

Diversity and Importance of Fragrant Plants in the Hydrographic Network of the Mزاب Region (Northern Algerian Sahara)

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Article history:

Received: 3 September 2025

Accepted: 8 January 2026

Published: 30 June 2026

Keywords:

Aromatic plants,
Biodiversity,
Valorization,
Hydrological system,
North african desert.

Abstract

The Fragrant plants hold significant value in various fields, including health, food, pharmacy, cosmetics, and phytopharmacy. The objective of this study is to examine the diversity and importance of fragrant plants in the hydrographic network of the Mزاب region (Northern Algerian Sahara). For this purpose, following a subjective sampling method, we conducted 20 phytoecological surveys in four representative sites. To study diversity, we used ecological indices, functional traits and chorology. The results revealed the presence of 28 species belonging to 26 genera and 20 botanical families, with the most important being Apiaceae, Poaceae, and Brassicaceae, accounting for 32.46%, 20.52% and 20.05%, respectively. Morphological and biological spectra showed the dominance of perennial species (81.44%) and chamaephytes (60.82%). The chorological spectrum revealed the dominance of Mediterranean-Saharo-Arabian species, followed by Saharo-Arabian elements, with 51.31% and 28.30%, respectively. Fragrant plants (56.25%) overwhelmingly dominate the studied vegetation cover compared to non-fragrant plants (43.75%). These multi-use plants constitute a raw material for the development of a bio-industry in arid zones, based on the use of bioresources and environmental conservation.

<https://dx.doi.org/10.52951/dasj.26180101>

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Introduction

Arid desert regions occupy about 30% of the Earth's surface, with the Sahara being the largest, extending across the northern third of the African continent from the Atlantic Ocean to the Red Sea (Le Houérou, 1990; Ozenda, 2004; Abd El-Ghani *et al.*, 2017). These regions are characterized by extreme climatic conditions (aridity, intense evapotranspiration, significant thermal variation, drought, and strong winds), (Le Houérou, 1990; Ozenda, 2004), as well as distinctive geomorphological landscapes (wadi beds: temporary watercourses, depressions, regs: flat

surfaces covered with a thin layer of sand or gravel, sandy soils, djebels, saline soils, and rocky soils), which shape the existence of living plants highly adapted to arid environments (Quézel, 1965; Chehma, 2005; Chakkour *et al.*, 2024). Furthermore, microorganisms in the Algerian Sahara survive through extreme adaptations. They produce protective sheaths and secondary metabolites to resist desiccation and intense UV radiation. Many enter prolonged dormancy, reviving only during rare moisture events. Others colonize protective niches, like those under soil or stones, to find refuge from the surface extremes (Tata *et al.*, 2019; Novello *et al.*, 2023).

In the Algerian Sahara, which covers more than 85% of the national territory (~2 million km²), plant species and vegetation develop in two forms (diffuse and contracted) depending on the geomorphological units (Ozenda, 2004). These units host multipurpose plants, including fragrant species with benefits for humans, animals, and microorganisms. These fragrant plants, also known as aromatic or odorous plants, emit pleasant scents and are commonly used in gardens and landscapes to enhance sensory experiences and promote relaxation (Kieliszek *et al.*, 2020; Stefanakis *et al.*, 2022).

In the Sahara, Le Houérou (1990) reported the presence of 3,000 plant species, of which 2,800 are flowering plants. These desert plants have been extensively studied in Algeria in biological and ecological contexts (Médail and Quézel, 2018).

The Algerian Sahara is home to a diverse array of aromatic plants with significant roles in traditional medicine. Ethnobotanical studies reveal their use in various therapeutic preparations, including decoctions, infusions, and ointments, to treat ailments such as digestive issues, skin diseases, and respiratory conditions (Lakhdari *et al.*, 2016). This practice reflects a rich tradition of herbal medicine, with local healers relying on accumulated knowledge to address community health concerns (Benarba, 2016). However, despite their cultural and medicinal importance, the fragrant flora of the Saharan regions remains notably understudied. In this context, our work aims to: (i) demonstrate the importance of fragrant plants associated with the hydrographic networks of the Mزاب region, and (ii) define functional groups of plants in the Saharan environment through the analysis of biodiversity and functional traits (morphological types, biological types, plant types concerning odor, and biogeographical types).

Materials and Methods

1. Study area

The study area is located in the Ghardaïa province (32°29'00" N, 3°41'00" E), situated in the northern Algerian Sahara. The climate of this region is hot and hyper-arid (Martonne aridity index = 1), with the dry season lasting throughout the year. The total annual precipitation is 40.0 mm. The coldest month is January, with an average temperature of 4.4°C (±3.2°C), while the hottest month is July, with a maximum temperature of 42.7°C (±4.6°C). Potential evapotranspiration (PET) peaks at 233.9 (±20.3) mm, with an annual average PET of 139.9 (±19.3) mm (Bouallala *et al.*, 2023).

The first site (site 1) has an altitude of approximately 514 m and the following geographical coordinates: 32°26'53" N, 3°39'38" E. This rocky wadi bed with light sand

deposits is characterized by a steppe formation dominated by *Deverra scoparia* subsp. *scoparia*, *Antirrhinum ramosissimum* and *Cymbopogon schoenanthus*.

The second site (site 2) has an altitude of approximately 523 m and the following geographical coordinates: 32°11'26" N, 3°40'31" E. This sandy wadi bed is characterized by a steppe formation dominated by *Deverra scoparia* subsp. *scoparia*.

The third site (site 3) has an altitude of approximately 457 m and the following geographical coordinates: 32°8'38" N, 3°47'12" E. This rocky wadi bed with light sand deposits is characterized by a steppe formation dominated by *Deverra scoparia* subsp. *scoparia* and *Cymbopogon schoenanthus*.

The fourth site (site 4) has an altitude of approximately 449 m and the following geographical coordinates: 32°18'57" N, 3°48'56" E. This sandy wadi bed is characterized by a steppe formation dominated by *Deverra scoparia* subsp. *scoparia*, *Cymbopogon schoenanthus* and *Moricandia arvensis*.

2. Plant sampling, data collection and analysis

In each site, we conducted five floristic surveys of 100 m² each during the autumn of 2022. For each survey, we recorded the altitude, geographical coordinates, overall coverage, and a list of species, along with their densities and Braun-Blanquet abundance-dominance coefficients:

+: rare individuals and very low coverage;

1: few or fairly abundant individuals, but low coverage less than 1/20 of the area;

2: abundant or very abundant individuals covering 1/20 to 1/4 of the area;

3: any number of individuals, covering 1/4 to 1/2 of the area;

4: any number of individuals, covering 1/2 to 3/4 of the area;

5: any number of individuals, covering more than 3/4 of the area.

The identification of the recorded plants was based on the published work of Quézel and Santa (1962-1963).

3. Analysis of plant diversity

3.1. Plant diversity

3.1.1. Shannon-Wiener diversity index

The Shannon-Wiener diversity index (H') is computed from quantitative or semi-quantitative vegetation data. A higher index value corresponds to heightened diversity (Le Floch *et al.*, 2008):

$H' = -\sum_{i=1}^S (p_i \times \log_2 p_i)$. With $p_i = n_i/n$, where p_i is the proportion of individuals of species i (n_i) out of the total number of individuals (n) of all species.

3.1.2. Equitability index "E"

Equitability is the ratio between the Shannon-Wiener diversity index (H') and the maximum diversity (H_{\max}). Equitability is high when all species are well represented (Le Floch *et al.*, 2008).

$E = H' / H_{\max}$, Where $H_{\max} = \log_2 S$.

3.2. Plant functional traits (PFT)

3.2.1. Morphological types

Based on the adaptation strategies of plants to develop in different environments, we distinguish between perennial and annual species. The determination of morphological types was based on the works of Quézel and Santa (1962- 1963); Ozenda (2004).

3.2.2. Biological types

Plants have been classified into five main categories to protect themselves against unfavorable seasons: therophytes, geophytes, hemicryptophytes, chamaephytes and phanerophytes (Al-Shaye *et al.*, 2020). The determination of biological types in this work was based on the book by Quézel (1965).

3.2.3. Plant types based on odor

Odor is a very important criterion for plant identification, as there are plants with pleasant smells and others with foul odors. The determination of plant odor types was based on the works of Quézel and Santa (1962-1963); Ozenda (2004) and our field observations.

4. Chorological types

According to Quézel (1978), the study area belongs to the Holarctic region, specifically to the Saharo-Arabian region (Saharan sub-region), and to the Northern Saharan domain. The determination of biological types was based on the works of Quézel and Santa (1962-1963) and Quézel (1965). For the study of functional traits and chorology, we established two types of spectra: a raw spectrum based on richness and an actual spectrum based on abundance.

Statistical analysis

Before each test, normality and homogeneity of variance were verified using the Shapiro-Wilk and Bartlett tests. An analysis of variance (ANOVA) was used to evaluate differences between the sites in terms of plant abundance (N), species richness (S), Shannon index (H'), and evenness (E). Tukey's HSD (Honestly Significant Difference) pairwise comparison tests were used with $p < 0.05$. All statistical analyses were performed using R software version 4.2.2 (R Core Team, 2022).

Results and Discussion

1. Flora composition, structure and diversity

The results show that the study area harbors 28 species and 26 genera belonging to 20 botanical families (Table 1). The most represented families are Apiaceae (32.46%), followed by Poaceae (20.52%) and Brassicaceae (20.05%), although their relative importance varies between sites. The dominance of Poaceae and Brassicaceae reflects their adaptation to the edaphoclimatic conditions of the Saharan environment and their capacity to produce abundant seeds, which favors dispersion and colonization of diverse habitats (Al-Robai *et al.*, 2017; Gamoun *et al.*, 2018).

The boxplots (Figure 2) indicate that site 1 is the richest (18 species; max = 12, min = 9), while site 4 is the least rich (12 species; max = 10, min = 5). ANOVA revealed a significant

difference in species richness between sampling sites ($F(3,16) = 5.29$, $P < 0.01$). Several authors have emphasized that the composition of plant communities is closely related to site-specific environmental characteristics and anthropozoic factors, such as edapho-topographic heterogeneity, water balance, soil type, drainage, and fertility (Jones *et al.*, 2006; Neffar *et al.*, 2016; Chenchouni, 2017). According to Saco *et al.* (2007) heterogeneity in soil surface features, topography, physicochemical properties, and biological activity can strongly influence vegetation patterns.

Site 4 is the most abundant (382 individuals), site 2 is the least abundant (146 individuals), and the most abundant species are *Deverra scoparia* subsp. *scoparia*, *Cymbopogon schoenanthus*, and *Moricandia arvensis* with 348, 218, and 142 individuals, respectively (Appendix1). The analysis of variance shows a significant difference in specific abundances between the studied sites ($F(3,16) = 9.64$, $P < 0.001$).

The most important species in terms of coverage is by far *Deverra scoparia* subsp. *scoparia*, which shows abundance-dominance coefficient values ranging between 3 and 4 in site 4, between 2 and 3 in site 3, between 1 and 3 in site 2, and 2 in site 1 ([Appendix 1](#)).

Table 1. Family, morphological (morph) type, life form, chorological type, and plant type of vegetal species in the hydrographic network of the Mزاب region (Northern Algerian Sahara)

Familles	Species	M.T	Life form	C.T	P.T
Poaceae	<i>Cymbopogon schoenanthus</i> (L.) Spreng.	Per	Hem	T-M-SA	Odorant plant
Apiaceae	<i>Deverra scoparia</i> Coss. & Durieu subsp. <i>scoparia</i>	Per	Cham	M-SA	Odorant plant
Chenopodiaceae	<i>Hammada articulata</i> (Moq.) O.Bolòs & Vigo	Per	Cham	M-SA	Non-odorous plant
Caryophyllaceae	<i>Gymnocarpos decander</i> Forssk.	Per	Cham	M-SA	Odorant plant
Thymelaeaceae	<i>Thymelaea microphylla</i> Coss. et Dur.	Per	Cham	M-SA	Non-odorous plant
Fabaceae	<i>Retama raetam</i> (Forssk.) Webb	Per	Phan	SA	Non odorous plant
Asclepiadaceae	<i>Pergularia tomentosa</i> L.	Per	Cham	SA	Non odorous plant
Liliaceae	<i>Asphodelus tenuifolius</i> Cav.	Ann	Ther	M-SA	Non odorous plant
Brassicaceae	<i>Zilla macroptera</i> Coss.	Per	Cham	SA	Non odorous plant
Rutaceae	<i>Haplophyllum tuberculatum</i> (Forssk.) A.Juss.	Per	Hem	SA	Odorant plant
Brassicaceae	<i>Farsetia hamiltonii</i> Royle	Per	Cham	SA	Non odorous plant
Asteraceae	<i>Launaea glomerata</i> Hook. f.	Ann	Ther	M-SA	Non odorous plant
Lamiaceae	<i>Salvia aegyptiaca</i> L.	Per	Cham	SA	Odorant plant
Fabaceae	<i>Ononis angustissima</i> Lam.	Per	Cham	M-IT	Non odorous plant

Boraginaceae	<i>Heliotropium undulatum</i> Vahl.	Per	Cham	SA	Non odorous plant
Cistaceae	<i>Helianthemum lippii</i> (L.) Dum. Cours.	Per	Cham	M-SA	Non odorous plant
Cistaceae	<i>Helianthemum kahiricum</i> Delile	Per	Cham	M-SA	Non odorous plant
Capparaceae	<i>Cleome arabica</i> L.	Ann	Ther	SA	Odorant plant
Asteraceae	<i>Rhanterium suaveolens</i> subsp. <i>intermedium</i> (Pomel) Quézel & Santa	Per	Cham	SA	Non odorous plant
Resedaceae	<i>Randonia africana</i> Coss.	Per	Cham	SA	Non odorous plant
Brassicaceae	<i>Moricandia arvensis</i> (L.) DC.	Ann	Ther	M-SA	Non odorous plant
Convolvulaceae	<i>Convolvulus supinus</i> Coss. & Kralik	Ann	Ther	SA	Non odorous plant
Zygophyllaceae	<i>Fagonia microphylla</i> Pomel	Per	Cham	SA	Non odorous plant
Zygophyllaceae	<i>Fagonia glutinosa</i> Delile	Ann	Ther	SA	Non odorous plant
Fabaceae	<i>Argyrolobium uniflorum</i> (Descne.) Jaub. et Spach.	Per	Cham	M-SA	Non odorous plant
Scrophulariaceae	<i>Antirrhinum ramosissimum</i> Coss. et Durieu	Per	Cham	SA	Non odorous plant
Poaceae	<i>Pennisetum dichotomum</i> (Forsk.) Delile.	Per	Cham	SA	Non odorous plant
Ephedraceae	<i>Ephedra alata</i> Decne.	Per	Cham	SA	Non odorous plant

Ann: Annuals, Per: Perennials, Cham: Chamaephytes, Hem: Hemicryptophytes, Phan: Phanerophytes, Ther: Therophytes, M-SA: Mediterranean-Saharo-Arabian; SA: Saharo-Arabian; T-M-SA: Tropico-Mediterranean-Saharo-Arabian; M-IT: Mediterranean-Irano-Turanian. C.T.: Chorological types; M.T.: Morphological types; P.T.: Plant types.

The Shannon-Weaver index (Figure 1) shows values ranging between 1.58 and 1.89 in station 1, between 1.45 and 2.01 in station 2, between 1.60 and 1.95 in station 3, and between 1.10 and 1.78 in station 4. The analysis of variance shows a significant difference between the sites in the Shannon-Weaver index values ($F_{(3,16)} = 4.09$, $P < 0.05$).

The equitability index shows values ranging between 0.47 and 0.61 in site 1, between 0.61 and 0.83 in site 2, between 0.63 and 0.75 in site 3, and between 0.59 and 0.79 in site 4 (Figure 1). The analysis of variance shows a significant difference between the sites in equitability values ($F_{(3,16)} = 5.08$, $P < 0.05$).

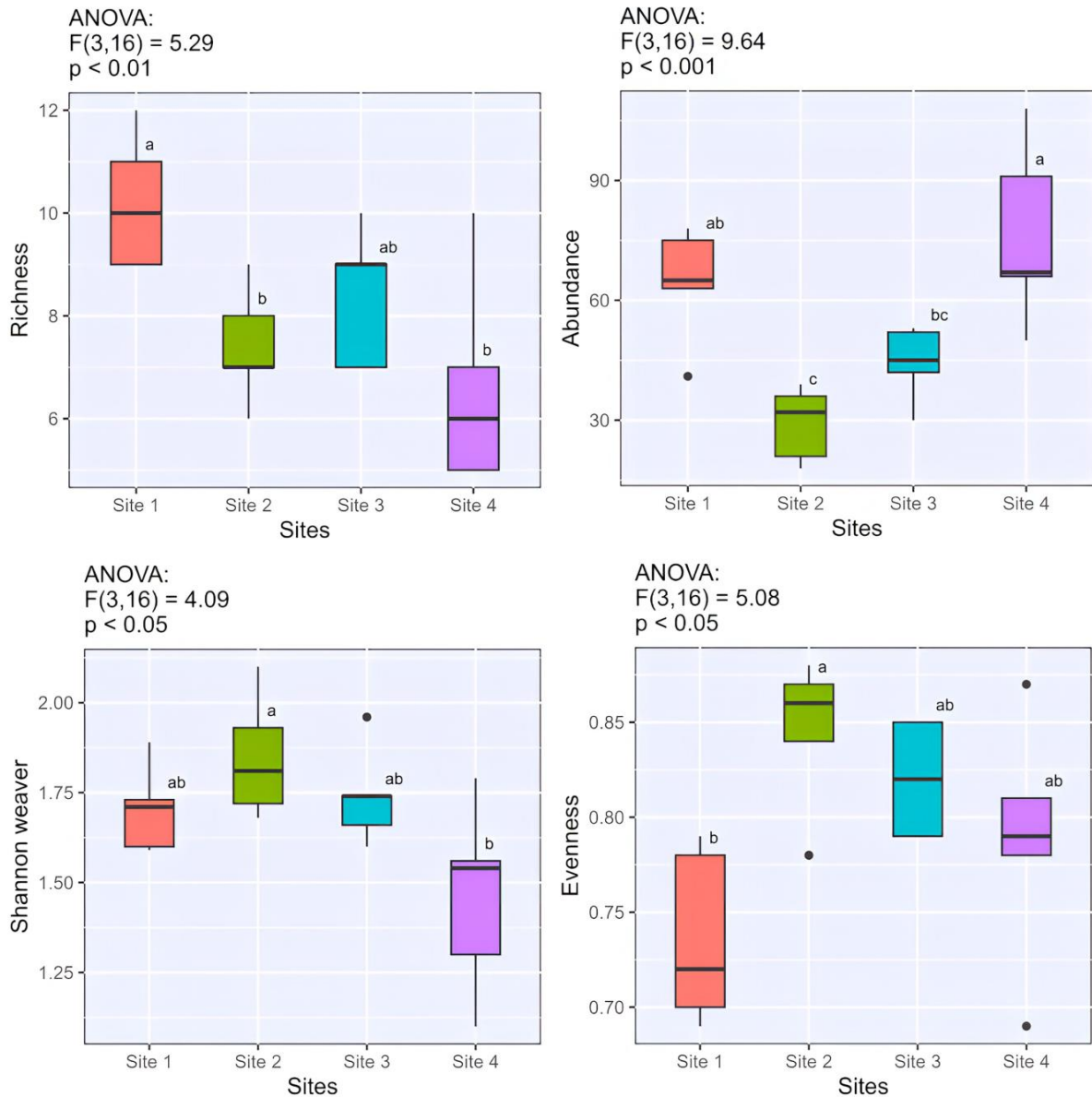


Figure 1. Boxplots showing the variation in vegetation diversity parameters across different sites in the Mزاب region (Northern Algerian Sahara)

2. Functional traits

2.1. Morphological spectra

The morphological spectra (Figure 2 A) reveal the dominance of perennial species (81.44%) over annual species (18.56%) in the study region. At the site level, this pattern is consistent, with perennials prevailing regardless of whether raw or actual spectra are considered. Such dominance of perennial species has also been reported in several studies on Saharan flora and vegetation (Azizi *et al.*, 2021; Bouallala *et al.*, 2023).

2.2. Biological spectra

The biological spectra of the study region (Figure 2 B) show a clear dominance of chamaephytes (60.82%), represented by *Deverra scoparia* subsp. *scoparia*, *Hammada articulata*, *Gymnocarpus decander*, *Thymelaea microphylla*, *Pergularia tomentosa*, *Zilla*

macroptera, *Farsetia hamiltonii*, *Salvia aegyptiaca*, *Ononis angustissima*, *Heliotropium undulatum*, *Helianthemum lippii*, *Helianthemum kahiricum*, *Rhanterium suaveolens* subsp. *intermedium*, *Randonia africana*, *Fagonia microphylla*, *Argyrobium uniflorum*, *Antirrhinum ramosissimum*, *Pennisetum dichotomum*, and *Ephedra alata*. In contrast, at site 4, therophytes reach a relatively high proportion (42.93%) in the actual spectrum, represented by *Asphodelus tenuifolius*, *Launaea glomerata*, *Moricandia arvensis*, and *Convolvulus supinus*. At the other sites, chamaephytes dominate more clearly, exceeding 58% in both raw and actual spectra.

Overall, biological spectra confirm the predominance of chamaephytes across most sites in the study region, except at site 4, where therophytes prevail. The dominance of chamaephytes is consistent with previous studies on Saharan vegetation (Azizi *et al.*, 2021), and reflects their adaptation to arid conditions and tolerance of low temperatures (Gamoun *et al.*, 2018). Therophytes, on the other hand, adopt different adaptive strategies in desert environments. Several authors suggest that their presence is closely linked to precipitation, as they survive unfavorable seasons in the form of seeds (Quézel, 1965; Barbero *et al.*, 1990; Chehema and Youcef, 2009). Others emphasize their association with soil surface conditions (Kadi-Hanifi, 2003). Moreover, habitat disturbance is known to favor therophytes in ecosystems with diverse compositions and structures.

2.3. Spectra of fragrant plants

The raw spectra (Figure 2 C) reveal a clear dominance of non-fragrant plants across the sites and in the study region, with percentages exceeding 69%. In contrast, the actual spectra show that, apart from site 2 where non-fragrant plants prevail (65.75%), the study region and the other sites are dominated by fragrant plants, with proportions exceeding 50%. Six fragrant species were recorded: two well represented (*Deverra scoparia* subsp. *scoparia* and *Cymbopogon schoenanthus*) and four less represented (*Gymnocarpos decander*, *Haplophyllum tuberculatum*, *Salvia aegyptiaca*, and *Cleome arabica*).

The spectra of plant types based on odor indicate that the study region and most sites are dominated by aromatic plants, particularly *Cymbopogon schoenanthus* and *Pituranthos scoparius*, in terms of abundance-dominance and density. This dominance may be explained by their adaptation to grazed pastures, as they are minimally or poorly consumed by livestock in Saharan regions (Chehema, 2006). Moreover, these plants are of little interest to the desert locust, the major pest of plant bioresources in the Sahara and Sahel (Duranton *et al.*, 2012).

3. Chorological spectra

Except for site 2, where the Mediterranean-Saharo-Arabian element (*Deverra scoparia* subsp. *scoparia*, *Hammada articulata*, *Gymnocarpos decander*, *Thymelaea microphylla*, *Asphodelus tenuifolius*, *Launaea glomerata*, *Helianthemum lippii*, *Helianthemum kahiricum*, *Moricandia arvensis*, and *Argyrobium uniflorum*) shows a high rate, the raw chorological spectra reveal high percentages of the Saharo-Arabian element (*Retama raetam*, *Pergularia tomentosa*, *Zilla macroptera*, *Haplophyllum tuberculatum*, *Farsetia hamiltonii*, *Salvia aegyptiaca*, *Heliotropium undulatum*, *Cleome arabica*, *Rhanterium suaveolens* subsp. *intermedium*, *Randonia africana*, *Convolvulus supinus*, *Fagonia microphylla*, *Fagonia*

glutinosa, *Antirrhinum ramosissimum*, *Pennisetum dichotomum*, and *Ephedra alata*) in the other sites and across the study region.

However, the actual spectra indicate the dominance of the Mediterranean-Saharo-Arabian element, with percentages exceeding 37%, followed by the Saharo-Arabian element, which ranges from 16.49% to 40.41% (Figure 2 D). The most important Mediterranean-Saharo-Arabian species are *Deverra scoparia* subsp. *scoparia* and *Moricandia arvensis*, whereas the most important Saharo-Arabian species are *Antirrhinum ramosissimum* and *Farsetia hamiltonii*.

Overall, the chorological spectra highlight the dominance of the Mediterranean-Saharo-Arabian element, followed by the Saharo-Arabian element. The presence, and in some cases abundance, of Mediterranean-Saharo-Arabian taxa has been widely reported in studies of Saharan flora and vegetation under both natural and anthropogenic conditions (Bouallala *et al.*, 2023). Mediterranean-Saharo-Arabian plants thrive in the Sahara Desert, likely due to compensatory factors such as soil water availability (Azizi *et al.*, 2021). In contrast, the Saharo-Arabian element is generally regarded as the biogeographic group best adapted to desert conditions, including climatic, edaphic, and anthropogenic constraints (Médail and Quézel, 2018).

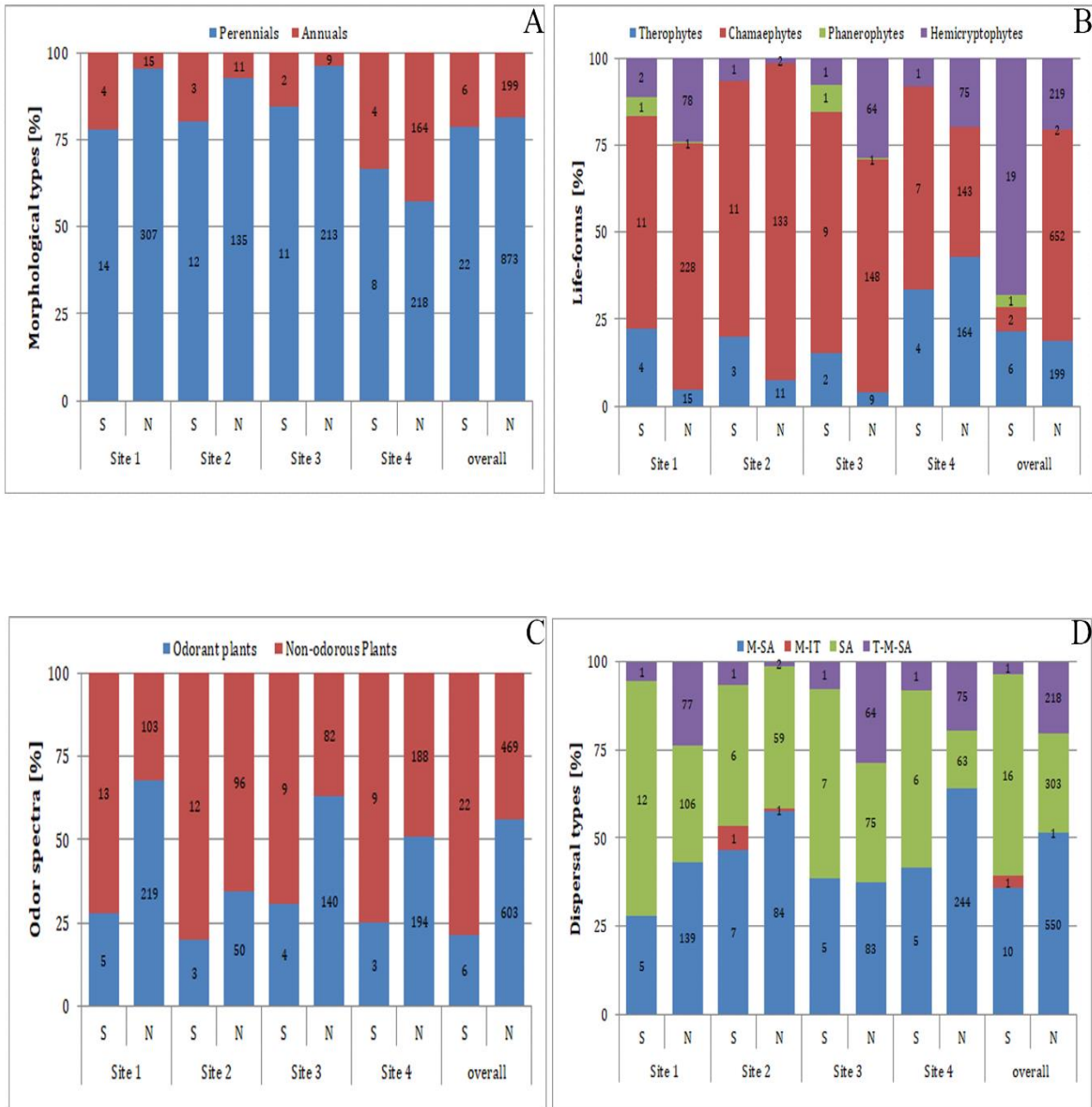


Figure 2. Raw biological spectra (based on species richness 'S') and actual spectra (based on abundance 'N') of plant functional traits (morphological types, life forms, plant types and chorological types) characterizing the sites in the Mزاب region (Northern Algerian Sahara)

Conclusions

Revealed the presence of 28 species and 26 genera belonging to 20 botanical families, with a strong abundance of Apiaceae represented by a single fragrant species containing 348 individuals. The morphological and biological spectra showed the dominance of perennial species that are well adapted to the conditions of hyper-arid environments compared to annual species, and the dominance of chamaephytes over other biological types in the majority of the studied sites. According to species richness, non-fragrant plants are the most

representative at the site and regional levels, but in terms of abundance, fragrant plants dominate the vegetation cover in the majority of sites, while non-fragrant plants are less significant. The most important fragrant species are *Deverra scoparia* subsp. *scoparia* and *Cymbopogon schoenanthus*, which are well represented in the studied sites, while the least represented fragrant species are *Gymnocarpus decander*, *Haplophyllum tuberculatum*, *Salvia aegyptiaca* and *Cleome arabica*. The chorological analysis highlighted the importance of two biogeographic elements: the Saharo-Arabian element in terms of richness and the Mediterranean-Saharo-Arabian element in terms of abundance. Overall, this work provides a database for the management and conservation of Saharan ecosystems that include fragrant plants. These high-value species can be exploited to develop an agro-industry in arid regions based on the utilized plant resources: in traditional pharmacopoeias, food preparation, cosmetics, renewable energy and other applications beneficial to the Saharan human population.

Acknowledgments

We thank the editor and two anonymous reviewers for their constructive comments, which helped us to improve the manuscript.

Conflict of interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Funding Declaration

This study was not funded by any source.

Author Contribution

M. Bouallala: Conceptualization, Methodology, Data curation, Resources, Writing original draft, Writing - review & editing. N. Bouras: Validation, Writing - original draft, M. Souddi: Supervision, Data curation, Formal analysis, Visualization. M. D. Holtz: Investigation, Data curation.

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