be used in certain areas to clean the soil of harmful heavy elements and return it to normal life. Can Atriplex halimus be used in Jordan to clean the soil and improve its properties? This is especially true in areas characterized by high levels of salinity, which are not suitable for growing crops that cannot tolerate high levels of salinity. Is it possible to reduce their salinity level after planting them, and how many agricultural seasons does this require? In the field of energy, perhaps there should be studies that clarify the amount of energy that can be obtained from the dry mass of Atriplex halimus and whether it can be used as a biofuel, which may reduce direct dependence on energy sources coming from fossil fuels. This, in turn, reduces the energy bill in countries that do not produce fossil fuels, such as Jordan, and contributes to reducing pollution. It is necessary to expand studies related to the medicinal uses of Atriplex halimus. Could there be medicinal materials that can be obtained and sold in pharmacies? Can it be used directly for human nutrition, or does it require processing? Can it be a source of pure salt? Future studies can answer these questions and many others.

Conclusion

The importance of cultivating *Atriplex halimus* in the Jordanian desert environment emerges from the harsh characteristics of the Jordanian desert environment. Jordan faces significant challenges due to its arid climate, limited arable land, and acute water scarcity. These conditions necessitate the adoption of resilient agricultural practices and plant species that thrive under harsh environmental conditions. *Atriplex halimus* (Mediterranean saltbush) emerges as a promising candidate for sustainable agriculture and ecological restoration in Jordan's desert regions. *Atriplex halimus* is highly resistant to prolonged periods of drought, due to its deep root system and efficient water-use strategies. This characteristic aligns well with Jordan's minimal rainfall and dependence on limited water resources. The plant thrives in saline soils, making it suitable for cultivation in areas with high soil salinity or irrigation with brackish water. Jordan's salinized soils, especially in regions like the Jordan Valley, can benefit significantly from this trait. *Atriplex halimus* stabilizes soil and prevents desertification, a pressing concern in Jordan's expanding desert areas. Its dense root system enhances soil structure and reduces erosion. Its leaves provide a valuable source of fodder for livestock, especially in regions where conventional forage crops fail due to water scarcity. This feature supports pastoral communities in the Jordanian desert. By sequestering carbon and adapting to extreme conditions, the plant contributes to mitigating climate change impacts—a significant concern for Jordan's agricultural sector. Cultivating *Atriplex halimus* offers a practical solution to Jordan's water scarcity and arid conditions by providing drought- and salt-tolerant forage and enhancing soil health. As desertification accelerates in Jordan, *Atriplex halimus* stands out as a natural defense, stabilizing soils and reclaiming degraded lands. Jordan's future in agriculture lies in water-efficient species like *Atriplex halimus*, capable of thriving with minimal water input. By integrating *Atriplex halimus* into agro-pastoral systems, Jordanian farmers can secure a reliable forage source, even during prolonged droughts. Cultivating *Atriplex halimus* supports Jordan's sustainability goals by combating desertification, supporting biodiversity, and mitigating climate impacts. By leveraging the unique properties of *Atriplex halimus*, Jordan can address critical environmental challenges while supporting sustainable agricultural practices. This aligns with the nation's long-term goals of water conservation, land reclamation, and food security.

Recommendations

Given the unique characteristics and advantages of the *Atriplex halimus* plant, which can withstand the harsh conditions of the vast Jordanian desert environment, we recommend that government sectors and government support institutions, represented by the Ministry of Agriculture, develop programs aimed at raising environmental awareness of the importance of this plant among the inhabitants of the extensive Jordanian rangelands, in order to protect it from overgrazing. We also recommend the necessity of establishing special reserves for its cultivation in arid lands in order to provide a safe habitat for many desert organisms and enhance biodiversity in the Jordanian desert. Due to its high tolerance to salinity, we recommend planting it in highly saline soils that are unsuitable for other crops until these soils are rid of the high levels of salinity. We also recommend that research institutions, universities, agricultural institutes, and companies specializing in agricultural scientific research expand studies to identify and discover more of the properties of this plant in both the medical and nutritional fields, as our study has shown its uses in traditional folk medicine in the cultures where it occurs naturally.

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نبات الأتريبلكس الملحي المتوسطي (Atriplex halimus L.): نبات ملحي واعد لمكافحة التصحر في الأردن

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ملخص

ينتمي نبات الأتريبلكس الملحي المتوسطي (Atriplex halimus L.) إلى الفصيلة القطيفية (Amaranthaceae). وهو شجيرة معمرة ملحية، تتميز بقدرتها على التكيف مع البيئات القاسية وشبه القاحلة، وتُعد من الأنواع النباتية المقاومة والمتعددة الاستخدامات. ويُعتبر الأردن من أفقر دول العالم من حيث موارد المياه الطبيعية، حيث تشغل المناطق الصحراوية أكثر من ثلاثة أرباع مساحة البلاد. وبالنظر إلى ظروف الاحتباس الحراري، والتصحر، وقلة الأمطار، وندرة المراعي والأعلاف الخضراء، يُعد نبات الأتريبلكس الملحي المتوسطي (A. halimus) واعدًا في مواجهة هذه التحديات. تستعرض هذه الدراسة التصنيف العلمي لنبات الأتريبلكس الحلمي (Atriplex halimus)، وتوزيعه الجغرافي، ووجوده في الأردن، واستخداماته، وخصائصه التشريحية والمظهرية. كما تسلط الضوء على أهم خصائصه التي تجعله نباتًا متكيفًا مع البيئة الصحراوية. ويمكن الاستنتاج أنه من خلال الاستفادة من الخصائص الفريدة للأتريبلكس الحلمي، يستطيع الأردن مواجهة التحديات البيئية الحرجة مع دعم الممارسات المستدامة. ويتماشى هذا مع أهداف الدولة طويلة الأجل في ترشيد استهلاك المياه، واستصلاح الأراضي، وتحقيق الأمن الغذائي.

الكلمات الدالة: الأتريبلكس الحلمي، الجفاف، الملوحة، الإجهاد المائي، التصحر، النباتات الملحية، النباتات الصحراوية.

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