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New perspectives, additions, and amendments to plant endemism in the Egyptian flora

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Abstract

Endemism is one among other important concepts in biodiversity, biogeography, and conservation tasks. Based on herbarium specimens kept in some local herbaria, a large number of published literature, and available information; we compiled a comprehensive list, and an updated assessment of the Egyptian endemic and near-endemic taxa. The application of quantitative approaches to the distribution patterns, conservation status, and habitat preference of endemic taxa in Egypt was provided. Comparisons of the near-endemic taxa with other neighbouring flora were explained. For each taxon, the distribution patterns, most preferable habitat, biological spectrum, and taxa among 14 phytogeographical regions (Operational Geographical Units; OGUs) of Egypt were determined. The taxonomic degrees of differentiation among endemic taxa were represented by differentiation indices. Two different indices were used to assess endemism: single-region endemic taxa (SRES), and multiple-region endemic taxa (MRES). The majority of endemic and near-endemic taxa were recorded from the mountainous Sinai (S), and the Mareotis sector of the Mediterranean coastal land (Mm). In this study, 19 endemics (out of 70) and 76 near-endemics (out of 181) are newly added taxa. In general, the most represented families in endemic and near-endemics were: *Asteraceae, Caryophyllaceae, Lamiaceae*, and *Fabaceae*. More than 60% of the endemic taxa occurred in the sandy plains and wadies and the rocky plains and mountains. The application of hierarchical cluster analysis to the occurrences of 70 endemic taxa in the 14 studied OGUs revealed 5 main floristic groups (I – V); each characterized by certain OGUs. We provided 8 groups of near-endemic taxa representing their extension in other neighbouring countries. The presented data will help to fill the gap in our knowledge of endemism; a baseline information to understand biogeographical processes.

Keywords: Arid environment, biogeography, distribution patterns, habitat diversity, phytogeography

Introduction

The main floristic features in most countries are determined by specific components of endemic taxa, which in turn play an essential role in biodiversity (Estill & Cruzan, 2001) and conservation systems (Fois et al., 2017). Endemism is a focal point of biogeographic studies (Crisp et al., 2001; Huang et al., 2011). Assuming that all individuals of a taxon are confined to a given area or habitat, pure endemic taxa can be classified based on evolutionary history (neo- and paleo-endemics) or habitat specificity (Kruckeberg & Rabinowitz, 1985; Ferreira & Boldrini, 2011). Considering the size and limits of that area (Ladle & Whittaker, 2011), endemic taxa may be local (restricted to a small area), provincial (restricted to the limits of a province), national (restricted to the limits of a nation), regional (restricted to a geographical region), and continental (restricted to a continent). Performing biogeographical aspects of endemic taxa, endemism refers to taxa that have small distribution ranges or are restricted to a particular geographic region (area) or habitat type (Anderson, 1994). Because endemic taxa are unevenly distributed worldwide, some areas are very poor in such taxa, whereas others include high numbers. The loss of natural habitats, high sensitivity to human disturbance, and environmental changes may be attributed to the extinction of endemic plants (Thomas et al., 2004; Borokini, 2014; Abdelaal et al., 2018). The extinction of these taxa is considered a significant threat to biodiversity; therefore, most are included in the Red Data List. Near-endemism is used to describe taxa with few records outside the target region (Noroozi et al., 2019). Certain dispersal events and temporary establishment in different habitats have resulted in near-endemic species (Matthews et al., 1993). Studying the distribution patterns of endemic taxa is a core issue in priorities for biodiversity conservation, such as important plant areas (IPA; Darbyshire et al., 2017), key biodiversity areas (KBA; IUCN, 2012), and the criteria for zero-extinction sites (ZES; Ricketts et al., 2005; http://zeroextinction.org/the-alliance/about-the-alliance).

Worldwide, the significant role of endemic plants in biodiversity has been addressed by various studies to fully understand and assess (qualitatively and quantitatively) this relationship. Crisp et al. (2001), focused on the role of environmental factors in the distribution patterns of endemism in Australian flora, Van Der Werff and Consiglio (2004), provided insights into the role of elevational gradients and biological spectrum for the distribution patterns of endemics in Peru, Figueiredo et al. (2009), presented the first account on the diversity and endemism in the Flora of Angola, Kallimanis et al. (2010), indicated the strong correlation between endemic taxa richness and biogeographical variables on islands of the Aegean archipelago, Huang et al. (2011), provided the most comprehensive list of Chinese endemic seed plants and their basic composition and distribution features, Darbyshire et al. (2019), reviewed the diversity of endemic and near-endemic taxa in Mozambique that helped in identifying the Important Plant Areas (IPA), Demissew et al. (2021), discussed the future perspectives of local diversity and plant endemism in Ethiopia and Eritrea, Mehrabian et al. (2021), determined the Areas of Endemism (AOE) based on the distribution patterns and priorities for conservation of endemic Iranian Monocots.

The application of a biogeographical approach to endemism proved to be a useful tool for determining the distribution patterns and diversity of endemic taxa. Rosser and Eggleton (2012), indicated that higher-rank taxa (e.g. genera and families) can be used successfully as alternatives to species richness, and nearly all studies showed that genus richness is a better surrogate of species richness than family or order richness. Clustering techniques, based on environmental datasets and the distribution of endemic taxa, have been largely used in biogeography and for the definition of endemic-rich regions where conservation actions should be implemented. Médail et al. (1998), and Verlaque et al. (2001), reported the significant role of plant life forms in conservation and the impacts of global climate change.

Located in the north-eastern corner of the African Sahara, Egypt (between latitudes 22° and 32° N and longitudes 25° and 37° E) is the crossroads between Africa and Asia and adjoins the Mediterranean basin. The River Nile and the Red Sea are the two main corridors that link Egypt with tropical and equatorial Africa and the tropical Indian Ocean. Therefore, its flora of about 2145 species and 220 infraspecific taxa (Boulos, 2009) is unique and comprises taxa of the Saharo-Arabian, Sudano-Zambezia, Irano-Turanian, and Mediterranean phytogeographical regions. Egypt has a hyper-arid environment (Abd El-Ghani et al., 2017a), which is reflected by harsh environmental conditions (Hegazy & Lovett-Doust, 2016), with scanty rainfall (50-100 mm year-1) and high temperatures (Zahran & Willis, 2009). Desert (Eastern, Western, and Sinai) is the prevailing landscape comprising more than 90% of the total area (1 million km2). Consequently, desert vegetation is by far the dominant natural plant life and is mainly composed of xerophytic shrubs and subshrubs (Salama et al., 2016). Over the past decades, several approaches have been applied to study the endemic and near-endemic taxa in the flora of Egypt. Täckholm (1974), and Boulos (1995, 2009) enumerated these taxa and confirmed their locations. The scattered published works between 2013 and 2021 (Hosni et al., 2013; Shaltout et al., 2018; Abdelaal et al., 2018; El-

Khalafy et al., 2021; Abdelaal et al., 2020) contributed significantly to the increase and improvement of our information on this group of species. For a long time, the number of endemic taxa in Egyptian flora was a matter of controversy. Sixty-nine taxa were enumerated by Täckholm (1974), 60 by Boulos (2009), 76 by Hosni et al. (2013), 48 by Abdelaal et al. (2018), 140 by Abedelaal et al. (2020) and 41 by El-Khalafy et al. (2021). This incongruence in numbers can be attributed to updated taxonomy and updated distribution information. Therefore, a final checklist of endemic and near-endemic taxa in Egypt is urgently recommended.

This study presents a thorough update on other surveys conducted during the last decades. The application of quantitative approaches to the distribution patterns, conservation status, and habitat preference of endemic taxa in Egypt is assessed. Comparisons of the near-endemic taxa with other neighboring flora are elucidated. This work aims to establish a concrete complied updated checklist of the endemic and near-endemic taxa in Egypt and presents an informative baseline for further cooperation toward conservation purposes. The pattern of distribution of taxa in genera and families is useful for conservationists (Fenner et al., 1997).

Material and methods

Definitions of endemics and near-endemic

In this study, taxa occurring within the political borders of Egypt are referred to as" endemic", and those known globally outside the Egyptian borders are referred to as"near-endemic". As there is no perfect definition of"near-endemic", we tried to be as objective as possible when applying the above-selected criterion.

Data collection and data sources

For the compilation of this checklist, several data sources were used, such as monographs, articles, and relevant floras (Al-Eisawi, 1982 for Jordan; Gawhari et al., 2018 for Libya, Flora of Israel online, https://flora.org.il/en/plants; flora of Saudi Arabia online, http://plantdiversityofsaudiarabia.info/Biodiversity-Saudi-Arabia/Flora/Flora.htm; and flora of Lebanon online, http://lebanon-flora.org), and all recently revised taxonomic treatments of certain taxa. The main electronic sources and online global databases were used are: Global Biodiversity Information Facility (GBIF; http://www.gbif.org/occurrence), Plants of the World Online (POWO; http://www.plantsoftheworldonline.org), World Checklist of Selected Plant Families (WCSP; http://wcsp.science.kew.org/home.do), Euro+Med PlantBase (http://ww2.bgbm.org/ EuroPlusMed/query.asp), African Plant Database (APD; http://www.ville-ge.ch/musinfo/bd/cjb/africa), International Plant Names Index (IPNI; http://www.ipni.org), World

Flora Online (WFO; https://www.worldfloraonline.org), WFO Plant List (https://wfoplantlist.org/plant-list).

In addition, specimens kept in some local herbaria (Cairo University herbarium, CAI; Tanta University, TANE; Agricultural Museum, CAIM; Alexandria University, ALEX; Ain shams University, CAIA) were used, of which CAI is the richest specimen of endemic taxa of Egypt. These herbaria are part of the National Network of Egyptian Herbaria project (FLORAEGYPT) funded by the Egyptian Academy of Science and Technology, which aims to provide a database of Egyptian flora through specimens lodged in all local herbaria. The nomenclature of plant taxa was critically checked using (IPNI and POWO). Plant family circumscription follows the Angiosperm Phylogeny Group (APG III, 2009) and Stevens (2001). Herbarium abbreviations are followed (Thiers, 2023). In this study, a combination of herbarium specimens and various relevant references was used to ensure that the scope and precision of the distribution data were reliable. Moreover, an effort was made to collect up-to-date distribution data to ensure that the results reflect current distribution patterns. Based on the collected information, we compiled a database of Egyptian endemic flora, including species names, family names, growth forms, habitats, distribution ranges at the phytogeographical region level, and the threat status of each species.

Geographical distribution patterns, biological spectrum, and degree of differentiation, the distribution patterns of endemic and near-endemic taxa among the different phytogeographical regions of Egypt (Fig. 1, El Hadidi, 2000) were determined according to the locations reported on herbarium specimen labels and in the literature. For each taxon, the distribution information was based on the presence/absence and endemic/non-endemic status of each region. For near-endemic taxa, the other country (or countries) in which the taxa occur was recorded to show how far the species extends beyond Egypt. In this study, the distribution patterns of endemic and near-endemic taxa across the entire country were examined.

To detect the distribution patterns of endemic taxa, each phytogeographic region was referred to as an operational geographical unit (OGU). In this analysis, 14 OGUs were used (see Fig.1 for full names). Distribution maps of endemic taxa were prepared using ArcGIS 10.4 software (ESRI, 2016) and based on the geographical locations obtained with GPS for each specimen within its OGU. The endemic and near-endemic vascular plants of Egypt are presented in Supplementary Tables 1 and 2, respectively; both include intraspecific taxa (subspecies and varieties).

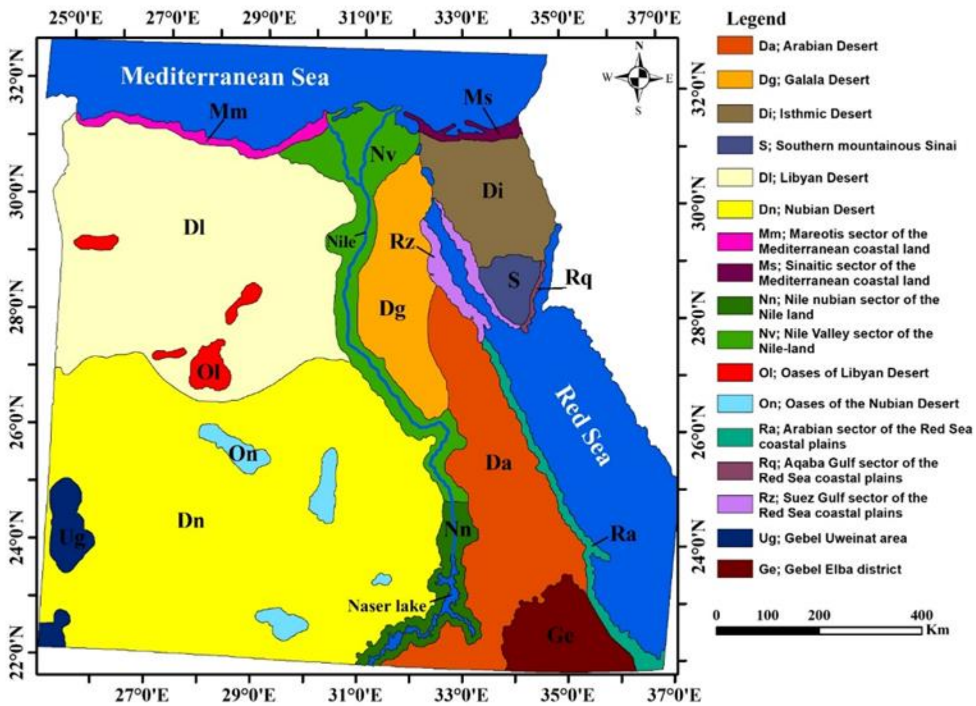

Figure 1. Phytogeographic regions (Operational Geographical Units) of Egypt (after El Hadidi, 2000)

For the analysis of the biological spectrum, the growth forms in both endemic and near-endemic species were classified into four types: trees (T), shrubs (S), perennial herbs (PH), and annuals (A). The significance of the distribution patterns of growth forms in each OGU was examined using the t-test option in SPSS version 16.0 for Windows. The taxonomic degrees of differentiation among endemic taxa were represented by differentiation indices (Huang et al., 2016), which included a species differentiation index (Ds), a genus differentiation index (Dg), and a species–family differentiation index (Dsf). The functions of the three indices are shown as follows:

Species differentiation index (Ds) = Ns/Ng; Genus differentiation index (Dg) = Ng/Nf; Species–family differentiation index (Dsf) = Ns/ Nf, where Ns is the number of taxa endemic to an OGU, Ng is the number of genera of endemic flora in an OGU, and Nf is the number of families of endemic flora in an OGU.

Assessment of endemism and beta diversity

For each OGU, assessment of endemism was based on two different indices: (1) single-region endemic taxa (SRES), which is the number of taxa endemic to a single phytogeographic region (OGU), and (2) multiple-region endemic taxa (MRES), which is the number of taxa endemic to more than one phytogeographic region (OGU). Pearson’s correlations were used to test the correlations of any pair of different aspects of endemism using SPSS software version 16.0 for

Windows. Beta diversity among the 14 OGUs was analysed using the Chao-Jaccard index, which considers unseen shared taxa and is more appropriate for the evaluation of similarity between samples of different sizes with numerous rare taxa (Chao et al., 2005). For this purpose, the program Estimates for Windows version 7.5 (Colwell, 2005) was used.

Habitat specificity

In addition, each endemic taxon was assigned to the most preferable habitat. For this purpose, 7 main habitats were determined: sandy plains and wadies (SPW), rocky plains and mountains (RPM), arable lands (AL), moist ground and canal banks (MGCB), stony ground (SG), coastal sandy plains (CSP), and dry salt marshes (DSM).

Conservation status

The most important source of information concerning the global conservation status of species is the IUCN, 2012. The conservation status of each taxon was evaluated using the categories proposed by this system. In this study, a scale of seven categories was used as follows: Extinct (EX), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), and Data Deficient (DD).

Statistical analyses

A presence/absence data matrix of 70 endemic taxa and 14 OGUs was established to construct homogeneous groups of phytogeographical regions. A hierarchical cluster analysis was performed with PC-ORD version 5 for Windows (McCune & Mefford, 1999) using Jaccard's index of similarity as the distance measure and flexible beta (beta=-0.8) as the group linkage method. The resulting groups will be named henceforth as 'floristic groups'. For near-endemic taxa, the classification of a presence/absence data matrix of 181 taxa and 10 countries (including Egypt) was performed using the UPGMA clustering method and the Baroni–Urbani Busert coefficient as a similarity method using the MVSP version 3.13g (Kovach, 2007).

The Indicator Species Analysis (ISA: Dufrêne & Legendre, 1997) was performed using PC-ORD version 5 for Windows (McCune & Mefford, 1999) to identify species that discriminate between cluster floristic groups (I-V). This method calculates relative abundances (RA) and relative frequencies (RF) of taxa in each group and derives a percentage indicator value (IV) for each taxon across the groups. The higher the (IV) score, the more closely correlated the taxon was to a particular floristic group. A Monte Carlo test was used to evaluate the statistical significance of the maximum indicator value recorded for a given taxon. Significant differences among floristic groups were tested using the Multi-Response Permutation Procedure (MRPP; PC-ORD version 5 for Windows), which was applied with Sorensen (Bray-Curtis) distance measures on a matrix of 14 OGUs and 70 endemic taxa, and two test statistics were calculated. The T statistic measured between-group differences. A large negative T value (≤ -9.0) indicates high segregation (i.e., the more negative the test statistic, the greater the species differences among the groups). The A statistic estimated within-group homogeneity and was chance-corrected. The A statistic ranged from (0.0–1.0) with higher values indicating a high degree of homogeneity. A is usually < 0.1 when there are many species. The significance of the null hypothesis of no differences among groups was assessed using a Monte Carlo permutation procedure with 1000 permutations.

To identify changes in floristic composition in the 14 OGUs, nonmetric multidimensional scaling (NMDS; PC-ORD version 5 for Windows) using Sorensen's coefficient as the distance measure (McCune & Grace, 2002) was applied as an ordination method. Solutions were obtained for dimensions 1 and 2, and the best solution, in terms of the trade-off between complexity associated with increased dimensionality and reduction of stress, was chosen for interpretation (McCune & Mefford, 1999). Stress levels of 10–20 are considered good solutions (Peck, 2010). The significance of the results was tested using a Monte Carlo permutation procedure. To assess the major examined variables that affect the distribution of endemic taxa in the 14 studied OGUs, a stepwise multiple regression analysis was performed using STATISTICA software version 8.0 (Statsoft, 2007).

Results

Verification of taxa and degree of differentiation

Endemic taxa

In total, 70 taxa (44 perennials, 26 annuals) of endemic plants belonging to 28 families and 56 genera were recognized (Supplementary Table 1), of which 19 taxa are new additions. Five families with the highest number of taxa: Asteraceae (9 taxa), Caryophyllaceae (8 taxa), Lamiaceae (7 taxa), Fabaceae (5 taxa), and Brassicaceae (4 taxa), constituted 47.1% of the total taxa. Important genera with the highest number of taxa were *Silene* (6 taxa), *Euphorbia* (3 taxa), *Allium*, *Muscari*, *Anthemis*, *Ifloga*, *Teucrium*, *Limonium*, and *Fagonia* (2 taxa for each). The degree of differentiation among the endemic taxa was unevenly distributed across Egypt. Table (1) showed that the species differentiation (D_s) was the highest (2) in Sinai, the Suez Gulf sector of the Red Sea coastal plains (Rz) is 1.5, followed by the Mareotis sector of the Mediterranean coastal land (1.2). The remaining 11 OGUs were equally distributed. The genus differentiation (D_g) was the highest (1.7) in the Nile Valley, followed by the Mareotis sector of the Mediterranean coastal land

(Mm) with a value of 1.3, and the lowest (0.5) was in Sinai). The pattern for the species–family differentiation index (D_{sf}) followed the same pattern for genus differentiation (Table 1).

Near-endemic taxa

One hundred and eighty-one near-endemic taxa (91 perennial herbs, 32 shrubs, 57 annuals, and one tree) belonging to 39 families and 113 genera were recognized; of which 76 are new additions (Supplementary Table 2). For comparison, Table (2) showed that similarities between the dominant endemic and near-endemic plant families exist, where Asteraceae (30 taxa), Fabaceae (17 taxa), Caryophyllaceae, and Lamiaceae (12 taxa for each) were the most species-rich families. The latter four families constituted 71 taxa (39.2%) of the total near-endemic taxa. Although Poaceae is the most representative family in the flora of Egypt (240 taxa; 11% of the total flora), it was not represented among the important families of the endemic taxa or in near-endemics. In addition to the previously reported endemic grass *Bromus aegyptiacus*, three grasses are newly added in this study, viz., *Bromus sinaicus* (Hack.) Tackh., *Eragrostis nitida* Link, and *Rostraria pumila* var. *glabrescens* (Täckh.) Hosni. Similarly, the near-endemic grasses included three newly added taxa, viz., *Aegilops longissima* Schweinf. & Muschl., *Trisetaria koelerioides* (Bornm. & Hack.) Melderis and *Stipagrostis shawii (*H.Scholz) H.Scholz (Supplementary Table 2). *Allium* (10 taxa), *Astragalus* and *Silene* (6 taxa for each), *Bellevalia* and *Centaurea* (5 taxa for each), and *Anthemis, Muscari, Verbascum,* and *Veronica* (4 taxa for each) included the highest numbers of species.

Table 1. Taxonomic diversity and degree of differentiation of endemic species for each Operational Geographical Unit (OGU) in Egypt. Ds= Species differentiation index, Dg= Genus differentiation index, Dsf= Species–family differentiation index

OGUs	Taxonomic diversity			Differentiation indices		
	No. of families	No. of genera	No. of species	Ds	Dg	Dsf
S	14	12	24	2	0.5	1.7
Di	8	8	8	1	1	1
Ms	5	5	5	1	1	1
Mm	11	14	17	1.2	1.3	1.5
Nv	6	10	10	1	1.7	1.7
Nn	3	3	3	1	1	1
Dl	1	1	1	1	1	1
Ol	1	1	1	1	1	1
On	3	3	3	1	1	1
Dg	6	7	7	1	1.2	1.2
Ge	4	4	4	1	1	1
Ra	5	5	5	1	1	1
Da	3	3	3	1	1	1
Rz	5	4	6	1.5	0.8	1.2

Table 2. Important plant families with the highest numbers (and percentages) of endemic and near-endemic taxa compared to the most species-rich families for the total flora of Egypt (after Boulos 1995-2009).

Endemics	No of taxa (%)	Near-endemics	No of taxa (%)	Total flora	No of taxa (%)
Asteraceae	9 (12.8)	*Asteraceae*	30 (16.6)	*Poaceae*	240 (11.0)
Caryophyllaceae	8 (11.4)	*Fabaceae*	17 (9.4)	*Fabaceae*	235 (10.7)
Lamiaceae	7 (10.0)	*Caryophyllaceae*	12 (6.6)	*Asteraceae*	230 (10.4)
Fabaceae	5 (7.1)	*Lamiaceae*	12 (6.9)	*Brassicaceae*	110 (5.0)
Brassicaceae	4 (5.7)	*Amaryllidaceae*	11 (6.1)	*Amaranthaceae*	96 (4.4)
Amaryllidaceae	3 (4.3)	*Asparagaceae*	11 (6.1)	*Caryophyllaceae*	83 (3.8)
Asparagaceae	3 (4.3)	*Brassicaceae*	10 (5.5)	*Lamiaceae*	54 (2.4)
Euphorbiaceae	3 (4.3)	*Apiaceae*	7 (3.9)	*Euphorbiaceae*	53 (2.4)
Zygophyllaceae	3 (4.3)	*Plantaginaceae*	6 (3.3)	*Apiaceae*	51 (2.3)
Total taxa	70		181		2200

Biological spectrum

Endemic taxa

In general, none of the endemic trees were represented among other growth forms (Supplementary Table 1). In terms of the total number of endemic taxa, shrubs and perennial herbs had the highest number (44 taxa, 62.8%), and a lower proportion were annuals (26 taxa, 37.2%). *Asteraceae* had the highest numbers of annuals (6 taxa), followed by *Brassicaceae* (5 taxa), *Caryophyllaceae*, and *Fabaceae* (3 taxa for each). Figure (2A) summarizes the distribution of growth forms in each of the 14 OGUs. The highest numbers of shrubs (8 taxa, 72.2% of the total shrubs) and perennial herbs (14 taxa, 42.4% of the total perennial herbs) were recorded from the mountainous Sinai (S). The annuals showed their highest record in (Mm) with 11 taxa (42.2% of the total annuals), followed by (Nv) with 7 taxa (27%). The endemic taxa were represented by annuals in the Dl, Ol, and GE regions. Whereas the distribution patterns of growth forms in each OGU showed insignificant differences (results not shown) for Nn (p=0.08), Dl (p=0.31), Ol (p=0.31), On (p=0.08) and Da (p=0.08), the distribution patterns of the remaining OGUs differed significantly (p ranged between 0.001 and 0.01).

Near-endemic taxa

The general distribution of the 181 near-endemic taxa in the different categories (Fig. 2B) indicated the dominance of the perennial herbs (91 taxa, 50%), followed by annuals (57 taxa, 31%). The tree was the least represented (one taxon, 1%), whereas *Medemia Argun* was the only recorded taxon.

Families with the highest number of perennial herbs were *Asteraceae* (15 taxa), *Asparagaceae* (11 taxa), *Amaryllidaceae* (10 taxa), *Caryophyllaceae* and *Plantaginaceae* (6 taxa for each), and *Fabaceae* and *Lamiaceae* (5 taxa for each). Thirty-two shrubs (18%) were enumerated from 17 families, of which *Lamiaceae*, *Fabaceae*, *Tamaricaceae*, and *Zygophyllaceae* included the highest numbers of taxa (7, 4, 3 and 3, respectively). Amongst other taxa, *Verbascum letourneuxii*, *Origanum isthmicum*, *Pterocephalus sanctus*, *Taverniera aegyptiaca*, and *Zygophyllum dumosum* can be mentioned. Perennial herbs and shrubs constituted about 68% of the total near-endemics. Annuals constituted 57 taxa (31%) of the total near endemics belonging to 16 families, where *Asteraceae* (14), *Fabaceae* (8), *Brassicaceae* (7), and *Caryophyllaceae* (5) included the highest numbers of taxa (Supplementary Table 2). Such annuals included, amongst others, *Centaurea glomerata*, *Senecio glaucus* sub sp. *glaucus*, *Crepis aculeata*, *Lotus nubicus*, and *Silene palaestina*.

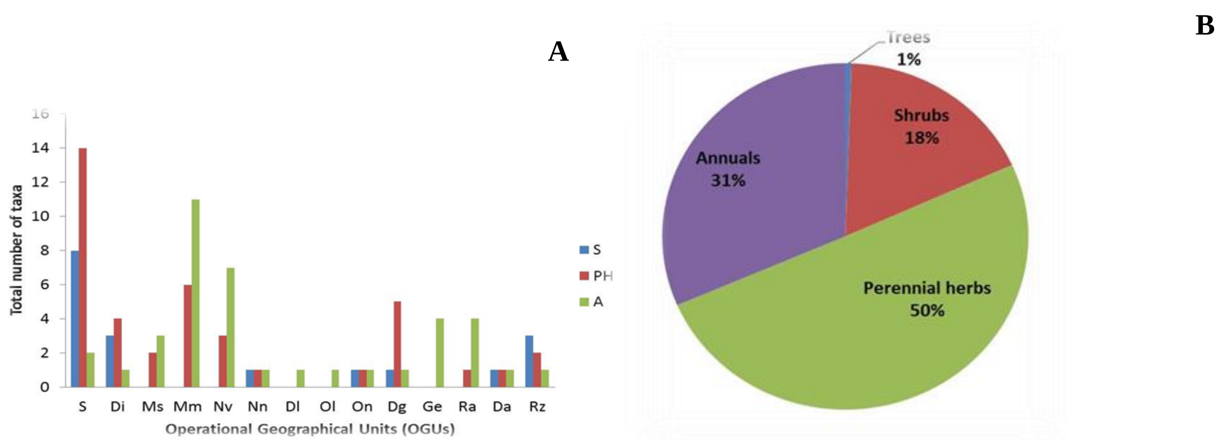

Figure 2. (A) Distribution of growth forms of the endemic taxa (S=shrubs, PH=perennial herbs, A= annuals) in the 14 OGUs. **(B)** Proportionate of near-endemic growth forms. For abbreviations of OGUs, see Fig. (1).

Geographical distribution patterns and beta diversity

Endemic taxa

Based on their geographical distribution, two patterns were identified: (1) multiple region endemic taxa (MRET) that are widely distributed and recorded in more than one OGU, and (2) single region endemic taxa (SRET) that are narrowly distributed and recorded in one OGU.

As revealed from analysis (Supplementary Table 1), 20 taxa (about 28.6% of the endemic taxa) were identified as multiple region endemic taxa (MRET). Among the OGUs, the mountainous Sinai (S) included the highest number of endemic taxa (24 taxa, 34.3% of the total endemics), followed by the Mareotis sector of the Mediterranean coastal land (Mm) with 17 taxa (24.3%) and the Nile Valley (Nv) with 10 taxa (14.3%; Table 1). The lowest numbers of endemic taxa were found in the Libyan Desert (Dl) and Oases of Libyan Desert (Ol); both with single taxon (1.4%). *Hyoscyamus boveanum* occurred in 5 of the 14 OGUs (Supplementary Fig. 1A), mainly distributed in the Arabian Desert (Da), along the Suez Gulf of the Red Sea (Rz), the Isthmic Desert (Di), the mountainous Sinai (S), and the Nile Valley (Nv). Sixteen taxa (80%) were found in two OGUs, none of which was known from the Libyan Desert (Dl) and its Oases (Ol and On): *Nasturtiopsis integrifolia* (Brassicaceae), *Euphorbia obovata* (Euphorbiaceae), and *Teucrium leucocladum* var. *glandulosum* (Lamiacaeae). On the other hand, 4 taxa were confined to the OGUs located east of the country (Dg, Ge, Ra, Da, and Rz), such as *Ifloga spicata* subsp. *elbaensis* (Asteraceae), *Biscutella didyma* var. *elbensis* (Brassicaceae), *Silene villosa* var. *erecta* (Caryophyllaceae) and *Solanum nigrum* var. *elbaensis* (Solanaceae). Two endemic species, *Pancratium arabicus* (Amaryllidaceae) and *Euphorbia punctata* (Euphorbiaceae), were confined to the Mediterranean regions (Ms and Mm). *Euphorbia obovata* (Euphorbiaceae) and *Origanum syriacum* subsp. *sinaicum* (Lamiaceae) was confined to the OGUs of the Sinai Peninsula (Di and S).

The single region endemic taxa (SRET; Supplementary Fig. 1B) comprised 50 taxa (71.4%), with the highest proportions from the mountainous Sinai OGU (15 taxa, 30%), and the Mediterranean OGUs (14 taxa). In terms of characteristic endemic taxa, *Bufonia multiceps*, *Rosa arabica*, *Primula boveana*, and *Euphorbia sanctae-catharinae* characterized the Sinai (S) OGU (Supplementary Fig. 1C), whereas *Allium mareoticum, Muscari albiflorum, Veronica anagalloides* subsp. *taeckholmiorum,* and *Limonium mareoticum* characterized the (Mm) OGU. The lower proportion (4 taxa) was counted from the oases of the Libyan Desert, such as *Ducrosia ismaelis*, *Melilotus serratifolius*, *Rhazya greissii*, and *Apium graveolens* var. *bashmensis.* Remarkably, none of the SRET groups were confined to the Gebel Elba region (Ge) and Libyan Desert region (Dl). Pearson's correlation coefficients between different pairs of aspects of endemism (Table 3) indicated that the genus differentiation index (Dg) was insignificantly negatively correlated with other aspects, whereas the species-family differentiation index was positively correlated with most of the measured aspects. MRES and SRES showed significant positive correlations with each other (*r*=0.63) and with most of the examined aspects.

Table 3. Pearson's correlation coefficients (r) between aspects of endemism. Ds= Species differentiation index, Dg= Genus differentiation index, Dsf= Species–family differentiation index, multiple region endemic taxa, SRET= Single region endemic taxa. **= Correlation is significant at the 0.01 level, *=Correlation is significant at the 0.05 level.

Aspects of endemism	No families	No genera	No species	Ds	Dg	Dsf	MRET
No families							
No genera	0.93**						
No species	0.97**	0.91**					
Ds	0.74**	0.47	0.77**				
Dg	-0.16	0.22	-0.14	-0.61*			
Dsf	0.74*	0.82**	0.85**	0.62*	0.23		
MRET	0.85**	0.76**	0.83**	0.74**	-0.18	0.71**	
SRET	0.90**	0.87**	0.95**	0.68**	-0.09	0.81**	0.63*

For estimation of beta-diversity, the Chao-Jaccard index (C-J; Supplementary Table 3A) showed a clear separation between the endemic taxa in the 14 OGUs with high similarity between Di and both S (C-J=0.7) and Rz (C-J=0.8). Similar high similarities (C-J=0.9) were found between Mm and both Nv and Dl. As expected, the endemic taxa in Gebel Elba (Ge) showed high similarity with Ra (C-J=0.9). The highest numbers of shared taxa (7 taxa) occurred between S and Rz, between Mm and Nv (5 taxa), and between Ge and Ra (5 taxa).

Near-endemic taxa in Egypt

The analysis of the occurrences of the 181 near-endemic taxa revealed that *Reseda pruinosa* and *Allium tel-evidence* (Supplementary Table 4) had a wide range of distributions as it was found in more than four OGUs, mainly along the Mediterranean coast (Mm and Ms), in the Sinai Peninsula (Di and S), along the Red Sea coast (Ra and Rz), and in the Eastern Desert (Dg and Da). Seventy-nine taxa had a narrow range of distribution (confined to one OGU; Fig. 3); the highest number (43 taxa, 44% of this group) were known from Sinai OGUs (Di and S) such as *Saltia papposa, Astragalus amalecitanus, Pterocephalus sanctus, Veronica kaiseri, Zygophyllum propinquum* subsp. *migahidii, Lupinus palaestinus*, and *Silene hussonii*, followed by 19 taxa (25.3% of this group) from the Mediterranean region (Mm and Ms. OGUs) such as *Crepis aculeata, Nigella arvensis* subsp. *negevensis, Bupleurum nanum, Herniaria cyrenaica*, and *Ebenus armitagei*.

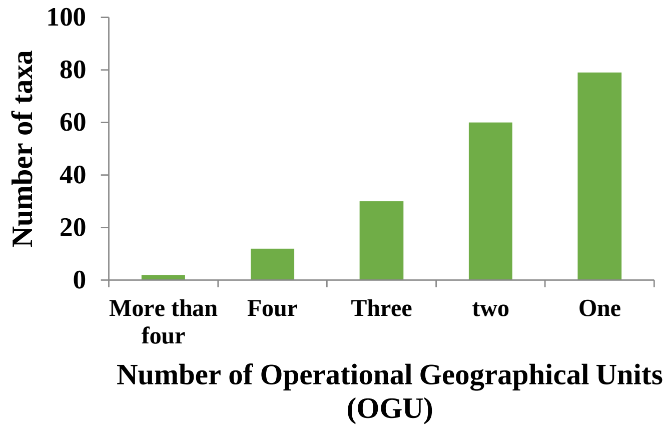

Figure 3. Occurrences of the numbers of near-endemic taxa in the OGUs occur

Sixty taxa showed occurrences in two OGUs, where 24 taxa (40% of this group) were mainly recorded from the Mediterranean OGUs (Mm and Ms) and penetrated the Sinai OGUs (Di and S), such as *Allium curtum* sub sp. *palaestinum, Bellevalia eigii, Alkanna strigose, Trigonella arabica*, and *Lycium schweinfurthii* var. *aschersohnii.* Another 25 taxa (41.7% of this group) showed penetration of their distribution from the northern OGU (Di) toward the southern OGU (S) of the Sinai Peninsula, including *Ferula sinaica, Eremogone sinaica, Origanum isthmicum, Convolvulus palaestinus,* and *Teucrium jordanicum* var. *jordanicum*.

The similarity between the recorded near-endemic taxa in previous works (Boulos, 2009; Hosni et al., 2013; Shaltout et al., 2018; POWO, and this study using Jaccard's index (Supplementary Table 3B).) indicated low similarity indices between taxa of this study and other works, but higher similarity index (0.89) with the taxa identified by POWO. Studies by Hosni et al. (2013) and Shaltout et al. (2018) showed high similarity indices with that of Boulos (2009).

Habitat specificity of endemic taxa

None of the endemic taxa were represented in all identified habitats. Two major habitats harboured the highest numbers of endemics: the sandy plains and wadies (SPW, 24 taxa) and the rocky plains and mountains (RPM, 19 taxa), which together constituted more than 60% of the taxa (Supplementary Table 5). The coastal sandy plains (CSP) and the dry salt marshes (DSM) included the lowest numbers of taxa; two for the former and one for the latter (Fig. 4A). When compared with other OGUs, the mountainous Sinai (S) included the highest number of taxa in the SPW, RPM and SG. Similar trends can be seen in AL, where the highest number of taxa occurred in Nv (Fig. 4B).

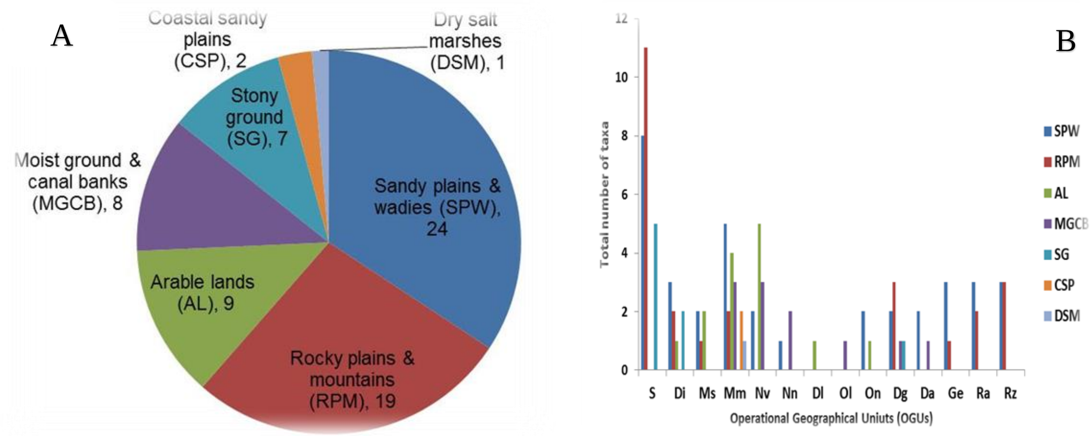

Figure 4. (A) Proportionate of habitats of endemic taxa, (**B**) Distribution patterns of habitats of endemic taxa in the OGUs. Abbreviations of habitats: AL=arable lands, CSP= coastal sandy plains, DSM= dry salt marshes, MDCB= moist ground, and canal banks, RPM= rocky plains and mountains, SG= stony ground (SG), SPW= sandy plains and wadies. For an explanation of OGUs, see Fig. 1.

Some taxa showed consistency to a certain habitat such as *Hyoscyamus boveanum* and *Pancratium arabicum* in sandy plains and wadies, *Allium crameri* and *Pterocephalus arabicus* in rocky plains and mountains, *Bromus aegyptiacus* and *Scorzonera drarii* in arable lands, *Sonchus macrocarpus* and *Apium graveolens* var. *bashmensis* in moist ground and canal banks, *Origanum syriacum* subsp. *sinaicum* and *Ballota kaiseri* in stony ground, *Atractylis carduus* var. *marmarica* in coastal sandy plains, and *Limonium mareoticum* in dry salt marshes). Shrubs and perennial herbs dominated both rocky plains and mountains (RPM) and stony ground (SG), but annuals dominated the arable land (AL) habitat. In terms of numbers of taxa, the pairwise correlations between different types of habitats of the endemic taxa (Table 4), the taxa of sandy plains and wadies (SPW), and the rocky plains and mountains (RPM) were strongly correlated with each other (r=0.86) and with the stony ground habitat (SG, r=0.74 for the former and r=0.91 for the latter). The moist ground and canal banks (MGCB) showed high correlations with those of the arable lands (AL, r=0.68). A strong correlation occurred between the taxa of the coastal sandy plains and those of the dry salt marshes (DSM, r=0.94). To examine the differences between habitats of the endemic taxa and their occurrences in OGUs, the results of the t-test revealed that Di and Mm were significantly different (p=0.047 for the former, and p=0.009 for the latter).

Conservation status of endemic taxa

In general, an assessment of conservation based on IUCN categories revealed that four major categories (CR, EN, EX, and VU) constituted 59 taxa (84.3% of endemics); the highest proportion was for critically endangered (26 taxa, 37%), followed by equal contribution (11 taxa) of the remaining three categories. Among the 17 families (34%) that represent the critically endangered taxa, *Caryophyllaceae* and *Lamiaceae* have the highest numbers of taxa (5 for the former and 3 for the latter). While *Asteraceae* and *Fabaceae* had the highest numbers in the extinct (EX) taxa, *Asteraceae, Brassicaceae*, and *Lamiaceae* were best represented in the vulnerable taxa (2 for each). *Silene* and *Euphorbia* were highly represented in the CR, whereas *Teucrium* was best represented in the VU taxa.

Table 4. Pearson's correlation coefficients (*r*) between habitats of endemic taxa. Abbreviations: SPW=sandy plains and wadies, RPM=rocky plains and mountains, AL=arable lands, MGCB=moist ground and canal banks, SG=stony ground, CSP= coastal sandy plains, DSM= dry salt marshes. **= correlations are significant at the 0.01 level, *=correlations are significant at the 0.05 level.

Habitats	SPW	RPM	AL	MGCB	SG	CSP
RPM	0.86**					
AL	0.07	-0.21				
MGCB	-0.04	-0.25	0.68**			
SG	0.74**	0.91**	-0.20	-0.26		
CSP	0.34	0.02	0.53*	0.57*	-0.12	
DSM	0.34	0.02	0.53*	0.57*	-0.12	0.94**

In terms of the numbers of taxa in OGUs assigned to each IUCN category (Fig. 5A), 17 (54.8%) out of the 31 critically endangered taxa and 12 (54.5%) out of 22 vulnerable taxa were recorded from (S) and (Mm). The near-threatened (NT) taxa were least represented throughout the OGUs. To habitats to conservation IUCN categories, while the sandy plains and wadies (SPW, 24 taxa) and the rocky plains and mountains (RPM, 19 species) included most endemic taxa (43 taxa, 61.4%), the coastal sandy plains (CSP) and the dry salt marshes (DSM) were the least represented. The taxa inhabited RPM and SPW (Fig. 5B) constituted the bulk of the critically endangered taxa (CR): 13 for the former and 7 for the latter. Meanwhile, the highest numbers of taxa that occurred in the EN and EX categories were from the sandy plains and wadies (SPW). Results of the ANOVA test indicated highly significant variations (F=12.45, p=0.001) between categories of IUCN. Although Pearson's correlation between the different types of habitats and IUCN categories showed a negative non-significant relation (r=-0.120, p=0.33), the correlation between aspects of endemism and IUCN categories was highly negatively significant (r=-0.39, p=0.001).

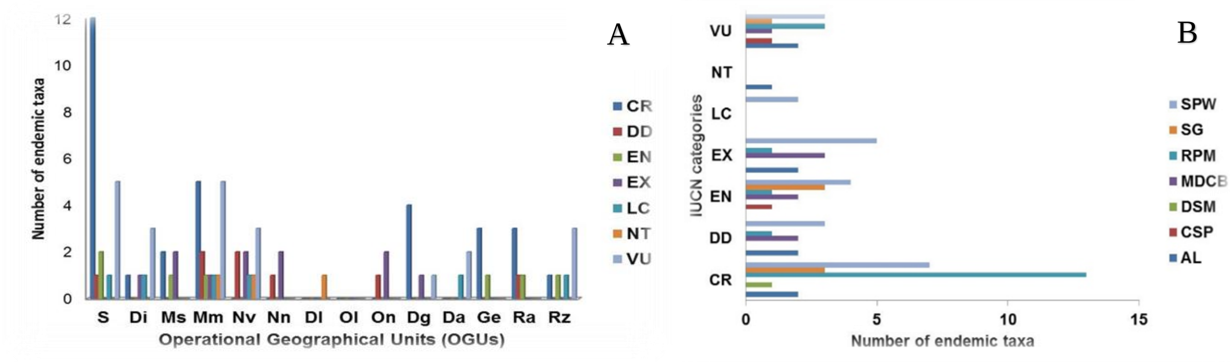

Figure 5. Distribution of IUCN categories of the numbers of endemic taxa: (A) in each OGU, (B) in the different habitats. IUCN Abbreviations: CR=critically endangered, VU=vulnerable, EN=endangered, EX=extinct, DD=data deficient, LC=least concern, NT=near threatened, Habitats' abbreviations: AL=arable lands, CSP= coastal sandy plains, DSM= dry salt marshes, MDCB= moist ground and canal banks, RPM= rocky plains and mountains, SG= stony ground (SG), SPW= sandy plains and wadies. For abbreviations of OGUs, see Fig. 1.

Table 5. Results of stepwise multiple regression analysis for 4 dependent variables of the 70 endemic taxa in 14 OGUs, S.E. = Standard error, **= significant at the 0.01 level, *= significant at the 0.05 level.

Dependent variable	Multiple R	R^2	Adjusted R^2	F	p	Intercept ± S.E.	Beta values (coefficients)		
							E	H	IUCN
Endemism type (E)	0.399	0.159	0.121	4.164	0.009**	2.038 ± 0.19			
Habitats (H)	0.318	0.101	0.060	2.481	0.068	4.565 ± 1.32	-0.07		
IUCN categories	0.416	0.173	0.135	4.594	0.005**	6.702 ± 1.21	0.40**	0.15	
Growth forms (GF)	0.290	0.084	0.042	2.021	0.119	1.182 ± 0.48	0.012	0.28*	0.54

Floristic regionalization

Endemic taxa

The application of cluster analysis of endemic taxa (Fig. 6 A and B) indicated the occurrence of some groupings of OGUs and showed some relations to the data in Supplementary Table (1). Consequently, upon projection of the floristic groups (I – V) on the 14 studied OGUs. The characteristic taxa of each floristic group, together with their significant variation (p-values) using the Monte Carlo test were shown in Supplementary Table (1).

Group (I) occupies the upper part of the dendrogram (Fig. 6A) and the easternmost OGUs of Egypt (Sinai Proper, Isthmic Desert, and the Suez Gulf sector of the Red Sea coastal plains), which are geographically very close together (Fig. 6B). This group included 28 taxa, the majority (24 taxa) was recorded from (S). The two taxa *Polygala sinaica* var. *sinaica*, *Hyoscyamus boveanus* shared the three OGUs. Four taxa showed consistency to (Di): *Allium crameri*, *Scorzonera drarii*, *Brassica deserti*, and *Zygophyllum migahidii* Hadidi var. *isthmia*.

Group (II) included OGUs in both sectors of the Mediterranean coastal land, which represents the northern borderline of the country. This group included 20 taxa, of which 17 were exclusively found in (Mm) such as *Bassia aegyptiaca*, *Anthemis microsperma*, *Veronica anagalloides* subsp. *taeckholmiorum*, *Silene apetala* var. *glabrata*, and *Bromus aegyptiacus*. Two taxa: *Euphorbia punctata* and *Pancratium arabicum* were common between the two OGUs of the Mediterranean region (Mm and Ms).

Group (III) is located in the middle of the dendrogram and includes three OGUs, two of which represent the North-South stretches of the Eastern Desert (Da and Dg) and the adjacent Nile Valley sector of Nile land. Seventeen taxa were included in this group, of which *Sonchus macrocarpus* was the only common among the three OGUs of this group. The (Nv) hosts the highest number of taxa (10), while (Da) is the least (3). Whereas 10 taxa were common between (Nv) and (Da), certain taxa were exclusively recorded from the (Nv) such as *Sinapis arvensis* subsp. *allionii*, *Fagonia taeckholmiana*, *Persicaria obtusifolia*, and *Trigonella media*.

Group (IV) apart from the Nubian Nile (Nn), included the three OGUs of the Western Desert. None of the 8 taxa included in this group were in common between the 4 OGUs (Nn, Dl, Ol, and On). Among the characteristic taxa: *Apium graveolens* var. *bashmensis* (Ol), *Atriplex nilotica* (Nn), Anthemis retusa (Dl) *Melilotus serratifolius*, and *Rhazya greissii* (On).

Group (V) included 5 taxa from two floristically and geographically related OGUs (Ra and Ge) and were placed in the lower part of the dendrogram. Apart from *Dicliptera aegyptiaca* that showed consistency to the (Ra), the remaining 4 taxa were in common: *Biscutella didyma* var. *elbensis*, *Ifloga spicata* subsp. *elbaensis*, *Silene villosa* var. *erecta*, *Solanum nigrum* var. *elbansis*.

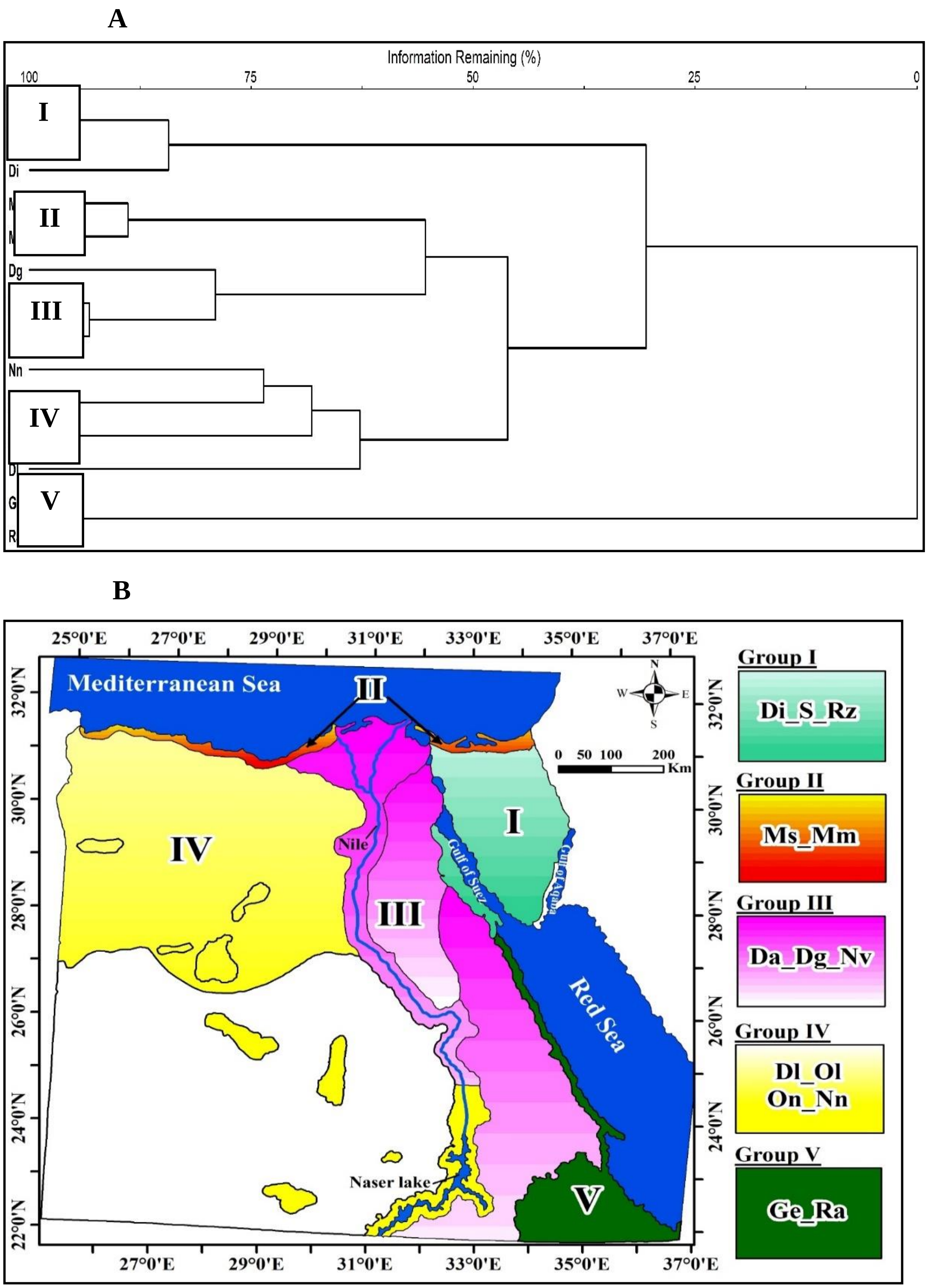

Figure 6. (A) Cluster analysis diagram of the 14 OGUs using Jaccard's index as a distance measure indicating the separation of the five floristic groups (I-V) of endemic taxa, **(B)** Distribution of floristic groups obtained from cluster analysis. For abbreviations of OGUs, see Fig. 1

The nonmetric multidimensional scaling (NMDS) ordination diagram along axes 1 and 2 (Fig. 7) distinguished the positions of the floristic groups (I-V) of endemic taxa and confirmed the results obtained from cluster analysis. It was found that each cluster floristic group can be linked between two and four of the studied OGUs. The final stress was 10.3, which produced a significant result in the Monte Carlo test (p=0.003). Along the negative end of axis 1 in the ordination plane, groups (IV) and (V) were separated, whereas group (III) occupied a median position. Along axis 2, the positive end was occupied by group (I), whereas group (II) split on its negative side.

The Multi-Response Permutation Procedures (MRPP) test revealed certain significant differences between floristic groups in the floristic matrix (chance-corrected within-group agreement A=0.17; p<0.0009) suggesting separated assemblages. The T statistic was -9.20, indicating dissimilarity among the 14 studied OGUs. The pairwise comparisons showed significant differences between most of the groups. Floristic differences between groups (II) and (III), between groups (II) and (V), and between (III) and (V) were insignificant (Table 6). The five groups (I –V) occupied different positions in the species space, as shown by the strong chance-corrected within-group agreement (*A*) and test statistics (*T*).

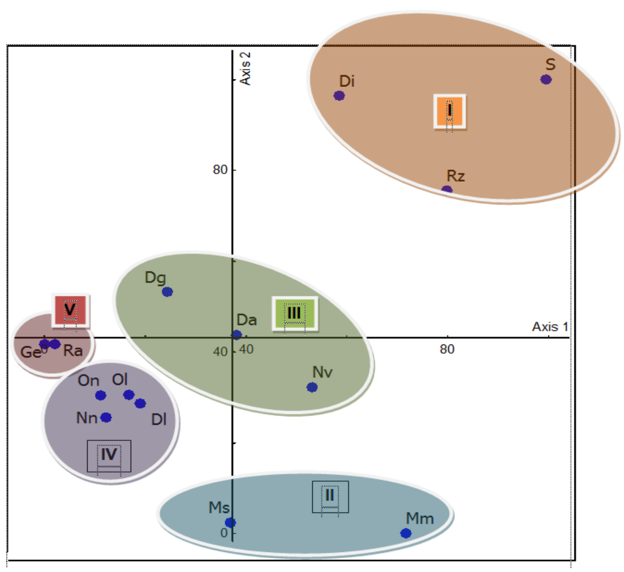

Figure 7. Non-metric Multidimensional Scaling (NMDS) ordination diagram along axes 1 and 2, showing the positions of separated floristic groups (I-V) of endemic taxa. For abbreviations of OGUs, see Fig. 1.

Table 6. Multiple pairwise comparisons of the MRPP statistics of the floristic groups (I-V) based on Bray-Curtis distance. *A*=change-corrected within-group agreement, *T*=difference between the observed and expected deltas. **= significant level at 0.01, *= significant level at 0.05, NS= Not significant

Group compared	*T*	*A*	*P* value
I vs. II	-2.13	0.092	0.00000000**
I vs. III	-2.58	0.062	0.024*
I vs. IV	-3.53	0.055	0.009**
I vs. V	-2.23	0.34	0.00000000**
II vs. III	-1.47	0.041	NS
II vs. IV	-2.49	0.023	0.02*
II vs. V	-1.41	0.35	NS
III vs. IV	-2.68	0.029	0.01*
III vs. V	-2.22	0.311	NS
IV vs. V	-3.00	0.22	0.02*

Near-endemic taxa

In terms of number of taxa extended to a country (countries) outside Egypt, Libya was the highest as extended in one country, followed by Palestine, whereas Palestine and Jordan were the highest as extended in two countries, and Palestine, Jordan, and Lebanon-Syria were the highest as extended in three countries (Supplementary Fig. 2). After the application of UPGMA cluster analysis on 181 near-endemic taxa in 10 countries using the Baroni–Urbani Busert coefficient as a similarity method, 4 main cluster groups (A- D) were obtained (Supplementary Figure 3A). Group (A) was the North-eastern-Mediterranean-group represented by Sinai, Palestine, Jordan, Lebanon, and Syria, group (B) was the Saharo-Arabian-Asiatic group represented by Saudi Arabia and Yemen, group (C) was the Sudanian-East African group represented by Sudan and Eritrea, and group (D) was the Mediterranean-North African group represented by Egypt, Libya and Tunisia (Supplementary Table 2). When locating the position of these groups on maps of the adjacent countries (Supplementary Figure 3B), overall distribution patterns can be detected and described as follows:

(I) North African extension: This group included 32 taxa (15 annuals, 11 perennial herbs, 6 shrubs) of Mediterranean origin recorded along the north western Mediterranean coast of Egypt. Twenty-six taxa occurred in Egypt and Libya, and 4 taxa were found in Libya and Tunisia other than Egypt. *Crepis libyca*, *Nonea vivianii*, *Herniaria cyrenaica*, *Silene fruticosa* subsp. *cyrenaica*, *Ebenus armitagei*, *Bellevalia sessiliflora*, and *Nigella arvensis* subsp. *taubertii* were examples of this group.

(II) Sudanian extension: This group comprises seven taxa, mostly of perennial herbs. Outside Egypt, 5 taxa extended their distribution into Sudan and the other two into Sudan and Eritrea were recorded. These taxa occurred in south and southeast Egypt and penetrated north and northeast Sudan. The endangered desert tree *Medemia argun* and two taxa of aquatic habitat (*Veronica anagallis-aquatica* var. *nilotica* and *V. scardica* sub sp. *africana*) were examples of this group.

(III) East Mediterranean extension: This group constituted 93 taxa (53.6% of the total near-endemics); of which 60 extended their distribution from the Sinai Peninsula (origin of penetration) north-eastward (Fig.10B) into Palestine, Jordan, Lebanon, and Syria. Altogether, the majority (90 taxa) of this group extended their distribution into Palestine other than Egypt (Supplementary Table 2), while 35 taxa exhibited their distribution in Palestine, Jordan, Lebanon, and Syria besides Egypt. Perennial herbs (46 taxa) dominated other growth forms (32 annuals, 15 shrubs). *Allium tel-avivense, Origanum isthmicum, Haloxylon negevensis, Bellevalia zoharyi, Pimpinella cretica* var. *petraea*, *Onopordum alexandrinum,* and *Lupinus palaestinus* were examples of this group.

(IV) East Mediterranean and Arabian Peninsula extensions: Thirty-eight taxa (26 perennial herbs, 6 shrubs, 6 annals) characterized this group, extending their distribution from Egypt eastward into Saudi Arabia and Yemen and north-eastward into East Mediterranean countries. A group of 28 taxa shared the distribution with Saudi Arabia, Palestine, and Jordan, including *Ferula sinaica, Atractylis mernephthae, Campanula dulcis, Silene hussoinii, Hypericum sinaicum, Stachys aegyptiaca, Astragalus intercedens, and Polygala sinaica* var. *glabrescens*.

(V) Sudanian and Arabian Peninsula: This group consisted of 5 taxa (4 shrubs), extending their distribution from south and east Egypt in two directions: southward into Sudan and Eritrea (e.g., *Pancratium tortuosum* and *Taverniera aegyptiaca*) and eastward into Saudi Arabia and Yemen (e.g., *Echinops hussonii* and *Tribulus spurius*).

(VI) North African, East Mediterranean, and Arabian extensions: *Echium longifolium, Erucaria microcarpa* , and *Echinops galalensis* constituted this group and were distributed outside the Egyptian borders in Libya, Palestine, Jordan, and Saudi Arabia (Supplementary Table 2).

(VII) North African and Sudanian extensions: This group included the annual grass *Stipagrostis shawii*, which extended its distribution westward into Libya and southward into Sudan.

(VIII) East Mediterranean, Sudanian, and Arabian Peninsula extensions: This group included the widely distributed perennial herb, *Caudanthera sinaica* which extended its distribution from East Egypt into Palestine, Saudi Arabia, and Sudan.

Discussion

Taxonomic differentiation and taxa verification

Over the past 5 decades, several publications (Täckholm, 1974; El Hadidi & Fayed, 1994/95; El Hadidi & Hosni, 2000; Boulos, 2009; Hosni et al., 2013; Abdelaal et al., 2018; El-Khalafy et al., 2021; Abdeaal, et al., 2020; Bedair et al., 2023) reported the numbers of endemic taxa in the flora of Egypt. However, an estimated definitive number is still inaccurate. The variations in the estimation of the total numbers of endemic taxa in publications over 50 years (1974-2023) were indicated in Supplementary Table (6). This study recognized 70 taxa (3.3% of the total flora) belong to 28 families and 56 genera, of which 19 taxa are newly added. The numbers of endemics were subjected to constant change as known areas of distribution expanded or if endemic taxa were taxonomically included under more widespread taxa. The possible major reasons for such differences can be attributed to (1) updated taxonomic investigations, (2) level of taxonomic ranks, (3) updated geographical ranges of taxa, (4) climate change, (5) human disturbances, and (6) habitat loss. Therefore, it is crucial to consider all of the aforementioned reasons when comparing the results of different studies. Due to extremely hot desert environmental conditions (Hegazy & Lovett-Doust, 2016; Abdelaal et al., 2020), similar trends of low endemism can be found in neighboring Libya (3.8%; Mahklouf and Etayeb (2019) Palestine (5.8%; Ighbareyeh et al. (2021), Saudi Arabia (10.7%; Attia at al. (2017), and Sudan (15%; Adam et al. 2020). In contrast, countries with wetter climates in the Mediterranean Basin and its islands such as Morocco, Greece, and Italy have higher levels of endemism such as Aedo et al. (2013), in Spain, Rankou et al. (2013), in Morocco, Dimopoulos et al. (2013), in Greece, and Fois et al. (2017), in Italy.

In the present study, the analysis of near-endemic recognized 181 taxa in 40 families and 111 genera, of which 76 are new additions. This number is much higher than the figures published by previous authors: 93 by Boulos (2009), 105 by Hosni et al. (2013), and 73 by Shaltout et al. (2018). More attention should be paid to the increasing numbers of near-endemic taxa, as often more vulnerable to extinction than widespread species. For conservation, serious steps can be taken toward their conservation by protecting their habitats and reducing the threats they face. In addition to the reasons mentioned above, there are a few other factors that could contribute to the increasing numbers of near-endemic taxa. For example, new technologies, such as DNA analysis, are making it easier to identify and distinguish between closely related species. This could lead to the discovery of more near-endemic taxa that were previously overlooked. Additionally, as climate change continues to accelerate, more and more plant species will likely be forced to shift their ranges, which could lead to the formation of new near-endemic taxa. Recently, the status of several near-endemic taxa was altered due to intensive studies on endemism in adjacent countries (El-Khalafy et al., 2021). This investigation shared 38 taxa with other relevant studies (the complete list can be requested from authors).

Taxonomic differentiation affects the conservation of endemism in Egypt by providing more information about distribution ranges, conservation status, and habitat preferences are prioritizing conservation efforts (Joshi & Janarthanam, 2000; Bonn et al., 2002) by identifying and protecting these unique and ecologically valuable plant species that are particularly vulnerable or threatened. The floristic analysis revealed that *Asteraceae*, *Fabaceae*, *Caryophyllaceae*, and *Lamiaceae* were the important families that included the highest number of taxa and constituted the major components of both endemic and near-endemics. These families represent the most common in the Mediterranean North African flora (White, 1993). In terms of floristic diversity, these findings were in line with those of Walas and Taib (2022), in Morocco, Moghanloo et al. (2023), in Iran, and Georghiou and Delipetrou (2010), in Greece.

Relative to their dominance in the flora of Egypt, Poaceae (240 taxa; 11% of the total flora) was not among families that harbour high numbers of endemic and/or near-endemic taxa. The low number of endemic grasses in Egypt coincides with those in neighbouring arid countries such as Saudi Arabia (11 endemic grasses out of 269 taxa; Chaudhary & Cope, 1983), Libya (2 out of 229; Al-Sghair et al., 2019) and Palestine (5 out of 196; Ali-Shtayeh et al., 2022). The lower number of endemic and near-endemic taxa in Poaceae than in some other plant families can be attributed to their good dispersal ability, cosmopolitan distribution, and often wind pollination (Ricklefs, 2008).

Biological spectrum

Wang et al. (2003), indicated that plants have evolved different life forms to adapt to the different conditions along the hydro thermic gradient. Accordingly, trees are well-suited to warm and wet climates, while shrubs are better adapted to dry climates. These functional types have been used to describe plant adaptation to certain ecological conditions (Salama et al., 2015). In this study, none of the endemic trees were represented among growth forms, while shrubs and perennial herbs were best represented (44 taxa, 62.8%). Similarly, the composition of a biological spectrum of the near-endemics follows the same trend as in endemics where perennials dominate (124 taxa, 68.5%). In general, the paucity of trees and the high presence of shrubs in the flora of Egypt reflects its harsh climate, poor soils, and long history of human disturbance (Bedair et al., 2021). The annuals had the lowest proportion of endemic (26 out of 70 taxa, 37%) and near-endemic taxa (57 out of 181 taxa, 31.5%). The results of this study contradict those of El-Khalafy et al. (2021), and Abdelaal et al. (2018), who reported the dominance of annuals among other growth forms. In this study, the Mareotis sector of the Mediterranean coastal land (Mm) harbors the highest number of annual taxa which can be attributed to high amounts of rainfall (annual mean 220−150 mm year^{-1}, Bedair et al., 2023) and mild temperature (mean annual from 25.3 to 13.3°C, Zahran & Willis, 2009). Annual plants are characterized by their short life cycle, which means that they must produce seeds and complete their life cycle within a single growing season. In addition, the desert landscape of Egypt is frequently subjected to physical disturbances such as sandstorms, droughts, and uncontrolled anthropogenic activities which are harmful environmental conditions not only for the growth of annuals but also for plant diversity and vegetation structure (Hussein et al., 2021). *Medemia Argun*, a known near-endemic tree from Egypt deserves special attention. The plant was known in Egypt since ancient times, and was found in ancient Egyptian tombs, and not recorded from Sudan since 1907 (Täckholm & Drar, 1950). Boulos (1966), discovered a few new living individuals in Kurkur Oasis (Western Desert, Egypt). The leaves were used by the local people in making mats and camel shackles. Whereas *Medemia Argun was* considered extinct in Sudan by Uhl and Drensfield (1987), new populations were discovered by Gibbons and Spanner (1996). Recently several *Medemia* palms were observed by Dina Ali and Rafik Khalil in Dungul Oasis (Boulos, 2005), Western Desert, Egypt.

Distribution patterns of taxa and habitat heterogeneity

The endemic plant species are often adapted to specific environmental conditions, such as soil type, topography, and climate, which restrict their distribution to a narrow geographic area. Grytnes and Vetaas (2002), indicated that topography can act as a barrier or facilitator for plant dispersal, leading to the formation of distinct geographic patterns of endemism. Mountains, valleys, and other landforms can restrict the movement of plants, resulting in the isolation of populations and the development of unique species. Mountainous regions can act as water catchment areas, leading to the formation of rivers, streams, and oases. These water sources support unique microhabitats and provide refuge for endemic plant species that are adapted to specific moisture requirements (Joshi & Janarthanam, 2004).

In this study, the distribution patterns of endemic taxa indicated that 20 taxa (28.6% of the total endemics) showed a wide range of distribution that occurred in more than one OGU (multiple regions endemic taxa, MRET), and 50 taxa (71.4% of the total) found in one OGU (single region endemic taxa, SRET). In both sets, the majority of these taxa were recorded from the mountainous Sinai (S), and the Mareotis sector of the Mediterranean coastal land (Mm). In the meantime, the sandy plains and wadies (SPW, 24 taxa) and the rocky plains and mountains (RPM, 19 taxa) were the main habitats which together formed more than 60% of the total endemic taxa. Similarly, higher numbers of near-endemic taxa were recorded from the Sinai and the Mediterranean OGUs. These findings were following those obtained by Hosni et al. (2013), Shaltout et al. (2018), and El-Khalafy et al. (2021). Taxa with larger distribution ranges will be less vulnerable to extinction from natural or anthropogenic threats (Wulff et al., 2013), and have higher genetic diversity, which can make them more adaptable to changing conditions (Lavergne et al., 2004).

Topographic complexity may cause gene-flow barriers among diverging populations, supporting reproductive isolation and hence local differentiation. The South Sinai mountainous region has rich plant diversity due to its extensive mountainous massif, which supports many microhabitats (Dawood et al., 2022). The high elevations in this region hinder the dispersal process of propagules, leading to an increase in endemic and near-endemic species (Ramadan et al., 2009; El-Keblawy, 2014). *Phlomis aurea* Decne (Lamiaceae), an endangered endemic shrub growing in the mountainous areas of the southern Sinai Peninsula (El Hadidi & Hosni, 2000) is recently subjected to a dramatic decline in its population unless conservation measures should be taken for protection against anthropogenic and environmental stresses (Serag et al., 2018).

The Mediterranean Basin is considered the world’s second-largest biodiversity hotspot (Lopez-Alvarado & Farris, 2022). Along the Mediterranean coast of Egypt, the vegetation is confined to microenvironments such as wadies, runnels, and depressions, where runoff water collects and provides sufficient moisture for plant growth (Salama et al., 2013). In a recent study on the Mediterranean endemic taxa in the Egyptian flora, Bedair et al. (2023), recognized 15 habitats supported the occurrence of 65 Mediterranean endemic taxa in Egypt, where the most represented habitats were the non-saline depressions followed by the coastal dunes. Many Mediterranean species are restricted to a single or few localities in sandy areas, isolated mountain ranges, or islands of unusual soils or rocky grounds, thus this region is characterized by a relatively high degree of endemism compared to other regions in Egypt (Zahran, 2010). Over the past 3 decades, the western Mediterranean coast of Egypt was subjected to uncontrolled human disturbances and sprawling urbanization projects (i.e., the establishment of tourist summer resorts) which significantly negatively affected the natural habitats supporting characteristic vegetation and flora (Bedair et al., 2023; Halmy, 2019). Consequently, these impacts can lead to declines in population size and range, as well as a decrease in genetic diversity and gene flow for both endemic and near-endemic taxa (Halmy et al., 2015 a and b). In this context, most of the calcareous dunes that were extended along the western Mediterranean coast become threatened habitats with endangered flora (Ahmed et al., 2014). *Ebenus armitagei* Schweinf. and Taub., *Nigella arvensis* L. subsp. *taubertii* (Brand) Maire, *Plantago crypsoides* Boiss., and *Centaurea glomerata* Vahl. were considered threatened near-endemic taxa that characterized this ecosystem.

Floristic regionalization

Endemic taxa

Five main floristic groups (I – V) have resulted after the application of cluster analysis on the occurrences of 70 endemic taxa in the 14 studied OGUs; each characterized by certain OGUs: (I) included the Sinai Peninsula (Di, S) and the Suez Gulf sector of the Red Sea coastal plains (Rz), (II) included OGUs of the Mediterranean coast (Mm, Ms), (III) included the Eastern Desert (Da, Dg) and the Nile Valley (Nv), (IV) included the Western Desert (Dl, Ol, On) and the Nubian Nile (Nn), and (V) included Gebel Elba highlands (Ge) and the Red Sea coast (Ra). Abdelaal et al. (2020) identified six biogeographical sectors and six subsectors when applying hierarchical clustering and indicator values analyses, based on the presence-absence matrix of 140 endemic taxa. The sectors were: (1) Libo-Nubian, (2) Nilotic, (3) Marioutico-Arishian, (4) Sinaico-Arabian, (5) Elbanian, and (6) Suezian, while the subsectors were: 2.1) Deltaic, 2.2) Fayoumian, 3.1) Marioutic, 3.2) Arishian, 4.1) Sinaic and 4.2) Arabian. Abdelaal et al. (2018) divided Egypt into 3 main groups: I (Eastern Egypt and the Sinai Peninsula), II (Western Egypt including the Western Desert and Oases), and III (Middle Egypt including the Nile lands). The results of this investigation were partially in agreement with both studies. The latter divisions ignored the Mediterranean and Gebel Elba regions as distinct phytogeographic territories with special flora (Abd El-Ghani et al., 2017a).

Although the Sinai Peninsula and the Eastern Desert of Egypt are two distinct geographical regions, they are also closely related. Geologically, the Sinai Peninsula and the Eastern Desert are both part of the Arabian-Nubian Shield (Said, 1962); a geological formation that is characterized by ancient Precambrian rocks. The two regions also share a similar climate, which is characterized by hot, dry summers and mild winters. However, the Sinai Peninsula receives more precipitation than the Eastern Desert, due to its higher elevation and its proximity to the Mediterranean Sea

(Abd El-Ghani et al., 2017b; Salama et al., 2013). On the other hand, the relationship between Gebel Elba and the Eastern Desert of Egypt is complex and multifaceted. Gebel Elba is both physically and ecologically distinct from the surrounding desert, but it is also an integral part of the region. It provides water, habitat, and recreation for the people and wildlife of the Eastern Desert of Egypt (Shaltout et al., 2016). Based on the information mentioned earlier, it seems that the recognized groups of endemic taxa presented in this study were more realistic and incongruent with the eco-geographical and floristic integration between the regions included. This study proved the insignificant relationship between the Gebel Elba group (group V) and the Eastern Desert (group III) which means high dissimilarity between the compositions of endemic flora. In the meantime, the Mediterranean group (group II) and the Eastern Desert group (group III) were insignificantly correlated. Such relations contradict the classifications of Abdalaal et al. (2018 & 2020).

Near-endemic taxa

When comparing the distribution patterns of the near-endemic taxa outside Egypt, Hosni et al. (2013) grouped their 105 taxa into 4 main territories: (1) North-eastern territory included Sinai, Galala desert, S and C Palestine with slight extensions to SW Jordan and NW Arabia, (2) North-western territory included NW Egypt to NE Libya, (3) South-western territory included SW Egypt, SE Libya, and NW Sudan, and (4) South-eastern territory included SE Egypt, Sudan with slight extension to SW Arabia. According to Hosni et al. (2013), the majority (92%; 56 taxa out of 61) of near-endemic taxa were mainly distributed in the north-eastern and the north-western territories. Due to differences in numbers and locations, it was not easy to compare such 4 territories with the 8 main groups indicated in this investigation. This can be reflected by the low Jaccard's similarity index (0.44) between this investigation and the latter. However, certain taxa showed similarity in their distribution, especially in the North-western and South-western territories such as *Crepis libyca*, *Silene biappendiculata* , and *Carthamus glaucus* subsp. *alexandrinus* in the former territory, and *Stipagrostis shawii* in the latter. Due to recent taxonomic revisions, 47 taxa were excluded from the list of near-endemics (recorded in previous studies) which either became synonyms to other taxa, their distribution became wider, or their status has been changed (full lists can be requested from authors). Such taxa that became endemic included, amongst others, *Allium crameri*, *Convolvulus schimperi*, *Ducrosia ismaelis*, *Euphorbia punctata*, and *Nepeta* *septemcrenata*. In addition, *Nigella arvensis* var. *beersherensis* and *Euphorbia bivonae* var. *sinaica* were not confirmed in the present study.

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