International Journal of Environmental Science and Technology (2023) 20:725–738
https://doi.org/10.1007/s13762-022-04573-2

ORIGINAL PAPER

Environmental parameters and habitats of *Dorema ammoniacum* (D. Don) in south-central Alborz *Dorema ammoniacum* (D. Don) habitat parameters in south-central Alborz

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Received: 22 June 2022 / Revised: 25 September 2022 / Accepted: 30 September 2022 / Published online: 1 November 2022

Abstract
Dorema ammoniacum (D. Don) is a medicinal species. Semnan province (the south-central Alborz Mountains) as on the origin of *Dorema ammoniacum* was studied to determine the ecological characteristics of species. It is important to know this species to conserve, repopulate, establish, and prevent its extinction so that this native species can be used for industrial purposes. A total of four habitats for species were identified in province: Garmsar (A), Semnan (B), Damghan (C), and Shahroud (D). In each habitat, five climatic and topographical factors were determined, such as elevation, evaporation rate, rainfall, temperature, and humidity percentage. Four to 6 transects of 150 m with a distance of 50 m from each other were established. Fifty-three samples were taken to analyze the physicochemical factors of the soil. Correlation relationships were determined by redundancy analysis. Habitat A exhibited the highest average densities, frequencies, and cover (0.098 m^2, 48.7%, and 29.7%, respectively) measurements. The density and coverage of habitat C (0.044 m^2 and 15%, respectively), and the frequency of habitat D (26%) were the lowest of *Dorema ammoniacum*. The results showed that *Dorema ammoniacum* needs light soil texture to survive in habitats. Salinity and alkalinity were not limits to soils in the studied habitats (average pH and electrical conductivity of 7.56 and 2.60). In addition, presence of gypsum, calcium, magnesium, sodium elements significantly affected the distribution and density of species and fissures, such as gypsum and calcium in the soil increased density. Conversely, magnesium and sodium elements of soil have a negative correlation with density of species.

Keywords Light soil · Semnan · Gypsum · Calcium · RDA (redundancy analysis)

Introduction

Dorema ammoniacum (D. Don) is a medicinal species of the Apiaceae family (Rechinger 1987; Mozaffarian 2007). All Dorema species that established with molecular markers belong to the Peucedanoides subfamily. The Peucedanoides subfamily includes species from Central Asia as well as the southwestern Iran and Turanian regions. (Panahi et al. 2015 and 2018). Plant list reports a total of 25 species in the genus Dorema, 12 of which are predominantly found in southwest and central Asia (Flora of the U.S.S.R, 1974; Amin 1991; Mozaffarian 2007; Rechinger 1987; Howes 1950; Zandpour et al. 2016). Dorema is represented by seven species, namely *D. aitchisonii* Korovin ex Pimenov, *D. ammoniacum* D.Don, *D. aucheri* Boiss., *D. aureum* Stocks, *D. glabrum* Fisch. and C.A. Mey., *D. hyrcanum* Koso-Pol. Additionally, *D. kopetdaghense* Pimenov, *D. aucheri* Boiss., and *D. ammoniacum* D.Don are native to Iran (V M Flora of Iran, Eskandani et al. 2014; Javadi et al. 2015; Naghibi et al. 2015; Sharafzadeh and Alizadeh 2012).

D. ammoniacum is a medicinal plant common to arid and semiarid regions of Central Asia, like Iran, Afghanistan, and Pakistan. It is a perennial monocarpic species. *D. ammoniacum* is famous all over the world for having a medicinal gum called Ammoniacom. In spring and early summer, it contains milky juice, known as gum ammoniacum. It is an oleo-gum-resin latex that forms naturally in cavities, stems, roots, and petioles. The local Persian names for *Desmodium Ammoniacum* are "Vashagh,"

Editorial responsibility: Jing Chen.

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"Vasha," "Kandal," "KomaKandal" (Zibaee et al. 2020; Mozaffarian 2007), which is known by its Arabic names: Oshaq, Kandal, Woshaj, Lazaq al-Dhahab, French name: Gomme ammoniaque and Urdu Name is Ushaq. From time immemorial, various species of genus of Dorema have been the source of oleic gum used in traditional medicine, including asafoetida, sagapenum, galbanum and ammoniacum (Abdevand et al. 2020) itself, as well as other foreign bodies (Mobeen et al. 2018). It serves as an antispasmodic, expectorant, carminative, diaphoretic, mild diuretic, poultice, prevention of diabetes, stimulant, antimicrobial, spleen and liver tonic, anticancer, and vasodilator, reducer of blood fats (V M Flora of Iran, Eskandani et al. 2014, Javadi et al. 2015, Naghibi et al. 2015, Sharafzadeh and Alizadeh 2012). Several studies were conducted in relation to identification of chemical compounds of the gum and volatile oil of different parts of *Dorema ammoniacum* D. Don. (Zandpour et al. 2016; Delnavazi et al. 2014; Yousefzadi et al. 2011a; Sajjadi et al. 2007; Appendino et al. 1991; and Arnone et al. 1992). In France, Ammoniacum is used for the production of glues and cosmetics. The essential oil of the *D. ammoniacum* fruit exhibited a low cytotoxic activity. Several studies have proved significant antimicrobial activity of the fruit essential oil and oleo-gum-resin from *D. ammoniacum* (Rajani et al. 2002).

D. ammoniacum grows up to 2.5–3 m tall at an altitude of 900–2500 m. *D. ammoniacum* is reported in arid regions with an average annual precipitation of 140–170 mm and a thermal range of − 5 to 38 °C (Zandpour et al. 2016).

D. ammoniacum has been reported in different parts of Iran, Esfehan, Yazd, Shiraz, Zahedan, Khorasan province and Semnan province (Rechinger 1987; Mozaffarian 2007). Semnan province covers an area of 95,815. Km^2; it occupies 5.9% of the total area of Iran and is the seventh province of Iran in terms of area and is situated in south-central Alborz Mountains (Lashkari and Riyazi 2016). The Central Alborz Ranges is a vast region, extending east to west from the Caspian Sea, with an average precipitation of more than 800 mm on the Northern side and less than 250 mm on the Southern side due to the barrier effect of the Alborz Mountain Ranges. The central and southern side of the Alborz Ranges are mostly formed of lime (calcite) and gypsum (calcium sulfate) beds. (Foroozan et al. 2020; Eilers, 2018). According to IUCN (Nature of Conservation for Union International) studies, *D. ammoniacum* is classified as a vulnerable and endangered species for Iran (Jalili and Jamzad 1999). The study and recognizing the ecological characteristics of *D. ammoniacum* species in Semnan province provides the required basic knowledge to conserve, rehabitation, establish and prevent the extinction of this native species, which will be one of the objective of this article.

Research carried out throughout the study was conducted from 2019 to 2021 in Semnan province.

Materials and methods

Description of the study area

Geographically, the Semnan province is located between 51° 51′–57° 3′ eastern longitudes and 34° 13′–37° 20′ northern latitudes on the southern slope of Alborz mountains. It is divided into Aradan, Damghan, Sorkheh, Shahroud, Garmsar, Mahdishahr and Miami, according to the latest subdivisions of the country (Lashkari and Riyazi 2016). There are two completely different temperature periods in Semnan province, cold and hot. The cold period lasts for only three months starting in December, January, and February, while the warm period lasts through the rest of the year. The temperature changes between the two periods are severe, and this is accompanied by a sudden increase in the intensity of the wind, as well as severe drought, loss of vegetation and a reduction in clouds and rainfall. Temperature changes in different parts of Semnan province are significantly influenced by the local factors, geographical location, influence and expansion of effective systems in the region as well as altitude. According to the data from synoptic stations in different parts of Semnan province in the last thirty years, the average temperature was 17 °C (− 5 to 37 °C). Many regions in Semnan province have low rainfall, especially in the southern and middle regions, where factors like subtropical high pressure in the summer, distance from the sea (lack of access to moisture sources), wind shelter, and lack of climbing allow for low rainfall. In the southwest or northwest of the country, as rain clouds cross the Zagros, Azerbaijan and Alborz highlands, these clouds suffer from severe moisture erosion and their ability to drop rain decreases gradually as they approach the center and east of the country. Semnan province is therefore a dry region with very low rainfall; the average annual rainfall is 137.3 mm and the average relative humidity is 42%. In recent years, the rainfall in Semnan province has decreased by 42.2 mm and humidity by 4%, while the temperature has increased by 0.7–1.5 °C (Islamic Republic of Iran Meteorological Organization).

Plant specimen, data collection, soil sampling and climatic factors

Throughout Semnan province, four main habitat species have been identified, including Garmsar heights, West Semnan heights, south of Damghan, and south of Shahroud (Biarjamand). Field surveys, Flora information (Rechinger 1987; Mozaffarian 2007), herbarium studies, and expert consultations were used to conduct this research. Based on climate and meteorological data from the closest stations, each habitat was assessed. In this regard, vegetation, climatic factors and soil parameters were measured in the region. In these habitats, 4–6 transects of 150 m were established with a random-systematic pattern, depending on vegetation conditions, ecological topography, and plant distribution patterns. Sampling was done in 4×4 m^2 plots along these transects. Totally 50–80 plots were measured in each location. Within each plot, the parameters of coverage percentage, density and frequency were recorded. Soil samples harvested from each habitat from a depth of 0–50 m and the parameters of organic carbon, $CaCO_3$, $CaSO_4$, pH, EC, calcium, magnesium, sodium, potassium, phosphorus, nitrogen, and soil texture were measured. Soil acidity is measured with a pH meter and electrical conductivity with an EC (electrical conductivity) meter. The hydrometric method also determined soil texture (Klute 1986). Organic carbon is measured by the Walkley–Black method (Walkley and Balck 1934). Nitrogen was measured by the Kjeldahl method (Bremner, 1970), absorbable phosphorus by the Olsen method (Olsen 1954), and potassium by the flame-photometry way (Skoog et al. 1990). Soil analysis performed in the soil science laboratory of Semnan Natural Resources Department. Comparison of different habitats in terms of phenological stages of the species is also examined. The phenological stages of Dorema stages were recorded in different habitats every two weeks. Data were entered in Excel software after initial processing, and habitats were compared in terms of climatic and soil parameters with Duncan test by IBM SPSS Statistics 25. The location of soil and plant samplings at each habitat is recorded using GPS and mapped in a GIS environment by the Arc-GIS 10.8. Correlation relationships between density, frequency and cover with other environmental factors were determined by direct gradient analysis or redundancy analysis (RDA), that were performed with Canoco 4.5 for Windows. Accompanied species of *D. Ammoniacum* were identified using appropriate recent keys including 'Flora Iranica,' 'Apiaceae mozafarian flora' 'Astragali of Iranian flora' and verified by herbarium experts of the Semnan University and the Natural Resources of Semnan Province.

Results and discussion

Botanical description of *D. ammoniacum*

D. ammoniacum is a perennial herbaceous, monocarpic, in which the fruit grows tall when ripe (1–2.5 m). It has a thick basal cover with a fibrous covering, stout and large, thick, with thickness 3–6 cm, cylindrical, branched and paniculate in the upper part, with long branches, sometimes branched, often without hairs, first greenish-gray, then brownish, with non-thick knots. Leaves are completely rosette-shaped, petiolate, average length 32 ± 2.2 and average width 22 ± 2.3, leaves lobed and having irregular loops, with three deep comb-shaped triple divisions, dimensions. Leaflets are with an average width of 2.5 ± 0.5 cm and an average length of 9.2 ± 3.4 cm, acute, the leaflets are often asymmetric and sometimes the leaves are stalked and have a large, triangular sheath and the stem of the embryo is deciduous and has long tip. Inflorescence is simple umbrella, flowers bisexual, elliptical to ovate flowers, light greenish-white flowers, lingual, without peduncle, covered with hairy hairs, integrated in alternating and very small umbrellas, spherical with a medium diameter of 8.5 ± 1.3 mm, petals white, hairy on the back, egg-shaped fruit wide to elliptical, 7.5 ± 1.6 mm long and 4.5 ± 0.5 mm wide and has-4 Vittae (Fig. 1).

Distribution, ecological conditions, vegetation survey and assessment of *D. ammoniacum*

D. ammoniacum habitats in Iran

The *D. ammoniacum* is the endemic species of Iran and was observed in the Alborz and Zagros mountains. The habitats of *D. ammoniacum* in Iran are as follows: Esfahan province: Ardestan, Taleghan 2500 m, Varian near Ardestan 2000 m; Kerman province: Rayen, Hezar 2500 m; Kashan province: Kahroud mountain; Baluchestan: Bazman—Taftan—Zahedan toward Malek Siah mountain 1100–1450 m; Semnan province: Damghan to Semnan, 20 km w of Damghan 1250 m; 98 km from Shahrud on road to Sabzevar 1400 m; Khorassan: 55 km NW of Torbate Heydaieh 1730 m; Tehran province: Karaj, 1810 m, Mahallat; Qazvin province: in the west and in Babakhdad, Harirud—Kohgiluyeh and Boyer Ahmad, Dena, Oshtrankooh, Lorestan, Hamedan, Alvand Mountains, Yazd, Fars, etc. (Fig. 2) (Mozaffarian 2007; Recinger, 1987).

D. ammoniacum habitats in the southern and central Alborz mountain range (Semnan province)

The province of Semnan is located in the southern and central parts of the Alborz mountain range and has been selected to study species distribution.

West to east, the province of Semnan contains the cities of Garmsar, Semnan, Damghan, and Shahroud. For a study of the vegetation points of the species (Fig. 3), Garmsar (west of Semnan), Damghan (south) and Shahroud (Biarjamand) were selected. Four main habitat areas were determined for *D. ammoniacum* in Semnan province. From west to east, they are habitat A (Garmsar heights), which includes the habitats of Aftar, Imamzadeh Abdullah, IJ and Javin, Rameh, habitat B (west of Semnan), which includes

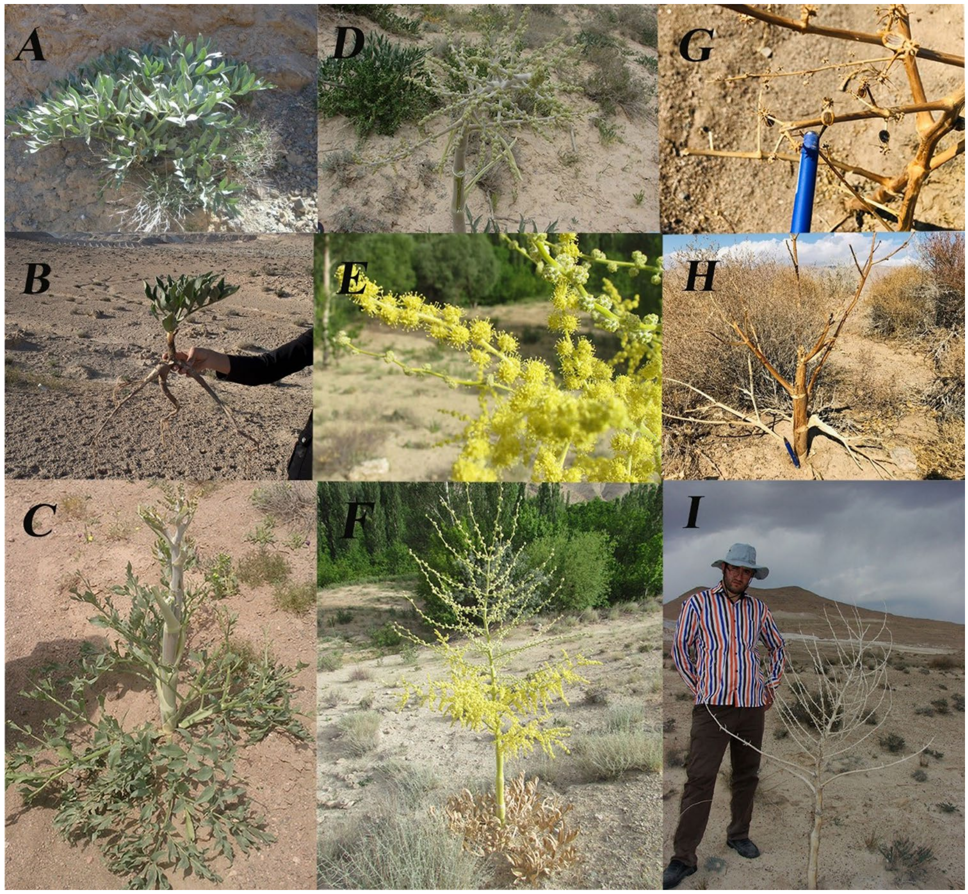

Fig. 1 *D. ammoniacum* in Semnan province; **A**:The vegetative stage in IJ and Javin; **B**: The first year of growth in Sorkheh and Momenabad; **C** and **D**: The beginning of the flowering stage in Hassanabad and Rashm; **E** and **F**: The flowering stage in IJ and Javin; **G**: The fruiting stage in Biarjomand and Toroud, **H**: The broken stem stage in Biarjomand and Toroud, **I**: The falling acorns in Sorkheh and Momenabad

Momenabad and Sorkheh. Habitat C (south of Damghan), which includes Hassanabad, Rashm, regions in the southern region of Haj Ali Ghoi desert, and Habitat D (south of Shahroud), which includes the habitats of Biarjomand, Kaftari mountains, North Chah Jam, Khah Farakh mountain, Six mountains.

Throughout the province, *D. ammoniacum* was commonly observed on high Rocky Mountains, composed mainly of limestone, shale, and sandstone, mostly without soil cover or with very thin pebble soil. In addition, the soils are relatively high to low hilly conglomerate and sandstone hills with rocky outcrops and shallow to moderately deep pebbled soils with light textures. These areas are also found on upper plateaus and terraces with shallow to moderately deep pebbled soils. Wind-blown pebbles, thin soil, medium texture, and relatively low salinity are characteristics of this province. As shown in the elevation map of Semnan province, the highest altitudes (1800–2200 m above sea level) are in the western parts of the province, whereas the lowest altitudes (1200–800 m above sea level) are in the eastern parts, indicating that vegetation is higher in the west than in the east.

Ecological factors of *D. ammoniacum* habitats

Because of various factors like subtropical weather in the summer and low rainfall in the central and southern parts of Semnan province, a lack of access to moisture sources (wind) shelter and lack of climbing factor, there is little rainfall in most of the province. In the Zagros, Azerbaijan and Alborz highlands, rainy air masses that enter the country from the west or northwest are subject to severe moisture evaporation and gradually move toward the country's center and east to produce rain. Rainfall is reduced. For this reason, Semnan province is a dry region with very little rainfall. The analysis of ecological factors showed that the highest and lowest mean temperatures were 18.60 ± 0.38 and 13.40 ± 0.41 °C, which relate to habitats B and A, respectively. 2025.66 ± 205.93 and 1148.66 ± 152.05 are the highest and lowest mean altitudes, which refer to habitats A and C, respectively. The highest and lowest rainfall averages are 170.30 ± 0.20 and 102.60 ± 0.30 mm, which are associated with habitats A and C, respectively. Habitats A and C show the highest and lowest mean humidity values of 50.66 ± 1.52 and 44.00 ± 0.9%, respectively. In habitats C and A, the mean

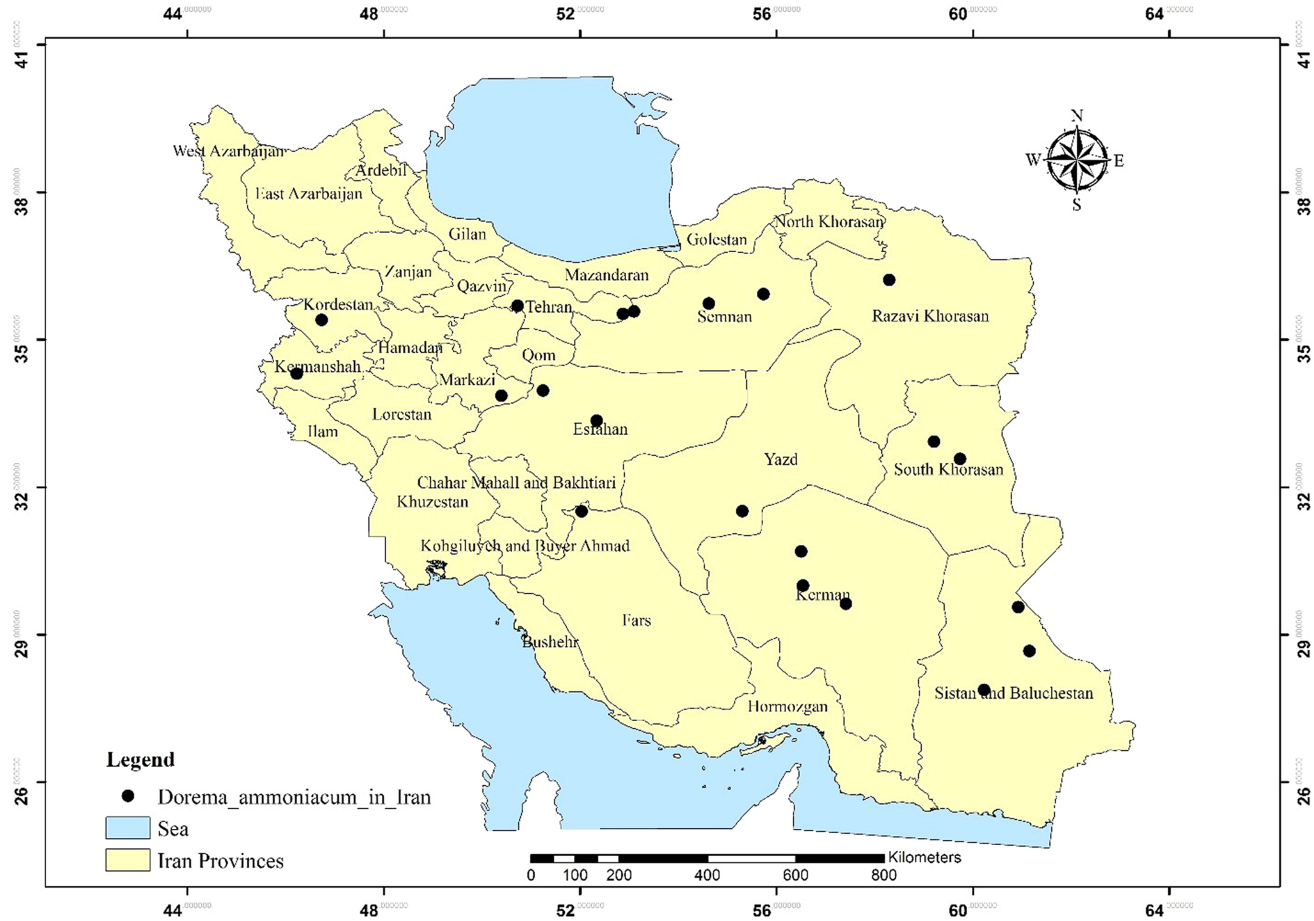

Fig. 2 Map of geographical distribution of *D. ammoniacum* in Iran

evaporation was 2580.00 ± 1.00 and 1870.00 ± 0.58 mm, respectively. In fact, habitat A has the highest altitude and rainfall, lowest temperature and evaporation rate. Climates in Habitat B, C, and D are characterized by the highest temperature ranges, maximum evaporation rates, and lowest rainfall rates, respectively. Additionally, it is important that all five climatic factors (altitude, temperature, rainfall, humidity, and evaporation) have statistical significance. (Table 1). Based on graphs displaying the synoptic situation in the Semnan province in these four habitats, the lowest temperature occurs in January and the highest temperature occurs in July. In these four habitats, the highest rainfall occurs in February and March, and the lowest rainfall occurs in August. The soil analysis showed that the highest percentage of sand is associated with habitat B and the lowest percentage is associated with habitat C, respectively, 80.78 ± 1.07 and 74.67 ± 0.58%. The highest percentage of silt is related to habitats A and C (16.6. 0.5a and 15.20 ± 1.00) and the lowest percentage of silt (10 ± 0.9) is related to habitat D. The highest levels of sodium and magnesium in habitat B are 3.50 ± 0.50 and 8.74 ± 0.90 Meq/l, respectively. The highest calcium content is in habitat A (31.53 ± 1.53 Meq/l) and the lowest is in habitat C (11.62 ± 1.47 Meq/l). The highest potassium content is related to habitat D (178.33 ± 16.87 Meq/l). The highest percentage of lime was observed in habitats C and D (16.40 ± 3.24% and 16.00 ± 2.58%), but the highest percentage of gypsum was observed in habitat A (23.67 ± 0.12%). Based on statistical analysis, all soil factors were significant except Clay and EC (electrical conductivity) factors (Table 1).

A comparison of phenological stages in habitats

As each plant begins to grow, it is affected by height, temperature, slope, etc. In general, *D. ammoniacum* grows earlier at lower altitudes and on southern slopes, and later at higher altitudes and on north slopes. In dry conditions, no rootstocks were found, while every two weeks phenological stages were examined in the field. Based on the study results, the beginning of the growing season in the studied habitats occurred in mid-March (habitats B and C) when a few seedlings emerged from the soil and the growing season began. The onset of growth is delayed and occurs in April in the northern slopes and altitudes of some habitats, such

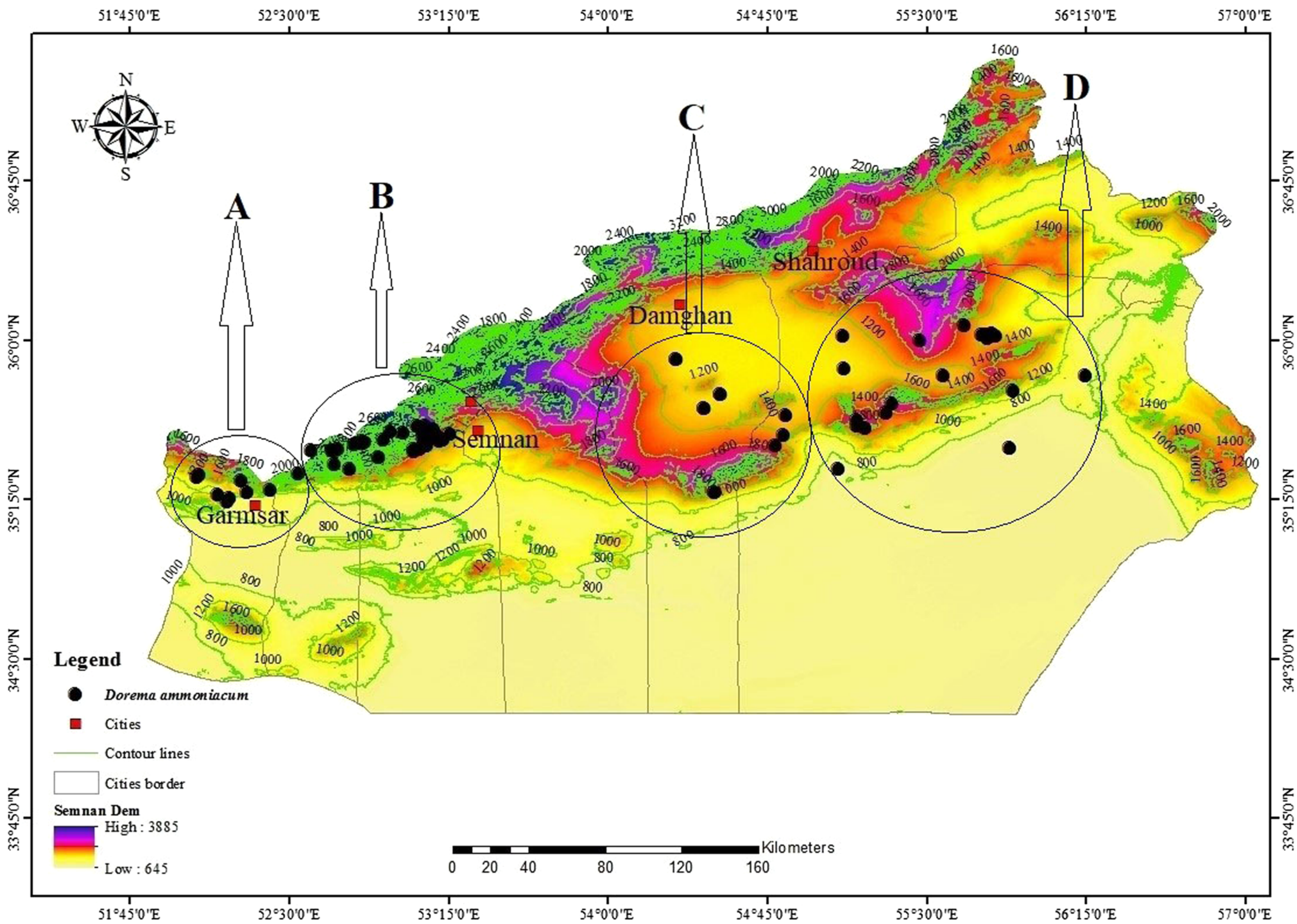

Fig. 3 Map of geographical distribution of *D. ammoniacum* in province of Semnan

as A. In Fig. 4, different phenological stages are shown in habitats A, B, C, and D.

Analyzing density, frequency, and cover parameters of *D. ammoniacum* and introducing associated species

According to phenological studies, plants reached their maximum growth in late May or early June, and at that time, measurements were taken to determine the density, frequency, and species cover of each habitat. Habitat A exhibited the highest average densities, frequencies, and cover of *D. ammoniacum* (0.098 m^2, 48.7%, and 29.7%, respectively) measurements. The density and coverage of *D. ammoniacum* of habitat C (0.044 m^2 and 15%, respectively) were the lowest, and the frequency of *D. ammoniacum* of habitat D (26%) was the lowest (Table 2, Fig. 5).

Associated species of *D. ammoniacum* from Asteraceae, Amaranthaceae, Polygonaceae families 20, 17 and 10%, respectively; Apiaceae, Boraginaceae, Euphorbiaceae, Caryophyllaceae and Fabaceae families each 7% and other families with lower percentages were found in habitats A, B, C and D. *Artemisia sieberi* from the Asteraceae, perennial, herbaceous to shrub, 20 to 50 cm high is an endemic Iranian-Turanian species and the dominant species in Semnan province (Ariapour et al. 2012; Azarnivand 2003; Rechinger 1987) which was observed in all habitats A, B, C and D. Species such as *Calligonum junceum*, *Heliotropium aucheri* and *Dendrostellera lessertii* were also present in all habitats. Species such as *Matthiola ovatifolia*, *Seidlitzia rosmarinus*, *Salsola tomentosa* and *Haloxylon ammodendron* were present in 75% of habitats. Also, the species showed good association with exclusive and gypsum species of Semnan such as *Astragalus semnanensis*, *Astragalus fridae*, *Euphorbia gypsicola*, *Moltkia gypsaceae* and *Gypsophila mucronifolia* in habitats A and B (Table 3).

Correlations between density, frequency and cover parameters of *D. ammoniacum* with other environmental factors

Various environmental variables (e.g., soil properties, elevation) were used in order to determine how much of

Table 1 Comparison of different ecological parameters in the studied habitats

	Ecological factors	A	B	C	D	*f*
Climate of habitat	Elevation	2025.66 ± 205.93[a]	1461.33 ± 133.23[b]	1148.66 ± 152.05[c]	884.67 ± 115.01[d]	62.484***
	Temperature (°C)	13.40 ± 0.41[d]	18.60 ± 0.38[a]	16.50 ± 0.49[b]	16.13 ± 0.31[b]	82.538***
	Rainfall (mm)	170.30 ± 0.20[a]	144.33 ± 0.2[b]	102.60 ± 0.30[d]	124.53 ± 0.25[c]	42,113.779***
	Relative humidity (%)	50.66 ± 1.52[a]	41.00 ± 1.00[d]	44.00 ± 0.9[c]	47.00 ± 1.1[b]	38.500***
	Evaporation (mm)	1870.00 ± 0.58[d]	2323.00 ± 2.00[c]	2580.00 ± 1.00[a]	2554.00 ± 2.00[b]	129,725.100***
Soil parameters	Depth	0–50	0–50	0–50	0–50	–
	Sand%	76.00 ± 06.02[b]	80.78 ± 1.07[a]	74.67 ± 0.58[b]	81.00 ± 1.20[a]	74.234***
	Silt%	15.20 ± 1.00[a]	11.21 ± 1.07[b]	16.6 ± 0.5[a]	10 ± 0.9[b]	38.318***
	Clay%	9.33 ± 0.01[a]	9.42 ± 0.72[a]	8.2 ± 0.57[b]	9.03 ± 0.02[a]	3.573*
	EC (d.s/m)	2.50 ± 0.01[a]	2.91 ± 0.31[a]	2.09 ± 0.03[b]	2.05 ± 0.01[b]	9.389*
	pH	7.06 ± 0.09[d]	7.31 ± 0.08[c]	7.42 ± 0.01[b]	7.94 ± 0.01[a]	62.573***
	Na (Meq/l)	2.70 ± 0.10[b]	3.50 ± 0.50[a]	2.43 ± 0.15[b]	2.39 ± 0.01[b]	11.216**
	Mg (Meq/l)	5.27 ± 0.90[b]	8.74 ± 0.90[a]	5.21 ± 0.10[b]	4.40 ± 0.10[b]	27.206***
	Ca (Meq/l)	31.53 ± 1.53[a]	28.68 ± 1.67[b]	11.62 ± 1.47[d]	12.90 ± 0.10[c]	177.224***
	K (mg/kg)	93.33 ± 30.41[b]	63.33 ± 15.28[b]	85.00 ± 21.04[b]	178.33 ± 16.87[a]	19.090**
	P (mg/kg)	2.67 ± .58[c]	0.93 ± 1.01[b] ±	7.00 ± 1.00[a]	8.33 ± 0.58[a]	54.939***
	N%	0.010 ± 0.00[b]	0.006 ± 0.03[c]	0.030 ± 0.00[a]	0.010 ± 0.00[b]	134.226***
	OC%	0.19 ± 0.02[b]	0.09 ± 0.03[d]	0.39 ± 0.01[a]	0.15 ± 0.01[c]	141.791***
	SAR	0.65 ± 0.01[b]	0.80 ± 0.01[a]	0.81 ± 0.15[a]	0.82 ± 0.02[a]	91.880***
	$CaCO_3$%	3.00 ± 2.15[c]	9.60 ± 4.93[b]	16.40 ± 3.24[a]	16.00 ± 2.58[a]	16.349**
	$CaSO_4$%	23.67 ± 0.12[a]	19.35 ± 0.56[b]	14.50 ± 0.10[d]	16.30 ± 0.10[c]	535.500***

* = $p \leq 0.05$, ** = $p \leq 0.01$, * ** = $p \leq 0.001$

Summary of Climate of Habitat and soil elements contents in four habitats. Summary statistics (mean ± standard error) and F-statistics from ANOVA among the four habitats groups (a, b, c and d), (A: IJ & Javin; B: Sorkheh & Momenabad; C: Hassanabad & Rashm; D: Biarjomand & Toroud)

the variability of vegetation data can be attributed to them. According to the results above, soil properties and topography had a significant impact on the clustering and occurrence of plant species. These results were visualized in ordination diagrams of RDA (redundancy analysis).

RDA (redundancy analysis) studies on *D. ammoniacum* found that the gypsum content in soil had the greatest positive effect on the frequency, density, and cover of the species, although height, rainfall, soil calcium, and clay in the soil texture also influenced the frequency and density. Also, according to the RDA chart, humidity significantly increased cover. By contrast, increasing factors such as temperature, evaporation, and calcium carbonate ($CaCO_3$) reduced the frequency, density, and cover (Fig. 6). Table 4 shows that the first and second axes of RDA (redundancy analysis) had eigenvalues of 0.98 and 0.02, respectively. In Table 4, the correlations of the factors are illustrated. Evaporation has a significant negative correlation with most factors except SAR (Sodium adsorption ratio). It was found that there was no correlation between moisture factor and sand content, sodium, magnesium, and SAR (Sodium adsorption ratio) of soils. Rainfall factor was positively correlated with height, soil clay content, EC (electrical conductivity), sodium content and calcium sulfate or gypsum content (correlation 0.98). Rainfall also showed a negative correlation with the amount of calcium carbonate or lime, SAR (Sodium adsorption ratio), organic carbon, nitrogen, phosphorus. Temperature showed a significant positive correlation with soil sand, magnesium and SAR (Sodium adsorption ratio). Temperature showed a significant negative correlation with calcium sulfate. Elevation factor showed a positive correlation with soil clay, EC, calcium content (0.90) and calcium sulfate (CaSO4) (0.98). Elevation factor also showed a negative correlation with soil phosphorus and SAR (Table 5.).

Discussion

Studies and field studies of the habitats of species and species in Semnan Province demonstrate *D. ammoniacum* is located at different altitudes compared to other provinces of Iran. The difference in height between the lowest point and highest point in Semnan province is approximately 1700 m, compared to 650 m in Fars province and 800 m in Yazd province. According to studies of climatic characteristics of *D. aucheri* habitats in Kohgiluyeh and Boyer-Ahmad

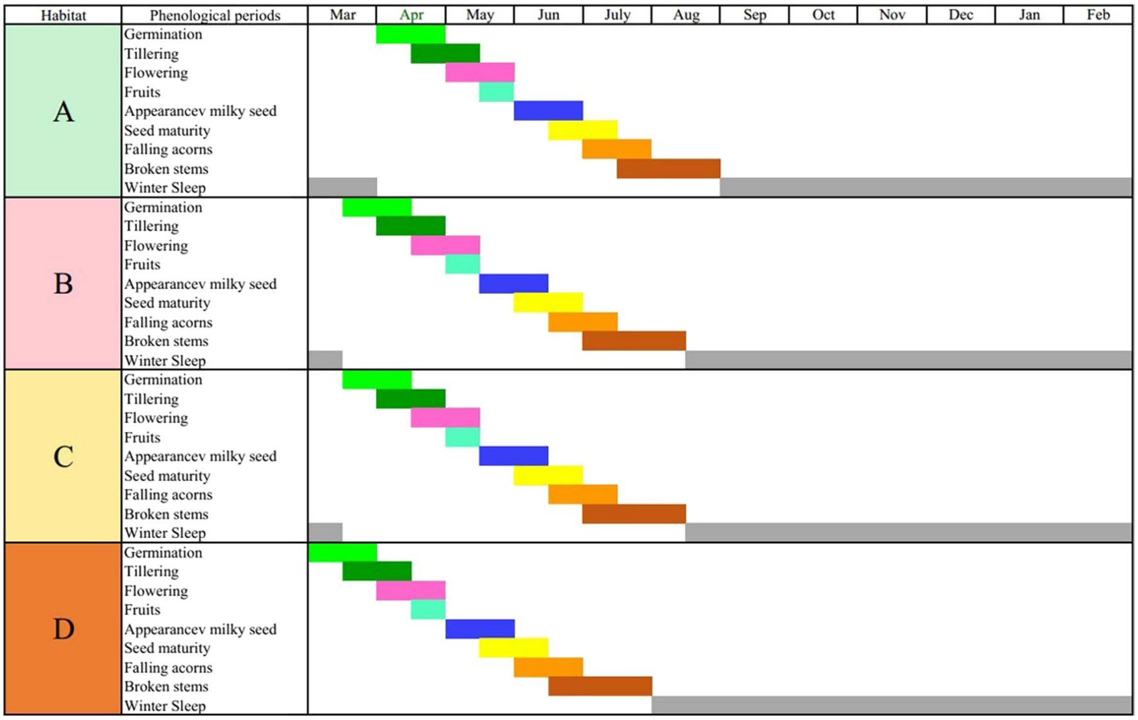

Fig. 4 The **A**, **B**, **C** and **D** habitats at various phenological stages (Germination, tillering, flowering, fruits, appearance milky seed, seed maturity, falling acorns, broken stems, winter sleep). (A: IJ and Javin; B: Sorkheh and Momenabad; C: Hassanabad and Rashm; D: Biarjomand and Toroud)

Table 2 Parameters of density, frequency and cover of *D. ammoniacum* in habitats of A, B, C and D

	A	B	C	D	*f*
Density (m^2)	0.098^a	0.068^b	0.044^c	0.060^{bc}	15.2*
Frequency (%)	48^a	36^b	21^c	26^d	244.133**
Cover (%)	29^a	18^b	15^c	17^{bc}	93.750**

Summary statistics (mean ± standard error) and F-statistics from ANOVA among the four habitats groups (a, b, c and d). A: IJ and Javin; B: Sorkheh and Momenabad; C: Hassanabad and Rashm; D: Biarjomand and Toroud

$* = p \leq 0.01$, $** = p \leq 0.001$

province, this species grows at higher altitudes than the altitude of *D. ammoniacum* habitat. *D. aucheri* grows in semiarid, temperate to cold climates and between 1600 and 3400 m above sea level. Therefore, the highest density of this species can be found at altitudes of 2300–3000 m above sea level and the habitat temperature ranges between − 11 and 35 °C (Kazemi et al. 2010). Among the Dorema genus, there are only two native species in Iran: *D. aucheri* and *D. ammoniacum*) Rechinger 1987). The present study confirms this issue and shows that this species in four habitats in the province, with an average altitude range from 800 to 2500 m

Fig. 5 Comparison of frequency, coverage and density parameters of *D. ammoniacum* in four habitats: A, B, C and D (A: IJ and Javin; B: Sorkheh and Momenabad; C: Hassanabad and Rashm; D: Biarjomand and Toroud)

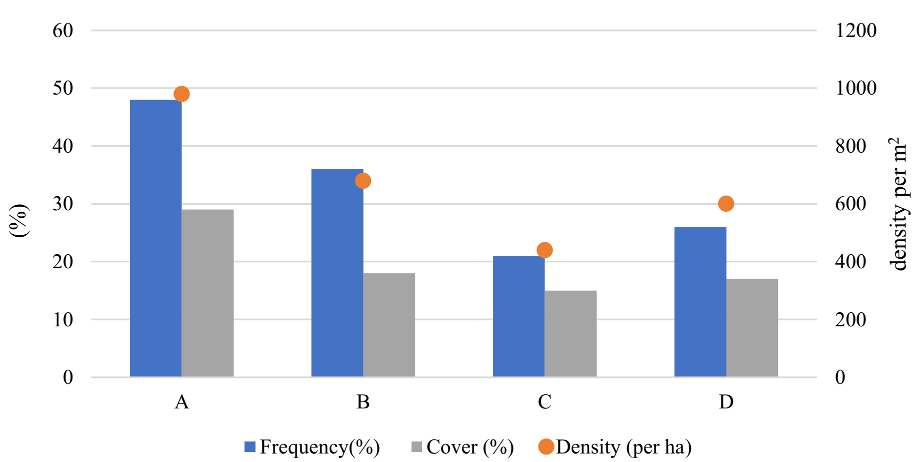

Table 3 Associated species of *D. ammoniacum* in habitats of A, B, C and D

Family	Species	Vegetation forms	A	B	C	D
Amaranthaceae	*Haloxylon ammodendron* (C.A.Mey.) Bunge	Ch		●	●	●
Amaranthaceae	*Aellenia subaphylla* (C.A.Mey.) Aellen	He			●	
Amaranthaceae	*Salsola tomentosa* (Moq.) Spach	He		●	●	●
Amaranthaceae	*Seidlitzia rosmarinus* Bunge ex Boiss	He		●	●	●
Amaranthaceae	*Noaea mucronata* (Forssk.) Asch. and Schweinf	He				●
Apiaceae	*Eryngium bungei* Boiss	He		●	●	
Apiaceae	*Prangos ferulacea* (L.) Lindl	Ch				●
Asteraceae	*Artemisia sieberi* Besser	Ch	●	●	●	●
Asteraceae	*Centaurea lachnopus* Rech. f	He		●		
Asteraceae	*Echinops nizvanus* Rech.f*	He		●		
Asteraceae	*Jurinea radians* Boiss.*	He	●			
Asteraceae	*Scariola orientalis* subsp. nuristanica Podl. and Rech.fil	He			●	
Asteraceae	*Cousinia deserti* Bunge	He				●
Boraginaceae	*Heliotropium aucheri* DC	He	●	●	●	●
Boraginanceae	*Moltkia gypsaceae* Rech. f.*	He	●	●		
Brassicaceae	*Matthiola ovatifolia* (Boiss.) Boiss	He		●	●	●
Capparidaceae	*Buhsea coluteoides* (Boiss.) Boiss. ex Bunge	He				●
Caryophyllaceae	*Gypsophila mucronifolia* Rech. F	He	●	●		
Caryophyllaceae	*Acanthophyllum microcephalum* Boiss	Ch	●		●	●
Cyperaceae	*Carex stenophylla* Wahlenb	He			●	●
Ephedraceae	*Ephedra intermedia*	He		●		
Euphorbiaceae	*Euphorbia gypsicola* Rech. f. and Aellen	He	●	●		
Euphorbiaceae	*Euphorbia bungei* Boiss	He	●	●		
Fabaceae	*Astragalus fridae* Rech. F	He	●	●		
Fabaceae	*Astragalus* semnanensis Rech. F	He	●	●		
Lamiaceae	*Stachy inflate* Benth	He		●		
plumbaginaceae	*Acantholimon cymosum* Bunge	Ch		●		
Polygonaceae	*Atraphaxis spinosa* L	Ch			●	
Polygonaceae	*Calligonum junceum* (Fisch. and C.A.Mey.) Litv	He	●	●	●	●
Rosaceae	*Amygdalus lycioides* Spach*	Ch/Ph	●	●		
Tamaricaceae	*Reumuria alternifolia*	He		●		
Thymelaeaceae	*Dendrostellera lessertii* (Wikstr.) Van Tigeh	He	●	●	●	●
Zygophyllaceae	*Zygophyllum europterum*	Ph	●	●	●	●

(A: IJ and Javin; B: Sorkheh and Momenabad; C: Hassanabad and Rashm; D: Biarjomand and Toroud; Ch: Chamaephytes; He: Hemicryptophytes; Ph: -Phanerophyte)

above sea level, average annual rainfall of 102–170 mm, and an average annual temperature of 1–19 °C, is also reliant on clean water sources. Several other provinces in Iran have similar climates, including Fars province with 150–200 mm of rainfall, in the altitude range of 800–1450 m (Gholami et al. 2000), Kerman province with an altitude of 2181 m above sea level has an average annual rainfall of 94 mm and an average temperature of 17.7 °C (Ghasemi-Arian et al. 2017), Sabzevar with an altitude of 1406 m above sea level has an average annual temperature of 14.22 and rainfall of 171 mm (Ghasemi-Arian et al. 2017). The climatic characteristics of Yazd province, with an altitude from 1800 to 2600 m above sea level, annual rainfall of 150 mm, and average temperature of 15.5 °C, are similar to those of Semnan province.

The four habitats studied in Semnan province range greatly in altitude from IJ and Javin habitats (A) (2025 m above sea level) to habitat D (884 m above sea level). Different habitats have different parameters of density, frequency, and canopy cover depending on climate factors. Therefore, IJ and Javin habitats (A) have the highest density (0.98 square meters), the highest frequency (48%) and the highest coverage (29%), as shown in Fig. 6. Phenological data collected from four habitats in Semnan province show that the onset of vegetative growth of *D. ammoniacum* was the earliest in habitat D (early March), the second in Sorkheh and Momenabad

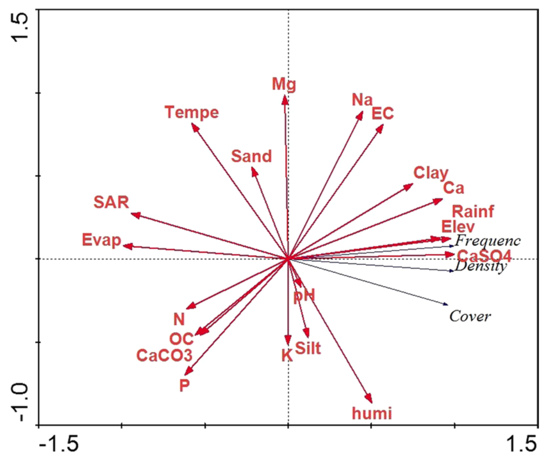

Fig. 6 RDA analysis; 20 Climatic factors of habitat Elev (Elevation), Rainf (Rainfall), humi (humidity), Tempe (Temperature) and soil including Sand, Silt and gypsum, sodium, magnesium, calcium, potassium, pH, EC and calcium sorbate in *D. ammoniacum*

Table 4 Eigenvalues of species-environment correlations at the first two RDA axes

Axes	Axis 1	Axis 2
Eigenvalues	0.98	0.02
Species-environment correlations	1	1
Cumulative percentage variance of species data	97.8	100
Cumulative percentage variance of species-environment relation	97.8	100

habitats (B) and C (mid-March), and the third in all of IJ and Javin habitats (A) (early April). The short phenological period of *D. ammoniacum* that occurs in Semnan province (late winter to before summer) allows the species to adapt to the harsh climate conditions of that region, such as high temperatures, high evaporation and low rainfall, especially in Hassanabad and Rashm habitats (C) and Biarjomand and Toroud habitats (D). Waterways and streams are common places to find *D. ammoniacum*. In habitats with more rainfall and lower temperatures, such as IJ and Javin habitats (A), the bases of the species are fresher than in other habitats. There have been reports of phenological periods in other provinces such as Kerman from mid-April to early May, Fars from mid-March to early March, and Yazd from mid-February to early March (Gholami et al. 2000; Ghasemnejad et al. 2014; Ghasemi-Arian et al. 2017; Zare et al. 2022; Rezaipoorbaghedar et al. 2014), and also the beginning of the phenological period of *D.aucheri* species in Kohgiluyeh and Boyer-Ahmad provinces has been reported since the end of March (Kazemi et al. 2010). Sand percentage in soil texture was higher in all habitats of *D. ammoniacum* (78.10% on average), but sodium and magnesium levels are lower than other regions of Semnan (Mohseni et al. 2017). A soil's texture (such as loam, sandy loam, or clay) is determined by the proportion of sand, silt, and clay particles present in the mineral fraction. Light soil is characterized by a high sand content, while heavy soil is primarily clay-based (Saskatoon 2009). Our results showed that *D. ammoniacum* prefers light soil, and that *D. ammoniacum* needs light soil texture to survive in habitats. In habitats IJ and Javin habitats (A), Sorkheh and Momenabad habitats (B), Hassanabad and Rashm habitats (C), and Biarjomand and Toroud habitats (D), all climatic and soil factors were significant. According to EC, pH, and SAR (Sodium adsorption ratio) analyses, the soil of the habitats for *D. ammoniacum* in Semnan province is not limited by salinity or alkalinity (pH and EC average 7.56 and 2.60, respectively). In addition, the results of statistical analysis of soil factors showed that the presence of gypsum, lime, calcium, magnesium, sodium elements significantly affected the distribution and density of species and fissures. Semnan province has a wide range of species density, with IJ and Javin habitats (A) having the highest density and the highest concentration of gypsum and calcium, and habitat C having the lowest density and the lowest concentration of gypsum and calcium. In addition, Ghasemi Arian's analysis of soil properties in Sabzevar habitats by Ghasemi Arian (2016) and Yazd province by Zare et al. (2022) confirmed these results and concluded that all organic matter, potassium, phosphorus, and lime in the soil increase the possibility of plant presence and density. However, factors such as cations, SAR, salinity (EC) and soil alkalinity reduce species density, as Hassanabad and Rashm habitats (C) showed the lowest density of species as well as the highest soil alkalinity and SAR.

SAR (sodium adsorption ratio) and soil alkalinity in the two habitats with the highest species density, IJ and Javin habitats (A) and the lowest Hassanabad and Rashm habitats (C), were compared. It was found that habitat C, which is located to the south of Hassanabad village and to the south of the Haj Ali Salt Lake, increases the SAR (sodium adsorption ratio) factor more than being on the beach at Haj Ali Gholi desert, Damghan playa (Taya et al. 2019). Hassanabad and Rashm habitats (C), located near the Damghan Playa, shows a decrease in density and other cover parameters as a result of greater evaporation than other areas. IJ and Javin habitats (A) have the highest density, and habitat C has the lowest density, as can be seen from the chart. According to climatic factors, IJ and Javin habitats (A) receive the highest amount of rainfall, but Hassanabad and Rashm habitats (C) receive the lowest amount of rainfall. Growing plants is affected significantly by climate, especially rainfall (Naseri et al. 2021). As such, vegetation distribution, type, and density are primarily dependent on climatic conditions and moderate temperatures, or, in other words, environmental conditions in a particular area (Ahmadi 2006). In arid

Table 5 Spearman correlation coefficients between explanatory variables by Canoco software analysis

	Evaporation	Humidity	Rainfall	Temperature	Elevation	Sand	Silt	Clay	EC	pH	Na	Mg	Ca	K	P	N	OC	SAR	$CaCO_3$	$CaSO_4$
Evaporation	1																			
Humidity	−0.56*	1																		
Rainfall	−0.94*	0.39	1																	
Temperature	0.64*	−0.99*	−0.46	1																
Elevation	−0.94*	0.34	0.84*	−0.43	1															
Sand	0.34	−0.55*	−0.00	0.58*	−0.44	1														
Silt	−0.25	0.44	−0.09	−0.46	0.39	−0.99*	1													
Clay	−0.65*	0.00	0.88*	−0.06	0.55*	0.48	−0.55*	1												
EC	−0.82*	−0.01	0.86*	−0.08	0.90*	−0.04	0.01	0.79*	1											
pH	0.015	0.22	0.23	−0.17	−0.33	0.68*	−0.77*	0.46	−0.18	1										
Na	−0.73*	−0.15	0.81*	0.06	0.83*	0.08	−0.10	0.80*	0.99*	−0.16	1									
Mg	−0.99*	0.58*	0.88*	−0.66*	0.96*	−0.47	0.39	0.54	0.79*	−0.14	0.69*	1								
Ca	−0.76*	−0.11	0.84*	0.01	0.84*	0.08	−0.10	0.83*	0.99*	−0.13	0.10*	0.72*	1							
K	0.46	0.17	−0.30	−0.08	−0.74*	0.52*	−0.5755*	−0.0907	−0.68*	0.84*	−0.6669*	−0.54*	−0.6403*	1						
P	0.86*	−0.11	−0.82*	0.21	−0.98*	0.29	−0.26	−0.62*	−0.97*	0.36	−0.93*	−0.87*	−0.93*	0.80*	1					
N	0.54*	−0.11	−0.79*	0.14	−0.34	−0.59*	0.68*	−0.96*	−0.57*	−0.71*	−0.58*	−0.41	−0.61*	−0.21	0.38	1				
OC	0.44	0.09	−0.72*	−0.06	−0.30	−0.69*	0.75*	−0.96*	−0.59*	−0.65*	−0.63*	−0.31	−0.65*	−0.16	0.38	0.98*	1			
SAR	−0.75*	−0.12	0.83	0.03	0.85*	0.06	−0.08	0.80*	0.99*	−0.16	0.10*	0.72*	0.10*	−0.67*	−0.94*	−0.59*	−0.63*	1		
$CaCO_3$	0.88*	−0.21	−0.78*	0.30	−0.99*	0.44	−0.41	−0.51*	−0.91*	0.44	−0.86*	−0.90*	−0.86*	0.83*	0.99*	0.27	0.25	−0.88*	1	
$CaSO_4$	−0.71*	−0.08	0.88*	0.01	0.70*	0.34	−0.39	0.96*	0.91*	0.21	0.93*	0.63*	0.94*	−0.35	−0.78*	−0.84*	−0.87*	0.93*	−0.68*	1

*Indicate values with correlations > ±0.50

and semiarid rangeland ecosystems, rainfall, frequency, and seasonal distribution have shown the greatest correlation with crop production among climatic variables (Abd Elahi et al. 2006; Khumalo and Holechek 2005; Karabulut 2002; Zarekia et al. 2012). Similarly, the RDA analysis (Fig. 6) indicated that rainfall and altitude factors positively affected density, frequency and cover of *D. ammoniacum*, while increased temperature and evaporation factors in the habitats negatively affected species. Yazd province has a limited niche for this species, as Zeare et al. (2010) also found. Rezaeipour Baghdar et al. (2014) have found that lime, bicarbonate ion, chlorine, calcium, sulfate, clay, and an increase in electrical conductivity all contribute to the high establishment of *D. ammoniacum* in soils. According to correlation analyses, one of the most important soil elements for the presence of *D. ammoniacum* was the gypsum parameter. Also, the presence of *D. ammoniacum* in Yazd province is dependent on gypsum. Sites A and B display a high percentage of gypsum (17–23%), while habitats C and D exhibit an average of 10–6% gypsum. *D. ammoniacum* grows in gypsum, but the amount of gypsum is not a limiting factor for the species. Even with a small amount of gypsum, the needs of the species can be met.

The presence of lime and gypsum has caused a noticeable increase in calcium ions in the soils of *D. ammoniacum* habitats, which was higher in IJ and Javin (A) and Sorkheh and Momenabad (B) habitats (31.53 and 28.68 Meq/l, respectively) than Hassanabad and Rashm habitats (C) and Toroud habitats (D) (11.62 and 12.9 Meq/l, respectively), Also gypsum status in A and B habitats was calculated higher than C and D, too. The range of changes in lime and gypsum is important in plant selection and on the other hand, the element calcium is common in both of the above factors. In fact, since this species is elusive, the presence of Ca^{+2} ions displaces excess sodium in the soil. Contrary to expectations, gypsum soils improve soil conditions for some plants to grow. Sodium is a barrier to plant growth in most desert soils. Sodium soils are dispersed soil particles and the presence of sodium prevents these particles from approaching each other and prevents the formation of soil structure and granulation, which gypsum solves this problem and improves the ratio of calcium to magnesium in the soil (Jafari and Tavili 2012), and as a result, gypsum soils have created conditions for the growth of species in Semnan province.

The amount of potassium ion in soils of *D. ammoniacum* habitats was high, especially in Hassanabad and Rashm habitats (C), which averaged 178.33 (mg/kg). Since Hassanabad and Rashm habitats (C) has the least amount of rainfall and the most amount of evaporation, the plant will have a small amount of water to grow. Since the element potassium causes resistance to drought and cold in plants by regulating osmotic pressure in root cells and leaf stomata and is one of the effective environmental factors in vegetation establishment (Parsamehr et al. 2015; Hasheminia and Haghnia 1999), it is possible that high levels of potassium in the C habitat have made the plant adaptable.

Artemisia sieberi and *Zygophyllum europterum* are one of the companion species in all IJ and Javin habitats (A), Sorkheh and Momenabad habitats (B), Hassanabad and Rashm habitats (C) and Biarjomand and Toroud habitats (D), which are the two dominant species in hot and dry regions of Iran, which was reported as the dominant and abundant species in the habitats of Yazd province along with *D. ammoniacum* species (Zare et al. 2022).

If the objective is to maintain genetic stock, cultivate and restore pastures, and exploit the species, it is suggested that ecologically distinct areas such as habitat A should be considered. The climate, soil, and topography in this region offer optimal conditions for growth of *D. ammoniacum*.

Conclusion

In this study, native and medicinal species of *D. ammoniacum* were investigated in four habitats: A: IJ and Javin; B: Sorkheh and Momenabad; C: Hassanabad and Rashm; D: Biarjomand and Toroud from the south–central Alborz Ranges (Semnan province, Iran). Thre was a strong positive correlation between abundance of the *D. ammoniacum* species, elevation and gypsum soil content. Gypophyte and calciphyte companion species were identified in these 4 habitats. abundance of the *D. ammoniacum* species were further negatively correlation with sodium content, EC (salinity) and soil pH. Among low plains, salinity and soil EC appear to restrict the presence and abundance of the *D. ammoniacum* species.

Acknowledgements We thank Sahar Akhlaghpour for soil analysis, Amir Maddah, and Kazem Taherian for their previous valuable studies on Semnan province habitats.

Declarations

Conflict of interest The authors have no conflicts of interest to declare.

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