Regional Records of *Tamarix* Species (Tamariacaceae) from Kerman City (Kerman, Iran)

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Abstract

The genus *Tamarix* (Tamaricaceae) is one of the important genera of medicinal plants, comprising approximately 70–104 species worldwide, of which about 35 species have been reported in Iran. In the present study, field botany, morphology, taxonomy, scanning electron microscopy (SEM), and biochemical analyses of the leaves and flowers of *Tamarix* species in Kerman City were conducted. Six species, including *T. kotschyi*, *T. androssowii*, *T. szowitsiana*, *T. tetragyna*, *T. karakalensis*, and *T. ramosissima*, were recorded. *T. androssowii* and *T. szowitsiana* showed a similar phylogenetic relationship, whereas *T. tetragyna* and *T. karakalensis* appeared in a distinct clade. SEM images provided evidence of salt glands and crystals of NaCl and $CaSO_4 \cdot 2H_2O$ in the leaves. These features indicate the migration of ions, including Na^+, Cl^-, K^+, Ca^{2+}, and SO_4^{2-}, from groundwater, surface water, soils, and sediments, followed by salt excretion through salt glands and the formation of salt crystals in the leaves. These findings were consistent with the high concentrations of Na^+, K^+, and SO_4^{2-} detected in the leaves and substrate soils. Concentrations of trace elements, particularly potentially toxic elements, were close to background levels and were comparable to published global data for *Tamarix* species, indicating no evidence of excessive accumulation of these elements in the studied plants. Furthermore, phytochemical extracts of *Tamarix* species may have beneficial applications in the treatment of type 2 diabetes, bacterial and fungal diseases, cancer, Alzheimer's disease, liver fibrosis, rheumatoid arthritis, and urinary stones.

Keywords: *Tamarix* species, Salt-tolerant, Salt crystals, Medicinal uses, Iran

Introduction

The genus *Tamarix* is becoming an important medicinal plant that distributed across in Europe, Asia, Africa, America, Oceania, and other regions of the globe with about 70 to 104 species (Fig. 1) (Li et al. ,2024; Terrones and Juan, 2023); Villar et al., 2019). *Tamarix* species are considered as salt-tolerant, halophytes, phreatophytes, and evergreen plants that mostly grow in arid, semi-arid, and hot regions along riversides, salty marshes and saline sediments,

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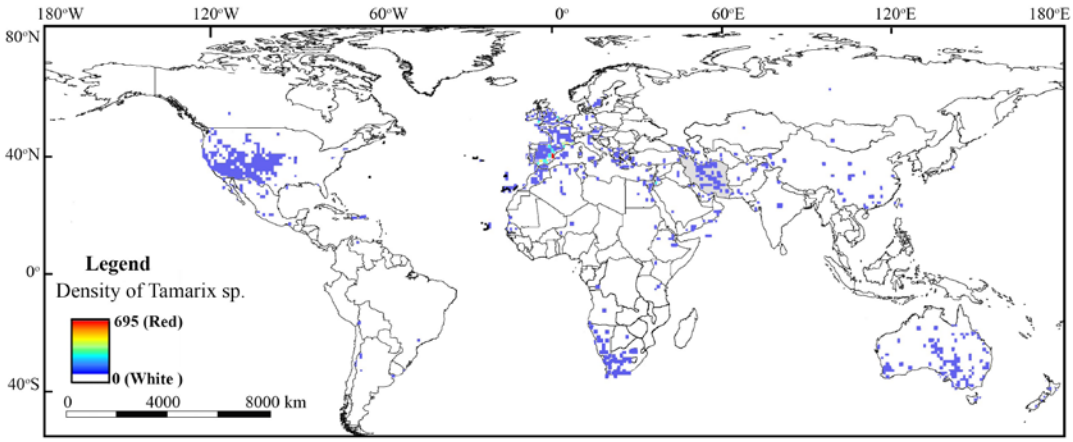


Fig. 1. Global distribution of *Tamarix* species with a considerable density in Iran (adopted from Mayonde et al., 2015)

where salinities range from 0.01% to more than 1%, NaCl. According to plant taxonomy (Tracy and Robbins 2009; Adams 2021; Villar et al. 2023), the genus Tamarisk is classified as: Tracheophytes, Angiospermae, Eudicots class, Magnoliopsida order, Caryophyllales family, Tamaricaceae genus, Tamarisk species.

Field and physical characteristics of the genus *Tamarix* display a shrubby plant ranging from 1-18 m height with rhombic, oval, needle-shaped leaves (1-2 mm) that contain white salt deposits on their surface due to evapor-transpiration and that the camels are the only livestock reported to feed (Adams, 2021). The red to purple and whitish-purple flowers are short with five stamens that are arranged in a 5 to 10 cm spike. The branches and twigs of *Tamarix* species are slender and delicate, with smooth, reddish-brown bark that becomes grayish-brown and furrowed as the plant mature. The wood of the *Tamarix* stem is hard and brittle, with the outer part being white and the inner part is reddish in color (Morisette et al., 2006).

The oldest reported fossils attributed to Tamarisk species, including *Tamarix minoa, Tamarix africana*, *Tamarix gallica*, were identified in the rock units of the western Mediterranean region dating to approximately 16 million years ago (Miocene) and from deposits dating from 2.58 million to 10,000 years ago (Pleistocene) (Terrones and Juan, 2023). Valuable studies in Iran reported (Abolhasni et al. 2020; Arianmanesh et al. 2015; Veisi et al. 2023; Sheidai et al. 2019) about 35 *Tamarix* species. In this study, a distribution map of the Tamarisk species is presented (Fig. 2), in all provinces under different climatic conditions, where the most abundant species are *Tamarix gallica, Tamarix aphylla*, and *Tamarix ramosissima*. Traditionally, *Gaz Angabin* of Khansar (Isfahan Province) and Gaz of Shahdad or Tamarix manna (Kerman Province) have been used in the preparation of nougat or Gaz sweet. Notably, in Persian culture, “Gaz” refers to *Tamarix.*

The term *manna* (*al-mann* in Arabic, Chapter Albaqarah, verse 57) refers to the exudate produced by the Tamarisk tree following insect feedingby *Euscelis decoratus*

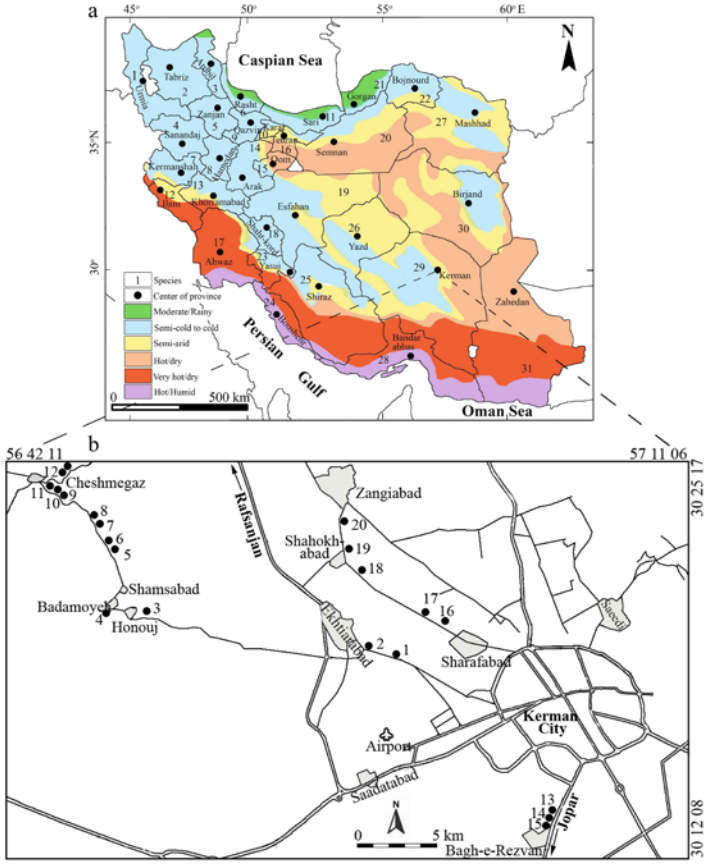


Fig. 2. Botanical and climatological map of *Tamarix* species in Iran. (a) distribution of *Tamarix* species in Iran, (b) sampling position of *Tamarix* species in Kerman city (Modified after Sheidai et al., 2019; Veisi et al., 2023; Abolhasani et al., 2020; Arianmanesh et al., 2015; Bahramsoltani et al., 2020; Mayonde et al., 2015, 1.*T. ramosissima Ledeb, T. octandra* , 2. *T. articulata, T.kotschyi,* 3. *T. austromongolica, T. ramosissima Ledeb,* 4. *T. ramosissima, Ledeb,* 5. *T. ramosissima Ledeb,* 6. *T. ramosissima Ledeb,* 7. *T. ramosissimma Ledeb,* 8. *T. ramosissima Ledeb,* 9. *T. habitatas,* 10. *T. ramosissima Ledeb,* 11. *T. aphylla, T. humboldtiana,* 12. *T. ramosissima Ledeb,* 13. *T. ramosissima Ledeb,T. aphylla,* 14. *T. habitatas,* 15. *T. kotschyi,* 16. *T. tetragyna,* 17. *T. passerinoides,* 18.*T. ramosissima Ledeb,* 19. *T. ramosissima Ledeb, T. aphylla,* 20. *T. ramosissima Ledeb, T. meyri,* 21. *T. arceuthoides,* 22. *T. ramosissima Ledeb, T. aphylla,* 23. *T. mascatensis,* 24. *T. aphylla, T. Jordanis,* 25. *T. tetrandra, T. mascatensis,* 26. *T. rosea,* 27. *T. ramosissima Ledeb,* 28. *T. tetrandra, T. humboldtiana,* 29. *T. kermanensis, T. karakalensis, T. ramosissima,* 30. *T. aphylla, T. hispida,* 31. *T. aphylla, T. humboldtiana.*

(Rahmani, 2004). Sheidai et al. (2019) reported various *Tamarix* species as primarily used as ornamental trees, windbreaks, and soil erosion control; however, more recent studies (Duan et al. 2022; Li et al. 2024; Aftabi 2024) show additional application

of *Tamarix* species in medicine, pharmacy, and environmental management (Figure 3). Comprehensive studies regarding Tamarisk species and their uses remain limited in Kerman city, although Baum (1967) only introduced *Tamarix kermanensis* as one of the important species. The main objectives of this study were to present a global distribution map of *Tamarix* species and their distribution in Iran, document regional records of *Tamarix* species in Kerman City, provide SEM images of the studied *Tamarix* species, characterize the macro- and microelement composition of *Tamarix* leaves, and discuss the major medicinal applications of *Tamarix* species and their potential environmental impacts.

Material and Methods

To identify Tamarisk species in the vicinity of the Kerman City, 24 leaf and flower samples were collected along Kerman-Jopar, Kerman-Cheshmehgaz, and Kerman-Zangiabad roads (Figure 2 and Table 1). The samples were dried for one month described by Mahdavi Maymand and Mirtadjdini (2011), Qaiser (1981), and Maden (2004) and were subsequently submitted to the Herbarium Laboratory of the Biology Department at Shahid Bahonar University of Kerman for identification. The*Tamarix* specieswere identified by Dr. Mirtadjadini and assigned Herbarium accession numbers ranging from 4700 to 4716.

Li et al. (2024) and Nisar et al. (2022) suggested that, for phytochemical, pharmacological, and medicinal applications of *Tamarix* species, the leaves, flowers, fruits, and other plant parts are dried in a shaded area, powdered and subsequently followed by dissolution and extraction.

To investigate the presence of salt glands and salt crystals in Tamarisk species, cleaned and dried leaves were analyzed using scanning electron microscopy (SEM) with a resolution of 3.5 nm and an acceler-

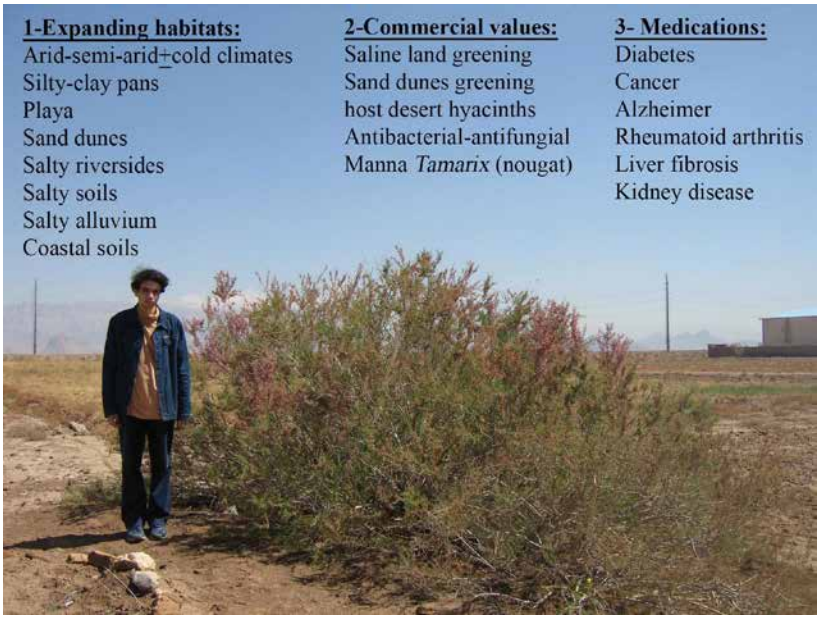


Fig. 3. Environments, commercial values and medicinal uses of the genus *Tamarix* (adopted from Duan et al., 2022; Li et al., 2024; Aftabi, 2024)

ating voltage 30,000 eV. The analyses were performed using an EDEX detector coupled to a Camscan MV 2300 instrument in the Department of Materials and Metallurgy Engineering at Shahid Bahonar University of Kerman, Iran. To integrate the phylogenetic associations of the *Tamarix* species, the morphological data were analyzed using SPSS software, and a dendrogram was constructed using Ward's linkage method with rescaled distance cluster combine. For the determination of biochemical determination of macro and microelements, the leaves were washed with distilled water, dried, powdered, and ashed, followed by dissolution in a mixture of HNO_3 and HCl (Atapour and Taheri, 2017). The concentrations of the elements were measured using inductively coupled plasma emission spectroscopy method (ICP-OES) (Varian-Agilent 700 Series) at the Applied Research Laboratory of Karaj branch of Geological Survey of Iran in Tehran. The accuracy, assessed against the certified reference materials (American National Standard 2001) ranged from 93.84 to 99.81%, respectively. The precision of the measurements was less than 10% RSD.

Table 1. Geographical position and herbarium numbers of *Tamarix* species in Kerman City

Sample No.	Herbarium No.	X	Y	Z	*Tamarix* Speice
1	4700	30°18'37.10"N	56°57'42.42"E	1749	*Tamarix cf androssowii*
2	4701	30°18'37.12"N	56°57'42.48"E	1749	*Tamarix szowitsiana*
3	4702	30°20'2.10"N	56°46'50.99"E	2184	*Tamarix szowitsiana*
4	4703	30°20'33.09"N	56°46'6.60"E	2274	*Tamarix szowitsiana*
5	4704	30°22'37.75"N	56°45'57.36"E	2202	*Tamarix szowitsiana*
6	4705	30°23'37.75"N	56°45'19.29"E	2126	*Tamarix kotschyi*
7	4706	30°23'37.54"N	56°45'19.29"E	2125	*Tamarix kotschyi*
8	4707	30°23'52.10"N	56°44'58.87"E	2125	*Tamarix kotschyi*
9	4708	30°23'49.64"N	56°45'12.80"E	2120	*Tamarix kotschyi*
10	4709	30°24'57.69"N	56°42'33.87"E	2167	*Tamarix kotschyi*
11	4709	30°24'57.56"N	56°42'33.89"E	2167	*Tamarix kotschyi*
12	4710	30°24'42.50"N	56°43'24.43"E	2161	*Tamarix kotschyi*
13	4711	30°12'32.80"N	57° 3'26.35"E	1768	*Tamarix cf androssowii*
14	4712	30°12'32.80"N	57° 3'26.33"E	1768	*Tamarix androssowii*
15	4713	30°12'32.56"N	57° 3'26.26"E	1768	*Tamarix Karakalensis*
16	4714	30°20'9.35"N	56°58'37.31"E	1749	*Tamarix androssowii*
17	4714	30°20'12.22"N	56°58'32.50"E	1749	*Tamarix androssowii*
18	4714	30°20'11.21"N	56°58'33.03"E	1749	*Tamarix androssowii*
19	4715	30°23'29.42"N	56°55'9.59"E	1737	*Tamarix androssowii*
20	4716	30°23'15.16"N	56°55'11.80"E	1737	*Tamarix tetragyna*

Results

Morphological studies and Tamarisk taxonomy

Morphological studies of 24 *Tamarix* samples revealed record several noteworthy species recorded in the Kerman City. The morphological characteristics of these species are presented in Tables 1 and 2, and Figure 4, and are described as below:

Tamarix androssowii Litv., Sched. Herb. Fl. Ross. 5: 41 (1905)

Tamarix androssowii (Fig. 4a, d) grows as a small tree (2- 3 m in height) with smooth, glabrous bark that is reddish-brown to brown. It ocuuresin sandy dunes, saline playas, and along riverbanks. The green to reddish-green vegetative branches reach nearly to 1 m in length and arise from the central branches of the plant, However, the youngest branches are attached to the main branches at nearly right angles. The green leaves growing on the main branches are 1-2 mm long and 0.5 mm wide, are amplexicaul form, whereas the leaves of younger lateral branches are green and egg-shaped with a layered margin and acute tips. The purple to purplish flowers bloom in May. Based on herbarium data (Fig. 4a, d, Table 2) and a comparison the morphological characteristics of the speciemens (Table 2) with published data (Baum 1967; Qaiser 1981; Sheidai et al. 2019; Arainmanesh et al. 2016), this tamarisk species resembles *T. androssowii*, which is reported for the first time in the Kerman City.

Tamarix kotschyi Bunge, Tent. Gen. Tamar. 30 (1852)

Tamarix kotschyi is a medium-sized species that predominantly grows along riversides, around springs and on spring sediments, reachinga height of 1- 2 min Cheshmehgaz Village (Fig. 2). Morphologically, the plant is characterized by greyish-brown to purplish-brown skin and sessile, green leaves measuring 1-2 mm in length long and 1 mm in width withtranslucent margins. The younger leaves may be amplexicaul and the purplish to light-purplish flowers bloom in May. Based on the herbarium data and comparized with published data (Fig. 4b, Table 2), the plant is is in consistent with *Tamarix* kotschyi and is reported here as a new record for the Kerman City.

Tamarix szowitsiana Bunge, Tent. Gen. Tamar.: 26 (1852).

Tamarix szowitsiana grows to 1-3 m in height and occurs in sandy, saline soils and along riversides. It is characterized by greyish-brown bark, on which sessile, ovate to egg-shaped leaves measuring 1-2 mm in lengt and approximately 0.5 mm in width. The purplish to light-purple flowers bloom in May. Based on herbarium data, morphological characteristics, and global distribution information (Tables 1 and 2, Fig. 4c), the specimens examined in this study are consistent with *Tamarix szowitsiana*, whichis reported here as a new record for Kerman City.

Tamarix karakalensis Freyn, Bull. Herb. Boissier, sér. 2, 3: 1060 (1903).

This *Tamarix* reaches a height of 1-3 m has reddish-brown bark and grows in sandy hills, sandy soils and river banks. The plant produces few bright-purplish to white flowers in April. The green, sessile leaves of 1-2 mm long and 0.75 mm wide, with a narrow base. Based on the herbarium data (Fig. 4e), morphological characteristics (Table 2), and

Table 2. Biometric and morphological aspects of *Tamarix* species studied and recorded in Kerman City (SABUKH = Shahid Bahonar University of Kerman Herbarium)

Taxa	Height	Leaves	Flowers	Disk	Racemes (length and width)	Sepal (shape and width)	Petal (shape and width)	Bract/ pedicel length	Herbarium number
T. kotschyi (7)	1-2m (2m)	Amplexicaul	4-merous	Synlo to parasynlophic	1-2 cm, 2-4 mm (1-3 cm, 3-4 mm)	Ovate, 0.7- 1mm (0.75- 1 m)	Elliptic, 1.5- 2mm (2-2.25 mm)	1-1.5	Mirtadjadini- Aftabi (SBUKH 4705-4710)
T.androssowii (7)	2-3 m (2-5 m)	Sessile	4-merous	Synlo to parasynlophic	1.2-3.5 cm, 3-4 mm (1.5 – 4 cm,3-5 mm)	Ovate to trullate, 0.7-1mm (1mm)	Obovate –elliptic, 1.5- 2 mm (2-2.25 mm)	1-1.25	Mirtadjadini-Aftabi (SBUKH 4700, 4711-4715
T.szowitsiana (4)	1-3 m (3-7m)	Sessile-elliptic	4-merous	Synlo to parasynlophic	1.7-4 cm, 6- 8 mm (2-4 cm, 6 mm)	Ovate-dentriculate, 1.2 mm (1-1.25 mm)	Elliptic- obovate, 1.5- 2mm (2.25-2.5 mm)	1-1.3	Mirtadjadini-Aftabi (SBUKH 4701-4704)
T. Tetragyna (1)	1-3 m (2-5 m)	Sessile-Ovate Sessile-ovate	4-merous to 4 and 5-merous	Paralophic	4-9 cm, 5-9 mm (5-15 cm, 8-10 mm)	Ovate-dentriculate, 1.5-2 mm (2 mm)	Elliptic-obovate, 2-5 mm (3.5- 5 mm)	1.5-2	Mirtadjadini-Aftabi (SABUKH 4716)
T.karakalensis (1)	1-3 m (2-3m)	Sessile-ovate	5-merous	Hololophic	0.7- 4 cm, 2-4 mm (0.5- 4 cm, 3-4 mm)	Trullate-ovate, 0.4-0.7 mm (0.5-0.75 mm)	Elliptic-obovate, 1-1.3 mm (1.25-1.5 mm)	1.5-2.5	Mirtadjadini-Aftabi SBUKH 4713
T.ramosissima (3)	1-3 m (1-6 m)	Sessile-ovate	5-merous	Hololophic	1.4-6.5 cm, 3-4 mm (1.5- 7 cm, 3-4 mm)	Trullate-ovate 0.5- 1 mm (0.5-1mm)	Elliptic- obovate, 1-1.7 mm (1-1.75 mm)	2.5-3	No enough data on leaves and flowers

The data in parenthesis represent numbers of samples and morphologic global data (bold data)

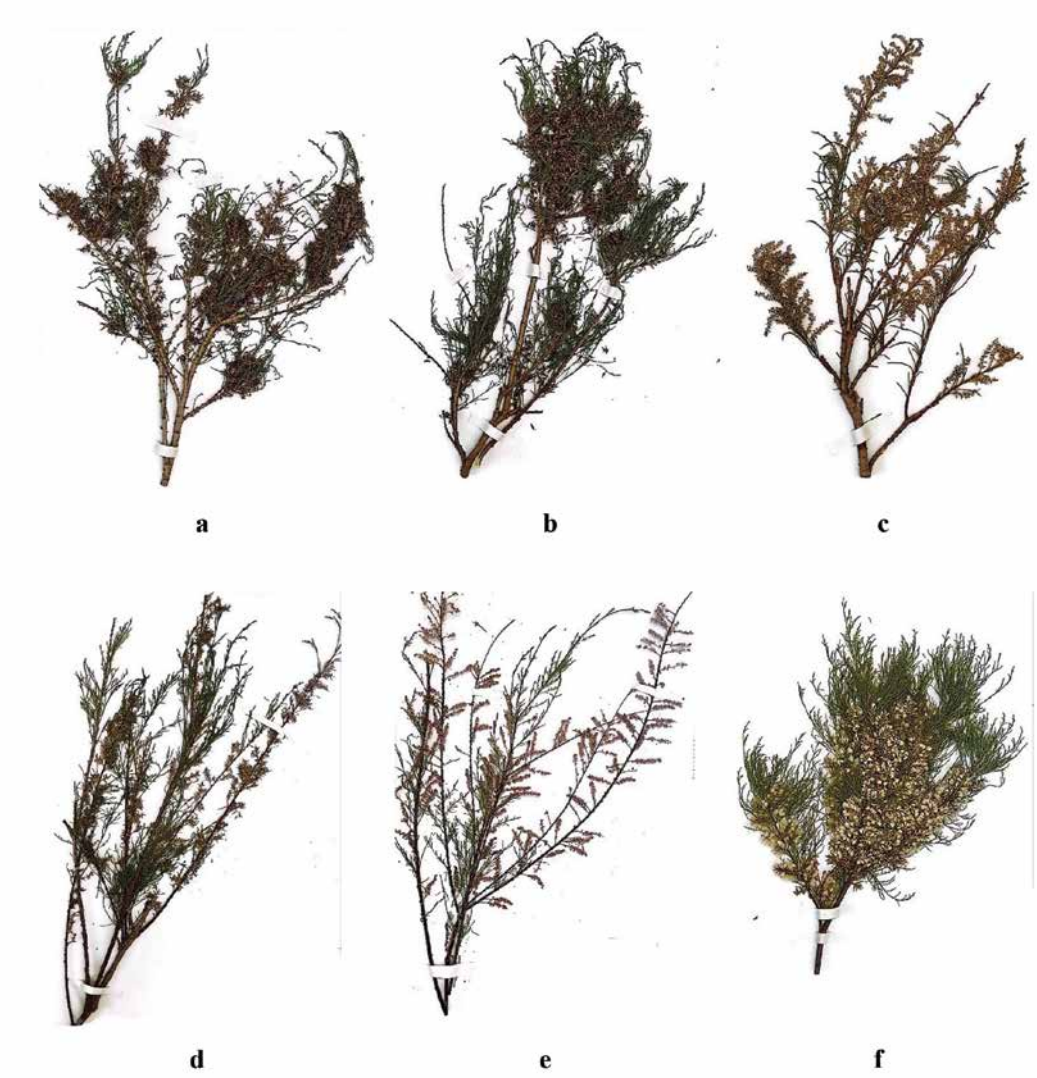


Fig. 4. Herbarium images of *Tamarix* species in Kerman City (a) *T. androssowii*, (b) *T. szowitssiana*, (c) *T. kotschyi*, (d) *T. androsswii*, (e) *T. karakalensis*, (f) *T.tetragyna*

comparison with global data, this plant species resembles *Tamarix karakalensis* resembles *Tamarix ramosissima*.

Tamarix tetragyna Ehrenb., Linnaea 2: 257 (1827).

This species grows to a height of 1-3 mand occurs in saline soils. The plants display smooth purplish to dark brown bark, on which narrow-based, sessile and egg-shaped leaves of 1-5 mm long and 1mm wide grow. The purplish to white flowers bloom in May. Based on herbarium data (Fig. 4f, No. 4716), morphological characteristics (Table 2), and global data, this species resembles *Tamarix tetragyna* and is reported for the first time in the Kerman city.

Tamarix ramosissima Ledeb., Fl. Altaic. 1: 424 (1829).

Tamarix ramosissima grows to a height 1-3 m and is also known as a highly branched salt cedar with lateral growth extending 2-3 m, whicht may exceed its height. It occurs in sandy hills, along small riversides, on sand dunes, and in saline soils. The plant is distinguished by reddish-brown bark and overlapping, blue-green, sessile -ovate, and

egg-shaped leaves measuring 2-3 mm in length and 1- 2 mm in width. The branch tips may bear few hairs and the purplish to white flowers bloom in April. In Based on bract-to-pedicel ratio (2.5-3, Table 2) and inflorescence characteristics, *Tamarix ramosissima* shows similarities to *Tamarix karakalensis*.

The phylogenetic dendrogram was constructed (Fig. 5) based on morphological characters, including the bark color, leaf and flower characteristics, inflorescence features, raceme length and width, sepal shape and length, petal shape and length, and bract-to-pedicelratio . Accordingly, the dendrogram indicates a considerable similarity between *Tamarix androssowii* and *Tamarix szowitsiana* in Clade I. *Tamarix Kotschyi* clustered separately in Clade II, whereas *Tamarix tetragyna* and *Tamarix karakalensis* are grouped in Clade III.

SEM analysis data

Some *Tamarix* species have been reported to exhibit salt glands and salt crystals as very small, dot-like features on the leaf surface. To investigate these features, *Tamarix* leaves were examined under SEM. As shown in Fig. 6, limited evidence of salt glands and crystals of sodium chloride (NaCl) and calcium sulfate dihydrate ($CaSO_4$, $2H_2O$) was observed in the different species examined. These salt glands are concentrated on the leaf surface and may have be associated with intense evaporation in arid and semi-arid regions as well as the migration of dissolved Na^+, K^+ and Ca^{2+} ions by surface waters, ground waters and moist in saline soils (Duan et al., 2022).

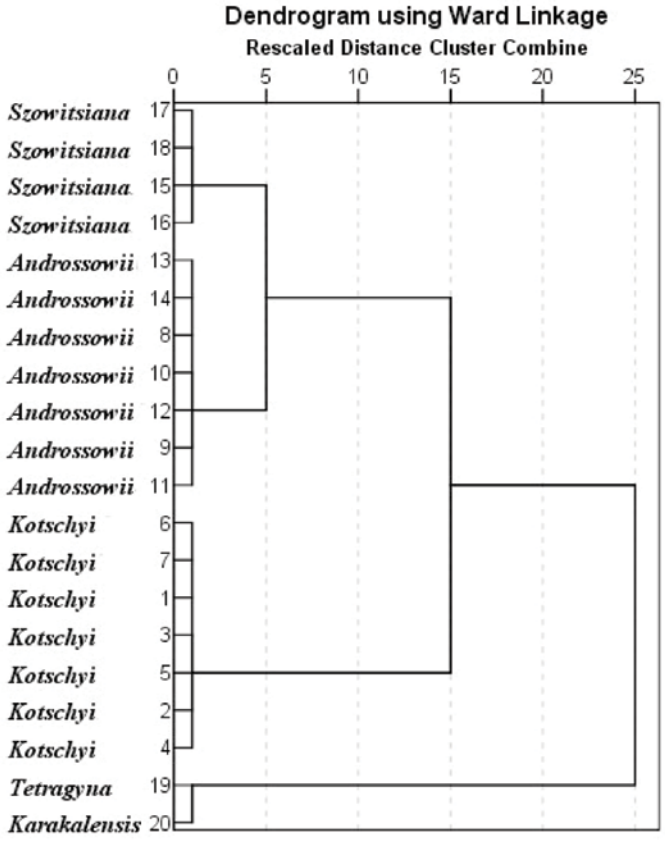


Fig. 5. Morphological dendrogram of *Tamarix* species in Kerman City

Biochemistry of macro and microelements in leaves

The concentrations of macro and microelements in *Tamarix* leaves are presented in Table 3 and compared with specific published data from various *Tamarix* species (Table 3). The results showed relatively high concentrations of sodium (759.7 µg), potassium (180.1 µg), and sulfur (500 µg) may be associated with the presence of salt glands and salt crystals. These findings are consistent with the SEM observations shown in Fig. 6. Based on Table 3, the highest concentrations of Na, K, and S were recorded in *Tamarix ramosissima* and in the substrate soils and sediments associated with the habitats of the studied *Tamarix* species. The metal bioaccumulation factor (MBAF) of the elements was calculated as the ratio of the concentration of elements in *Tamarix* leaves to its concentration in the substrate soil or sediment (Pachura et al., 2015). (MBAF values were classified as follows: (1) <0.01, no enrichment; (2) 0.01–0.1, weak enrichment; (3) 0.1–1, moderate enrichment; and (4) >1, high enrichment (Table 3). Table 3 shows that Na, P, and, S exhibit weak to moderate enrichment, whereas other elements do not show significant enrichmen in Tamarix leaves. On the other hand, the concentrations of toxic and heavy elements, including arsenic, lead, zinc, iron, manganese, titanium, molybdenum, and vanadiumare within the tolerable ranges reported for other *Tamarix* species worldwide and show no evidence of toxic effects on the studied *Tamarix* species.

Discussion

Discussion and possible medicinal applications and threats

The genus *Tamarix* (Tamaricaceae) comprises more than 70 species of the salt-tolerant, halophytes/phreatophytes plants that occur mainly in the arid, semi-arid and to a lesser extent, in cold regions of Northern Hemisphere. These species are reported to be useful as ornamental plants, windbreaks and afforestation of sand dunes and more importantly as medications for some diseases (Li et al., 2024; Aftabi, 2024; Maldonado, 2016). Paleo-geographically, the first generation of *Tamarix* probably appeared in the geological time of Eocene (54-36 million years ago) in the Mediterranean area under warm and humid climatic conditions (Zhang et al., 2018). In the geological time of Miocene (25.2-5.2 million years ago), due to the regression of the Tethys ocean the genus *Tamarix* expanded into the central Asia, China and probably western Asia under arid and cool climates (Zhang et al., 2018).

The global distribution of different *Tamarix* species in the world as well as their distributionin Iran (Figs. 1- 2) shows that these plants occur mostly in arid and semi-arid climates. Yet, some *Tamarix* species have been reported to occur in cold climates in the Northern Hemisphere, including Iran (Lehenhoff et al., 2011; Bean and Dudley, 2023; Sheidai et al., 2019). Lehenhoff et al. (2011) suggested that *Tamarix* seeds are more resistant to cold and temperate conditions, remaining viable at temperature -5 to 14 °C for up to 6 months, than under warm and hot conditions at 25-35°C for three months. Therefore, some *Tamarix* species may be capable of growing under cold climate conditions, provided that suitable soil

Table 3. Mean concentrations (ug/g) and metal bioaccumulation factors (MBACF) of macro-microelements in *Tamarix* species of Kerman city compared to *Tamarix s*pecies in Africa (Nedjimi, 2023; Soltan et al., 2004). The concentrations of all elements in substrate soils and sediments are in ug/g

Taxa	As	Al	Fe	K	Na	Mg	P	S	Mn
T. kotschyi (3)	0.01	4.1	2.86	112.6	169	56	26.6	100.15	0.422
MBACF	0.0004	0.0001	0.0001	0.006	0.009	0.004	0.046	0.200	0.0007
T. Androssowii (3)	0.01	5.01	3.24	166	166	74	20.7	293.8	0.358
MBACF	0.0004	$7.62*10^{-5}$	$7.77*10^{-5}$	0.008	0.008	0.006	0.036	0.588	0.0006
T. szowitsiana (3)	0.01	6	4.11	137.7	568.4	111.5	13.76	34.17	1.28
MBACF	0.0004	$9.13*10^{-5}$	$9.86*10^{-5}$	0.007	0.029	0.009	0.024	0.068	0.002
T. karakalensis (1)	0.01	5.72	3.62	170.45	43.3	118.2	10.94	29.76	1.41
MBACF	0.0004	$8.70*^{10-5}$	$8.68*10^{-5}$	0.009	0.002	0.009	0.020	0.060	0.002
T. tetragyna (1)	0.01	3.67	2.75	71.85	253.8	52.65	25.6	116.25	1.257
MBACF	0.0004	$5.58*^{10-5}$	$6.6*10^{-5}$	0.004	0.013	0.004	0.044	0.232	0.002
T. ramosissima (1)	0.01	3.71	2.36	180.1	759.7	97	13.3	148.43	1.93
MBACF	0.0004	$5.64*^{10-5}$	$5.66*10^{-5}$	0.009	0.039	0.007	0.023	0.297	0.003
T. gallica (Algeria)	0.29	---	458	6484	11082	---	---	---	---
T. nilotica (Egypt)	---	---	772	17888	16934	3158	---	---	79
Average in substrate soils and sediments	27	65716	41698	19798	19284	12698	571	500	596

Taxa	Ti	Cu	Mo	Pb	Zn	V	Sr	Ba	Li
T. kotschyi (3)	0.0964	0.115	0.002	0.007	0.367	0.004	1.36	0.045	0.2
MBACF	0.00001	0.003	0.0010	0.0003	0.004	0.00001	0.002	0.00001	0.005
T. Androssowii (3)	0.131	0.071	0.001	0.01	0.3	0.005	1.16	0.02	0.2
MBACF	$4.5*10^{-5}$	0.002	0.0005	0.0004	0.004	$5.38*10^{-5}$	0.002	$5.96*10^{-7}$	0.005
T. szowitsiana (3)	0.002	0.0001	0.024	0.005	0.2	0.006	0.8	0.05	0.04
MBACF	$6.87*10^{-7}$	$2.7*10^{-6}$	0.012	0.0002	0.0025	$6.45*10^{-5}$	0.001	$1.49*10^{-6}$	0.001
T. karakalensis (1)	0.14	0.11	0.001	0.006	0.24	0.005	0.9	0.05	0.07
MBACF	$4.81*10^{-5}$	0.003	0.0005	0.0002	0.003	$5.38*10^{-5}$	0.002	$1.49*10^{-6}$	0.002
T.tetragyna (1)	0.09	0.12	0.001	0.006	0.43	0.003	0.58	0.2	0.2
MBACF	$3.09*10^{-5}$	0.003	0.0005	0.0003	0.005	$3.23*10^{-5}$	0.001	$5.96*10^{-6}$	0.005
T. ramosissima (1)	0.09	0.11	0.005	0.009	0.03	0.003	0.4	0.03	0.04
MBACF	$3.09*10^{-5}$	0.003	0.0025	0.0004	0.0004	$3.23*10^{-5}$	0.0007	$8.94*10^{-7}$	0.001
T. gallica (Algeria)	---	---	---	---	20.5	---	---	8.8	---
T. nilotica (Egypt)	---	2.12	---	0.4	35	---	---	---	---
Average in substrate soils and sediments	2910	37	2	21	80	93	555	33540	40

and water salinity conditions are present. The distribution of 35 *Tamarix* species in Iran and Kerman City (Fig. 2a, b) highlights their potential as medicinal plant sources.

It has beensuggested that (Sheidai et al., 2019; Arianmanesh et al., 2015; Ijbari et al., 2014; Li et al., 2024) the best morphological features for distinguishing *Tamarix* species are primarily related to four-and-five-merous floral, the shape of the disk, and the shape of sepal and petals, although these features may show some degree of overlap among species (Bredenkamp and Phepho 2008). In this regard, this study presents some region-

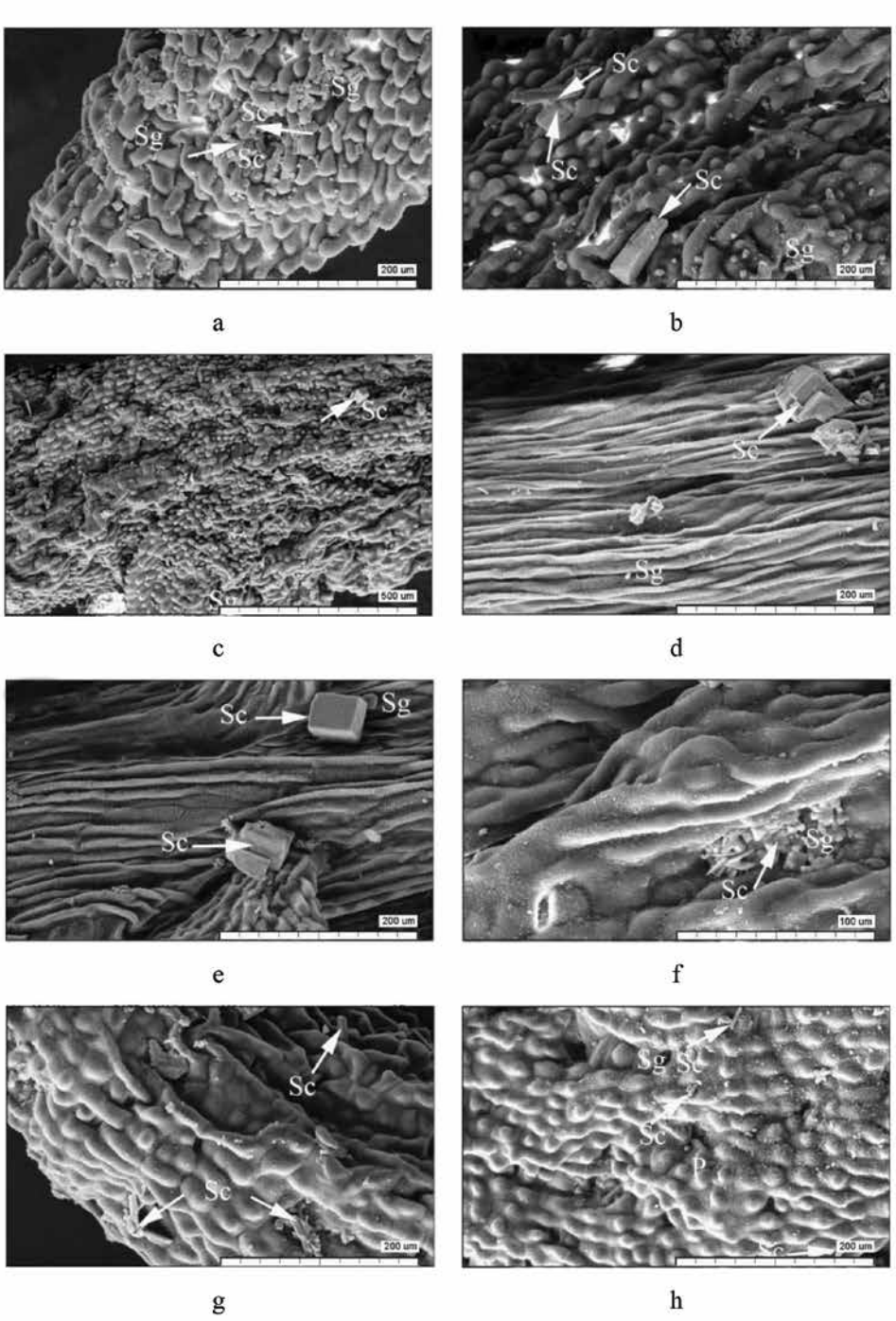


Fig. 6. SEM images of *Tamarix* species from Kerman City: (a) *T. androssowii*, (b) *T. szowitsiana*, (c) *T. kotschyi*, (d, e) *T. androssowii*, (f) *T. karakalensis*, (g) *T. tetragyna*, and (h) *T. tetragyna*. Sg, Sc, and P represent salt glands, salt crystals, and papillae, respectively. Salt crystals in (d) and (e) consist of NaCl, whereas those in the other SEM images consist of calcium sulfate ($CaSO_4 \cdot 2H_2O$).

al records of *Tamarix* species, as described in Tables 1 and 2, together with herbarium data (Fig. 4) and SEM images (Fig. 6). Morphologically, *Tamarix szowitsiana* and *Tamarix androssowii* show the greatest similarity in the dendrogram (Fig. 5). This similarity was also reported by Sheidai et al. (2019) and may be associated with their four--mer-

ous floral arrangements, sessile leaves, and similar disc morphology. The similarity of these two species with *Tamarix kotschyi* may be attributed primarily to their similar four-merous inflorescence and disk morphology. However, the amplexicaul nature of the leaves in *Tamarix kotschyi* represents a major morphological difference from other species. Some data (Shagholi et al. 2020; Arianmanesh et al. 2016) suggest that all three species could belong to the *Oligadenia* section. In the third branch of the cluster diagram (Fig. 5), *Tamarix karakalensis* and *Tamarix tetragyna* show morphological similarity, which may be associated with their five-merous inflorescences, a feature that not observed in the three previously mentioned species. The closet morphological similarity between *Tamarix karakalensis* and *Tamarix tetragyna* may be associated with a paralophic disk in *Tamarix tetragyna* and a hololophic disk in *Tamarix karakalensis*.

Table 2 shows that the bract-to-pedicel length ratio in *Tamarix karakalensis* is more similar to that of *Tamarix ramosissima*. This affinity was also reported by Baum (1967). It is noteworthy that *Tamarix ramosissima* is one of the most abundant species of *Tamarix* in Iran (Fig. 3). This species is mostly distinguished by its reddish to brownish bark, expanding branches, a high bract-to-pedicel length ratio (2.5-3) and five-merous inflorescence.

SEM images of dried leaves from the studied *Tamarix* species (Fig. 6) indicate the presence of papillate salt glands, sodium salt crystals and calcium sulfate crystals in different species. Sodium chloride crystals can be identified by their cubic crystalline structure, whereas calcium sulfate crystals are charecterized by their monoclinic prismatic crystals. The presence of these crystals suggests that surface waters, groundwaters, and soils associated with the habitats of the studied*Tamarisk* species contain relatively high concentrations of Na, Cl, Ca and S ions (Table 3). The migration of Na, K and S by groundwater and surface water to the leaves led may contribute to salt accumulation and crystallization on the leaf surface through evaporation and saturation. These findings are consistentwith those findings reported bySookbirsingh et al. (2010), Zhang et al. (2018), and Duan et al. (2022), who documented the occurrence of sodium chloride, potassium chloride, and calcium sulfate crystals on the leaves of the *Tamarix* species.

No additional data are currently available on the concentrations of macro-and microelements in the leaves of the *Tamarisk* species. Element concentrations exceeding natural background levels, especially those of potentially toxic elements, may adversely affect the growth and flowering of *Tamarix* species. The high values of toxic elements may seriously contaminate the *Tamarix* extracts and pose a potential risk to their phytochemical, pharmacological, and medicinal applications.

The biochemical data presented Table 3 show that the highest concentrations of Na (759.7 μg), K (180.1 μg), and S (148.43 μg) were recorded in the leaves of *T. ramosissima*, even though the concentrations of these elements were lower than the substrate soils. Among all the elements listed in in Table 3, Na, K, S, and P exhibited low to moderate

metal bioaccumulation factors, reflecting the presence of salt glands and crystals of sodium chloride and calcium sulfate in SEM images (Fig. 6) consistent with previous studies (Sookbirsingh et al., 2011; Duan et al. ,2022). Fortunately, the other elements detected in this study (Table 3) occured at very low concentrations (Table 3) that were close to or below the tolerance limits reported for other *Tamarisk* species worldwide Therfore, these elements are unlikely to pose a toxicity risk in the phytochemical extracts used for medicinal applications.

Recent studies (Alshehri et al., 2022, Nisar et al., 2022, Duan et al., 2022, Li et al., 2024, Aftabi et al., 2024) on medicinal plants have highlighted that *Tamarix* species are as potentially valuable sources for treatments of several diseases. In this context, diabetes mellitus is a metabolic disorder for which effective treatments are available, however, some synthetic α-glucosidase inhibitors may be associated with adverse effects, including hepatotoxicity. To addressthis issue, methalonic and ethalonic leaf extracts of *Tamarix aphylla, Tamarix nilotica*, *Tamarix dioica, Tamarix gallica, Tamarix articulate,Tamarix stricta* and other *Tamarix* species have demonstrated considerable antidiabetic potential. These extracts inhibit α-glucosidase and α-amylase activities, thereby potentially reducing carbohydrates digestion and helping to regulate blood sugar levels.

Most bacterial-fungal infections are treated with antibiotics, some of which may may cause allergies. However, Li et al. (2024) and Duan et al. (2022) suggested that the extracts of several *Tamarix* species, particularly *Tamarix gallica*, *Tamarix aphylla*, *Tamarix africana*, *Tamarix boveana*, *Tamarix ramosissima*, *Tamarix dioica*, *Tamarix arabica*, *Tamarix tetragyna*, *Tamarix karakalensis*, *Tamarix balansae*, and *Tamarix nilotica* can neutralize the harmful effects of bacteria and fungi.

Although effective treatments are available to manage some symptoms of Alzheimer's disease, no cure is currently available, and vitamin E and C can moderate the severity of the disease. Moreover, the antioxidant properties of extracts from *Tamarix gallica*, *Tamarix aphylla*, *Tamarix africana*, *Tamarix hispida*, *Tamarix ramosissima*, *Tamarix tetragyna*, *Tamarix karakalensis* and other *Tamarix* species may help mitigate oxidative damage and provide neuroprotective effects (Li et al. 2024; Duan et al. 2022).

Interestingly, syringic acid ($C_9H_{10}O_5$) is an antioxidant phenolic benzoic acid extracts from *Tamarix dioica*, *Tamarix hispida*, and *Tamarix ramosissima that* may prevent the progression of benign and malignant tumors and cancer cells. Methyl ferulate ($C_{11}H_{12}O_4$) is another antioxidant compound identified in the extracts of the various *Tamarix* species.that has been reported to exhibit cytotoxic activity against malignant cells associated with colorectal cancer (Duan et al. 2022; Li et al. 2024).

Rheumatoid arthritis is an autoimmune disease involving genetic and environmental factors. The compound Ramosissimin derived from *Tamarix ramosissima* extracts, may have potential for the treatment of this disease (Duan et al. 2022).

Liver fibrosis is a chronic liver disease that may initially be asymptomaticsbut can progressively lesions eventually develop into

liver cancer. pPhenolic and methanolic extracts from various *Tamarix* species have been reported to exhibit potential protective effects against liver fibrosis and liver cancer (Li et al. 2024, Duan et al. 2022).

Some kidney stones are composed primarily of calcium oxalate. Extract of *Tamarix hispida* and *Tamarix ramosissima* have been reported to exhibit potential anti-urolithiatic activity and may help inhibit the formation or growth of calcium oxalate and other urinary stones (Duan et al. 2022, Li et al. 2024). Despite the numerous reported medicinal applications of the *Tamarix* species, several disadvantages and potential threats have also been documented. Some fungal pathogenes, particularly species of *Botryosphaeria*, may cause branch dieback in different *Tamarix* species (Guerreio Madonado, et al. 2016). In addition, different *Tamarix* species excrete salts through their leaves and produce salt glands, and salt crystals, thereby increasing soil and sediment salinity and potentially inhibiting the growth of other plant species. (Ohrtman, 2009). Increased salinity in soils and sediments may also reduce interparticle bonding within soil-clay systems, thereby increasing soil susceptibility to soil erosion.

Conclusion

This paper highlights that the *Tamarix* species around the Kerman City mainly grow on alkali-tolerant salty sand dunes and soils. Morphological data indicated that the dominant occuring *Tamarix* species in this study area are *Tamarix kotschyi*, *Tamarix androssowii and Tamarix szowitsiana,* followed by the less frequently recorded *Tamarix ramosissima*, *Tamarix tetragyna*, and *Tamarix karakalensis*. Morphologically, *Tamarix androssowii* shows a greatest similarity to *Tamariix szowitsiana*, whereas *Tamarix karakalensis* shows relatively greater similarity to *Tamarix ramosissima* and *Tamarix tetragyna*. More importantly, SEM images displayed salt glands and crystals morphologically consistent with sodium chloride (NaCl) and calcium sulfate dihydrate ($CaSO_4 \cdot 2H_2O$), suggesting that the *Tamarix* species occur in alkaline and salinesoil environment. The bioaccumulation factors in *Tamarix* leaves and the concentrations of potentially toxic elements were within the ranges reported as tolerable for other *Tamarix* species. Therefore, these elements may not pose a significant environmental risks for using *Tamarix* extracts for medicinal applications. Further fresearch is warranted to investigate the molecular phylogeny and chemotaxonomy of *Tamarix* species and to develop a comprehensive atlas of *Tamarix* species. The main environmental threats associated with *Tamarix* species include fungi pathogens that cause branch dieback and the accumulation of salts in the substrate soils, which may increase the soil salinity and potentially inhibit the growth of neighboring plants species.

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Author contributions

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Declarations

Conflict of interest

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

Human and animal right

This manuscript does not contain any relationships with human participants or animals.

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