



RESEARCH ARTICLE

# Diachronic study of the floristic diversity of the Royal Mausoleum of Mauretania, Algeria

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## Abstract

This study aimed to provide knowledge on the mural flora of the Royal Mausoleum of Mauretania. Through floristic surveys, we compiled a catalogue listing 168 vascular plants belonging to 141 genera and 58 families. Asteraceae and Poaceae were the most dominant families, constituting 24.81% of the species. Dominant characteristics of this flora included therophytes (41.07%) and Mediterranean floristic elements (67.26%). To update the floristic list of the Mausoleum, we compared our data with 3 old lists from 1867, 1928 and 1985. The diachronic analysis reveals the persistence of 35 taxa representing 16.27% of 215 taxa listed since the first inventory, and the emergence of 30 new taxa (13.95%). The diversity of this wall flora is associated with changes in the landscape around the Mausoleum as well as its conservation status.

## Keywords

biological types, Diachronic approach, Endemism, Mural flora, Rarity

## Introduction

The Royal Mausoleum of Mauretania is a monument dating back to the first century BC from the time of Numidia (1). Constructed in a circular monument, it consists of large blocks of stone stacked atop each other without any connection. Since 1982, it has been classified as a UNESCO World Heritage Site. Additionally, since 2002, it has been included in the indicative list of UNESCO World Heritage under the category Royal Mausoleums of Numidia, Mauretania and pre-Islamic funerary monuments.

This protected cultural property, characterized as a rocky habitat, serves as a circulation, rest, feeding and reproduction zone for fauna as well as a dissemination zone for flora. The walls of this structure are home to a so-called mural flora, comprising plants species that naturally grow on the rocks surface, establish them in interstices and cracks and others that thrive at the base of walls. Despite annual weeding efforts carried out by the maintenance workers of the Tipaza sites and museums management, the site hosts a diverse and remarkable flora in terms of numerical abundance.

Research on mural flora is nearly non-existent in Algeria, with only 2 sites having been studied: the ruins of the Tlemcen region (2, 3) and the Royal Mausoleum of Mauretania (4-6). The present work undertaken in 2022, aims to compare the floristic inventories conducted by Jourdan in 1867, Maire and Senevet in 1928 and Wojterski in 1985 on the flora of the monument. This diachronic study involves examining changes in vegetation composition since the first inventory in 1867.

## Materials and Methods

### Description of the study area

The Royal Mausoleum of Mauretania, considered a stone tumulus of about 80000 m<sup>3</sup>, measures 60.9 meters in diameter and 32.4 m in height. The large blocks of stone are composed shell limestone for the base and yellowish sandstone for the cylindrical body and the stepped jacket (7). This monument is located (36° 34' 29" Nord, 2° 33' 12" E) in the commune of Sidi Rached, located 15 km southeast of the wilaya of Tipaza and 64 km from Algiers, on a ridge of the hills of the Algerian Sahel. It dominates the agricultural plain of Mitidja at an altitude of 261 m (Fig. 1). This territory belongs to the Algiers sector, specifically to the coastal sub-sector, subdivisions integrated into the Maghreb Mediterranean domain (8, 9).

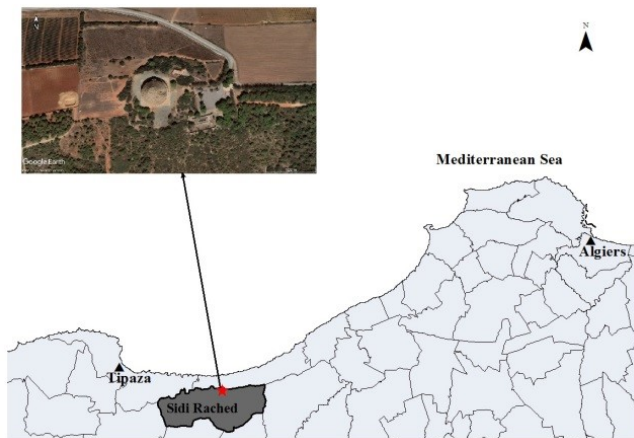


Fig. 1. Location of the Royal Mausoleum of Mauretania.

### Climatic condition

From a climatic point of view, the study area belongs to the subhumid bioclimatic stage with mild winters. The rainfall recorded at the Tipaza station during a 20-year period from 1988 to 2007 shows an annual average of 616 mm, falling

mainly from October to February. The average minimum temperature in the coldest month, January, is 4.8 °C and the average maximum in the warmest month, August, 31.6 °C. The average annual temperature is 18.57 °C.

### Floristic survey

Eighty floristic surveys were carried out and distributed over the 4 facades of the monument according to a systematic sampling. These surveys were conducted throughout the four seasons to identify all the species, including ephemeral ones. The vascular flora identified was determined using the standard flora (10, 11). Identification was confirmed through comparison with samples from the herbarium of the National Higher School of Agronomy in Algiers. The adopted nomenclature was that from the synonymic index of Dobignard and Chatelain (12) as well as an online platform "African Plant Database (version 4.0.0)" (13). The botanical classification used was from the 4<sup>th</sup> version of the phylogenetic classification established by the Angiosperm Phylogeny Group (14).

## Results

The listed species were characterized by their biological type according to the classification of Raunkiaer (15) and by their biogeographical types, as attributed from the flora of Algeria (10) and that of North Africa (11). These characteristics were utilized in the diachronic study for the comparison of inventories conducted earlier (4-6) and the latest inventory conducted in 2022.

### Floristic Diversity

In this study, a total of 168 species of vascular plants, including 3 trees and 11 shrubs, belong to 141 genera and 58 families (Table 1). Two families clearly dominated this flora: Asteraceae with 22 species and Poaceae with 18 species. Among all the families listed, 30 were represented by a single species each.

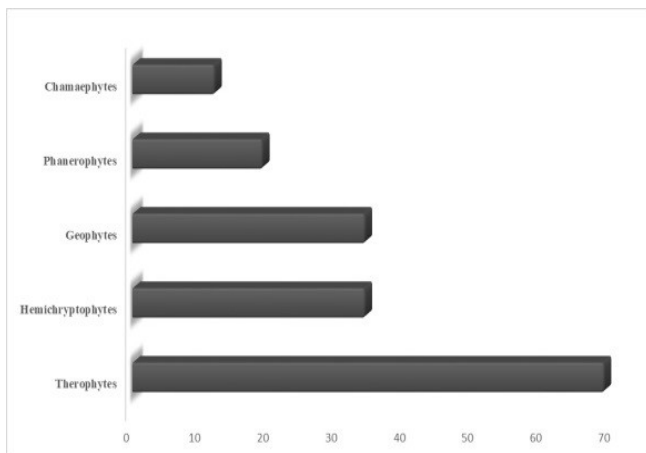
Table 1. Botanic families and respective number of genera and species.

Families	Genera	Species	Familles	Genera	Species	Familles	Genera	Species
Asteraceae	20	22	Asparagaceae	2	2	Resedaceae	1	1
Poaceae	16	18	Oleaceae	2	2	Linaceae	1	1
Apiaceae	8	7	Urticaceae	2	2	Anacardiaceae	1	1
Fabaceae	6	7	Papaveraceae	2	2	Rhamnaceae	1	1
Alliaceae	1	7	Caprifoliaceae	1	2	Malvaceae	1	1
Caryophyllaceae	3	6	Aspleniaceae	2	2	Thymaeliaceae	1	1
Geraniaceae	2	5	Convolvulaceae	1	2	Primulaceae	1	1
Hyacinthaceae	5	5	Ericaceae	1	2	Gentianaceae	1	1
Brassicaceae	4	4	Moraceae	1	1	Solanaceae	1	1
Crassulaceae	2	4	Pinaceae	1	1	Amaranthaceae	1	1
Cistaceae	2	4	Cupressaceae	1	1	Orobanchaceae	1	1
Boraginaceae	4	4	Fagaceae	1	1	Plantaginaceae	1	1
Lamiaceae	4	4	Cyperaceae	1	1	Polypodiaceae	1	1
Rubiaceae	3	4	Araceae	1	1	Dipsacaceae	1	1
Ranunculaceae	2	3	Asphodelaceae	1	1	Campanulaceae	1	1
Rosaceae	4	3	Rusaceae	1	1	Oxalidaceae	1	1
Euphorbiaceae	2	3	Smilacaceae	1	1	Apocynaceae	1	1
Scrophulariaceae	3	3	Valerianaceae	1	1	Chenopodiaceae	1	1
Ericaceae	2	3	Polygonaceae	2	1	Liliaceae	1	1
Orchidaceae	4	6						
Totals						58	141	168

## Biological spectrum

According to the classification of Raunkiaer (15), based on the position of permanent bud during the period of vegetative rest of higher plants, the distribution of the biological types of the species counted is characterized in the following diagram (Fig. 2) : Therophytes > Hemichryptophytes = Geophytes > Phanerophytes > Chamaephytes. A significant portion of the flora within the monument comprised of therophytes accounting for 69 taxa or 41.07% of the total number of species. Examples include *Borago officinalis* L., *Brassica fruticulosa* subsp. *cossoniana* (Boiss. & Reut.) Maire, *Bellis annua* L., *Carduus tenuiflorus* Curtis, *Calendula arvensis* (Vail.) L., *Cerastium glomeratum* Thuill., *Erodium chium* (L.) Willd., *Fumaria capreolata* L., *Hirschfeldia incana* (L.) Lagr. Foss., *Hordeum murinum* subsp. *leporinum* (Link) Arcang. and *Mercurialis annua* L.

Hemichryptophytes and geophytes constitute the second-highest category, each contributed 20.23% (34 species) of the inventoried flora. Notable Hemichryptophytes includes *Parietaria judaica* L., *Antirrhinum majus* L. and *Ampelodesmos mauritanicus* (Poir.) T. Durand & Schinz. As for the geophytes, they are composed of species such as *Ornithogalum narbonense* L., *Umbilicus rupestris* (Salisb.) Dandy and *Drimia maritima* (L.) Stearn. Phanerophytes and chamaephytes accounts for 19 species (11.30%) and 12 species (7.14%) of all taxa listed respectively (Fig. 2).



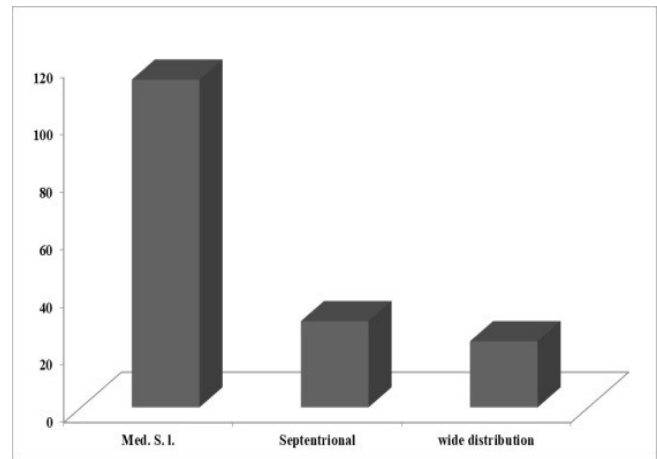
**Fig. 2.** The biological types of mural flora of the Royal Mausoleum of Mauretania.

## Biogeographical origin

Phytogeographically, the inventoried flora is characterized by a heterogeneous set of species with scattered origins. The analysis of the main chorological types encountered confirms the dominance of the Mediterranean element (Fig. 3), as is typical for all the countries in North Africa (16).

Of all the species listed, the Mediterranean element *sensu lato* dominates with 67.26% (113 species) of which 45.83% (i.e. 77 species) fall under the category of Mediterranean species *sensu stricto*.

The Mediterranean characteristic of the listed flora is nuanced by Euro-Mediterranean, Atlantic-



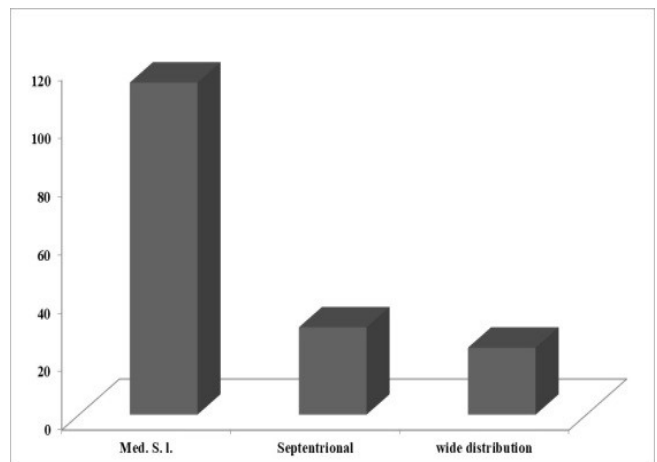
**Fig. 3.** Biogeographic origin of mural flora of the Royal Mausoleum of Mauretania.

Mediterranean, Eurasian and circumboreal influences. These northern taxa (Septentrional element) form a remarkable floristic group, comprising 19.04% (32 species) of the inventoried flora. Examples include *Anisantha madritensis* (L.) Nevski, *Fumana laevipes* (L.) Spach, *Convolvulus arvensis* L., *Geranium molle* L. and *Catapodium marimum* (L.) C.E. Hubb.

Widely distributed species were 23 in number, or 13.69% of the total flora. The most numerous correspond to cosmopolitan species such as *Chenopodium opulifolium* Schrad. ex W.D.J. Koch & Ziz, *Cerastium glomeratum* Thuill. and *Euphorbia peplus* L., as well as paleo-temperate species including *Dactylis glomerata* L. and *Papaver rhoeas* L. The studied mural flora shelters an Algerian-Tunisian endemic species at the limit of its distribution area. It is a geophyte: *Barnardia numidica* (Poir.) Speta.

## Diachronic comparison

The diachronic comparison revealed that 35 taxa, accounting for 20.83% of the species listed in 2022 and 16.27% of all the species (215 taxa) inventoried by various authors, are present in all 4 floristic lists (Table 2). Regarding the new taxa, 30 species, equivalent to 13.95%, have been newly established on the walls of the monument and 47 species (21.86%) have not been observed again (Fig. 4).



**Fig. 4.** Number of taxa listed on the Royal Mausoleum of Mauretania in 1867, 1928, 1985 and 2022.

**Table 2.** List of species recorded on the walls of the Royal Mausoleum of Mauretania in 1867, 1928, 1985 and 2022

Species recorded during the 4 inventories	Jourdan (1867)	Maire & Sevenet (1928)	Wojterski (1985)	Siab-Farsi et al. 2022
<i>Asplenium ceterach</i> L.	+	+	+	+
<i>Polypodium vulgare</i> L.	+	+	+	+
<i>Tetraclinis articulata</i> (Vahl) Mast.	+	+	+	+
<i>Ampelodesmos mauritanicus</i> (Poir.) T. Durand & Schinz	+	+	+	+
<i>Piptatherum miliaceum</i> (L.) Coss.	+	+	+	+
<i>Chamaerops humilis</i> L.	+	+	+	+
<i>Arisarum vulgare</i> O. Targ. Tozz.	+	+	+	+
<i>Asphodelus ramosus</i> L.	+	+	+	+
<i>Drimia maritima</i> (L.) Stearn	+	+	+	+
<i>Ruscus hypophyllum</i> L.	+	+	+	+
<i>Asparagus acutifolius</i> L.	+	+	+	+
<i>Asparagus albus</i> L.	+	+	+	+
<i>Smilax aspera</i> L.	+	+	+	+
<i>Quercus coccifera</i> L.	+	+	+	+
<i>Silene secundiflora</i> Otth	+	+	+	+
<i>Ranunculus bullatus</i> L.	+	+	+	+
<i>Lobularia maritima</i> (L.) Desv.	+	+	+	+
<i>Reseda alba</i> L. subsp. <i>alba</i>	+	+	+	+
<i>Umbilicus rupestris</i> (Salisb.) Dandy	+	+	+	+
<i>Lotus cytisoides</i> L.	+	+	+	+
<i>Geranium purpureum</i> Vill.	+	+	+	+
<i>Mercurialis annua</i> L.	+	+	+	+
<i>Elaeoselinum fontanesii</i> Boiss.	+	+	+	+
<i>Ferula communis</i> L.	+	+	+	+
<i>Fumana laevipes</i> (L.) Spach	+	+	+	+
<i>Arbutus unedo</i> L.	+	+	+	+
<i>Erica multiflora</i> L.	+	+	+	+
<i>Olea europaea</i> L.	+	+	+	+
<i>Prasium majus</i> L.	+	+	+	+
<i>Antirrhinum majus</i> L.	+	+	+	+
<i>Rubia peregrina</i> L.	+	+	+	+
<i>Lonicera implexa</i> Aiton	+	+	+	+
<i>Centranthus calcitrapae</i> (L.) Dufr.	+	+	+	+
<i>Phagnalon saxatile</i> (L.) Cass.	+	+	+	+
<i>Hyoseris radiata</i> L.	+	+	+	+
<i>Melica ciliata</i> L.	+	+	+	
<i>Chrysojasminum fruticans</i> (L.) Banfi	+	+	+	
<i>Allium roseum</i> L.	+	+		+
<i>Allium subvillosum</i> Salzm. ex Schult. & Schult. f.	+	+		+
<i>Prospero autumnale</i> (L.) Speta	+		+	+
<i>Silene vulgaris</i> (Moench) Garcke	+		+	+
<i>Papaver rhoeas</i> L.	+		+	+
<i>Fumaria capreolata</i> L.	+		+	+
<i>Sedum sediforme</i> (Jacq.) Pau	+		+	+
<i>Sedum caeruleum</i> L.	+		+	+
<i>Anthyllis vulneraria</i> subsp. <i>maura</i> (Beck) Maire	+		+	+
<i>Euphorbia peplus</i> L.	+		+	+
<i>Pistacia lentiscus</i> L.	+		+	+
<i>Rhamnus alaternus</i> L.	+		+	+
<i>Cistus monspeliensis</i> L.	+		+	+
<i>Cynoglossum creticum</i> Mill.	+		+	+
<i>Borago officinalis</i> L.	+		+	+
<i>Sherardia arvensis</i> L.	+		+	+

<i>Sonchus oleraceus</i> L.	+		+	+
<i>Dactylis glomerata</i> L.		+	+	+
<i>Lagurus ovatus</i> L.		+	+	+
<i>Barnardia numidica</i> (Poir.) Speta		+	+	+
<i>Prospero obtusifolium</i> (Poir.) Speta		+	+	+
<i>Allium ampeloprasum</i> L.		+	+	+
<i>Parietaria judaica</i> L.		+	+	+
<i>Clematis cirrhosa</i> L.		+	+	+
<i>Clematis flammula</i> L.		+	+	+
<i>Brassica cossoniana</i> Boiss. & Reut.		+	+	+
<i>Torilis arvensis</i> (Huds.) Link.		+	+	+
<i>Cistus heterophyllus</i> Desf.		+	+	+
<i>Phillyrea latifolia</i> L.		+	+	+
<i>Erodium malacoides</i> (L.) L'Hér.		+	+	+
<i>Leontodon tuberosus</i> L.		+	+	+
<i>Ophrys tenthredinifera</i> Willd.	+	+		
<i>Ruta chalepensis</i> L.	+	+		
<i>Marrubium vulgare</i> L.	+	+		
<i>Senecio leucanthemifolius</i> Poir. subsp. <i>leucanthemifolius</i>	+	+		
<i>Rumex bucephalophorus</i> L.	+		+	
<i>Daucus carota</i> subsp. <i>hispanicus</i> (Gouan) Thell.		+	+	
<i>Valerianella microcarpa</i> Loisel.	+			+
<i>Senecio vulgaris</i> L.	+			+
<i>Calendula arvensis</i> (Vaill.) L.	+			+
<i>Cynosurus echinatus</i> L.		+		+
<i>Gladiolus dubius</i> Guss. × <i>italicus</i> Mill.		+		+
<i>Sedum album</i> L.		+		+
<i>Erodium chium</i> (L.) Willd.		+		+
<i>Bellis sylvestris</i> Cirillo		+		+
<i>Asplenium trichomanes</i> L.			+	+
<i>Pinus halepensis</i> Mill.			+	+
<i>Anisantha madritensis</i> (L.) Nevski			+	+
<i>Arrhenatherum album</i> (Vahl) Clayton			+	+
<i>Avena sterilis</i> L.			+	+
<i>Catapodium marinum</i> (L.) C. E. Hubb.			+	+
<i>Catapodium rigidum</i> (L.) C. E. Hubb.			+	+
<i>Piptatherum coerulescens</i> (Desf.) P. Beauv.			+	+
<i>Polypogon monspeliensis</i> (L.) Desf.			+	+
<i>Rostraria cristata</i> (L.) Tzvelev			+	+
<i>Trachynia distachya</i> (L.) Link			+	+
<i>Carex halleriana</i> Asso			+	+
<i>Phoenix canariensis</i> H. Wildpret			+	+
<i>Allium paniculatum</i> subsp. <i>fuscum</i> (Waldst. & Kit.) Arcang.			+	+
<i>Allium sphaerocephalum</i> L.			+	+
<i>Polygonum aviculare</i> L.			+	+
<i>Chenopodium opulifolium</i> Schrad. ex W.D.J. Koch & Ziz			+	+
<i>Polycarpon tetraphyllum</i> (L.) L.			+	+
<i>Cerastium glomeratum</i> Thuill.			+	+
<i>Diplotaxis tenuifolia</i> (L.) DC.			+	+
<i>Hirschfeldia incana</i> (L.) Lagr.-Foss.			+	+
<i>Sanguisorba verrucosa</i> (G. Don) Ces.			+	+
<i>Rubus ulmifolius</i> Schott			+	+
<i>Hippocrepis multisiliquosa</i> L.			+	+
<i>Lotus ornithopodioides</i> L.			+	+
<i>Medicago polymorpha</i> L.			+	+
<i>Ononis hispida</i> Desf. subsp. <i>hispida</i>			+	+
<i>Geranium molle</i> L.			+	+
<i>Linum strictum</i> L.			+	+
<i>Malva multiflora</i> (Cav.) Soldano, Banfi & Galasso			+	+
<i>Daphne gnidium</i> L.			+	+
<i>Anethum foeniculum</i> L.			+	+
<i>Thapsia garganica</i> L.			+	+
<i>Kundmannia sicula</i> (L.) DC.			+	+
<i>Cistus salviifolius</i> L.			+	+
<i>Erica arborea</i> L.			+	+
<i>Lysimachia arvensis</i> (L.) U. Manns & Anderb.			+	+
<i>Blackstonia perfoliata</i> subsp. <i>grandiflora</i> (Viv.) Maire			+	+
<i>Convolvulus althaeoides</i> L.			+	+
<i>Convolvulus arvensis</i> L.			+	+
<i>Echium plantagineum</i> L.			+	+
<i>Verbena officinalis</i> L.			+	+
<i>Salvia verbenaca</i> L.			+	+
<i>Solanum nigrum</i> L.			+	+
<i>Verbascum sinuatum</i> L.			+	+
<i>Orobanche crenata</i> Forssk.			+	+
<i>Plantago lagopus</i> L.			+	+
<i>Galium murale</i> (L.) All.			+	+
<i>Sixalix atropurpurea</i> (L.) Greuter & Burdet			+	+

<i>Campanula erinus</i> L.			+	+
<i>Carduus tenuiflorus</i> Curtis			+	+
<i>Galactites tomentosus</i> Moench			+	+
<i>Centaurea sphaerocephala</i> L.			+	+
<i>Scolymus grandiflorus</i> Desf.			+	+
<i>Scolymus hispanicus</i> L.			+	+
<i>Cichorium intybus</i> L.			+	+
<i>Hedypnois rhagadioloides</i> (L.) F. W. Schmidt			+	+
<i>Achyrophorus valdesii</i> J.M. Jiménez, M. Ángeles & al.			+	+
<i>Urospermum picroides</i> (L.) Scop. ex F. W. Schmidt			+	+
<i>Helminthotheca echioides</i> (L.) Holub			+	+
<i>Sonchus tenerrimus</i> L.			+	+
<i>Reichardia picroides</i> (L.) Roth			+	+
<i>Crepis vesicaria</i> L.			+	+
<i>Anacamptis coriophora</i> (L.) R. M. Bateman, Pridgeon & M. W. Chase	+			
<i>Drimia undata</i> Stearn	+			
<i>Osyris alba</i> L.	+			
<i>Erophila verna</i> (L.) Chevall.	+			
<i>Erucastrum varium</i> (Durieu) Durieu	+			
<i>Ononis sicula</i> Guss.	+			
<i>Eryngium dichotomum</i> Desf.	+			
<i>Magydaris pastinacea</i> (Lam.) Paol. & Bég.	+			
<i>Centaureum erythraea</i> subsp. <i>suffruticosum</i> (Salzm. ex Griseb.) Greuter	+			
<i>Echium vulgare</i> L.	+			
<i>Cynoglossum mathezii</i> Greuter & Burdet	+			
<i>Lithospermum arvense</i> L.	+			
<i>Fedia cornucopiae</i> (L.) Gaertn.	+			
<i>Taraxacum obovatum</i> (Willd.) DC.	+			
<i>Drimia fugax</i> (Moris) Stearn		+		
<i>Orchis anthropophora</i> (L.) All.		+		
<i>Theligonum cynocrambe</i> L.		+		
<i>Hypericum australe</i> Ten.			+	
<i>Hypericum perforatum</i> L.			+	
<i>Hypericum pubescens</i> Boiss			+	
<i>Ajuga iva</i> (L.) Schreb.			+	
<i>Micromeria graeca</i> (L.) Benth. ex Rchb.			+	
<i>Veronica polita</i> Fr.			+	
<i>Anarrhinum pedatum</i> Desf.			+	
<i>Galium tunetanum</i> Lam.			+	
<i>Pallenis spinosa</i> (L.) Cass			+	
<i>Echinops bovei</i> Boiss.			+	
<i>Centaurea calcitrapa</i> L.			+	
<i>Helminthotheca glomerata</i> (Pomel) Greuter			+	
<i>Andryala integrifolia</i> L.			+	
<i>Filago pyramidata</i> L.			+	
<i>Rumex thyrsoides</i> Desf.			+	
<i>Paronychia argentea</i> Lam.			+	
<i>Papaver pinnatifidum</i> Moris			+	
<i>Fumaria parviflora</i> Lam.			+	
<i>Crataegus monogyna</i> Jacq.			+	
<i>Trifolium angustifolium</i> L.			+	
<i>Trifolium campestre</i> Schreb.			+	
<i>Trifolium stellatum</i> L.			+	
<i>Daucus muricatus</i> (L.) L.			+	
<i>Arundo donax</i> L.				+
<i>Hordeum murinum</i> L.				+
<i>Melica minuta</i> L.				+
<i>Phalaris paradoxa</i> L.				+
<i>Ornithogalum narbonense</i> L.				+
<i>Allium triquetrum</i> L.				+
<i>Gladiolus italicus</i> Mill.				+
<i>Ophrys fusca</i> Link				+
<i>Vinca difformis</i> Pourr.				+
<i>Ficus carica</i> L.				+
<i>Urtica urens</i> L.				+
<i>Silene colorata</i> Poir				+
<i>Silene pseudoatocion</i> Desf.				+
<i>Prunus spinosa</i> L.				+
<i>Cytisus villosus</i> Pourr.				+
<i>Geranium rotundifolium</i> L.				+
<i>Euphorbia helioscopia</i> L.				+
<i>Daucus carota</i> L. subsp. <i>carota</i>				+
<i>Echium sabulicola</i> Pomel				+
<i>Rosmarinus officinalis</i> L.				+
<i>Veronica cymbalaria</i> Bodard				+
<i>Misopates orontium</i> (L.) Raf.				+
<i>Galium verrucosum</i> Huds.				+
<i>Bellis annua</i> L. subsp. <i>annua</i>				+
<i>Erigeron bonariensis</i> L.				+
<i>Oxalis pes-caprae</i> L.				+
<i>Anacamptis papilionacea</i> (L.) R.M. Bateman, Pridgeon & M.W. Chase				+
<i>Simethis mattiazzi</i> (Vand.) G. López & C.E. Jarvis				+
<i>Allium chamaemoly</i> L.				+
<i>Dipcadi serotinum</i> (L.) Medik.				+



## Discussion

The flora listed in the Royal Mausoleum of Mauritania is highly diverse, with a total of 168 species. Asteraceae and Poaceae, accounting for a significant number of species, collectively contribute 40 species, representing 23.80% of the overall recorded total. The prominence of these families can be attributed to their substantial representation in the broader flora of Algeria (10). Specifically, these families contribute a substantial number of species with 408 and 284 species out of the 3139 species that comprise the flora of Algeria.

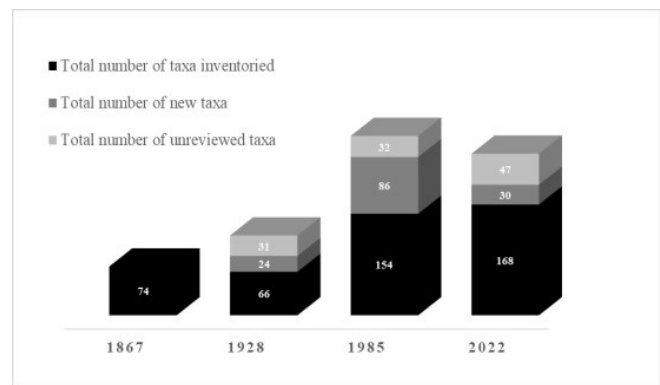
The conical shape and the isolated position of the Mausoleum expose it to winds, facilitating the establishment of numerous plant species, particularly therophytes. These pioneer species are undemanding and produce large quantities of seeds, giving them high invasive potential. Many Asteraceae, equipped with spangles or pappus, for anemochoric dispersion, such as *Sonchus oleraceus* L., *Senecio vulgaris* L., *Leontodon tuberosus* L. and *Reichardia picroides* (L.) Roth, along with certain lightweight-seeded Poaceae like *Dactylis glomerata*, *Lagurus ovatus* L. and *Cynosurus echinatus* L., thrive in this environment. In addition to wind dispersal, certain therophyte species can be carried by insects including ants, contributing to the dissemination of species such as *Euphorbia peplus* and *Mercurialis annua* L. (17).

The high prevalence of therophytes on the (4-6) can be attributed to the proximity of agroecosystems (vineyards, orchards, cereal crops, market gardening and wasteland), where a significant number of annual species are present. Monocarpic species, prevalent in various types of crops, outcompete other biological types (18). These plants are well-suited to disturbed and open environments, reappearing each year due to seed stock redistribution following agricultural practices (19). This biological type is a contemporary expression of adaptation to productive and disturbed habitats (20, 21). Many of these annual taxa identified on the Mausoleum have been previously documented by researchers (22-27), who focused on crop weeds and wastelands in the Tipaza region. Most of the listed species originate from the Mediterranean biogeographical element. Notably among these Mediterranean species is the presence of *Barnardia numidica*, an Algerian-Tunisian endemic species at the limit of its distribution area.

In addition to this species of high heritage value, *Tetraclinis articulata* (Vahl) Mast is identified among the listed flora. This conifer is recognized as an endemic western Mediterranean species, found in Tunisia, Algeria, Morocco, Spain and Malta, with isolated stations in the Algiers sector, particularly in the commune of Sidi Rached. This remarkable phanerophyte holds the status of a protected species, listed in the Algerian catalog of non-cultivated plant species, protected by Executive Decree No. 12-03 of 10 Safar 1433 - January 4, 2012 and is included in the red list of the IUCN (28). In addition to these 2 endemic species, 6 rare taxa in Algeria, according to the standard rarity criteria (10), are identified: *Allium ampeloprasum* L., *Piptatherum coerulescens* (Desf.) P.

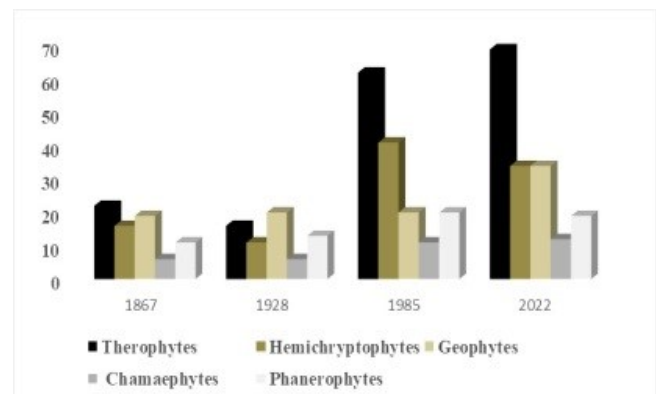
Beauv., *Silene secundiflora* Otth, *Diplotaxis tenuifolia* (L.) DC., *Geranium rotundifolium* L. and *Anacamptis papilionacea* (L.) R.M. Bateman, Pridgeon & M.W. Chase. The diachronic analysis of the inventoried taxa reports the presence of 35 species appearing in all 4 lists and 30 new species. It appears that species richness has evolved over the past 155 years.

The analysis of the biological spectra of the flora recorded in 1867, 1928, 1985 and 2022 reveals an increase in the different biological types over the 155 years (Fig. 5a). The main change consists of a slight reduction in the number of hemicryptophytes (from 26.62% to 20.23%) and phanerophytes (from 12.98% to 11.30%) between 1985 and 2022. The % of therophytes taxa, which represent the dominant biological type in the 3 inventories (1867, 1985 and 2022), shows a slight decrease (from 29.72% to 24.24%) between 1867 and 1928, likely related to the period when the inventory was carried out.



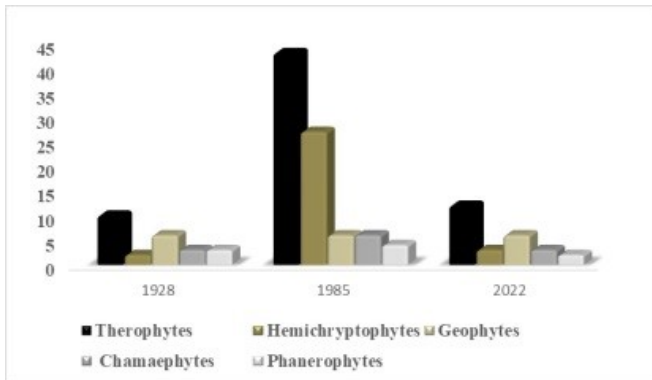
**Fig. 5a.** The biological types of taxa listed in 1867, 1928, 1985 and 2022.

Similarly, the new taxa (Fig. 5b) in the last 3 inventory periods show a strong implantation of therophytes (41.66% in 1928, 50% in 1985 and 46.15% in 2022) in the Royal Mausoleum of Mauretania, followed by geophytes (25% in 1928, 6.97% in 1985 and 23.07% in 2022), hemicryptophytes (8.33% in 1928, 31.39% in 1985 and 11.53% in 2022), chamaephytes (12.5% in 1928, 6.97% in 1985 and 11.53% in 2022) and phanerophytes (12.5% in 1928, 4.65% in 1985 and 7.69% in 2022). According to one report (29), therophytes represent the main biological type among the invasive species of the Mediterranean region, likely due to the proximity of agroecosystems near the Mausoleum.

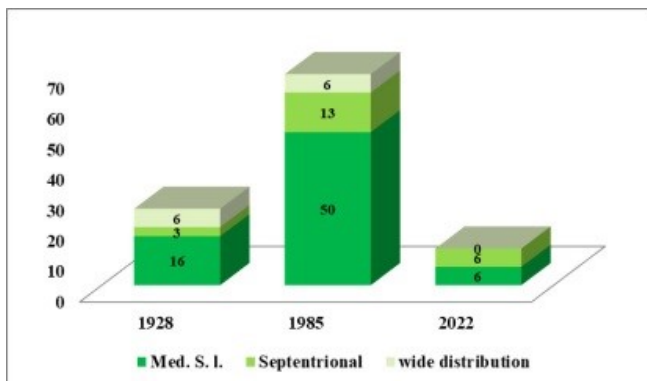


**Fig. 5b.** The biological types of new taxa listed in 1867, 1928, 1985 and 2022.

From a biogeographical point of view, the flora of the Mausoleum shows that the Mediterranean element (Fig. 6a) dominates in the 4 inventories (75.67%, 80.30%, 67.53% and 67.26%). The same is true for newly established taxa, where this phytochoric element represents around 2/3 of non-Mediterranean taxa (Fig. 6b). The ability to establish Mediterranean species contributes to maintaining floristic diversity, particularly of certain rare and endemic species such as *Silene secundiflora* and *Tetraclinis articulata*. Thirty taxa or 16.12% are newly implanted on the monument during the last inventory. Among these taxa not mentioned by the previous authors, we note the presence of 2 rare species, namely *Geranium rotundifolium* and *Anacamptis papilionacea*.



**Fig. 6a.** The biogeographical origins of taxa listed in 1867, 1928, 1985 and 2022.



**Fig. 6b.** The biogeographical origins of new taxa listed in 1867, 1928, 1985 and 2022.

The steady increase in the number of species at the monument over a century and a half is evident, despite the annual weeding efforts.

The Mausoleum not only harbors strictly mural species such as *Umbilicus rupestris* (Salisb.) Dandy, *Sedum caeruleum* L., *Sedum sediforme* L., *Sedum album* L., *Polypodium vulgare* L., *Parietaria judaica* L., *Galium murale* (L.) All., *Centranthus calcitrapae* (L.) Duf., *Campanula erinus* L., *Asplenium ceterach* L., *Asplenium trichomanes* L., but also serves as a reservoir for flora originating from habitats in close proximity to the site. These nearby habitats include preforest formations dominated by phanerophytes as well as agroecosystems invaded by therophytes. The latter habitat type, represented by various crop types, continues to proliferate throughout the Tipaza region, especially in the commune of Sidi Rached.

Another factor contributing to the change in the floristic diversity of the site is associated with apparent cracks in the blocks, where a soil-like accumulation has formed over centuries on the monument's foundations. This accumulation comprises debris from siliceous limestone and detritus from lichens, fungi and mosses (30). This substrate has the capacity to absorb and retain rainwater, providing humidity for an extended period, thus facilitating the establishment of numerous plant species (4). Herbaceous species with shallow rooting strategies, growing between the stone blocks, have no adverse impact and may even contribute to protecting the structure (31). However, the introduction of woody species, with their weight and extensive roots, could potentially damage the walls (32). There is a proposal on the development plan aimed at preserving and enhancing the Mausoleum, thereby maintaining its biodiversity.

## Conclusion

This study demonstrates that the Royal Mausoleum of Mauretania serves as a reservoir for numerous species from nearby habitats while also providing refuge for several noteworthy species, including 7 rare species, 2 endemic species and 1 nationally and internationally protected species (2). The diachronic analysis of the monument's flora revealed a shared floristic background among the four inventories, accounting for 16.27% of all species recorded since 1867, as well as the disappearance and introduction of new species. This shift in floristic composition is likely influenced by changes in the landscape in the commune of Sidi Rached (increased agroecosystems and decreased pre-forest habitats) and alterations to the monument (formation of cracks in the blocks), facilitating the establishment of numerous taxa. Sustaining biodiversity within the Mausoleum necessitates careful maintenance to control the growth of chamaephytes and phanerophytes that occupy joints and cavities between the blocks of the walls. Such plants often have extensive root systems that can impact the stability of the structure, in addition to contributing to erosion and exposure to atmospheric aggressions such as rain, hail and temperature variations. Additionally, restoration or consolidation efforts for precarious blocks should be initiated.

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## Authors' contributions

BS carried out research work, data analysis, and wrote original draft of the manuscript, YK supervision, writing review and editing and CB made illustrations. All authors read and approved the final manuscript.



## Compliance with ethical standards

**Conflict of interest :** The Authors declared no conflict of interest.

**Ethical issues:** None.

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