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THE CLIMATIC AND EDAPHIC REQUIREMENTS OF TWO NARROW ENDEMIC SPECIES FROM LAMIACEAE IN CENTRAL ANATOLIA, TÜRKİYE

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Abstract

The climatic and soil attributes of two narrow, endangered, endemic species of the Lamiaceae family, *Scutellaria yildirimlii* and *Sideritis gulendamii*, in the Central Anatolia region of Türkiye were investigated. Soil samples were collected from the distribution areas of the species, and various edaphic attributes, including texture, salinity, electrical conductivity (EC), pH, calcium carbonate ($CaCO_3$), and gypsum content, were analyzed. Meteorological data were utilized to identify the climatic preferences of these studied species. Results indicate that *Scutellaria yildirimlii* tolerates a wide range of soil textures but prefers slightly alkaline, non-saline, moderately calcareous soils, whereas *Sideritis gulendamii* favors clay-rich textures in neutral to slightly alkaline, non-saline conditions. Both species are found in marl soils, characterized by high calcium carbonate content. Climatic analyses suggest that both species are found in semi-arid areas influenced by a typical Mediterranean climate, characterized by hot, dry summers and cold, wet winters. The findings of this study offer important insights for developing effective habitat management strategies for the conservation of endemic species and provide crucial information for evaluating their sensitivity to potential climate change scenarios.

Key words: *Scutellaria yildirimlii*; *Sideritis gulendamii*; Climatic preferences; Edaphic attributes; Narrow endemic species

Introduction

The remarkable biological diversity present in the natural world today is the result of continuous evolutionary processes that have shaped life since its origin on Earth. In geological periods, tens of thousands of species have become extinct after mass catastrophes. However, the main cause of species extinction today is the rapid growth of the human population and the degradation of natural habitats (Primack, 2010). The ongoing extinction event, known as the "sixth extinction wave" has the potential to be the fastest and the most catastrophic (Ceballos *et al*., 2010). This diminishes the vital benefits people receive from nature, thereby threatening the quality of life for current and future generations (Butchart *et al*., 2025).

Factors such as destruction and fragmentation of habitats, global climate change, and over-exploitation of species for human use pose a major threat to biodiversity, putting many plant species at risk of extinction (López-Pujol *et al*., 2003). Endemic plant species with narrow distributions and specific habitat requirements are particularly more vulnerable to threats due to their limited ranges and ecological needs. *Scutellaria yildirimlii* Çiçek & Yaprak and *Sideritis gulendamii* H. Duman & Karaveliogullari of the Lamiaceae family are endemic to the inner region of Anatolia, Türkiye. *Scutellaria yildirimlii* consists of 6 distinct populations, while *Sideritis gulendamii* is represented by 7 populations. Both species are classified as Endangered (EN) according to the International Union for Conservation of Nature (IUCN) Red List Criteria, which assesses species based on factors such as population size, distribution, and environmental threats. The classification highlights the vulnerability of these species to habitat degradation, climate change, and other ecological pressures, emphasizing the urgent need for conservation efforts to safeguard their survival (Yıldırım *et al*., 2019).

Although numerous studies have been conducted on the these species (Kirimer *et al*., 2004; Martin *et al.*, 2009; Azizoğlu *et al*., 2011; Kaya *et al*., 2015; Yıldırım *et al.*, 2019, 2023, 2024), no research has been carried out regarding the ecological attributes of these species. This study aims to determine the climatic and edaphic requirements of the narrowly distributed, fragmented, endemic species *Scutellaria yildirimlii* and *Sideritis gulendamii* and to provide relevant information for the conservation management of these two species.

Material and Methods

Soil parameters analysis: To determine the locality information of *Scutellaria yildirimlii* and *Sideritis gulendamii*, herbarium specimens (ANK, HUB, GAZI, and ESSE) were examined, and a literature review was conducted (Yıldırım *et al.*, 2019, 2023, 2024). In 2016, field studies were conducted in 6 localities for *Sc. yildirimlii* and 7 localities for *Si. gulendamii* in the provinces of Ankara and Eskişehir (Fig. 1). Soil samples were collected from each locality where the studied species are found, at two different depths: surface, 15 cm, and 30 cm deep soil.

The collected soil samples were dried, homogenously mixed, and divided into 2 kg samples for physical and chemical analyses. These samples were analyzed for texture, salinity, electrical conductivity (EC), pH, calcium carbonate ($CaCO_3$), and gypsum content by the BIYOTAR Soil Analysis Laboratory (Ankara, Türkiye) as part of this study through the procurement of an external laboratory service.

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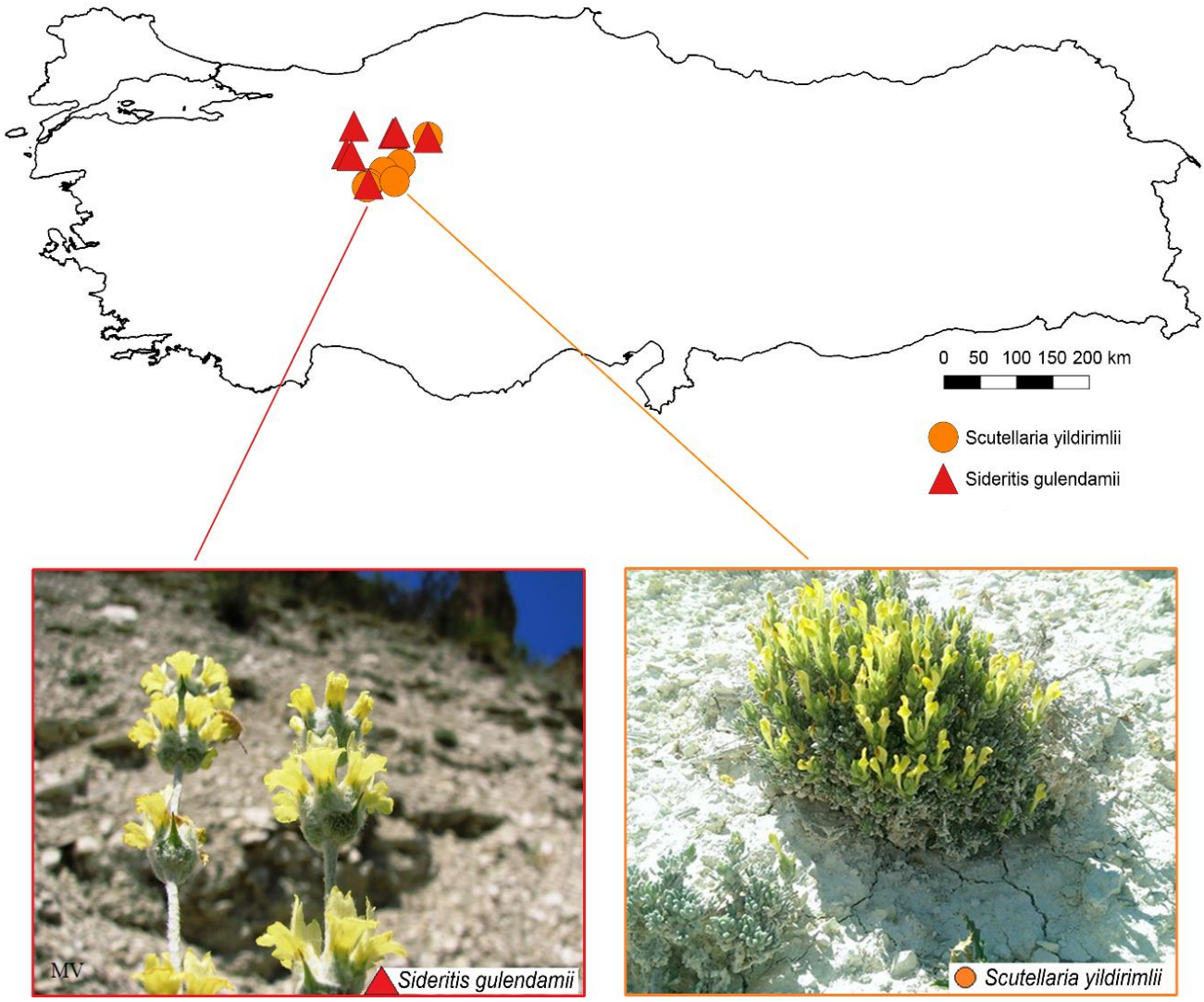

Fig. 1. Geographical location and distribution of *Si. gulendamii* and *Sc. yildirimlii* in central Türkiye.

The soil texture (percentages of sand, silt, and clay) was determined using the hydrometer method based on the sedimentation principles of Bouyoucos (1955). Soil texture is an important parameter as it provides information about the physical and chemical properties of the soil (Kaçar, 2016).

Soil pH is determined based on the measurement in a saturation paste prepared by bringing the soil to water saturation. After the pH meter is calibrated, the electrode is immersed into the paste extract for a direct pH reading. Following the measurement, the electrode is washed with deionized water and dried before proceeding to the next reading (Richards, 1954; Tüzüner, 1990).Soil pH affects the solubility and uptake of nutrients by plants, the microorganisms that decompose organic matter, the weathering of minerals that make up the soil, and the transportation or transformation of these minerals into insoluble compounds within the soil (Türüdü, 2004).

Electrical conductivity (EC) is generally a measure of the soluble salts in soils, or in other words, an indicator of salinity. The total salinity content of soils was determined by measuring the electrical conductivity of water-saturated soil and assessing salinity based on this resistance (Richards,1954; Tüzüner, 1990).

Calcium carbonate ($CaCO_3$) or lime is found in varying amounts in soils across different regions in Türkiye. For instance, in soils of arid and semi-arid regions, lime is generally present in high amounts due to low leaching, while in the sandy soils of rainy regions, it is found in lower quantities (Kaçar, 2016). Soils with lime content have a slightly alkaline or moderately alkaline pH value. On the other hand, soils with low lime content fall into the acidic pH category.

Gypsum occurs either as calcium sulfate ($CaSO_4$ $2H_2O$), which contains two molecules of water in its composition, or as anhydrite ($CaSO_4$), the anhydrous form of calcium sulfate (Alphen & Romero, 1971). There is a constant conversion between anhydrite and calcium sulfate dihydrate (gypsum) depending on their exposure to water. When buried several hundred meters deep, gypsum loses its water and transforms into anhydrate form. Conversely, when deep-seated anhydrite is uplifted closer to the surface, it absorbs water and converts back to gypsum (Verheye & Boyadgiev, 1997).

Climate analysis: Climatic data from the stations of Nallıhan, Beypazarı, Alpu, Ayaş, Sivrihisar, and Polatlı, the closest meteorological stations to the distribution areas of the species, were obtained from the General Directorate of Meteorology of Türkiye (Table 1). Bioclimatic interpretations were conducted according to Emberger bioclimatic classification system (Akman, 2011).

Table 1. The meteorological observation stations utilized in climate analysis.

Station name and covered species	Altitude (m)	Observation type and duration	Covered locations
Nallıhan *Si. gulendamii*	650	Temperature 53 years Precipitation 14 years	Ankara, Nallıhan, Sarıçal Mountain
Beypazarı *Si. gulendamii*	682	Temperature 57 years Precipitation 14 years	Ankara, Beypazarı-Başören village Ankara, Beypazarı İnözü Valley
Alpu *Si. gulendamii*	765	Temperature 18 years Precipitation 18 years	Eskişehir, Çırçır Eskişehir, Yukarıdoğanoğlu village
Ayaş *Sc. yildirimlii* *Si. gulendamii*	910	Temperature 15 years Precipitation 15 years	Ankara, Ayaş
Sivrihisar *Sc. yildirimlii* *Si. gulendamii*	1070	Temperature 55 years Precipitation 53 years	Eskişehir, Oğlakçı Eskişehir, Yeşilköy Eskişehir, Asağıkepen Eskişehir, Günyüzü, Kavuncu village
Polatlı *Sc. yildirimlii*	886	Temperature 53 years Precipitation 14 years	Ankara, Polatlı-Kızlarkayası

Results

Edaphic attributes

Texture analysis: The soil texture is determined by the relative proportions of sand, silt, and clay in the soil. The proportions obtained from the physical analysis of soil samples collected from the study areas are presented (Fig. 2). The soil samples from the Ayaş and Yeşilköy localities, from six different areas where the *Sc. yildirimlii* species is distributed, are clayey in texture; the soil samples from Kızlarkayası and Aşağıkepen are clay-loamy; and the soil sample taken from Kavuncu is sandy-clayey. The soil samples taken from seven different areas where the *Si. gulendamii* species is distributed, showing the following textures: the soil samples from Ayaş, Sarıçal, Çırçır, and Yukarıdoğanoğlu localities are clayey; the soil samples from Başören and İnözü Valley localities are sandy-clay-loamy; and the soil sample from Aşağıkepen locality is clay-loamy.

pH analysis: The pH values of the soil samples collected from the study areas were classified based on the threshold values reported by Richards (1954). According to these thresholds, soils are categorized as follows: pH < 4.5, Strongly Acidic; 4.5 – 5.5, Moderately Acidic; 5.5 – 6.5, Slightly Acidic; 6.5 – 7.5, Neutral; 7.5 – 8.5, Slightly Alkaline; and pH > 8.5, Strongly Alkaline.

Soil pH values for *Sc. yildirimlii* ranged from 7.59 (Ayaş) to 8.01 (Aşağıkepen), indicating a preference for slightly alkaline soils. The pH range for *Si. gulendamii* was found to be between 7.33 (Sarıçal) and 8.07 (Başören). According to these findings, while the soil sample from Sarıçal exhibited neutral properties, the samples from other localities were slightly alkaline (Fig. 3).

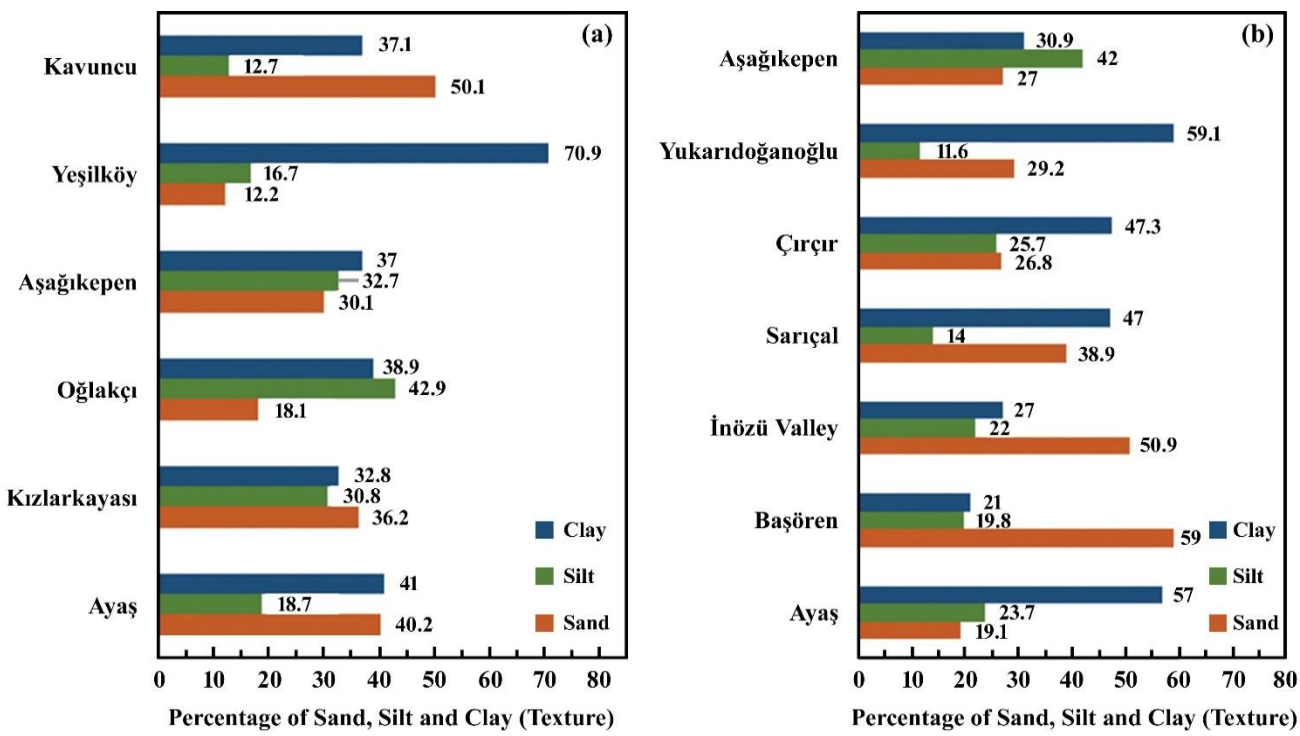

Fig. 2. Soil texture data showing the percentage of sand, silt, and clay in the soil samples of (a) *Sc. yildirimlii* and (b) *Si. gulendamii* populations.

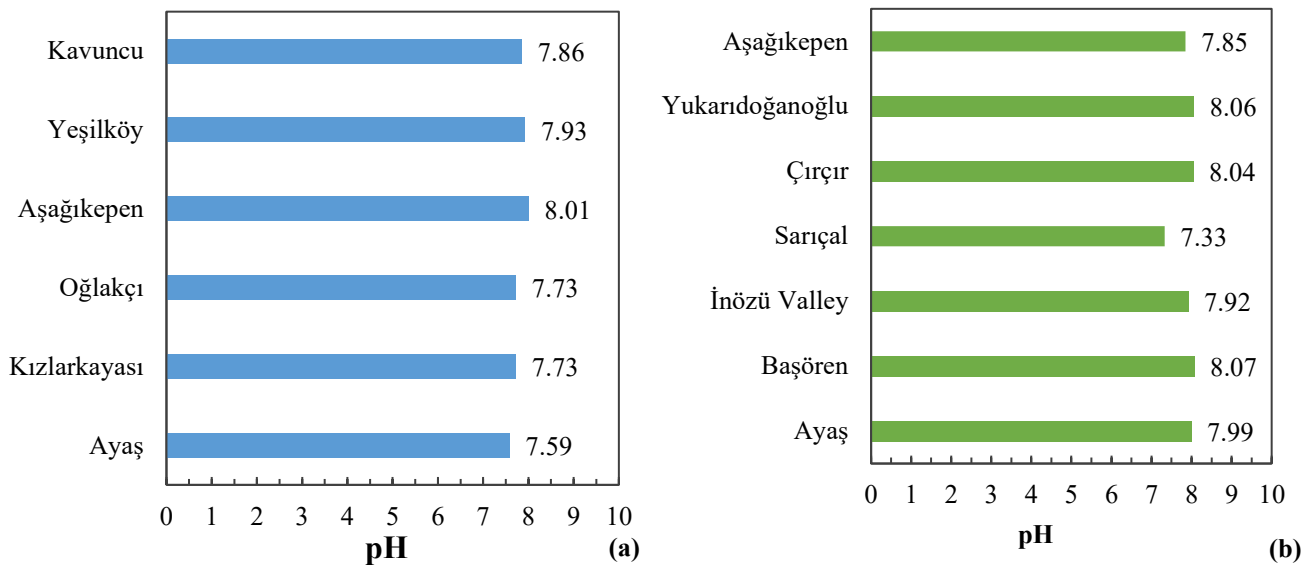

Fig. 3. pH values of the soil samples of in (a) *Sc. yildirimlii* and (b) *Si. gulendamii* populations.

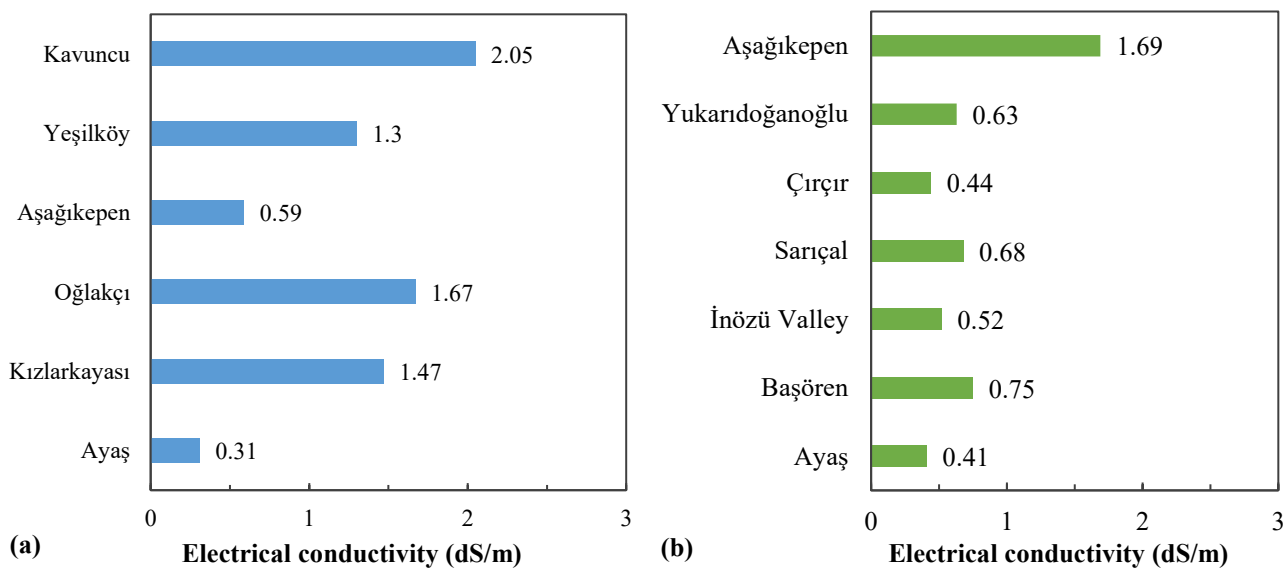

Fig. 4. EC (dS/m) values of the soil samples of (a) *Sc. yildirimlii* and (b) *Si. gulendamii.*

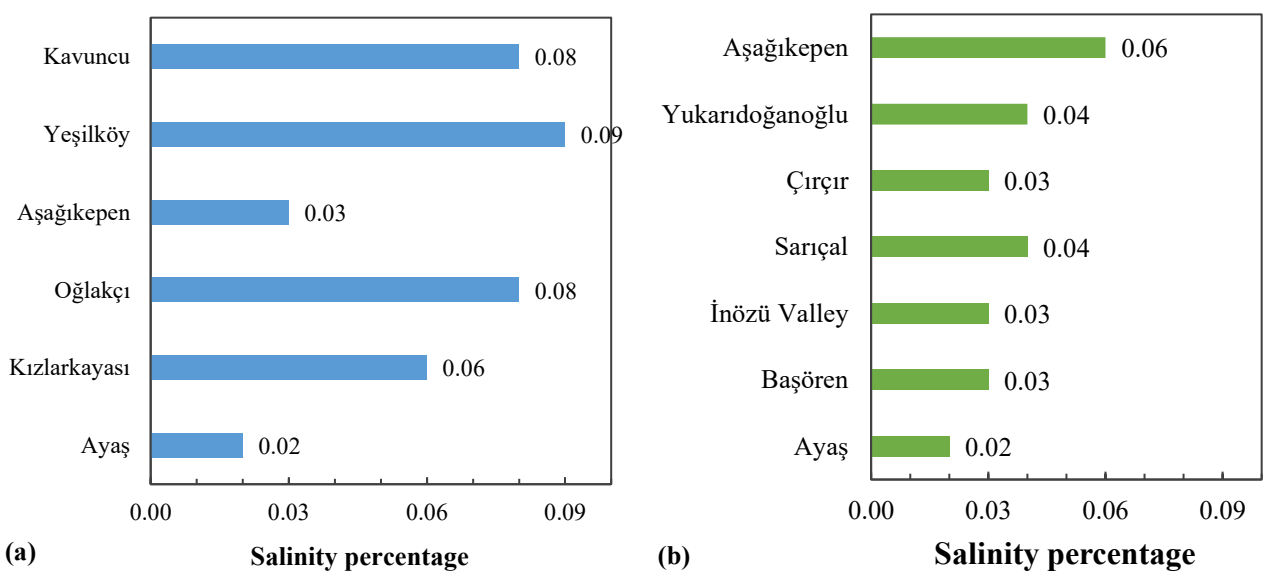

Fig. 5. Salinity Percentage values of the soil samples of (a) *Sc. yildirimlii* and (b) *Si. gulendamii.*

Electrical conductivity (EC) and salinity analysis: The salinity measures of soil samples collected from the study areas were classified according to the threshold values reported by Tüzüner (1990) (Table 2). The EC values in *Sc. yildirimlii* populations ranged from 0.31 dS/m (Ayaş) to 2.05 dS/m (Kavuncu). The salinity in these areas varied between 0.02% (Ayaş) and 0.09% (Yeşilköy). For *Si. gulendamii*, these values ranged from 0.41 dS/m (Ayaş) to 1.69 dS/m (Aşağıkepen), with salinity content ranging between 0.02% (Ayaş) and 0.06% (Aşağıkepen). These findings indicate that both species prefer non-saline soils (Figures 4 and 5).

Table 2. Classification of soils based on salinity and EC values (Tüzüner, 1990).

Salinity level	Total salinity (%)	EC (dS/m)
Non-saline	0.00 – 0.15	0 – 4
Slightly saline	0.15– 0.35	4 – 8
Moderately saline	0.35– 0.65	8 – 15
Strongly saline	> 0.65	> 15

Lime ($CaCO_3$) analysis: The percentage of lime in soil samples collected from the study area was classified based on the limit values reported by Ülgen & Yurtsever (1995), as follows: 0 – 1% low lime, 1 – 5% limy, 5 – 15% moderately calcareous, 15 – 25% high lime, and > 25% extremely calcareous. In areas where *Sc. yildirimlii* is distributed, the lowest lime content was recorded in Kavuncu with 5.74%, while the highest was measured in Aşağıkepen with 14.7%. Among the study areas, Aşağıkepen has the highest lime percentage. This suggests that this species thrives in moderately calcareous soils. For *Si. gulendamii*, the lowest lime content was observed in İnözü Valley with 3.30%, whereas the highest was recorded in Ayaş with 14.5%. Based on these results, it can be concluded that this species thrives in limy and moderately calcareous soils (Fig. 6).

Gypsum analysis: Soils containing more than 2% gypsum are designated as gypsic soils. These soils often have subsoil layers with a gypsum content greater than 14% In the areas where *Sc. yildirimlii* is distributed, the lowest gypsum content was recorded at 0.09% in the Oğlakçı locality, while the highest gypsum percentage was measured at 0.17% in the Yeşilköy locality. In the habitats of *Si. gulendamii*, the lowest gypsum content (0.08%) was measured at the Ayaş and Başören village stations. These represent the lowest gypsum values recorded across the study areas. The highest gypsum percentage for this species was measured at 0.14% in Sarıçal. Based on this, since the gypsum content in the soils where the species are found does not exceed 2%, they do not fall into the gypsum-rich soil class, but it can be stated that there is a small amount of gypsum present in these soils (Fig. 7).

Climatic Preferences: The meteorological data from climate stations near the study areas were utilized to characterize the climate of the distribution areas of the studied species (Nallıhan, Beypazarı, Alpu, Ayaş, Sivrihisar, and Polatlı). The analyses of the climatic data, based on all the collected information, are summarized (Table 3).

At the Nallıhan station, the average wind speed is 1.7 m/s, with predominant wind directions from the west (133,351 times) and north (86,954 times). At the Beypazarı station, the average wind speed is 1.8 m/s, with prevailing winds from the north-northeast (55,667 times) and the south-southwest (55,206 times). At the Alpu station, the average wind speed is 1.2 m/s, and the dominant wind directions are from the west (29,240 times) and the north (24,920 times). In Ayaş, the average wind speed is 1.4 m/s, with winds mainly blowing from the north-northeast (19,080 times) and the north-northwest (13,064 times). At the Sivrihisar station, the average wind speed is 2.4 m/s, with dominant winds from the south (230,000 times) and the north-northeast (58,597 times). Finally, at the Polatlı station, the average wind speed is 2.6 m/s, and the prevailing winds are from the north-northeast (65,183 times) and the northeast (44,566 times) (Fig. 8).

Table 3. Bioclimatic analysis of the meteorological stations closest to the distribution areas of *Sc. yildirimlii* and *Si. gulendamii*.

Meteorological Station / Bioclimatic Parameters	Nallıhan *Si. gulendamii*	Beypazarı *Si. gulendamii*	Alpu *Si. gulendamii*	Ayaş *Sc. yildirimlii* *Si. gulendamii*	Sivrihisar *Sc. yildirimlii* *Si. gulendamii*	Polatlı *Sc. yildirimlii*
P (mm)	350.0	410.1	376.8	427.1	391.6	364.2
M (°C)	31.6	32.2	30.4	29.4	29.0	30.6
m (°C)	– 2.4	–1.8	– 4.2	– 2.9	– 3.2	– 3.4
Q	35.7	41.8	38.1	46.1	42.5	37.3
PE (mm)	45.1	58.2	53.7	58.0	62.0	59
S	1.42	1.80	1.76	1.97	2.13	1.92
Precipitation regime	W.Sp.F.Su.	W.Sp.F.Su.	Sp.W.F.Su	Sp.W.F.Su	Sp.W.F.Su	Sp.W.F.Su
Precipitation regime type	Eastern Mediterranean Type 1	Eastern Mediterranean Type 1	Eastern Mediterranean Type 2	Eastern Mediterranean Type 2	Eastern Mediterranean Type 2	Eastern Mediterranean Type 2
Bioclimatic classification	Semi-arid sub cold mediterranean bioclimate	Semi-arid sub cold mediterranean bioclimate	Semi-arid sub very cold mediterranean bioclimate	Semi-arid upper cold mediterranean Bioclimate	Semi-arid sub very cold mediterranean bioclimate	Semi-arid sub very cold mediterranean bioclimate

P: Mean annual precipitation (mm), M: Mean maximum temperature of the warmest month (°C), m: Mean minimum temperature of the coldest month (°C), Q: Precipitation-temperature coefficient ($Q = 2000 \times P / M^2 - m^2$), PE: Summer precipitation (mm), S: Aridity indices (S = PE / M), Sp: Spring, W: Winter, F: Fall, Su: Summer

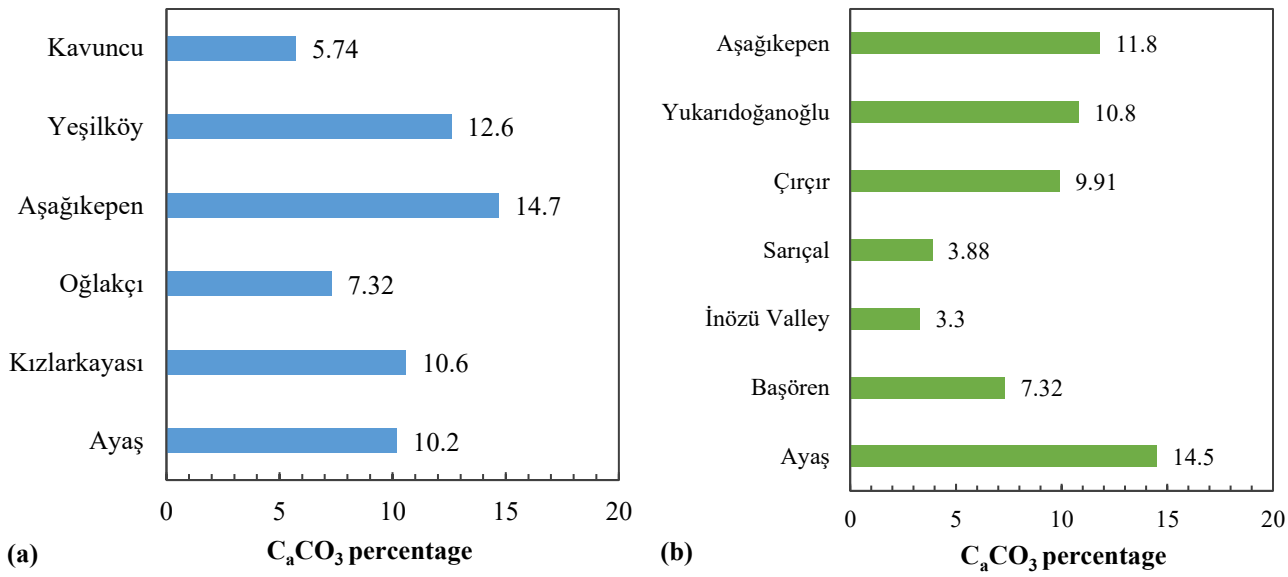

Fig. 6. $CaCO_3$ percentage of the soil samples of (a) *Sc. yildirimlii* and (b) *Si. gulendamii.*

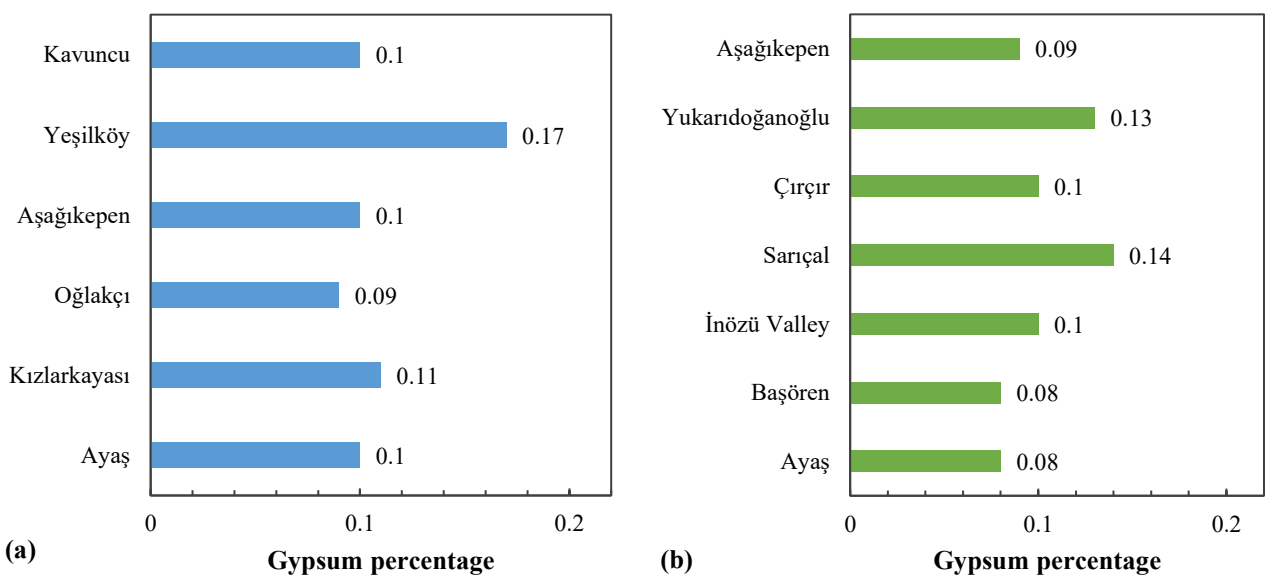

Fig. 7. Gypsum percentage of the soil samples of (a) *Sc. yildirimlii* and (b) *Si. gulendamii*.

The study area exhibited a significant variation in annual average rainfall. For *Sc. yildirimlii* annual average rainfall were recorded as Ayaş (427.1 mm), Sivrihisar (391.6 mm), and Polatlı (364.2 mm). Due to the annual average rainfall in the study areas ranging between 250 - 550 mm, these regions are categorized as semi-arid (Akman, 2011). The seasonal precipitation regime for all three stations follows the order of Spring, Winter, Fall, and Summer, corresponding to the Eastern Mediterranean Precipitation Regime Type 2 (Akman, 2011). The fact that the drought index (S) value is less than 5 at all seven stations indicates that the regions are under the influence of the Mediterranean climate (Table 3).

For *Si. gulendamii*, the annual average rainfall is measured as follows: Ayaş (427.1 mm), Beypazarı (410.1 mm), Sivrihisar (391.6 mm), Alpu (376.8 mm), and Nallıhan (350.0 mm). According to the climate classification, the study areas are classified as semi-arid (Akman, 2011). The seasonal precipitation regime at the Nallıhan and Beypazarı stations follows the order of Winter, Spring, Fall, and Summer, corresponding to the Eastern Mediterranean Precipitation Regime Type 1. In contrast, at the Alpu, Ayaş, and Sivrihisar stations, the order is Spring, Winter, Fall, and Summer, corresponding to the Eastern Mediterranean Precipitation Regime Type 2 (Akman, 2011). Similar to *Sc. yildirimlii*, the drought index values suggest that the distribution areas of *Si. gulendamii* are influenced by the Mediterranean climate (Table 3).

The ombrothermic (precipitation-temperature) diagrams drawn according to the Gaussen method (1955) for the study areas are presented (Fig. 9). A significant summer drought was observed in the study areas, except for Nallıhan and Beypazarı meteorological stations, drought started in May and lasted for 4 months, while in these two stations, a 5-month drought starting in April was observed. The arid severity was relatively more intense in Beypazarı, Nallıhan, and Ayaş compared to Alpu, Sivrihisar, and Polatlı.

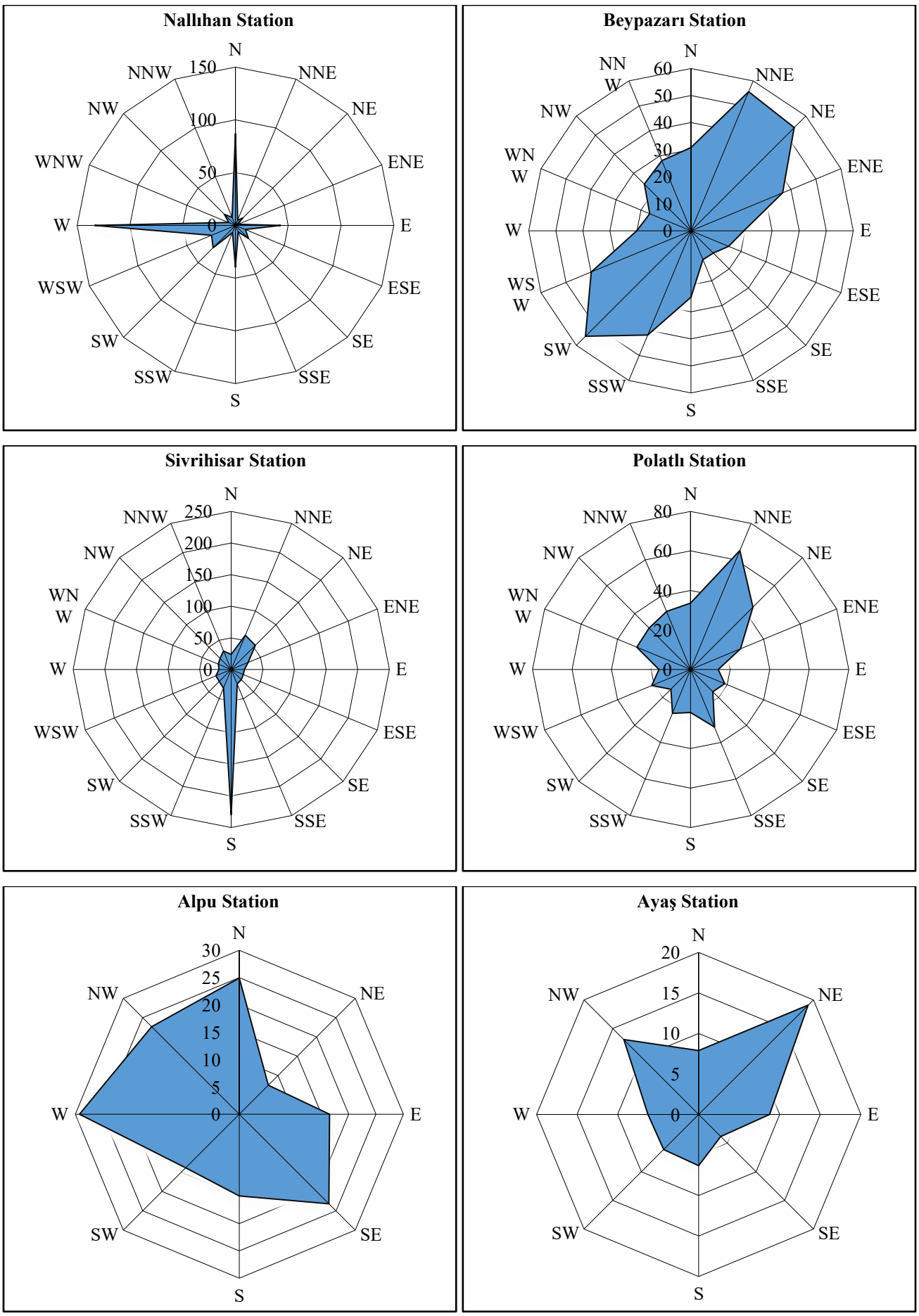

Fig. 8. Wind roses for the stations showing the total number of wind occurrences in thousands.

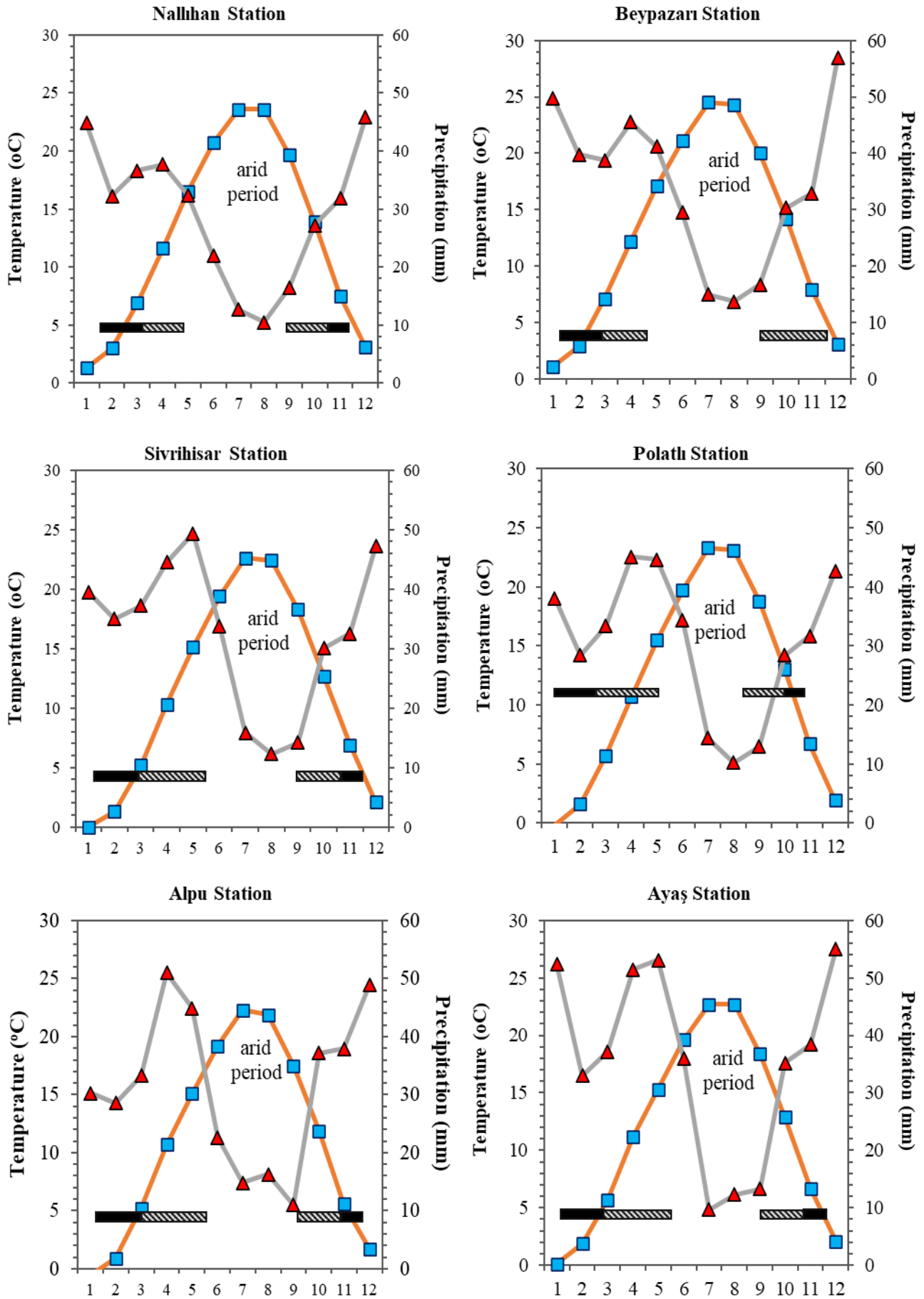

Fig. 9. Ombrothermic diagrams of the stations. (■ : The absolute frost months, ▨ : The possible frost months, : Temperature, : Precipitation).

Conclusions and Discussion

This study focuses on the soil characteristics and climatic preferences of the endangered narrow endemic species *Sc. yildirimlii* and *Si. gulendamii*, which grow only in marl-gypsum soils in the provinces of Ankara and Eskişehir. Like these species, several other narrow endemics in Central Anatolia show similar ecological characteristics. Numerous studies in the region have reported how such species are restricted to unique soil and climatic conditions, such as *Campanula damboldtiana* P. H. Davis & Sorger (Ayyıldız *et al*., 2020), *Muscari adilii* M. B. Güner & H. Duman (Keser *et al*., 2023), *Astragalus beypazaricus* Podlech & Aytaç, and *Aethionema turcica* H. Duman & Aytaç (Ayyıldız *et al*., 2024).

According to the soil texture analysis results of *Sc. yildirimlii*, the areas where it is distributed contain clay, clay loam, silty clay loam, and sandy clay soils, indicating that it does not exhibit a specific preference in terms of soil texture. These areas exhibit slightly alkaline, non-saline, and moderately calcareous soil characteristics. According to the soil analysis results for *Si. gulendamii*, the areas where it is distributed have clay, clay loam, and sandy clay loam soils. While the species does not exhibit a specific preference for soil texture, it can generally be said to favor soils with a relatively higher clay content. The study areas exhibit neutral or slightly alkaline, non-saline, moderately calcareous, or calcareous soil characteristics. The marl soil composition is formed by the mixture of clay and calcium carbonate in varying ratios (Öztürk *et al*., 2018). The presence of clay and lime in the areas where the studied species are found allows these soils to be classified as marl soils. Although these species do not grow on gypsum bedrock, they are found in soils containing small amounts of gypsum.

Bioclimatic analysis revealed that *Sc. yildirimlii* was observed in a semi-arid upper cold Mediterranean bioclimate and a semi-arid sub-very cold Mediterranean bioclimate. *Si. gulendamii* performed to grow in a semi-arid sub-cold Mediterranean bioclimate, a semi-arid sub-very cold Mediterranean bioclimate, and a semi-arid upper-cold Mediterranean bioclimate. The most characteristic feature of the Mediterranean climate is the hot and dry summers and the cold and wet winters (Akman, 2011). Based on this finding, the drought tolerance mechanisms of the species may enhance future research.

Genetic diversity analyses conducted using ISSR markers revealed varying levels of genetic diversity among *Sc. yildirimlii* populations. According to the results, the populations ranked from highest to lowest in terms of genetic diversity are Oğlakçı, Aşağıkepen, Yeşilköy, Ayaş, Kızlarkayası, and Kavuncu (Yıldırım *et al*., 2023). The average wind speed recorded at the Polatlı station (2.6 m/s), representing the Kızlarkayası population, and the Sivrihisar station (2.4 m/s), representing the Oğlakçı, Aşağıkepen, Yeşilköy, and Kavuncu populations, was notably higher than that at the Ayaş station (1.4 m/s). Gene flow between plant populations is largely determined by the extent of long-distance dispersal (Heydel *et al.*, 2014). In this context, we observed relatively high genetic diversity in *Sc. yildirimlii* populations near the Polatlı and Sivrihisar meteorological stations (Yıldırım *et al*., 2024), where high average wind speeds have been recorded. This observation suggests the hypothesis that wind speed may potentially influence gene flow through seed dispersal between populations.

In a study on the genetic diversity of *Si. gulendamii*, the ranking of genetic diversity of the populations, from highest to lowest, was as follows: Yukarıdoğanoğlu, Çırçır, Sarıçal, Ayaş, Asağıkepen, İnözü Valley, and Başören (Yıldırım *et al.*, 2024). Among the meteorological stations, Sivrihisar station recorded the highest annual average wind speed at 2.4 m/s. This was followed by Beypazarı station (1.8 m/s), Nallıhan station (1.7 m/s), Ayaş station (1.4 m/s), and Alpu station (1.2 m/s). The Aşağıkepen population, located near the Sivrihisar station, which recorded the highest wind speed, exhibits only a mid-range level of genetic diversity. Importantly, no clear or consistent relationship was observed between wind speed and genetic diversity in *Si. gulendamii*. There is no precise information on the pollination mechanism of studied species, but they are expected to have a similar mechanism to their relatives, i.e., insect pollination. Nevertheless, it is clear that more detailed studies are needed to evaluate whether the wind will have an effect if the populations are close or whether it will affect the movement of the pollinator.

As a result, this study provided important information on the ecological requirements of *Sc. yildirimlii* and *Si.gulendamii* with comprehensive soil samples from different localities and detailed climate analyses. These findings offer critical information for developing suitable habitat management practices aimed at conserving these endemic species and evaluating their sensitivity to potential future climate change scenarios.

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Conflict of interest

The authors declare that they have no conflicts of interest.

Authors' Contribution

Merve Yıldırım: Review of the literature, field work, data acquisition and collection, data analysis and interpretation, manuscript writing. Gül Nilhan Tuğ: Research planning, field work, data analysis and interpretation, and assessment of the manuscript. Ahmet Emre Yaprak: Research design, field work, data analysis, and interpretation

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