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The Resilience of *Ephedra alata* Decne in Two Regions of Egypt: Soil Properties, Tissues Anatomy, and Physiological Responses

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EPHEDRA is an important genus of the Ephedraceae family and is widely distributed in arid and semi-arid environments worldwide. This study systematically investigated the specific environmental factors affecting the population dynamics and distribution of Ephedra sinica at eight sites in two distinct ecological zones: Wadi Degla and El-Tour. Based on a comprehensive soil analyses, important physicochemical properties such as soil moisture content (2.38-10.29%), pH (7-8), total dissolved solids (TDS: 3349.7-6447.9 ppm), electrical conductivity (EC: 4.99-9.55 ds/m), calcium carbonate concentration ($CaCO_3$: 40.53-61.31%), and organic matter content (0.23-1.83%) were significantly different. The concentrations of water-soluble anions {CO_3- (3.52-6.59 $mmol_c/L$), HCO_3^- (3.03-6.11 $mmol_c/L$), Cl^- (5.11-22.16 $mmol_c/L$), and SO_4^{2-} (22.30-50 $mmol_c/L$)} and cations {Na^+ (6.88-24.25 $mmol_c/L$), K^+ (1.28-2.86 $mmol_c/L$), Ca^{2+} (31.97-49.83 $mmol_c/L$), and Mg^+ (6.77-30.54 $mmol_c/L$)} were also measured. In addition to soil composition, the anatomy of roots, stems, and leaves was also studied. Physiological analyses included chlorophyll content, protein and carbohydrate concentrations, and plant responses to drought stress and soil limitations such as salinity. The results highlight the remarkable ecological resilience of ephedra, confirming its ability to survive and thrive in a variety of soil types and environmental stresses, thus enhancing its resilience to harsh environments.

Keywords: *Ephedra*, Soil analyses, El-Tour, Wadi Degla, Biochemical screening, Environmental factors.

1. Introduction

Ephedra alata Decne belongs to the gymnosperm group, specifically the division Gnetophyta. The Gymnosperms are a primitive group of vascular seed plants with their origin dating back to the Devonian Period of Paleozoic era (385–359 m years old). Theophrastus coined the term 'Gymnosperm' in his Historian Plantarum (350–287 BCE). The Gymnosperms represented by about 1000 species, which belong to 83 genera and 12 families and distributed largely across the temperate regions of world. In India, there occur 161 taxa (154 species six varieties and 1 forma) representing 46 genera and 11 families (Srivastava, 2021). Of these, 76 taxa are indigenous with 19 endemics. The Gymnosperms are one of the most threatened plant groups, with 40% of the species at the high risk of extinction, about twice as many as the most recent estimates for all plants, i.e. 21.4% (Forest et al., 2018).

Ephedra alata Decne is a compact, evergreen shrub that remains nearly leafless. It typically grows between 60 and 90 cm tall, featuring slender green stems that can stand upright or lean slightly. These stems, about 1.5 mm in diameter, are marked by fine ridges and narrow channels, often tapering to a pointed tip. Nodes are 4 to 6 cm apart, and small triangular leaves appear at the stem nodes. The nodes are characteristically reddish brown. The stems usually branch form the base. They bear minute, yellow-green flowers and fruits, and emit a strong pine-like odor and have an astringent taste (Blumenthal et al., 1995 and Fukushima, 2004). This plant is a common shrub that comes from North Africa, Southern Europe, and Southwestern North America and is found in many different countries. This therapeutic plant belongs to the genus Ephedra (Elhadef et al., 2020).

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Most ephedra species have evolved to thrive in deserts and arid environments. Their distribution and abundance are significantly influenced by various environmental conditions and stresses (Alqarawi et al., 2014). Abiotic factors such as high and low temperatures, drought, and salinity severely impede plant growth and development (Badawy et al., 2024). These stresses can cause biochemical disturbances that lead to reduced growth and development, inhibition of photosynthesis, loss of membrane integrity, and increased production of reactive oxygen species. Plants synthesize certain osmoregulators as an effective strategy to mitigate oxidative damage and help cope with adverse conditions (Ghanem et al., 2002). These osmoregulators play important roles in scavenging free radicals, regulating cellular redox potential, regulating osmotic pressure, stabilizing membranes and proteins, and maintaining relative water levels necessary for plant growth and metabolism (Tan et al., 2006).

In light of the above, this study aimed to investigate the adaptability of ephedra to different environmental conditions, with a particular focus on its physiological and structural adaptations, and to evaluate its potential use for soil stabilization and crop sustainability in arid and semi-arid regions.

2. Materials and Methods

2.1. Study area

Egypt's roughly one million square kilometers are separated into four distinct geographical regions: 1. The Nile River, encompassing the Nile Valley, Nile Delta, and Nile Fayium 2. The Sinai Peninsula, the Eastern Desert, and the Western Desert (Zaharan and Willis, 2009). The most important and unique kind of natural plant life in Egypt is the desert vegetation. The environmental condition of the Egyptian deserts is arid and/or extremely arid. The most prevalent type of desert vegetation is made up of perennial plants, which are also thought to be a good predictor of the ecosystem (Zahran et al., 2009).

The geographical boundaries of the Wadi Degla study area are defined by latitudinal coordinates between 29°58'29.749" and 29°55'45.343"N and longitudinal coordinates between 31°21'15.876" and 31°27'4.57"E .This area located between latitudes and longitudes and it was thirty kilometers long. It travels through the Eastern Desert's limestone rocks, which can grow up to 50 meters high along the wadi. Al-Qattameyah-Al-Sukhna Road and other urban settlements in the Al-Maadi area occupy the about 200 km2 wadi (Megahed and El Bastawesy, 2020). The Egyptian Metrological Authority reports that the wintertime mean yearly rainfall was 23 mm (EMA, 2019). At 578 meters above sea level (a.s.l.), the Wadi has a considerable gradient, dropping around 10 meters every kilometer along the stream's path. It empties into Gabal (Mountain) Abu Shama. Additionally, debouching at 21 meters above sea level into the Nile Valley. The elevations of the wadi's study sites vary; the downstream portion ranges from 85 to 200 m above sea level, the midstream from 220 to 330 m above sea level, the upstream from 340 to 420 m above sea level, and the (downstream) tributaries from 140 to 250 m above sea level.

El-Tour region is in South Sinai which is characterized by a short rainy season in the cold winter (annual precipitation is usually around 40 mm) and long dry warm summer, this region is in the middle sector of the El-Qaa plain, south - east Gulf of Suez, Sinai. El-Tour study area is defined by geographical boundaries consisting of latitudinal coordinates between 28°22'12.797" and 28°7'20.983"N, along with longitudinal coordinates from 33°29'52.962 to 34°1'11.078"E, encompassing an area of roughly 4 by 3 km (12 km2), respectively. Additionally, the El-Qaa Quaternary alluvial aquifers screened ground water bores produce up to 16,000 m 3 each day. El-Tour and Sharm El-Sheikh mostly use the water for drinking, despite the fact that it is somewhat brackish with 500 parts per million of dissolved salt. In this regard, several electrical conditions were examined for the freshwater aquifer in the research area in conjunction with aquifer hydraulic characteristics (Moustafa and Zaghloul, 1996).

Fig. 1. Map showing the two studied regions in Egypt.

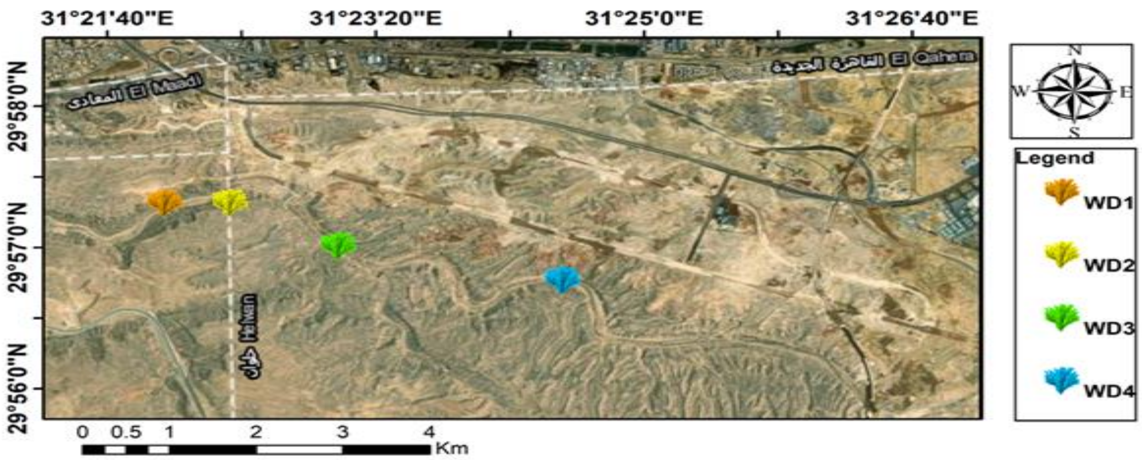

Fig. 2. Map showing the studied locations in Wadi degla (Cairo).

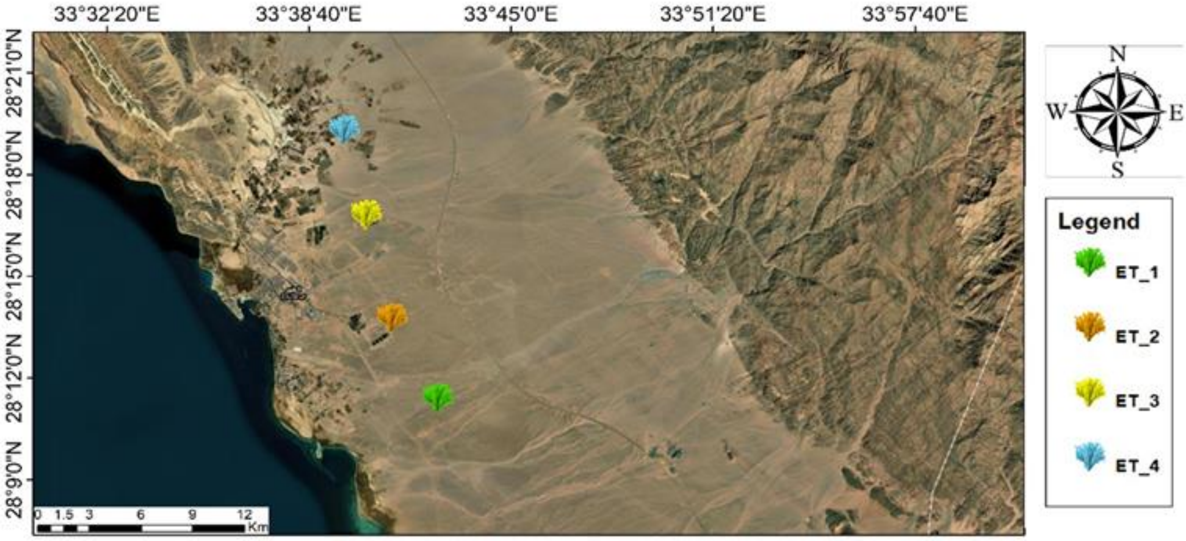

Fig. 3. Map showing the studied locations in EL-Tour (South Saini).

2.2. Distribution and description of the studied plant

The genus grows primarily in northern and western China, northern India, and Spain. It is native to the temperate and subtropical regions of Europe, Asia, and America. The Rocky Mountains in the United States are home to ephedra plants. In Asia, Ephedra alata is found in Saudi Arabia, Iraq, Iran, Palestine, Lebanon, Jordan, and Syria; in Africa, it is found in Algeria, Egypt, Libya, Morocco, Tunisia, Mauritania, Chad, and Mali (Ebadi, 2007).

Ephedra alata Decne belongs to the Ephedraceae family and is called Alanda in Arabic. The closest living relative of the angiosperm, this species is a perennial genus that can grow to a height of over one meter, has an astringent taste and a strong pine odor, and is a member of the Gentiles plant. Iran, Algeria, Egypt, Palestine, Lebanon, Jordan, Iraq, Saudi Arabia, Morocco, Libya, and Tunisia are among the countries where this plant is indigenous (Alqarawi et al., 2014). The plant is a tiny, perennial, stiff shrub that is light green, dioeciously branched, and about 50 to 100 cm tall. The leaves on the twigs appear to be reduced to small scales, and the cones are a sessile in shape and grouped in the axils or at the terminals of the branches (Nawwar et al., 1985).

Twenty-four samples from eight habitats were chosen in the period from April 2023 to March 2025 for study of soil and plant tissue of *Ephedra alata* Decne plant was collected from two regions in Wadi degla (Cairo) and EL-Tour (South Saini) in Egypt. These samples were distributed in eight locations, four in Wadi degla namely: WD_1, WD_2, WD_3 and WD_4, and four in EL- Tour (Southern Sinai) namely ET_1, ET_2, ET_3 and ET_4. Soil and plant tissue samples were collected from three sites in each location.

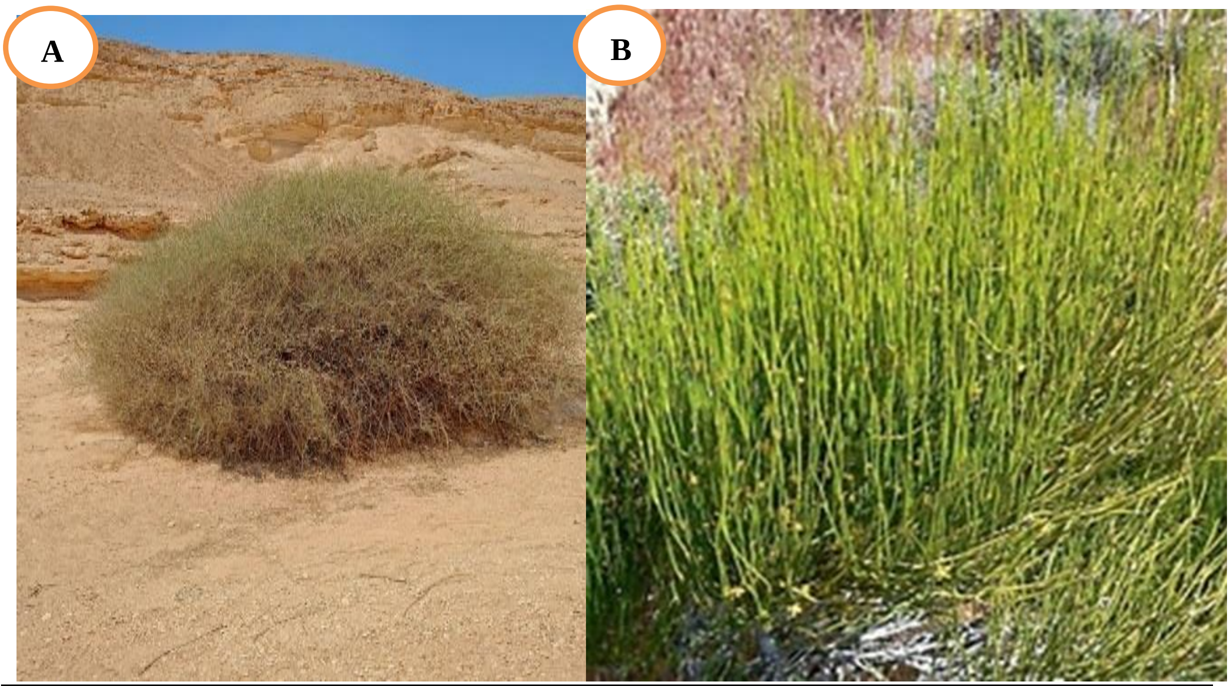

Fig. 4. Pure vegitation of *Ephedra alata* Decne (photo A), and Enlarged photo of *Ephedra alata* Decne (photo B).

2.3. Soil analyses

Soil samples were air dried, grinded, sieved and kept for chemical analyses according to methods of Sparks et al. (2020) for the determinations of pH, TDS, EC, CO_3^{--}, HCO_3^{-}, SO_4^{--}, Cl^-, Na^+, K^+, Ca^{++} and Mg^{++}. Calcium carbonate was determined by titration against 1.0 N HCl. Also, chlorides and organic matter were determined. While EC and TDS were measured by electrical conductivity meter and TDS meter, respectively.

2.4. Plant tissue analyses

The root, stem, and leaf anatomy of *Ephedra* were examined to gain insights into its structural characteristics. Regarding plant tissue analyses, chlorophylls and carotenoids were determined according to the method described by Vernon and Selly (1966). Carbohydrates and proteins were determined by the method of Umbriet et al. (1969) and Lowry et al. (1951), while the illustrated techniques of Bates et al. (1973) and Zhang et al. (2015) respectively assayed proline and malondialdehyde (MDA).

2.5. Statistical analyses

A two-way ANOVA was performed to identify significant differences between the studied regions (Wadi Degla and El-Tour) and locations (1, 2, 3, and 4) with α = 0.05 as the significance level. Shapiro-Wilk's test and Levene's median test were used to confirm the assumptions of normality and homogeneity of variances, respectively. To guarantee reliable results, the proper data transformations were used if these presumptions were broken.

3. Results

3.1. Ecological studies

Data presented in Table (1) observed that the moisture content of the soil (S M C) recorded the highest value in WD_1 by approximately 6.58%, while the lowest value was in WD_2 by approximately 2.83%. This study showed that the proportions are somewhat close of soil reaction (pH) was slightly alkaline and ranged between 7and 8. The values of total dissolved salts (TDS) and electrical conductivity (EC) showed variation from 3349.7 to 6447.9 ppm and 4.99 to 9.55 µs/ cm, the highest value was recorded in WD_2 while the lowest value was recorded in WD_1 respectively. Calcium carbonate content ranged from 40.53 % to 46.87 %, while organic matter contents ranged from 0.83 % to 1.83 %. The highest values of organic carbon and Calcium Carbonate were recorded in WD_4 and lowest value recorded in WD_2 and WD_3, respectively.

Magnesium content showed a range from 10.28 to 30.54 mmolc/L, while sodium content ranged between 6.88 and 20.63 ppm. Potassium content ranged from 1.29 to 2.86 ppm. The highest value of Mg^{++} recorded in WD_2 and lowest value in WD_1, Na^+ and K^+ was recorded high value in WD_2, WD_3 and the lowest value recorded in WD_1, WD_4 respectively. Concerning calcium content ranged from 34.17 and 48.49 mmolc/L. Regarding water-soluble anions, results indicated that Carbonates content varied from 3.52 to 5.37 mmolc/L, with highly significant differences between regions, while bicarbonates content ranged between 3.03 and 6.11 mmolc/L. Chlorides content ranged from 15.28 to 44.91 mmolc/L. The highest values of CO_3, HCO_3 and Cl_2 were recorded in WD_3, WD_2 and WD_3 respectively, On the other hand the lowest value for three parameters was recorded in WD_1. Sulphates content ranged between 33.14 and 50.86 mmolc/L. The highest value of SO_4^{--} was recorded in WD_2 and lowest value in WD_1.

Table 1. The physical and chemical properties of soil at four sites in Wadi Degla (Cairo).

Parameters		Wadi Degla			
		WD_1	**WD_2**	**WD_3**	**WD_4**
M.C %		6.58 ± 0.40 c	2.83 ± 0.01 d	3.09 ± 0.31 d	3.92 ± 0.69 d
pH		7 ± 0.06 bc	7.63 ± 0.09 ab	7.87 ± 0.03 a	8 ± 0.06 a
TDS (ppm)		3349.7 ± 5.01 f	6447.9 ± 39.7 a	5346.4 ± 104.3 c	02± 30.02 e
EC ($dS\ m^{-1}$)		4.99 ± 0.39 c	9.55 ± 0.34 a	8.69 ± 0.50 ab	5.46 ± 0.35 c
O.M (%)		0.84 ± 0.02 bc	0.83 ± 0.02 bc	1.04 ± 0.02 ab	1.83 ± 0.11 a
$CaCO_3$(%)		43.51 ± 1.51 cd	41.1 ± 1.91 cd	40.53 ± 1.99 d	46.87 ± 0.43 bc
Water soluble cations	**K^+ ($mmol_c$ /L)**	1.43 ± 0.02 c	2.67 ± 0.02 a	2.86 ± 0.04 a	1.29 ± 0.03 c
	Na^+ ()	6.88 ± 0.50 d	19.25± 0.59 b	17.23 ± 1.12 b	11.72 ± 0.64 c
	Ca^{++} ($mmol_c$/L)	35.17 ± 0.94 c	42.42 ± 0.92 b	48.49± 0.88 a	34.17 ± 1.11 c
	Mg^{++} ($mmol_c$/L)	10.28 ± 0.99 d	30.54 ± 1.69 a	21.73 ± 1.39 b	15.88 ± 0.75 c
Water soluble anions	**CO_3^{--} ($mmol_c$/L)**	3.52 ± 0.09 d	5.32± 0.25 c	5.37 ± 0.15 c	4.923 ± 0.07 c
	HCO_3^- ($mmol_c$/L)	3.03 ± 0.10 c	6.11± 0.29 a	4.91± 0.33 ab	3.89± 0.45 bc
	Cl^- ($mmol_c$/L)	5.11 ± 0.23 f	20.16 ± 1.28 bc	15.11 ± 1.34 a	9.01 ± 0.45 e
	SO_4^{--} ($mmol_c$/L)	33.14 ± 0.73 c	50.86 ± 1.46 a	42.83 ± 1.54 b	39.48 ± 1.19 b

Data presented in Table (2) indicated that the results of the soil moisture content recorded the highest values (10.29%) in ET_2 and lowest values (6.99%) in ET_4, soil reaction (pH) was slightly alkaline and ranged between (6.83 to 7.90). The values of Total dissolved Salts (TDS) and Electrical conductivity (EC) showed variation from (3387.69 to 6046.40 ppm) and 6.99 to 8.58 µs/ cm, the highest value was recorded in ET_3 and ET_2, while the lowest value was recorded in ET_4 and ET_1 respectively. Calcium carbonate content ranged from 45.95 % to 61.31 %, while organic matter contents ranged from 0.23 % to 0.93 %. The highest values of calcium carbonate and organic matter were recorded in ET_4, ET_3, and lowest value recorded in ET_3 and ET_2, respectively.
Concerning water-soluble cations, calcium content ranged from 31.97 to 49.09 mmolc/L. Magnesium content showed a range from 9 6.77 to 18.28 mmolc/L. Sodium content ranged between 8.72 and 24.25 ppm. Potassium

content ranged from 1.28 to 2.74 ppm. The highest value of Ca^{++} , Mg^{++}, Na^{+} and K^{+} was recorded in ET_2 , ET_4 , ET_2 and ET_2 and the lowest value recorded in ET_4, ET_2, ET_4 and ET_4 respectively.

Regarding water-soluble anions, results indicated that Carbonates content varied from 5.33 to 6.95 mmolc/L, with highly significant differences between regions, while bicarbonates content ranged between 3.81 and 5.87 mmolc/L. Chlorides content ranged from 10.21 to 22.16 mmolc/L. The highest values of CO_3^{--}, HCO_3^{-} and Cl_2^{-} were recorded in ET_4, ET_2 and ET_3 respectively. On the other hand, sulphates content ranged between 22.30 and 40.01 mmolc/L. The highest value of SO_4^{--} was recorded in ET_4 and lowest value in ET_1.

Table 2. The physical and chemical properties of soil at four sites in EL-Tour (South Saini).

Parameters		EL-Tour (South Saini)			
		ET_1	**ET_2**	**ET_3**	**ET_4**
M.C %		8.77 ± 0.31 ab	10.29 ± 0.50 a	9.20 ± 0.21 a	6.99 ± 0.49 bc
pH		7.9 ± 0.12 a	7.8 ± 0.06 a	6.83 ± 0.26 c	7.47 ± 0.26 abc
TDS (ppm)		4353.01 ± 7.1 d	3410.2 ± 8.7 f	6046.4 ± 10.7 b	3387.69 ± 3.15 f
EC (dS/m)		6.99 ± 0.39 bc	8.58± 0.28 ab	7.69 ± 0.64 ab	7.79± 0.289 ab
O.M, %		0.42 ± 0.02 cd	0.23 ± 0.01 d	0.93 ± 0.03 ab	0.69 ± 0.01 bcd
$CaCO_3$,%		50.57 ± 0.62 b	49.95 ± 1.07 b	45.95± 1.02 bcd	61.31 ± 0.72 a
Water soluble cations	**K^{+} ($mmol_c$/L)**	1.84 ± 0.04 b	2.74 ± 0.13 a	2.72± 0.12 a	1.28 ± 0.034 c
	Na^{+} ($mmol_c$/L)	11.32 ± 0.85 c	24.25± 0.14 a	19.97± 0.16 b	8.72 ± 0.65 cd
	Ca^{++} ($mmol_c$/L)	43.17 ± 0.94 b	49.09 ± 1.32 a	49.83± 0.74 a	31.97 ± 0.59 c
	Mg^{++} ($mmol_c$/L)	7.46 ± 0.49 d	6.77 ± 0.29 d	14.82 ± 0.34 c	18.28 ± 0.25 bc
Water soluble anions	**CO_3^{--} ($mmol_c$/L)**	5.59 ± 0.09 bc	6.47 ± 0.31 ab	5.33 ± 0.38 c	6.95 ± 0.19 a
	HCO_3^{-} ($mmol_c$/L)	5.73± 0.14 a	5.87± 0.47 a	3.81± 0.26 bc	4.16 ± 0.30 bc
	Cl^{-} ($mmol_c$/L)	10.21 ± 0.40 d	21.45 ± 0.34 ab	22.16 ± 1.09 a	10.96 ± 0.25 c
	SO_4^{-} ($mmol_c$/L)	22.30 ± 0.59 d	25.90 ± 0.72 d	31.87 ± 0.74 c	40.01 ± 1.09 b

3.2. Anatomical characters

3.2.1. Root Anatomy

Figure (5) showed the transverse section of root anatomy of *Ephedra alata* Decne and observed the outermost layer of the cortex pilliferous layer (PL) replaces the original epidermal layer. The Cortex consists of polygonal cells and differentiated into two types of tissues (outer and inner cortex), outer parenchymatous, inner sclerenchymatous and there is parenchymatous pith in the center.

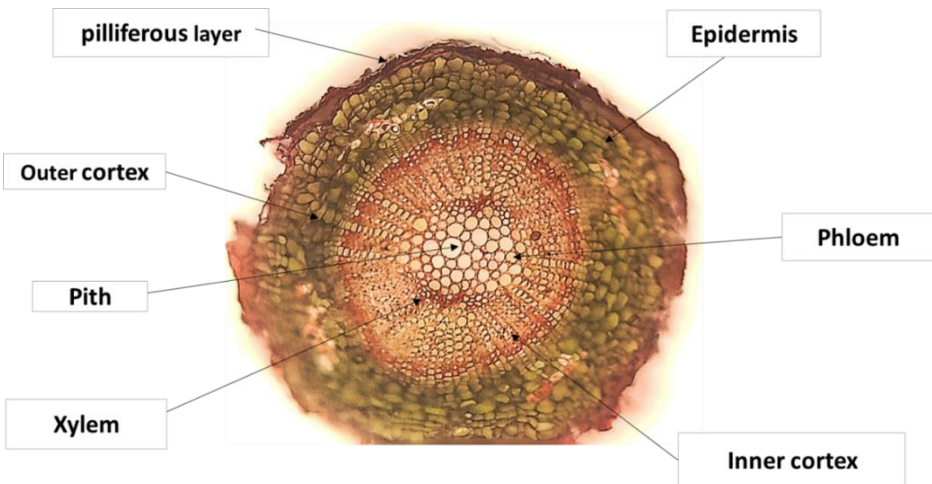

Fig. 5. Thin section of *Ephedra alata* Decne root.

3.2.2. Stem Anatomy

In figure 6 The transverse section of the stem in *Ephedra alata* is almost circular thick layer of cuticle covering the outermost layer of the epidermis. Numerous sunken stomata found in the grooves break the continuity of the epidermis. Additionally, the cortex differentiates into parenchyma, collenchyma, and sclerenchyma. The thick-walled sclerenchyma and the vascular cylinder are separated by a broad zone of thin-walled, chlorophyll-containing green cells. The distinctive characteristic of Ephedra wood is the presence of vessels. In this green area, there are also sporadic sclerenchyma patches. There is parenchymatous pith in the middle.

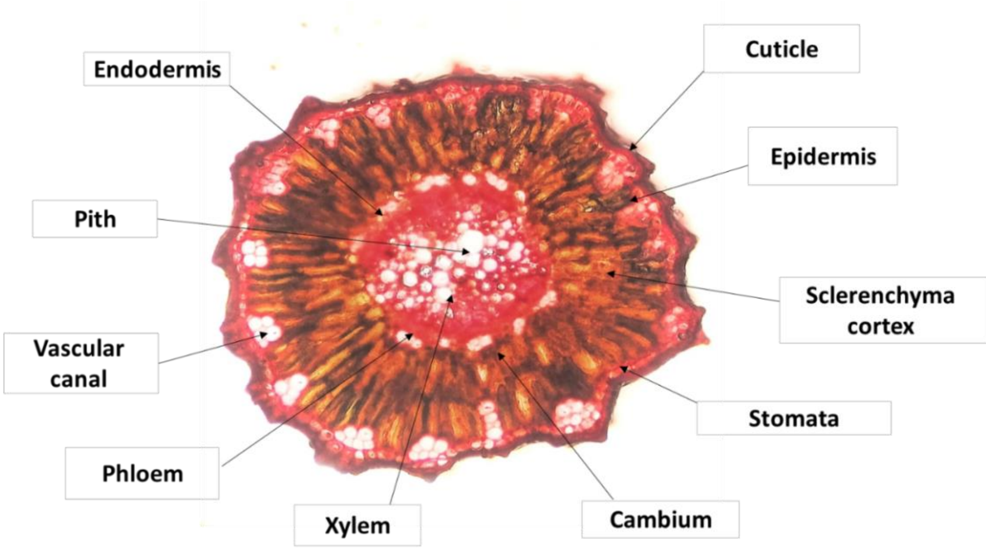

Fig. 6. Thin section of *Ephedra alata Decne* stem.

3.2.3. Leaf Anatomy

Figure 7 showed that the transverse section in leaf of *Ephedra alata,* The scaled, shortened, and membrane-bound leaves have a slightly oval shape. The upper and bottom layers of the epidermis are made up of elongated or oval cells that are each single-layered and covered in a thin layer of cuticle. If there are stomata, they are sunken. The parenchymatous and palisade areas have a lot of air gaps. There are two different vascular bundles.

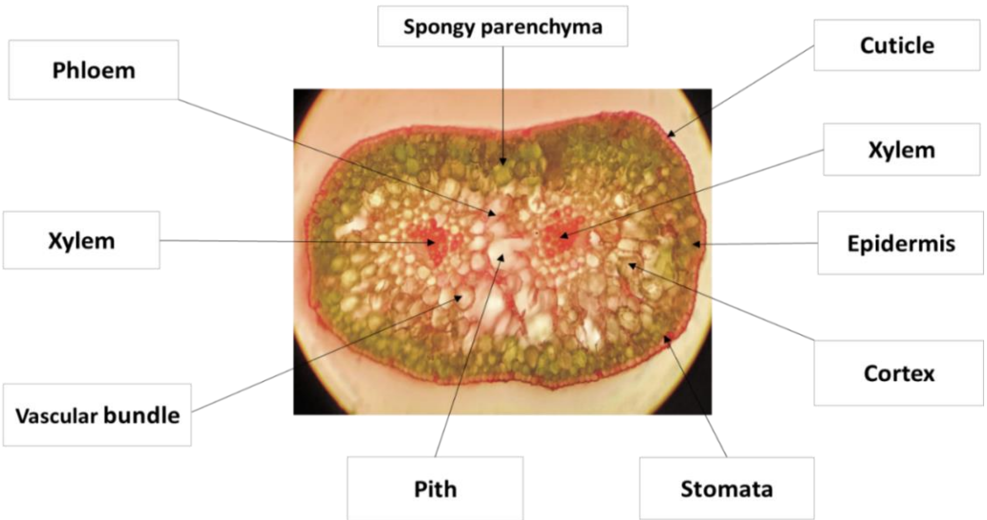

Fig. 7. Thin section of *Ephedra alata* Decne leaf.

3.3. Physiological screening in plant tissues

3.3.1. Chlorophylls and carotenoids

The data in Figure 8 illustrate the significant variations in pigment content in ephedra leaves within the study area. Chlorophyll *a* contents ranged from 1.5 (mg/g fresh weight) to 2.2 (mg/g fresh weight), with the highest value recorded in WD_4 and the lowest in ET_1. Chlorophyll b content ranged from 0.9 to 1.4 (mg/g), with WD_3 having the highest and ET4 the lowest. Among them, the total chlorophyll content in WD_1 reached the highest value (3.8 mg/g), and the total chlorophyll content in ET_4 reached the lowest value (2.5 mg/g). The highest carotenoid content was 1.3 (mg/g) in ET_3, and the lowest was 0.7 (mg/g) in WD_3.

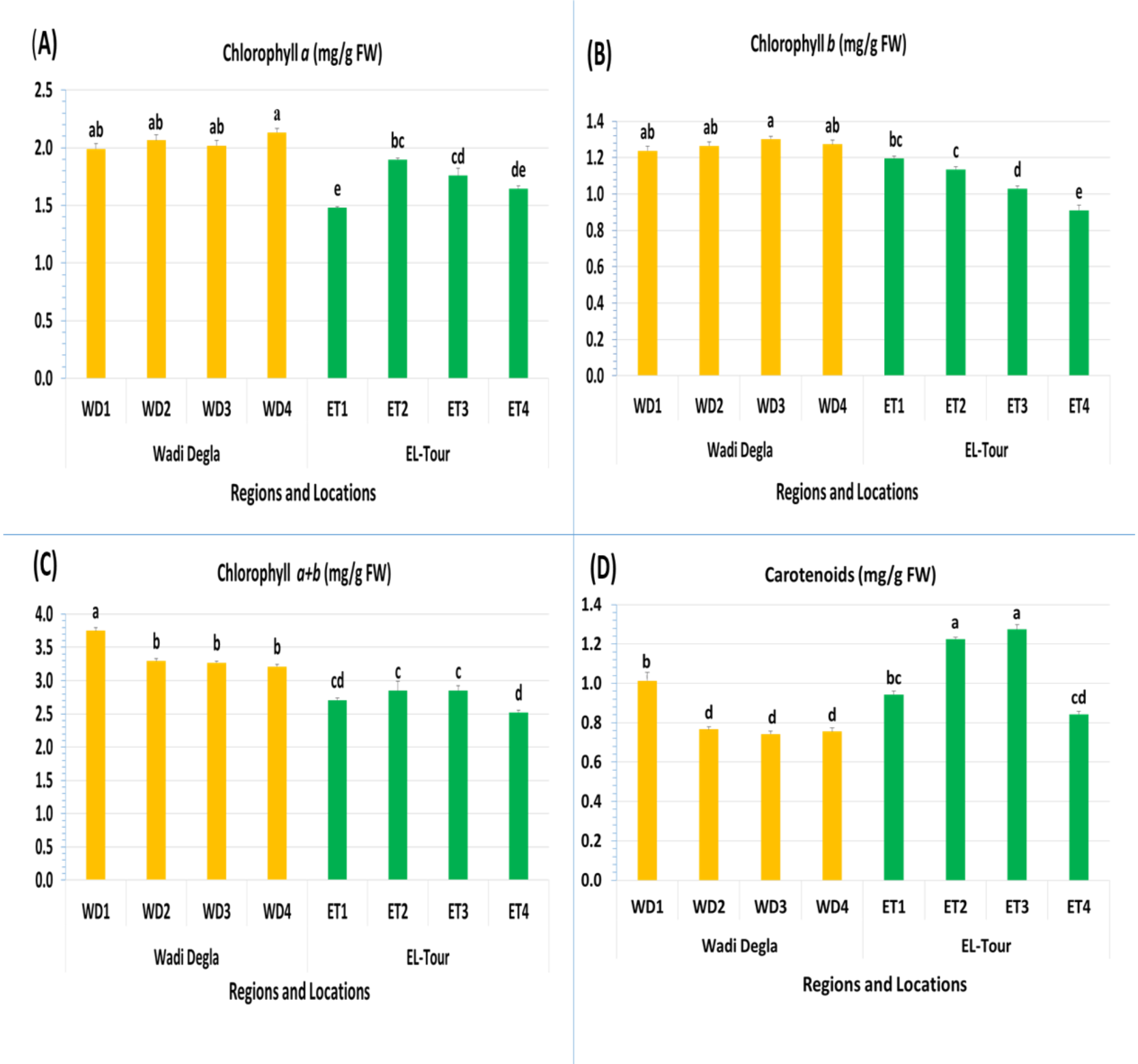

Fig. 8. The contents of photosynthetic pigments represented in chlorophyll *a* (A), chlorophyll *b* (B), total chlorophylls (C) and carotenoids (D) in different locations in Wadi Degla and El-Tour.

3.3.2. Carbohydrates and proteins

The data presented in Figure (9) showed significant differences in the carbohydrate and protein levels of ephedra plants in the studied habitats. Total carbohydrates in ephedra increased significantly in WD_1, with the highest content (92.32 mg/g), while they decreased in WD_2, with the lowest content (57.61 mg/g). Regarding protein content, we observed that the levels of all soluble proteins in Wadi Degla decreased significantly compared to the other protein levels in the phase. Protein contents ranged from 4.8 to 26.8 mg/g, with the highest values in ET_2 and the lowest values in WD_4.

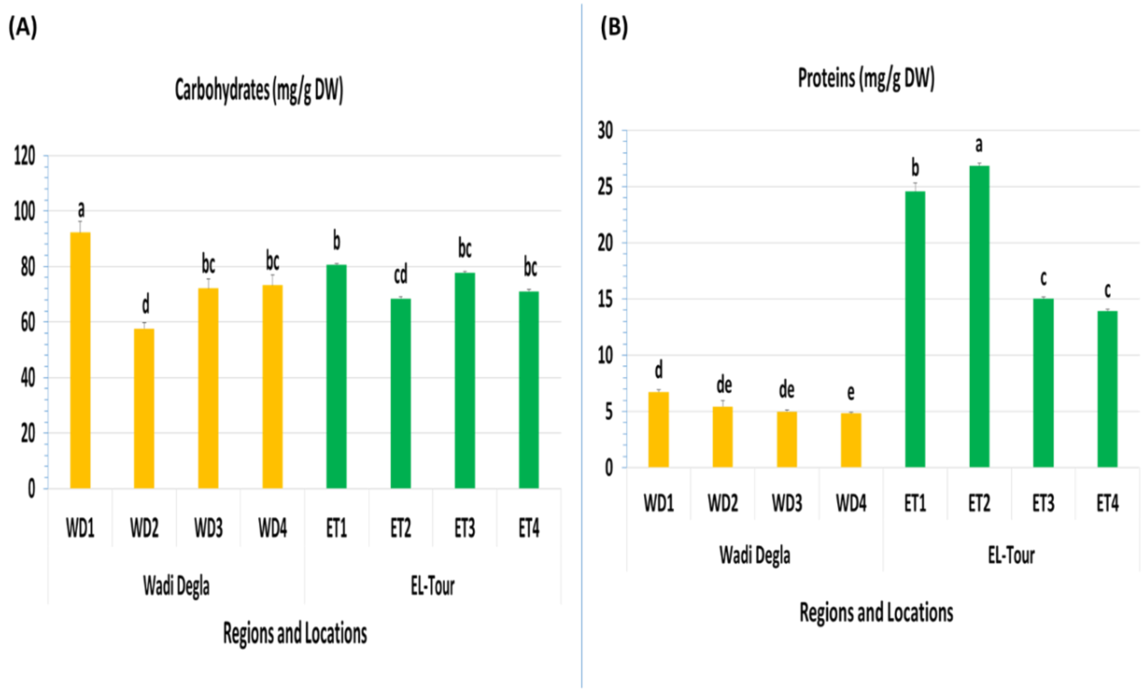

Fig. 9. The contents of total soluble carbohydrates (A) and total soluble proteins (B) in different locations in Wadi Degla and El-Tour.

3.3.3. Free proline and malondialdehyde

The results of this study showed significant differences in the accumulation of free proline and malondialdeic acid in ephedra plants within the study area, as shown in Figure 10. Proline showed significant accumulation in Wadi Degla and El-Tour, with the most significant accumulation occurring in ET_4. Regarding MDA accumulation, it was observed that this metabolite increased significantly in El-Tour and accumulated more than other metabolites in Wadi Degla. MDA content ranged from 0.4 to 2.8 mg/g, with the highest value in ET_2 and the lowest in WD_1.

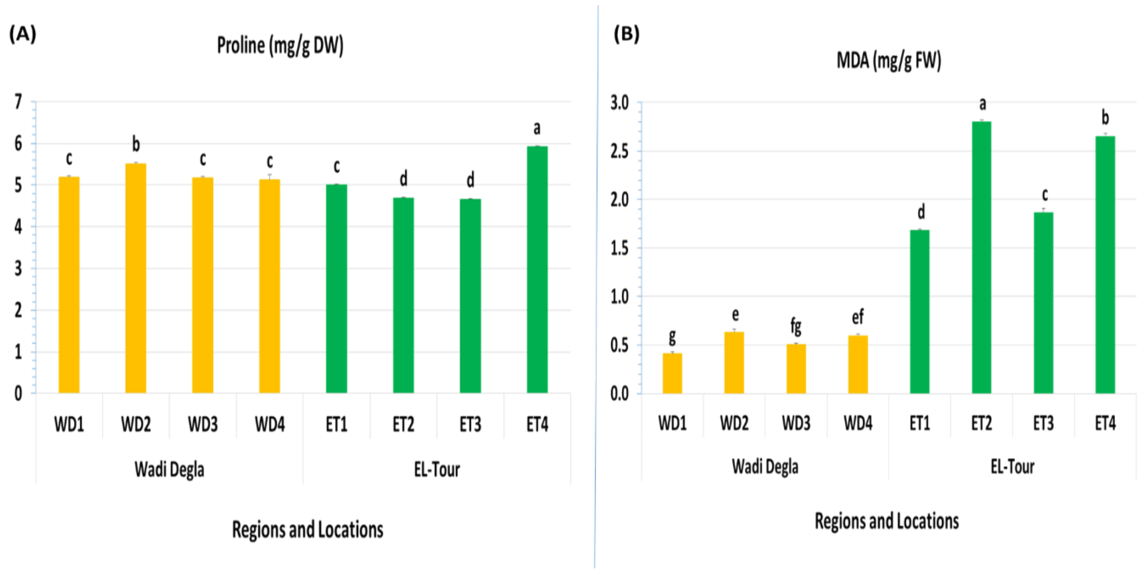

Fig. 10. The contents of free proline (A) and malondialdehyde (B) in the studied locations in Wadi Degla and El-Tour.

4. Discussion

Ephedra alata Decne, a small perennial shrub, belongs to the gymnosperm group, one of the oldest lineages of vascular seed plants. Given its ecological importance and therapeutic potential, along with the pressing conservation challenges facing gymnosperms, understanding their characteristics and adaptive strategies is essential to guiding conservation efforts and sustainable use practices.

This study comprehensively analyzed the ecological, physiological, and anatomical characteristics of E. alata from different collection sites, revealing significant differences in soil parameters and plant responses. Notably, plants on the upper slopes grew more vigorously than those on the lower slopes. This trend appears to be linked to topography-induced soil acidification, as rainwater runoff is believed to increase the acidity of basic soils by leaching alkaline minerals from higher elevations (Huntley, 2023). Rainfall plays a major role in this process, washing away alkaline ions such as calcium and magnesium and replacing them with more acidic elements such as iron and aluminum (Fageria and Nascenti, 2014). Furthermore, while moist soils promote plant growth, the accumulation of organic waste may contribute to increased soil acidity, especially in areas with high rainfall, making soils more acidic than those in arid environments (Bishour and Sayegh, 2007; Yaalon, 1997).

To explore these dynamics, we evaluated 14 soil parameters in Wadi Degla and El-Tour: MC, pH, TDS, EC, Na^+, K^+, Ca^{++}, Mg^{++} CO_3^{--}, HCO_3^-, Cl^-, SO_4^{--}, OM and $CaCO_3$. Soil analyses showed that, the soil moisture content were 6.58% and 2.83% in Wadi Degla, and 10.29% and 6.99% in El-Tour. Soil pH was slightly alkaline (7.0–8.0) in Cairo, while it ranged between 6.83 and 7.90 in South Sinai. These patterns highlighted changes in key soil properties, such as magnesium, sodium, organic carbon, chloride, electrical conductivity, and dissolved solids. It has previously been shown that the accumulation of ions in soil, particularly potassium, calcium, magnesium, and chloride ions, increases with decreasing moisture content (Greenway and Osmond, 1972). Hazelton and Murphy (2007) highlighted the importance of electrical conductivity as an indicator of the accumulation of dissolved salts, particularly sodium, potassium, calcium, magnesium, chloride, sodium sulfate, and carbon dioxide ions, which can negatively affect plant health, soil structure, and land productivity. According to Yassin et al. (2023), high $CaCO_3$ levels reduce soil fertility and hinder crop productivity. Meanwhile, organic matter and carbon remain essential for maintaining fertility (Abd El-Ghani, 1998), while sodium management is essential for saline and sodic soils. This view is supported by Abdel Khalik et al. (2013) and Al-Attar et al. (2013), who documented significant spatial variations in soil pH, electrical conductivity, mineral content, and texture among different plant communities in Saudi Arabia. In arid desert ecosystems, such as those discussed in this study, the influence of soil physical and chemical properties on species distribution and community composition is significant and well documented (Abd El-Ghani et al., 2017; Hussein et al., 2021). Soil physical and chemical properties can significantly impact ecosystem health, leading to reduced biodiversity and agricultural productivity (El-Ramady et al., 2024). Recent studies have highlighted changes in moisture content and salinity-related parameters, such as electrical conductivity, total dissolved solids, and chloride, sodium, and magnesium content, as key environmental factors. These factors significantly promote the differentiation of ecological communities, which in turn shapes species diversity patterns (El-Sayed et al., 2024).

Anatomical studies have revealed distinct structural adaptations in *E. alata*, including the development of more prominent epidermal tubercles, numerous subepidermal fiber bundles, and a scalloped cuticle. The reduced presence of subepidermal parenchyma likely contributed to increased mechanical strength and decreased transpiration efficiency, reflecting adaptation strategies for survival under diverse environmental conditions (Baker, 1982; De Micco and Aronne, 2012).

Since plants cannot move, they face a variety of environmental stresses. Harsh conditions (below or above optimal levels) limit plant growth and development. Drought, low or high temperatures, salinity, acidic conditions, heavy metal stress, etc. are the main abiotic stresses that harm plants (Chaves and Oliveira, 2004; Badawy et al., 2025).

Photosynthesis uses photons to create various organic molecules and is an important metabolic process that promotes plant growth. In the current study, chlorophyll content was found to be lower in the Artur area compared to the Tigris Valley. This decrease can be attributed to environmental and soil stresses, such as low humidity levels (drought) and high salinity (excessive sodium concentrations). The decreased photosynthesis may be due to the inhibition of important enzymes in the photosynthetic electron transport chain and the Calvin cycle, as well as impaired gas exchange properties (Farooq et al., 2016). According to the study by Anjum et al. (2011), multiple stresses impair the photosynthetic system, reduce gas exchange, and hinder growth and production. Protein degradation and lipid oxidation are critical for chloroplast structure and pigmentation and may lead to disruptions in metabolic processes, thus reducing the net photosynthetic rate under drought stress (Marcińska et al., 2013). The results of a recent study showed that the El-Tour region contains higher levels of carotenoids than the Wadi Degla region. Carotenoids are non-enzymatic antioxidants produced under adverse conditions, and increasing their content can enhance antioxidant activity (Nejadalimoradi et al., 2014).

Carotenoids are precursors to key plant hormones, such as abscisic acid and strigolactones, which regulate stress responses, seed dormancy, and root structure. In addition, carotenoid-derived molecules can act as internal signals that regulate plant growth and environmental responses. These pigments protect plant tissues from photooxidative damage by quenching chlorophylls and ractive oxygen species that can form under high light intensity. This function is essential for maintaining the integrity of photosynthesis (Sun et al., 2022).

Increased soluble sugar and protein content can serve as an energy source for plants under both normal and stressed conditions (Rai, 2002). Carbohydrates are essential components of living cells, serving as the primary energy source for metabolic processes and providing the carbon skeleton required for other biological compounds. Our current study showed that the carbohydrate content of ephedra plants was similar across all study sites, but that carbohydrate content increased significantly at site WD1. This increase may be attributed to the high magnesium concentration in the region. Magnesium is essential for promoting plant growth and differentiation. It is the central ion in the chlorophyll structure and aids in carbon dioxide fixation, chlorophyll synthesis, and the formation of sugars and proteins (Konate et al., 2017; Khalid et al., 2022). On the other hand, proteins are macromolecules important for every physiological function in plant cells. The results of the case study showed that protein content in the Tigris Valley region was extremely low, likely due to low humidity levels and drought. Previous studies have shown that drought reduces protein levels (Demirtas et al., 2010; Liu et al., 2018). Stressed plants may increase the activity of protease enzymes, which degrade proteins and lead to the accumulation of reactive oxygen species (ROS) and damage to cell membranes (Miller et al., 2010; Radhakrishnan and Lee, 2013).

Our study showed that proline levels were similar across all study sites, but the most significant increase was observed in El-Tour4. Proline is a low-molecular-weight osmotic regulator that plays a critical role in regulating osmotic pressure, removing reactive oxygen species, and maintaining cell integrity under stress conditions (Szabados and Savouré, 2010). Higher MDA levels were observed in the El-Tour region, suggesting that ephedra thrives in a stressful environment. This stress may be due to the high sodium levels in these regions. Plants may increase the activity of protease enzymes when under stress, which can lead to protein degradation and the production of high levels of reactive oxygen species. These factors damage cell membranes, DNA, pigments, proteins, and lipids (Miller et al., 2010; Radhakrishnan and Lee, 2013). Our results highlight the importance of MDA and proline as indicators of environmental stress and the physiological mechanisms by which plants cope with stress.

5. Conclusions

This study demonstrated that *Ephedra alata* Decne exhibited remarkable adaptability to the diverse environmental conditions of Wadi Degla and El-Tour. Comparing two different regions (Wadi Degla in Cairo and El-Tour in South Sinai) revealed clear differences in soil properties in terms of moisture, acidity, dissolved salts, and electrical conductivity. These differences, in turn, affect plant tissue composition and physiological responses. The results indicated that variations in soil ions and chemical elements play a fundamental role in shaping adaptive anatomical traits, such as modifications in the structure of roots, stems, and leaves. These modifications contributed to reducing water loss and improving the plant's ability to withstand environmental stresses such as drought and saline agriculture. Physiologically, the levels of chlorophyll, sugars, and proteins varied, as did the accumulation of substances such as proline and malondialdehyde, indicating a comprehensive response to climatic challenges and changing soil conditions. Thus, the study confirms the potential of *Ephedra alata* as a promising option for land reclamation and the development of sustainable agricultural systems in arid and semi-arid regions, given its multiple adaptive mechanisms that demonstrate its ability to survive and thrive in harsh conditions. This research paves the way for future researchers to expand the scope and application, such as exploring different expressions of pathways for drought and salinity tolerance in *Ephedra alata* across multiple geographical locations, as well as a clear evaluation of medicinally active compounds.

List of abbreviations:

A S L = Above Sea Level
B C E = Before Common Era
ET = EL-Tour
EC = Electrical Conductivity
E. alata D = *Ephedra alata* Decne
EMA = Egyptian Meteorological Authority
WD = Wadi Degla
S M C = Soil Moisture Content
T D S = Total Dissolved Salts
O M = Organic Matter
M D A = Malondialdhyde

R O S = Reactive Oxygen Species
PL = Pilliferous layer

Declarations

Ethics approval and consent to participate

Consent for publication: All authors have agreed to the publication of the manuscript.

Data Availability: The datasets generated during and/or analyzed during the current study are available from the corresponding author.

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References

Abd El-Ghani, M. M., Francisco M. H., Liu H., and Rahmatullah Q. (2017). *Plant Responses to Hyperarid Desert Environments*. Springer.

Abd El-Ghani, M. M. (1998). Environmental correlates of species distribution in arid desert ecosystems of eastern Egypt. J. of Arid Envir.38(2), 297-313. doi.org/10.1006/jare.1997.0323.

Abdel Khalik, K., El-Sheikh M., and El-Aidarous A. (2013). Floristic diversity and vegetation analysis of Wadi Al-Noman, Mecca, Saudi Arabia. Turk. J. Bot. 37: 894-907.doi.org/10.3906/bot-1209-56.

Alatar, A., El-Sheikh, M.A., and Thomas, J., (2013). Vegetation analysis of Wadi Al-Jufair, a in Najd, Saudi Arabia. Saudi J. Biol. Sci. 19: 357- 368. doi.org/10.1016/j.sjbs.2011.09.004.

Alqarawi, A., Hashem, A., Abd Allah, E., Alshahrani, T., & Huqail, A. (2014). Effect of salinity on moisture content, pigment system, and lipid composition in Ephedra alata Decne. *Acta Biologica Hungarica*, *65*(1), 61–71. https://doi.org/10.1556/ABiol.65.2014.1.6 .

Anjum, S. A., Wang, L., Farooq, M., Xue, L., & Ali, S. (2011). Fulvic acid application improves the maize performance under well-watered and drought conditions. *Journal of Agronomy and Crop Science*, *197*(6), 409–417. https://doi.org/10.1111/j.1439-037X.2011.00483.x .

Badawy, A. A., Alshammari, W. K., Salem, N. F. G., Alshammari, W. S., & Hussein, H. A. (2025). Arginine and spermine ameliorate water deficit stress in fenugreek (*Trigonella foenum-graecum* L.) by enhancing growth and physio-biochemical processes. *Antioxidants*, *14*(3), 329. https://doi.org/10.3390/antiox14030329

Badawy, A. A., Alamri, A. A., Hussein, H.-A. A., Salem, N. F. G., Mashlawi, A. M., Kenawy, S. K. M., & El-Shabasy, A. (2024). Glycine betaine mitigates heavy metal toxicity in *Beta vulgaris* (L.): An antioxidant-driven approach. *Agronomy*, *14*(4), 797. https://doi.org/10.3390/agronomy14040797

Baker EA (1982). Chemistry and morphology of plant epicuticular waxes. In: Cutler DF, Alvin KL, Price CE (Eds) the plant cuticle. Academic, London, pp 139–165.

Bashour, I. I., & Sayegh, A. H. (2007). Methods of analysis for soils of arid and semi-arid regions (p. 119). Rome, Italy: Food and agriculture organization of the United Nations.

Bates, L. S., Waldren, R. P. A., & Teare, I. D. (1973). Rapid determination of free proline for water-stress studies. *Plant and soil*, *39*, 205-207.

Blumenthal M and King P. Ma huang.(1995). ancient herb, modern medicine, regulatory dilemma. A review of the botany, chemistry, medicinal uses safety concerns, and legal status of ephedra and its alkaloids. Herba Gram; 34: 22-57.

Chaves, M. M., & Oliveira, M. M. (2004). Mechanisms underlying plant resilience to water deficits: prospects for water-saving agriculture. *Journal of Experimental Botany*, *55*(407), 2365–2384.

De Micco, V., & Aronne, G. (2012). Morpho-anatomical traits for plant adaptation to drought. In Plant responses to drought stress: From morphological to molecular features (pp. 37-61). Berlin, Heidelberg: Springer Berlin Heidelberg.

Demirtas, Ç., Yazgan, S., Candogan, B. N., Sincik, M., Büyükcangaz, H., & Göksoy, A. T. (2010). Quality and yield response of soybean (Glycine max L. Merrill) to drought stress in sub--humid environment. *African Journal of Biotechnology*, *9*(41), 6873–6881.

Ebadi M. (2007). Pharmacodynamic basis of herbal medicine. 2 nd ed. CRC Press, Taylor & Francis Group 311-318.

Elhadef, K., Smaoui, S., Fourati, M., Ben Halima, H., Chakchouk Mtibaa, A., Sellem, I (2020). A review on worldwide Ephedra history and story: from fossils to natural products mass spectroscopy characterization and biopharmacotherapy potential. Evidence-Based Complementary Altern. Med. 2020, 1–22. doi:10.1155/2020/1540638.

El-Ramady, H., Brevik, E. C., Abowaly, M., Ali, R., Saad Moghanm, F., Gharib, M. S. and Prokisch, J. (2024). Soil degradation under a changing climate: management from traditional to nano-approaches. Egyptian Journal of Soil Science, 64(1), 287-298. https://doi.org/10.21608/ejss.2023.248610.1686

El-Sayed, H. M., Marie, A. H., Safaa M. I. and Shaimaa G. S. (2024). Assessing soil-vegetation relationships in south western sinai, Egypt." *Egyptian Journal of Soil Science* 64(4):1677–95. doi: 10.21608/ejss.2024.310926.1837.

EMA (2019). Egyptian Meteorological Authority (1949–2019). Cairo, Egypt.

Fageria, N. K., & Nascente, A. S. (2014). Management of soil acidity of South American soils for sustainable crop production. Advances in agronomy, 128, 221-275.

Farooq, M. A., Ali, S., Hameed, A., Bharwana, S. A., Rizwan, M., Ishaque, W., Farid, M., Mahmood, K., & Iqbal, Z. (2016). Cadmium stress in cotton seedlings: Physiological, photosynthesis and oxidative damages alleviated by glycinebetaine. *South African Journal of Botany*, *104*, 61–68. https://doi.org/10.1016/j.sajb.2015.11.006 .

Forest, F., Moat, J., Baloch, E., Brummitt, N.S., Bachman, S.P., Ickert-Bond, S., Hollingsworth, P.M., Liston, A., Little, D.P., Mathews, S., Rai, H., Rydin, C., Stevenson, D.W., Thomas, P. & Buerki, S. (2018). Gymnosperms on the EDGE. Science Reports 8: 6050. DOI: 10.1038/s41598-018-24365-4.

Fukushima K. Bioactivity of Ephedra (2004). Integrating cytotoxicity assessment with real-time biosensing. MS cthesis. University of Maryland, College Park.

Ghanem, N.A.E , M.B. Haroun, A.A. El- Hela, A.T. Salama &A. Talaha. (2002). Phytochemical and antimicrobial activity of *Sequoia Sempervirens* (D.Done) Endll. Leaves cultivated in Egypt. N. Egypt. J. microbiology, vol. I ,January , ISSN 1678 – 1219.

Greenway, H., and Osmond, C.B. (1972). Histo- Anatomical strategies of Chenopodiaceae halophytes: adaptive, ecological and evolutionary implication. WSEAS Trans. Bio. & Biom. 12(4):204-218.

Hazelton, P., and Murphy, B. (2007). Interpreting Soil Test Result: What do all the Number Mean Commonwealth Sci. and Indus. Res. Org. Pub. Coll., Aust. 152.

Huntley, B. J. (2023). Soil, water and nutrients. In Ecology of Angola: Terrestrial biomes and ecoregions (pp. 127-147). Cham: Springer International Publishing.

Hussein, E. A., Monier M. A-E., Rim S. H. and Lamiaa F. S. (2021). Do Anthropogenic Activities Affect Floristic Diversity and Vegetation Structure More than Natural Soil Properties in Hyper-Arid Desert Environments? *Diversity* 13(4). doi: 10.3390/d13040157.

Khalid, U., Sher, F., Noreen, S., Lima, E. C., Rasheed, T., Sehar, S., & Amami, R. (2022). Comparative effects of conventional and nano-enabled fertilizers on morphological and physiological attributes of Caesalpinia bonducella plants. *Journal of the Saudi Society of Agricultural Sciences*, *21*(1), 61–72. https://doi.org/10.1016/j.jssas.2021.06.011 .

Konate, A., He, X., Zhang, Z., Ma, Y., Zhang, P., Alugongo, G. M., & Rui, Y. (2017). Magnetic (Fe3O4) nanoparticles reduce heavy metals uptake and mitigate their toxicity in wheat seedling. *Sustainability*, *9*(5), 790.

Liu, C. J., Wang, H. R., Wang, L., Han, Y. Y., Hao, J. H., & Fan, S. X. (2018). Effects of different types of polyamine on growth, physiological and biochemical nature of lettuce under drought stress. *IOP Conference Series: Earth and Environmental Science*, *185*(1). https://doi.org/10.1088/1755-1315/185/1/012010 .

Lowery, O.H.; Rosebrough, N.J.; Farr, A.L. and Randall, R.J. (1951). Protein measurement with the folin reagent. J. Biol.Chem.193:265-275.

Marcińska, I., Czyczyło-Mysza, I., Skrzypek, E., Filek, M., Grzesiak, S., Grzesiak, M. T., Janowiak, F., Hura, T., Dziurka Michałand Dziurka, K., others, Dziurka, K. D. M., & others. (2013). Impact of osmotic stress on physiological and biochemical characteristics in drought-susceptible and drought-resistant wheat genotypes. *Acta Physiologiae Plantarum*, *35*(2), 451–461. https://doi.org/10.1007/s11738-012-1088-6

Megahed HA, El Bastawesy MA (2020). Hydrological problems of §ash §oods and the encroachment of wastewater af fecting the urban areas in Greater Cairo, Egypt, using remote sensing and GIS techniques. Bull Natl Res Centre P 44:188.

Miller, G. A. D., Suzuki, N., Ciftci-Yilmaz, S., & Mittler, R. O. N. (2010). Reactive oxygen species homeostasis and signalling during drought and salinity stresses. *Plant, Cell and Environment*, *33*(4), 453–467. https://doi.org/10.1111/j.1365-3040.2009.02041.

Moustafa, A.M. and Zaghloul, M.S. (1996). Environment and vegetation in the montane Saint Catherine area, South Sinai, Egypt. Journal of Arid Environments 34, 331–349.

Nawwar M, Barakat H, Buddrust J, Linscheidt M (1985). Alkaloidal, lignan and phenolic constituents of Ephedra alata. Phytochemistry 24(4):878–879.

Nejadalimoradi, H., Nasibi, F., Kalantari, K. M., & Zanganeh, R. (2014). Effect of seed priming with L-arginine and sodium nitroprusside on some physiological parameters and antioxidant enzymes of sunflower plants exposed to salt stress. *Agricultural Communications*, *2*(1), 23–30.

Radhakrishnan, R., & Lee, I. J. (2013). Ameliorative effects of spermine against osmotic stress through antioxidants and abscisic acid changes in soybean pods and seeds. *Acta Physiologiae Plantarum*, *35*(1), 263–269. https://doi.org/10.1007/s11738-012-1072-1.

Rai, V. K. (2002). Role of amino acids in plant responses to stresses. *Biologia Plantarum*, *45*(4), 481–487.

Sparks, D. L., Page, A. L., Helmke, P. A., & Loeppert, R. H. (Eds.). (2020). *Methods of soil analysis, part 3: Chemical methods*. John Wiley & Sons.

Srivastava, R.C. (2021). Living Gymnosperms in India. Independenlty Published 333 pp. ISBN-13:979-8526023504.

Sun, T., Sombir R., Xuesong Z. and Li L. (2022). Plant carotenoids: Recent advances and future perspectives." *Molecular Horticulture* 2(1):3.

Szabados, L., & Savouré, A. (2010). Proline: a multifunctional amino acid. *Trends in Plant Science, 15*(2), 89–97.

Tan, Y., Liang, Z., Shao, H., & Du, F. (2006). Effect of water deficits on the activity of anti-oxidative enzymes and osmoregulation among three different genotypes of Radix Astragali at seeding stage. *Colloids and Surfaces B: Biointerfaces*, *49*(1), 60–65. https://doi.org/10.1016/j.colsurfb.2006.02.014 .

Umbriet, W.W.; Burris, R.H.; Stauffer, J.F.; Cohen, P.P.; Johsen, W.J.; Lee page, G.A.; Patter, V.R. and Schneicter, W.C. (1969). Manometric techniques, manual describing methods applicable to the studs of tissue metabolism. Burgess publishing co., U.S.A; pp.239.

Vernon, L.P. and Seely, G.R. (1966): The chlorophylls. Academic press. New York and London.

Yaalon, D. H. (1997). Soils in the Mediterranean region: what makes them different?. Catena, 28(3-4), 157-169.

Yassin, S.A., Awadalla, S.Y., El-Hadidi, E.M., Ibrahim, M.M., Taha, A.A. (2023). Assessment of the compost addition and sandification to overcome the calcium carbonate problems in heavy clay calcareous soils at ElFarafra oasis – Egypt J Soil Sci 63: 311-323. https://doi.org/10.21608/ejss.2023.212242.1596.

Zahran M, Willis A (2009). The Vegetation of Egypt, 2nd ed. Springer, Berlin, 213–221.

Zahran MA, Willis AJ, Mosallam HM, Bazaid S (2009). Ecology and Sustainable Development of the Red Sea Coastal Deserts. Publishing Al-Taif University, Saudi Arabia, p 455.

Zhang Z, Huber DJ, Qu H, Yun Z, Wang H, Huang Z, Huang H, Jiang. (2015). Enzymatic browning and antioxidant activities in harvested litchi fruit as influenced by apple polyphenols. Food Chemo 171:191–199. https://doi.org/10.1016/j.foodchem.2014.09.001.