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BIOGEOGRAPHY AND DIVERSITY OF THE TUBIFLORAE IN EGYPT

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Abstract. The species distribution and biogeography of the Egyptian Tubiflorae were examined in detail. We found 284 species of vascular plants belonging to 96 genera and 12 families. The most species-rich families were Scrophulariaceae, Boraginaceae, Labitae, Convolvulaceae and Solanaceae, constituting more than 85% of total species in the order. The generic spectrum was dominated by a suite of species-rich genera (*Convolvulus, Heliotropium, Veronica, Solanum, Salvia, Cuscuta, Echium, Ipomoea, Orobanche*). Therophytes were the most dominant life forms among the families, followed by chamaephytes and hemicryptophytes. Boraginaceae and Scrophulariaceae had the highest share of annuals. Remarkable distribution patterns of the life forms in the seven studied biogeographic zones were noted. Trees were dominant in the Mediterranean zone, while shrubs, perennial herbs and therophytes were dominant in the Sinai. Altogether 8 endemic species and 14 near-endemics were included in the Tubiflorae of Egypt, mostly from southern Sinai. We found that Labiatae and Scrophulariaceae were the families with a higher concentration of endemics. Notably, *Teucrium* was among the genera of Mediterranean Africa with the highest endemism. Gamma diversity varied from 171 in the Sinai Peninsula to 43 and 39 in the oases of the Western Desert and along the Red Sea, respectively. Interestingly, the highest significant values of similarity and species turnover (beta diversity) were found between the oases and the Nile lands. We note the combined effect of both temperature and precipitation on the species richness of Tubiflorae in the seven biogeographic zones. Almost half of the species showed a certain degree of consistency, that is, with narrow geographic expansion. On the basis of UPGMA clustering and PCoA analysis, 4 floristic groups were recognized, each including one or more biogeographic zones. The occurrence of the species of Tubiflorae in adjacent regional floras and their phytochorological affinities are discussed.

Key words: geographical distribution, gamma diversity, Egypt, flora, endemics

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INTRODUCTION

Tubiflorae is by far the largest order of the Egyptian vascular flora. Generally, Diels (1936) recognized the order Tubiflorae to be composed of 8 suborders and 23 families of the flowering plants. Hutchinson (1959) organized the families in 5 orders: Verbenales, Solanales, Personales, Boraginales and Lamiales. In Egypt it is represented by 5 suborders (Convolvulineae, Boragineae, Verbenineae, Solanineae, Acanthineae), 96 genera, 12 families (Convolvulaceae, Boraginaceae, Verbenaceae, Avicenniaceae, Labiatae, Solanaceae, Scrophulariaceae, Orobanchaceae, Globulariaceae, Acanthaceae, Pedaliaceae, Lentibulariaceae) and 284 species comprising 13.7% of the total flora. It is a group of great importance, not only for its species diversity but also for the capacity of their species to colonize a great variety of environments, the wide range of life forms, habitats and distribution patterns (Täckholm 1974; Boulos 2000, 2002). A third of its species have been considered endangered and vulnerable (El Hadidi 1979). Boulos (1989) enumerated 14 desert plant species of promising economic potential. The order also includes shrubs that present clear adaptations to the arid and semi-arid environs (e.g., pubescence and spinescence), which have made them highly diverse in Egypt and the entire Middle East and Mediterranean North Africa. The order provides a model system for the study of arid biogeographical patterns, and could produce useful information for the conservation of certain vegetation enclaves inside the country and the whole region. The Convention on International

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Trade in Endangered Species of Wild Fauna and Flora (CITES 1990) includes most of the families of Tubiflorae in its Appendix 2, and a considerable number of its species are listed in Appendix 1.

Biological diversity, or biodiversity, refers to the variety of distinct ecosystems or habitats, the number and variety of species within them, and the range of genetic diversity within the populations of these species. Two attributes of biodiversity have attracted particular attention from the international conservation community: species richness (the total number of species in an area) and endemism (the number of species in that area that occur nowhere else). Because these two attributes reflect the complexity, uniqueness and intactness of natural ecosystems, they are believed to indicate overall patterns of biodiversity in a useful manner. Phylogenetic diversity is in part a function of the size of a flora, and in part a function of the pattern of distribution of the species into higher taxa (Fenner *et al.* 1997). Recently the pattern of species distribution among higher taxa has been shown to be an effective indicator of phylogenetic diversity (Williams & Humphries 1994).

The biogeography of the flora of Egypt is still poorly documented, and with a few notable exceptions (El Hadidi *et al.* 1996; Abd El-Ghani & El-Sawaf 2004) there have been few attempts to analyze the biogeographical implications of most species distribution patterns. Khedr *et al.* (2002) reported that the flora of Egypt contains many families and genera relative to the number of species (120 families, 742 genera, 2088 species) and a relatively large number of oligotypic families, each represented by only one or a few species. They suggested that a flora in which the species are distributed among numerous genera or families, or other higher-order ranks, should contain greater phylogenetic diversity and genomic information than one in which the same number of species is concentrated into fewer higher-order taxa. The high fraction (97%) of native species in the Egyptian flora may reflect fewer opportunities to acquire more species per genus or per family, due to fewer successful biotic invasions as well as lower speciation rates.

Although some families of Egyptian Tubiflorae have been taxonomically revised (Boulos 2000, 2002), our basic knowledge of the diversity and biogeography of this order is still fragmentary. This paper attempts to analyze and interpret its diversity in relation to the relative family and genus sizes, spatial distribution patterns and phytogeography of the members of Tubiflorae in Egypt. It also stresses the need to combine taxonomic, floristic and life form differentiation along with biogeographical parameters to understand the relationship between plant habit and speciation propensity in the Tubiflorae.

MATERIAL AND METHODS

The provisional account presented here was based on the authors' experience from field work carried out for several years at all seasons in different parts of Egypt, especially those from the oases of the Western Desert, Sinai and Gebel Elba. In addition, an inventory of all available herbarium collections from Egypt was compiled, and taxonomic determinations were revised. Plant materials assembled during their field work by M. M. Abd El-Ghani in western Saudi Arabia and S. El-Naggar in Gebel Akhdar, Libya, were also used. Specimens were examined from the herbarium of Cairo University (CAI), the herbarium of the Agriculture Museum (CAIM) and the Herbarium of Assiut University (AST). Taxonomic revisions for some families and genera of Egyptian Tubiflorae were also consulted (El-Husseini 1986; El-Husseini & Zareh 1989; Hepper 1998; El Hadidi *et al.* 1999). Nomenclature and species distribution was based mainly on Täckholm (1974), Boulos (2000, 2002) for Egypt, Collenette (1985), Chaudhary and Al-Jowaid (1999) for Saudi Arabia, and Jafri and El-Gadi (1977–1984) for Libya. The system of phytogeographical territories of Egypt proposed by El Hadidi (2000) was adopted in this study. Each territory will be here referred to as a 'biogeographic zone.' Seven major biogeographic zones were included in this study: the Mediterranean (M), Nile region (N), Eastern Desert (De), Sinai Peninsula (S), Red Sea coastal land (R), Gebel Elba (Ge) and the oases of the Western Desert (O).

The biogeographical analysis was done down to species level. The species list that formed the basis of the analysis was prepared using the authors' plant collections and field notes, and all relevant references and floras of Egypt and adjacent countries. Two levels of biogeographic analysis were considered: genera and species. For the analysis, the number of species each genus possesses weighted the importance of genera. For each species the following attributes were also recorded: life span (annual or perennial), and life form categories identified according to Raunkiaer's system of classification (Raunkiaer 1937). When several life forms were given for a species, the most representative species was chosen. The phytogeographical affinity of each taxon was also included. The latter information was determined largely from sources such as Wickens (1976), Zohary (1972) and Feinbrun-Dothan (1978). When these resources for a single taxon gave more than one phytogeographical element, the most appropriate was chosen.

Based on the presence-absence matrix of the 284 species in the seven major biogeographic zones of Egypt, cluster analysis was performed using the agglomerative algorithm UPGMA included in the Multivariate Statistical Package MVSP for Windows, version 3.1 (Kovach 1999). The obtained groups were represented in a dendrogram. Principal coordinate analysis (PCoA) was preferred, using the product-moment correlation as a coefficient. We preferred PCoA to PCA (principal component analysis) because it performs better on data sets with missing data (Rohlf 1972). Gamma diversity was calculated as the total number of species in each biogeographic zone. Species turnover (beta diversity) was calculated using Jaccard's index of similarity since it provides a way to measure species turnover between different areas (Whittaker 1960; Magurran 1988). A value of one represents complete similarity. Fifty percent turnover of species composition, termed half change, is used as the unit of beta diversity. All the statistical analyses employed SPSS for Windows version 10.0.

RESULTS AND DISCUSSION

TAXONOMIC COMPOSITION

The flora of Egypt is a widespread mid-continental flora characterized by low mean genus size and very low endemism (Fenner *et al.* 1997). It has a low level of speciation and a high level of monotypism, with very few genera having more than 30 species. The continuous geographic distribution of habitats and relative lack of reproductive isolation are perhaps the most important factors influencing the rate of speciation in this country. Khedr *et al.* (2002) found that the number of species per family in Egypt was higher in cosmopolitan families and families whose dominant mode of dispersal is abiotic and which possess a herbaceous growth habit. Yet the actual family speciation rate (i.e., number of varieties per species) did not differ in those types of families. Our results confirm that species diversity was unevenly distributed between taxonomic groups (Table 1). Family size in the Egyptian Tubiflorae was relatively high: 5 dominant cosmopolitan families (Scrophulariaceae, Boraginaceae, Labiatae, Convolvulaceae and Solanaceae) had more than 30 species comprising 87.7% (249 species of the total species in the order), and 6 families had less than 10 species each (Table 1). There were a suite of species-rich genera, but the majority (50) of the 96 genera were represented by a single species. The most species-rich genera were *Convolvulus* (23), *Heliotropium* (17), *Veronica* (13), *Solanum* (11), *Salvia* (9), *Cuscuta* and *Echium* (8 each), and *Ipomoea* and *Orobanche* (7 each). Altogether, they constitute 36.3% of the total number of the order (284), while monospecific genera (40) accounted for 14.1%.

Table 1. Summary of systematic diversity of the families of Tubiflorae in Egypt. S/G – species per genera.

Family	Number of species (S)	% of species	Number of genera (G)	S/G
Scrophulariaceae	60	21.1	17	3.5
Boraginaceae	58	20.4	19	3.0
Labiatae	54	19.0	22	2.8
Convolvulaceae	46	16.2	10	4.6
Solanaceae	31	11.0	8	3.8
Orobanchaceae	11	3.9	2	5.5
Verbenaceae	8	2.8	6	1.3
Acanthaceae	8	2.8	6	1.3
Pedaliaceae	3	1.1	3	1.0
Lentibulariaceae	2	0.7	1	2.0
Avicenniaceae	1	0.3	1	1.0
Globulariaceae	2	0.7	1	2.0
Total	284	100	96	3.0

The overall lower species/genus ratio (3.0) for the whole order may explain its higher diversity. Interestingly, lower S/G ratios (1–2) were estimated in Lentibulariaceae, Globulariaceae, Verbenaceae, Acanthaceae, Pedaliaceae and Avicenniaceae, in-

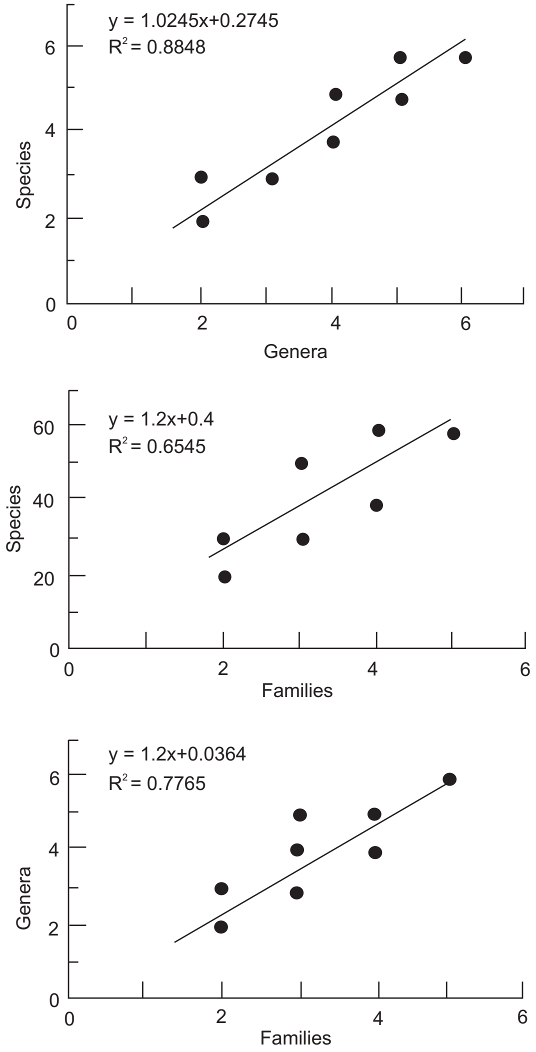

Fig. 1. Relationships between taxa richness of Egyptian Tubiflorae at different levels.

dicating higher diversity among families. The relationships among taxonomic ranks of species, the largest genera and the species-rich families with respect to their species richness, along with fitted regression equations (models), are shown in Figure 1. There was a significantly positive correlation ($p<0.005$) between species, genera and family level. Thus, the higher taxonomic units such as genera or families may be employed as surrogates for predicting species diversity in the Egyptian Tubiflorae.

LIFE STRATEGIES OF SPECIES

The life form spectrum within the families of the order showed dominance of therophytes (annuals), followed by chamaephytes and hemicryptophytes (Fig. 2). Non-succulent trees, parasites and perennial herbs (terrestrial or aquatic) were all represented by fewer species than in other categories. An overall comparison of frequencies for the different categories of life forms showed significant variation among families ($p<0.001$). Boraginaceae and Scrophulariaceae had the highest share of annuals. The uncontested leader for shrubs and shrublets was Labiatae, whereas Orobanchaceae was strictly for parasites. Notably, Convolvulaceae was the only family in which all life form categories were represented. Here we note that most genera of the Egyptian Tubiflorae had a single characteristic life form. However, some genera exhibited diversity. *Convolvulus* had several different life forms, particularly annual erect herbs, dwarf shrubs and shrublets, and twiners or climbers. *Heliotropium* had both annuals and shrubs, while *Nicotiana* was represented by two species, one a tree and the other an erect annual herb. The wide range of tolerance of the members of this order enabled the genera to occupy a wide range of habitats. For example, *Limosella* and *Bacopa* (Scrophulariaceae) were subaquatic in water courses, *Stachys* and *Thymus* (Labiatae) an indicator of stony ground (Girgis 1972), *Lamium, Convolvulus, Mentha, Veronica* and *Datura* were alien weeds of the agro-ecosystem, and *Trichodesma, Salvia, Hyoscyamus, Scrophularia*, *Lavandula* and *Lycium* were dominants of the Egyptian desert ecosystem. Though few in number, parasitic genera were of special interest. Besides *Orobanche* and *Cistanche* (Orobanchaceae), *Cuscuta* (Convolvulaceae), *Striga* (Scrophulariaceae) were encountered in this study.

The distribution of the life form categories within the seven biogeographic zones is presented in Figure 3. The composition of life forms reflects the response of vegetation to variation of certain environmental factors. In this study area, the preponderance of therophytes, chamaephytes and hemicryptophytes over other life forms is a response

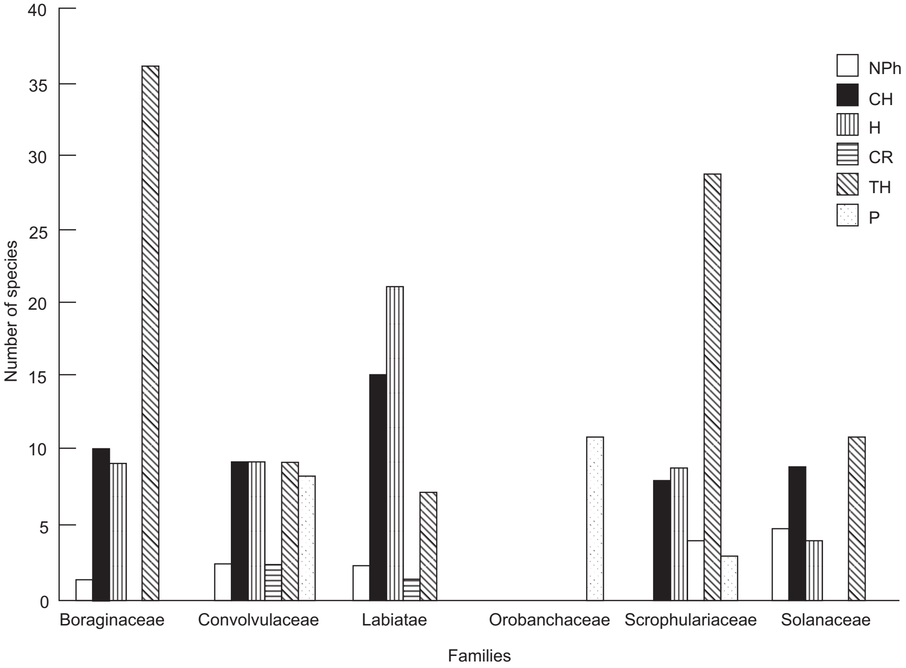

Fig. 2. Life form spectrum within the species-rich families of Tubiflorae. CH – chamaephytes, CR – cryptophytes, H – hemicryptophytes, NPh – nanophanerophytes, P – parasites, and TH – therophytes.

to the hot dry climate, topographic variations and human and animal interference (Abd El-Ghani 1998; Abd El-Ghani & Amer 2003; Salama *et al.* 2003). The abundance of cryptophytes along the Nile banks may be related to their rhizomatous growth habit, which is believed to be more resistant to decomposition under water submergence. This detected distribution pattern conforms to previous studies in this zone, especially those of Shaltout and Sharaf El-Din (1988). It is of interest to note that the trees of Tubiflorae grow well in the Mediterranean zone, while shrubs, perennial herbs and therophytes occur in Sinai. The high percentages of therophytes and hemicryptophytes coincide with the floristic characters of arid zones in the Mediterranean Basin, and in general the floras of arid and semi-arid zones (Migahid *et al.* 1971; Bornkamm & Kehl 1985; Pignatti & Pignatti 1989).

ENDEMISM

Studies have focused predominantly on determining patterns of endemism at global and regional scales (Cowling 1983; Major 1988). Endemics are usually rare and restricted to a rather small geographical region, so they deserve special attention for their conservation. No endemic families are known from the Middle East and North Africa (Boulos 1997). Zohary (1973) suggested that the source of this poverty lies in the huge stretches of open and almost plantless desert which provide no isolating barrier against contact with adjacent countries, themselves part of the extremely barren Sahara. The major families with the highest numbers of endemic species in tropical areas are Asclepiadaceae, Acanthaceae, Liliaceae (*sensu lato*) and Euphorbiaceae, and in temperate areas Labiatae, Compositae, Scrophulariaceae and Cruciferae. Taxa endemic to Egypt are very few: 61 species or 2.9% of the total flora; 60.7% of these endemics are known from Sinai (Boulos 1995; Ayyad *et al.* 2000). The highest endemism within families of the Egyptian vascular flora is in Labiatae (10.9%), followed by Liliaceae (10.4%) and Scrophulariaceae (6.5%).

It has been estimated that 8 endemic and 14 near-endemic species are in taxa of the Egyptian

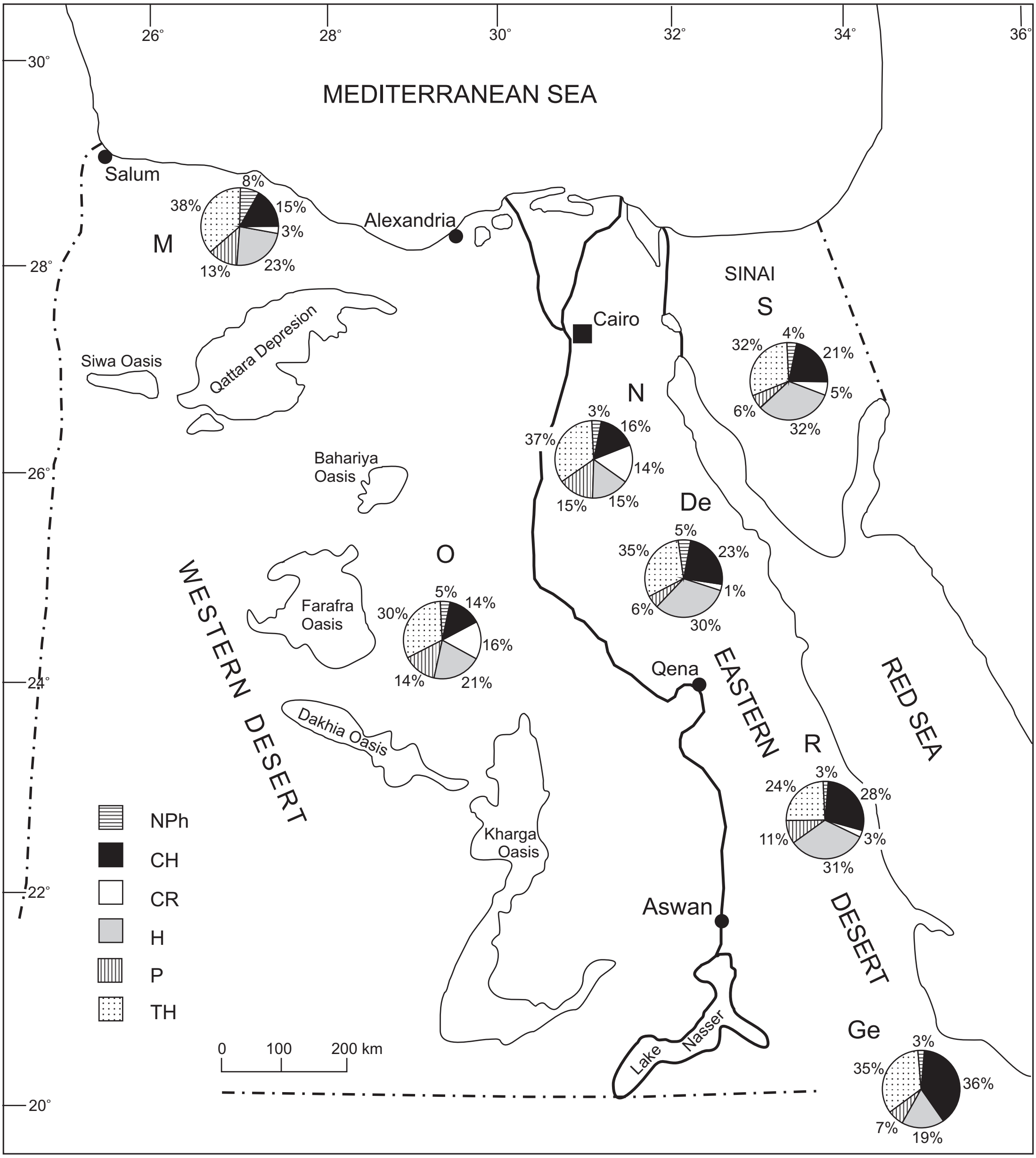

Fig. 3. Distribution of life forms in different biogeographic zones of Egypt. De – Eastern Desert, Ge – Gebel Elba, M – Mediterranean, N – Nile region, R – Red Sea coastal land, S – Sinai Peninsula, and O – oases; for abbreviations of life forms see Fig. 2.

Tubiflorae. This study showed that the majority of the endemic species in the Tubiflorae of Egypt were recorded from southern Sinai (Sinai proper *sensu* El Hadidi 2000) in the rugged mountainous areas that have the highest peaks in Egypt (Zohary 1973; Moustafa & Klopatek 1995). Labiatae (4 species) and Scrophulariaceae (3 species) were the families with the higher concentration of endemics. *Teucrium* and *Veronica* were endemic-rich genera. Similarly, Libya and Saudi Arabia have most of their endemics in mountainous regions: Gebel Akhdar in Libya (Boulos 1975), and the highlands of southwestern Saudi Arabia (Chaudhary 1999–2001). Both are considered endemic-rich areas for vascular plants of the Middle East (Boulos 1997).

Comparing the level of endemism among the species of Tubiflorae in the regional floras of Egypt, Libya and Saudi Arabia, we found that endemic species (*sensu lato*) were not very numerous and can be estimated at 39 taxa (Table 2). The highest number of endemics was recorded in Libya (13.0 or 7.5% of the total flora), followed by Egypt (8 or 11% of the total flora), and none in the flora of Saudi Arabia. At the generic level, 6 genera were restricted or nearly restricted to Libya (*Onosma, Convolvulus, Ballota, Teucrium, Parentucellia, Orobanche*), and three to Egypt (*Phlomis, Anarrhinum, Hyoscyamus*). Among genera of Mediterranean Africa, *Teucrium* is the one with with the highest endemism. It is represented by 67 species, of which 44 or 65.7% are endemic (Greuter *et al.* 1986). Despite the importance of endemic species in their regional floras, they have been poorly studied. More research is needed on the management requirements of the endemic taxa in the Middle East and Mediterranean North Africa.

VARIATION OF GAMMA AND BETA DIVERSITY

Gamma diversity differed considerably among the studied biogeographic zones of Egypt (Table 3). The Sinai Peninsula was the richest in species (171); the number of species was lowest in the oases of the Western Desert (43) and along the Red Sea coastal lands (39). Interestingly, the highest significant values of Sørensen's coefficient of floristic similarity (0.4, $p = 0.01$) and species turnover (0.6) were found for the oases and the Nile land (Table 4). Clearly, the floristic composition of these two zones is closely related, with many species in common. Fakhry (1973, 1974) reported the existence of a historical connection between the two biogeographic zones. Until 1968, all travellers and government officials used an important ancient caravan route linking the oases with the Nile Valley (near Minya on the Nile) for oasis commerce. The low gamma diversity and species turnover of the Gebel Elba may be related to the fact that most of its species are highly specific to the prevailing environmental conditions and geographic situation. This means that species replacement or biotic change is low in this area (Wilson & Shmida 1984). The combined effect of climate (temperature, rainfall) and human activities (grazing, building of new settlements, establishment of summer resorts) along the coasts of the Mediterranean and the Red Sea substantially altered the vegetation structure and the floristic composition of these biogeographic zones, creating new habitats not found earlier (Ayyad & Fakhry 1996), with reduced gamma and beta diversity.

Climatic zonation is probably the most important factor influencing plant distribution, particularly summer heat, winter cold and precipitation (Zahran & Willis 1992). On the other hand, as minimal precipitation and frequent droughts characterize arid zones, water availability may be one of the primary factors controlling the distribution of species (Yair & Danin 1980; Abd El-Ghani 2000). Table 5 gives some climate data from selected meteorological stations climatic characteristics of selected sites to represent each of the studied biogeographic zones. The most striking climatic feature is the precipitation gradient. Temperatures below zero can be reached in the more continental parts of the Western Desert, and soil surface frost is a regular phenomenon in the mid-winter months. The gamma diversity gradient decreases from the less arid Sinai Peninsula to the more arid oases and Red Sea coastal lands.

We studied the combined effect of temperature and precipitation on gamma diversity of Tubiflorae in the seven studied biogeographic zones. When the correlation analyses were performed independently for temperature or rainfall at each zone with gamma diversity, the results showed weak correlations (Spearman rank correlation coefficient $r = 0.175$, $p = 0.43$ for temperature; $r = 0.23$, $p = 0.27$ for rainfall), but gamma diversity showed high significant positive correlations with both temperature and rainfall in Sinai ($r = 0.39$, $p = 0.01$), but not in the Mediterranean zone ($r = 0.17$, $p = 0.50$), nor in the oases ($r = 0.67$, $r = 0.01$). Therefore, colder temperature and rela-

Table 2. Endemic and near-endemic species in the species-rich families of Tubiflorae of Egypt, Libya and Saudi Arabia. + – present.

Taxa	Endemics			Near-Endemics		
	Libya	Egypt	Saudi Arabia	Libya	Egypt	Saudi Arabia
Boraginaceae						
Heliotropium longiflorum (A. DC.) Hochst & St. *ex* Bunge						+
Nonea viviani A. DC.				+	+	
Onosma cyrenaica Durand & Barratte	+					
Convolvulaceae						
Convolvulus maireanus Pamp.	+					
C. shimperi Boiss.					+	+
C. spicatus Hallier.f.					+	
Labiatae						
Ballota andreuzziana Pamp.	+					
Marrubium deserti Noe *ex* Coss.				+		
Micromeria guichardii (Quézel & Zaffran) Brullo & Furnari	+					
M. serbaliana Danin & Hedge		+				
Nepeta cyrenaica Quézel & Zaffran						
N. septemcrenata Benth.					+	+
N. vivianii (Coss.) Bég. & Vacc.	+					
Origanum cyrenaicum Bég. & Vacc.	+					
O. isthmicum Danin		+				
O. syriacum L. subsp. *sinaicum* (Boiss.) Greuter & Burdet		+				
Phlomis aurea Decan.		+				
Stachys tournefortii Poiret				+		
Teucrium apollinis Maire & Weiller	+					
T. barbeyanum Ascher. & Taubert	+					
T. davaeanum Cosson	+					
T. lini-vaccarii Pamp.	+					
T. zanonii Pamp.	+					
Thymus decussatus Benth.					+	+
Orobanchaceae						
Orobanche cyrenaica Beck	+					
Scrophulariaceae						
Anarrhinum forsskalii (J. E. Gmel.) Cufod. subsp. *pubescens* (Fresen.) D. A. Sutton		+				
Kickxia floribunda (Boiss.) Täckh. & Boulos					+	+
K. macilenta (Decne.) Danin					+	
K. pseudoscoparia V. W. Smith & D. A. Sutton					+	+
Linaria joppensis Bornm.					+	
Parentucellia floribunda Viv.	+					
Verbascum fruticulosum Post					+	+
V. letourneuxii Asch.				+	+	
V. schimperianum Boiss.					+	+
Veronica anagallis-aquatica L. var. *nilotica* R. Uechtr.					+	
V. kaiseri V. Täckh.		+				
V. musa V. Täckh. & Hadidi		+				
Solanaceae						
Hyoscyamus boveanus (Dunall) Asch. & Schweinf.		+				
Solanum sinaicum Boiss.					+	

Table 3. Gamma diversity of the families of Tubiflorae recorded in the studied biogeographic zones of Egypt, with their total numbers and percentages (for abbreviations see Fig. 3).

Family	Biogeographic zone						
	N	M	O	S	R	GE	De
Scrophulariaceae	18	13	9	36	10	12	13
Boraginaceae	27	28	7	39	9	13	19
Labiatae	3	15	3	42	4	8	17
Convolvulaceae	17	17	11	22	5	19	12
Solanaceae	15	10	7	21	4	8	13
Orobanchaceae	6	10	2	6	3	2	4
Verbenaceae	4	3	3	2	1	3	0
Acanthaceae	0	0	0	1	1	8	2
Pedaliaceae	0	0	0	0	0	2	1
Lentibulariaceae	1	0	1	0	0	0	0
Avicenniaceae	0	0	0	1	1	1	0
Globulariaceae	0	2	0	1	1	0	1
Total number of species	91	98	43	171	39	76	82
% of the total	32	34.5	15.1	60.2	13.7	26.7	28.9

tively high precipitation may play a major role in decreasing species richness. The relationship between climate and species distribution has long been studied in other parts of the world: among others, Freitag (1986) in Iran and Afghanistan, Rahman and Wilcok (1991) in southeast Asia and the Indian Subcontinent, Cowling *et al.* (1994) in arid and semi-arid southern Africa, and Gómez-Gonzáles *et al.* (2004) in the Iberian Peninsula and Balearic Islands.

GEOGRAPHICAL EXPANSION AND LOCAL DISTRIBUTION PATTERN

Our results demonstrated a very strong geographical pattern in the distribution of the Egyptian species of Tubiflorae. There were few highly frequent species and very many that were infrequent. The majority of species were narrowly distributed. Almost half (48%) of the species showed a certain degree of consistency, where they were confined to a single biogeographic zone (Table 6). These species were distributed as follows: 18 in the Nile land (e.g., *Ipomoea carnea, Heliotropium amplexicaule, Limosella aquatica, Striga hermonthica, Lentibularia inflexa*), 22 in the Mediterranean (e.g., *Echium plantagineum, Thymus capitatus, Veronica persica, Globularia alypum, Cistanche violacea*), 2 in the oases (*Striga gesnerioides, Utricularia gibba*), 54 in the Sinai Peninsula (e.g., *Paracaryum calathicarpum, Alkanna orientalis, Thymus decussatus, Nepeta septemcrenata, Solanum sinaicum, Verbascum schimperianum, Kickxia macilenta, Veronica kaiseri*), one in the Red Sea (*Kickxia nubica*), 34 in Gebel Elba (e.g., *Seddera arabica, Heliotropium zeylanicum, Lantana rugosa, Leucas urticifolia, Barleria hochstetteri, Peristrophe paniculata*) and 5 in the Eastern Desert (e.g., *Ipomoea pes-caprae, Podonosma galalense, Lavandula multifida*). Only 2 (*Trichodesma africanum, Solanum nigrum*) of the 284 species that have a wide ecological and coenological range of distribution occur in all 7 studied biogeographic zones, and 29 species (*ca* 10% of the total) had a frequency of more than 50% (i.e., recorded in 4 zones; see Fig. 4).

Figure 5 shows the dendrogram obtained with UPGMA clustering of species according to geographical similarity. Four floristic groups (1–4) of Tubiflorae were detected for Egypt. The PCoA results support this classification (Fig. 6). Floristic group 1 includes the species of Tubiflorae in both the Nile lands and the oases, as these two regions were closely related either commercially or through the introduction of field crops. Several common alien weed species of arable land may grow in both agro-ecosystems. This is consistent with the findings of Abd El-Ghani and El-Sawaf (2004)

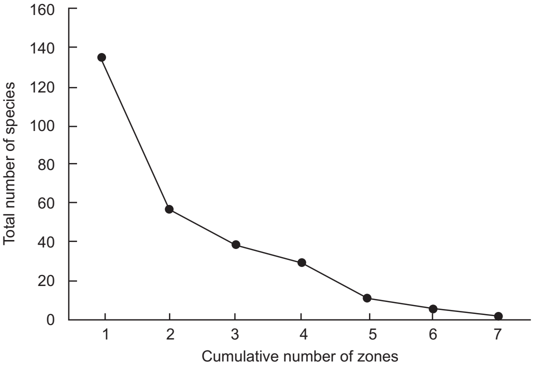

Fig. 4. Species distribution in the biogeographic zones (cumulative numbers).

Table 4. Sørensen coefficients of floristic similarity (lower half), and beta diversity (upper half) between the seven studied biogeographic zones of Egypt. * = $p<0.05$, ** = $p<0.01$ (for abbreviations see Fig. 3).

Biogeographic zone	N	M	O	S	GE	De	R
N		0.5	0.6	0.4	0.2	0.4	0.1
M	0.3		0.3	0.5	0.1	0.3	0.2
O	0.4**	0.2		0.2	0.2	0.2	0.1
S	0.2	0.3	0.1		0.2	0.5	0.2
GE	0.1	0.07	0.1	0.2		0.3	0.4
De	0.2	0.2	0.1	0.3*	0.2		0.3
R	0.1	0.02	0.04	0.2*	0.3*	0.3*	
Gamma diversity	91	98	43	171	76	82	39

in their account of the diversity and distribution of plant species in the agro-ecosystems of Egypt; they reported a clearer segregation of the species composition in both the Nile lands and the oases biogeographic zones than in the others.

Floristic group 2 characterizes the Mediterranean region, in which 34.5% of the species of Tubiflorae were recorded. Certain families showed higher presence in this zone (e.g., Orobanchaceae, Globulariaceae). Despite the length of the shores on the Mediterranean Sea, the gamma diversity of Tubiflorae ranked second. The primary cause of the decline of biodiversity is not direct human exploitation but the habitat destruction that inevitably results from the expansion of human populations and human activities (Wilson 1988). The western Mediterranean coastal strip has been subjected to ecosystem degradation and species impoverishment due to the way in which man has used and misused the natural resources of the zone. A variety of human-induced stresses have already taken their toll on ecosystems. With so many habitats being lost, the populations of many species are being dramatically reduced. Continued uncontrolled wood-cutting, overgrazing and rain-fed farming for cultivation of annual crops have dominated the Mediterranean zone for centuries. More recent land uses have been even more devastating; these include intensive irrigated agriculture, excavation of limestone ridges for brickmaking, which endangers many chasmophytic species, and the occupation of large areas of coastal sand dunes by summer resorts, which endangers many psammophytic species. Ayyad and Fakhry (1996) made an overview of plant biodiversity in the western Mediterranean desert of Egypt in terms of habitat, community and species diversity. They concluded that human impacts on biodiversity may be either sudden and/or radical (e.g., establishment of new settlements and summer resorts) or gradual (e.g., grazing of wild vegetation). Generally, loss of species is the ultimate result.

Table 5. Annual means of climatic data of representative meteorological stations in each of the studied biogeographic zone (after Zahran & Willis 1992; Abd El-Ghani 1998, 2000). Max – maximum, Min – minimum.

Biogeographic zone	Temperature (°C)		Rainfall (mm year $^{-1}$)	Relative humidity (%)
	Max	Min		
Mediterranean				
Sallum	24	14	90	65
Mersa Matruh	24	14	144	66
Alexandria	25	16	192	68
El-Arish	26	12	180	70
Nile land				
Menofiya	28	14	3	65
Faiyum	29	14	11	51
Luxor	33	16	<1	35
Oases of the Western Desert				
Siwa	30	13	10	41
Bahariya	30	14	4	39
Kharga	32	16	<1	31
Sinai proper (south Sinai)				
Saint Catherine	25	5	45	38
Red Sea coastal lands				
Suez	31	17	16	53
Hurghada	28	19	4	46
Quseir	28	19	3	50

Table 6. Distribution patterns of species of the Egyptian Tubiflorae confined to a certain biogeographic zone. For zone abbreviations, see Fig. 3. + – recorded.

Species	Biogeographic zone						
	N	M	O	S	R	GE	De
Ipomoea carnea Jacq.	+						
I. eriocarpa R.Br.	+						
Dichondra micrantha Urb.	+						
Cuscuta monogyna Vahl	+						
C. epilinum Weihe	+						
Heliotropium curassavicum L.	+						
H. amplexicaule Vahl	+						
Clerodendrum acerbianum (Vis.) Benth. & Hook.f.	+						
Physalis angulata L.	+						
Salpichroa origanifolia (Lam.) Baill.	+						
Nicotiana plumbaginifolia Viv.	+						
Sutera glandulosa Roth	+						
Limosella aquatica L.	+						
Striga hermonthica (Delile) Benth.	+						
S. asiatica (L.) Kuntze	+						
Parentucellia viscosa (L.) Caruel	+						
Lindernia parviflora (Roxb.) Haines	+						
Utricularia inflexa Forssk.	+						
Convolvulus humilis Jacq.		+					
C. lineatus L.		+					
C. stachydifolius Choisy		+					
Calystegia silvatica (Kit.) Griseb.		+					
Heliotropium hirsutissimum Grauer		+					
Buglossoides incrassata (Guss.) I. M. Johnst.		+					
Nonea melanocarpa Boiss.		+					
Echium glomeratum Poir.		+					
E. plantagineum L.		+					
E. sabulicola Pomel		+					
Thymus capitatus (L.) Link		+					
Prasium majus L.		+					
Teucrium brevifolium Schreb.		+					
Linaria micrantha (Cav.) Hoffmanns. & Link		+					
Scrophularia canina L.		+					
Veronica anagalloides Guss. subsp. *taeckholmiorum* Chrtek & Osb.-Kos.		+					
V. persica Poir.		+					
V. syriaca Roem. & Schult.		+					
Globularia alypum L.		+					
Orobanche lavandulacea Rchb.		+					
O. schultzii Mutel		+					
Cistanche violacea (Desf.) Beck		+					
Striga gesnerioides (Willd.) Vatke			+				
Utricularia gibba L.			+				
Convolvulus spicatus Hallier f.				+			
C. schimperi Boiss.				+			
C. scammonia L.				+			

Table 6. *Continued*

Species	Biogeographic zone						
	N	M	O	S	R	GE	De
C. palaestinus Boiss.				+			
Heliotropium bovei Boiss.				+			
H. makallense O. Schwartz				+			
Paracaryum rugulosum (DC.) Boiss.				+			
P. bungei (Boiss.) Brand				+			
P. calathicarpum (Stocks) Boiss.				+			
Lappula sinaica (DC.) Asch. & Schweinf.				+			
Asperugo procumbens L.				+			
Alkanna orientalis (L.) Boiss.				+			
A. strigosa Boiss. & Hohen.				+			
Nonea ventricosa (Sm.) Griseb.				+			
Mentha spicata L.				+			
Origanum syriacum L. subsp. *sinaicum* (Boiss.) Greuter & Burdet				+			
O. isthmicum Danin				+			
Thymus decussatus Benth.				+			
Satureja serbaliana (Danin & Hedge) Greuter & Burdet				+			
S. myrtifolia (Boiss. & Hohen.) Greuter & Burdet				+			
Ziziphora capitata L.				+			
Z. tenuior L.				+			
Salvia multicaulis Vahl				+			
S. dominica L.				+			
S. sclarea L.				+			
Nepeta septemcrenata Benth.				+			
Stachys nivea Labill.				+			
Ballota saxatilis C. Presl				+			
B. kaiseri Täckh.				+			
Phlomis aurea Decne.				+			
Eremostachys laciniata (L.) Bunge				+			
Ajuga chamaepitys (L.) Schreb. subsp. *tridactylites* (Benth.) P. H. Davis				+			
Solanum sinaicum Boiss.				+			
S. villosum (L.) Mill.				+			
Nicotiana rustica L.				+			
Hyoscyamus reticulatus L.				+			
Verbascum fruticulosum Post				+			
V. schimperianum Boiss.				+			
V. sinaiticum Benth.				+			
V. eremobium Murb.				+			
V. decaisneanum Kuntze				+			
Anarrhinum pubescens Fresen.				+			
Linaria joppensis Bornm.				+			
L. simplex Desf.				+			
Kickxia macilenta (Decne.) Danin				+			
K. scariosepala Täckh. & Boulos				+			
Scrophularia libanotica Boiss.				+			
Veronica kaiseri Täckh.				+			
V. macropoda Boiss.				+			

Table 6. *Continued*

Species	Biogeographic zone						
	N	M	O	S	R	GE	De
V. campylopoda Boiss.				+			
Kickxia nubica (Skan) Dandy					+		
Convolvulus rhyniospermus Choisy						+	
Jacquemontia tamnifolia (L.) Griseb.						+	
Merremia aegyptia (L.) Urb.						+	
M. semisagitata (Peter) Dandy						+	
Ipomoea obscura (L.) Ker Gawl.						+	
Evolvulus alsinoides (L.) L.						+	
E. nummularius (L.) L.						+	
Seddera arabica (Forssk.) Choisy						+	
Cuscuta chinensis Lam.						+	
Heliotropium zeylanicum (Burm.f.) Lam.						+	
H. strigosum Willd.						+	
Brandella erythraea (Brand) R. R. Mill						+	
Lantana viburnoides (Forssk.) Vahl						+	
L. rugosa Thunb.						+	
Priva cordifolia (L.) Greene						+	
Plectranthus hadiensis (Forssk.) Spreng.						+	
Orthosiphon pallidus Royle *ex* Benth.						+	
Satureja biflora (D. Don) Briq.						+	
Leucas neuflizeana Courbai						+	
L. urticifolia (Vahl) R. Br.						+	
Solanum aethiopicum L.						+	
S. carense Dunal						+	
S. forsskaolii Kotschy *ex* Dunal						+	
Kickxia hastata (R. Br. *ex* Benth.) Dandy						+	
Scrophularia arguta Sol.						+	
Schweinfurthia pedicellata (T. Anderson) Balf.f.						+	
Barleria hochstetteri Nees						+	
Ruellia patula Jacq.						+	
Ecbolium viride (Forssk.) Alston						+	
Justicia heterocarpa T. Anderson						+	
J. schimperi (Hochst.) Dandy						+	
Peristrophe paniculata (Forssk.) Brummitt						+	
Pedalium murex L.						+	
Rogeria adenophylla J. Gay *ex* Delile						+	
Ipomoea pes-caprae (L.) R. Br.							+
Podonosma galalensis Schweinf. *ex* Boiss.							+
Lavandula atriplicifolia Benth.							+
L. multifida L.							+
Sesamum alatum Thonn.							+
Cressa cretica L.	+	+	+	+	+	+	
Cuscuta planiflora Ten.	+	+	+	+	+	+	
Hyoscyamus muticus L.	+	+	+	+	+	+	
Orobanche ramosa L.	+	+	+	+	+	+	
Trichodesma africanum (L.) var. *africanum*	+	+	+	+	+	+	+
Solanum nigrum L.	+	+	+	+	+	+	+

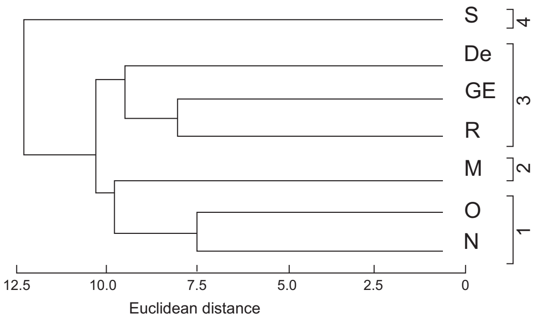

Fig. 5. UPGMA dendrogram of similarity among the analyzed biogeographic zones. 1–4 – floristic groups (for abbreviations of zones see Fig. 3).

Floristic group 3 includes three closely related biogeographic zones; the Eastern Desert, Gebel Elba and the Red Sea coastal lands. It is not surprising that these three zones form one entity; they can be called the 'Eastern Desert complex' group. Forty-nine species of the order were found in this complex of narrowly and widely distributed species (Table 6). *Podonosma galalensis, Sesamum alatum, Satureja biflora* and *Leucas neufliziana* were recorded in the three zones.

Geographical areas with high species richness, high endemism, and/or a high number of rare or threatened species have been defined as biodiversity hotspots, and are considered in setting priorities for conservation planning (Myers 1990; Reid 1998). In spite of its interesting biogeographical and botanical features, the Gebel Elba mountain range has been overlooked in most global biodiversity assessments (Heywood & Watson 1995). Of the 142 threatened woody perennial plant species in *The Plant Red Data Book of Egypt* (El Hadidi *et al.* 1992), 56 or 39.4% are known from the Gebel Elba area. Endangered and rare species include *Seddera arabica* (Forssk.) Choisy (Convolvulaceae), *Cordia sinensis* Lam. (Boraginaceae), *Lantana viburnoides* (Forssk.) Vahl (Verbenaceae) and *Solanum albicaule* Ky. *ex* Dun (Solanaceae). Its ecological features, together with its particular geographic location, seem to have promoted plant diversity, singularity and endemism in this biogeographic zone. It comprises elements of the Sahelian regional transition zone (*sensu* White & Léonard 1991) and represents the northern limit of this geoelement in Africa. A phytogeographical analysis of some arboreal species in Egypt revealed that the Red Sea coast represents the main pathway for penetration of arboreal species to Egypt, together with the southern border of the Western and Eastern Deserts (Hassan & Abd El-Ghani 1992).

The Sinai group, group 4, represents the most diversified and species-rich zone of the Egyptian Tubiflorae. The natural conditions and geographical location of the Sinai Peninsula make it a very distinctive region. The Sinai Desert is a 'Saharan type' desert (Mcginnies *et al.* 1968) linking Asia with Africa, and constitutes a transition between the Egyptian Deserts and those of the Middle East. The great diversity of climate (mean annual precipitation ranges from *ca* 100 mm in the north near the Mediterranean to 5–30 mm in the south) and of rock and soil types provides habitats for some 900 species and 200–300 associations (Danin 1986). It is also interesting phytogeographically, as it borders the Mediterranean, Irano-Turanian, Saharo-Arabian and Sudanian regions (Zohary 1973). Recent studies on plant diversity in southern Sinai (Moustafa & Klopatek 1995; Moustafa *et al.* 2001) reported that many species were now under threat due to severe human impacts such as over-cutting for fuel, over-collection, overgrazing, tourism and urbanization. The Labiatae, Compositae and Gramineae contribute many of these species. Threatened endemic species of the St. Catherine area (southern Sinai) are stressed by grazing due to their high palatability for domestic animals (e.g., *Anarrhinum pubescens, Veronica islensis, V. kaiseri*) or are used frequently in folk medicine and gradually are diminishing in coverage and number (e.g., *Nepeta septemcrenata, Ballota kaiseri*).

OCCURRENCE OF THE TUBIFLORAE IN ADJACENT COUNTRIES

The highlands of western Saudi Arabia and Gebel Akhdar in northeastern Libya are among the major species-rich and endemite-rich areas in the Middle East (Boulos 1997). The distribution of species within the major six families (Boraginaceae, Convolvulaceae, Labiatae, Orobanchaceae, Scrophulariaceae, Solanaceae) of the Tubiflorae in Egypt, Gebel Akhdar (Libya) and western Saudi Arabia,

Table 7. Occurrence of species (excluding endemics) within the major six families of the Tubiflorae in Egypt, Libya and Saudi Arabia. + – recorded. Borag. – Boraginaceae, Conv. – Convolvulaceae, Lami – Lamiaceae, Orob. – Orobanchaceae, Scro. – Scrophulariaceae, Solan. – Solanaceae. ES – Euro-Siberian, M – Mediterranean, IT – Irano-Turanian, SA – Saharo-Arabian, SZ – Sudano-Zambezian, COSM – cosmopolitan, Nat – naturalized, PAL – palaeotropical, PAN – pantropical. Sources: [1] – S. El-Naggar; unpublished data, [2] – M. Abd El-Ghani; unpublished data.

Species	Family	Libya[1]	Egypt	Saudi Arabia[2]	Chorotype
Borago officinalis L.	Borag.	+			M
Cynoglossum cheirifolium L.	Borag.	+			M
Echium arenarium Guss.	Borag.	+			M
E. humile Desf.	Borag.	+			M
E. italicum L.	Borag.	+			M
E. parviflorum Moench	Borag.	+			M
E. tuberculatum Hoffmanns & Link	Borag.	+			M
Elizaldia calycina (Roem. & Schultes) Maire	Borag.	+			M
Nonea micrantha Boiss. & Reuter	Borag.	+			M
N. vesicaria (L.) Reichenb.	Borag.	+			M
Convolvulus supinus Cosson & Kralik	Conv.	+			M
C. tricolor L.	Conv.	+			M
Ballota hirsute Benth.	Lami.	+			M
Linaria laxiflora Desf.	Lami.	+			M
Micomeria Juliana (L.) Reichenb.	Lami.	+			M
Nepeta scordotis L.	Lami.	+			M
Phlomis floccosa D. Don	Lami.	+			M
Teucrium campanulatum L.	Lami.	+			M
Thymus algeriensis Boiss. & Reut.	Lami.	+			M
Anarrhinum fruticosum Desf.	Scro.	+			M
Antirrhinum siculum Mill.	Scro	+			M
Bellardia trixago (L.) All.	Scro,	+			M
Parentucellia latifolia (L.) Caruel	Scro.	+			M
Verbascum balli (Batt.) Qaiser	Scro.	+			M
V. blatteria Boiss.	Scro.	+			M
V. tripolitanum Boiss.	Scro.	+			M
V. cymbalaria Bod.	Scro.	+			M
Neatostema apulum (L.) I. M. Johns.	Borag.	+			M + SA
Cuscuta epithymum (L.) Murray	Conv.	+			M + SA
C. europaea L.	Conv.	+			M + SA
Mentha aquatica L.	Lami.	+			M + SA
Veronica hederifolia L.	Scro.	+			M + SA
Convolvulus cantabaricus L.	Conv.	+			M + IT
Sideritis curvidens Stapf	Conv.	+			M + IT
Scrophularia peregrina L.	Scro.	+			M + IT
Linaria arvensis (L.) Desf.	Scro.	+			M + ES
Veronica agrestis L.	Scro.	+			M + ES
Sideritis romana L.	Conv.	+			IT + Libya
Veronica peregrine L.	Scro.	+			ES (Nat.)
Ipomoea cairica (L.) Sweet	Conv.		+		PAL
Ipomoea eriocarpa R. Br.	Conv.		+		PAL
Ipomoea purpurea (L.) Roth.	Conv.		+		PAL
Jacquemontia tamnifolia Choisy	Conv.		+		PAL
Lindernia parviflora (Roxb.) Haines	Scro.		+		PAL
Ipomoea carnea Jacq.	Conv.		+		PAN
Ipomoea obscura (L.) Ker Gawl.	Conv.		+		PAN
Marremeia aegyptiaca (L.) Urb.	Conv.		+		PAN
Solanum elaeagnifolium Cav.	Solan.		+		PAN
Ballota damascene Boiss.	Lami.		+		M
Micromeria sinaica Benth.	Lami.		+		M
Salvia dominica L.	Lami.		+		M
Veronica scardica Griseb.	Scro.		+		M

Table 7. *Continued*

Species	Family	Libya	Egypt	Saudi Arabia	Chorotype
Podonosma galalensis Schweinf. & Boiss.	Borag.		+		SA
Convolvulus hystrix Vahl	Conv.		+		SA
Verbascum eremobium Murb.	Scro.		+		SA
Veronica rubrifolia Boiss. subsp. *respectatissima* M. A. Fisch.	Scro.		+		SA
Nogalia drepanophylla (Baker) Verdc.	Borag.		+		SZ
Evolvulus nummularis (L.) L.	Conv.		+		SZ
Kickxia nubica (Skan) Dandy	Conv.		+		SZ
Paracaryum calathicarpum (Stacks) Boiss.	Conv.		+		IT
Convolvulus palaestinus Boiss.	Conv.		+		IT
Kickxia gracilis (Benth.) D. A. Sutton	Scro.		+		IT
Echium glomeratum Poiret	Borag.		+		M + SA
Alkanna strigosa Boiss. & Hohen.	Borag.		+		M + IT
A. orientalis (L.) Boiss.	Borag.		+		M + IT
Heliotropium bovei Boiss.	Borag.		+		M + IT
H. rotundifolium Lehm.	Borag.		+		M + IT
Nonea melanocarpa Boiss.	Borag.		+		M + IT
Convolvulus scammonia L.	Conv.		+		M + IT
Convolvulus stachydifolius Choisy	Conv.		+		M + IT
Cuscuta monogyna Vahl	Conv.		+		M + IT
Cuscuta palaestina Boiss.	Conv.		+		M + IT
Ballota saxatilis C. Presl	Lami.		+		M + IT
Eremostachys laciniata (L.) Bunge	Lami.		+		M + IT
Salvia multicaulis Vahl	Lami.		+		M + IT
Salvia palaestina Benth.	Lami.		+		M + IT
Salvia sclarea L.	Lami.		+		M + IT
Hyoscyamus reticulatus L.	Solan.		+		M + IT
Nonea ventricosa (Sm.) Griseb.	Borag.		+		M + ES
Kickxia elatine (L.) Dumort.	Scro.		+		M + ES
Veronica catenata Pennell	Scro.		+		M + ES
Lappula sinaica (A. DC.) Asch. & Scweinf.	Borag.		+		SA + IT
Cistanche salsa (C. A. Mey.) C. Beck	Orob.		+		SA + IT
Anticharis linearis (Benth.) Hochst. & Asch.	Scro.		+		SA + IT
Veronica campylopoda Boiss.	Scro.		+		SA + IT
Striga asiatica (L.) Kuntze	Scro.		+		SA + SZ
Paracaryum intermedium (Fresen.) Lipsky	Scro.		+		M + SA + IT
Cuscuta approximate Bab.	Conv.		+		M + SA + IT
Scrophularia sinaica Benth.	Scro.		+		M + SA + IT
Calystegia silvatica (Kit.) Griseb.	Conv.		+		M + IT + ES
Cuscuta epilinum Weihe	Conv.		+		M + IT + ES
Ziziphora capitata L.	Lami.		+		M + IT + ES
Z. tenuior L.	Lami.		+		SA + IT + ES
Dicandra micrantha Urb.	Conv.		+		Nat.
Ipomoea hederacea Jacq.	Conv.		+		Nat.
Ipomoea pes-caprae (L.) R. Br.	Conv.		+		Nat.
Nicotiana plumbaginifolia Viv.	Solan.		+		Nat.
Nicotiana rustica L.	Solan.		+		Nat.
Physalis angulata L.	Solan.		+		Nat.
Physalis ixocarpa Hornem.	Solan.		+		Nat.
Cordia abyssinica R. Br.	Borag.			+	SZ
Ocimum hadinese Forssk.	Lami.			+	SZ
Cressa cretica L.	Conv.	+	+	+	COSM
Convolvulus arvensis L.	Conv.	+	+	+	COSM
Lamium amplexicaule L.	Lami.	+	+	+	COSM
Mentha pulegium L.	Lami.	+	+	+	COSM
Teucrium polium L.	Lami.	+	+	+	COSM
Datura sramonium L.	Solan.	+	+	+	COSM
Solanum schimperianum Hochst. & A. Rich	Solan.	+	+	+	COSM

Table 7. *Continued*

Species	Family	Libya	Egypt	Saudi Arabia	Chorotype
Ajuga iva (L.) Schreb.	Lami.	+	+	+	M
Salvia verbenaca L.	Lami.	+	+	+	M
Arnebia tinctoria Forssk.	Borag.	+	+	+	SA
Echium longifolium Delile	Borag.	+	+	+	SA
Ogastema pusillum (Bonett & Barratte) Brummitt	Borag.	+	+	+	SA
Convolvulus prostrates Forssk.	Conv.	+	+	+	SA
Teucrium decaisne C. Presl	Lami.	+	+	+	SA
Misopates orontium (L.) Rafin.	Scro.	+	+	+	SA
Scrophularia canina L.	Scro.	+	+	+	SA
Scrophularia hypericifolia Wydl.	Scro.	+	+	+	SA
Scrophularia libanotica Boiss.	Scro.	+	+	+	SA
Echiochilon fruticosum Desf.	Borag.	+	+	+	M + SA
Echium horridum Batt.	Borag.	+	+	+	M + SA
Echium rauwolfii Delile	Borag.	+	+	+	M + SA
Trichodesma africanum (L.) R. Br.	Borag.	+	+	+	M + SA
Heliotropium hirsutissimum Grauer	Borag.	+	+	+	M + SA
Linaria albifrons (Sm.) Spreng.	Scro.	+	+	+	M + SA
Linaria haelava (Forssk.) F. Dietr.	Scro.	+	+	+	M + SA
Linaria simplex Desf.	Scro.	+	+	+	M + SA
Linaria tenuis (Viv.) Spreng.	Scro.	+	+	+	M + SA
Kickxia aegyptiaca Nàbělek	Scro.	+	+	+	M + SA
Scrophularia arguta Sol.	Scro.	+	+	+	M + SA
Cistanche phelypaea (L.) Cout.	Orob.	+	+	+	M + SA
Orobanche cernua Loefl.	Orob.	+	+	+	M + SA
Hyoscyamus albus L.	Solan.	+	+	+	M + SA
Lycium europaeum L.	Solan.	+	+	+	M + SA
Anarrhium forsskahlii (J. E. Gmel.) Cufod. subsp. *forsskahli*	Scro.	+	+	+	M + SZ
Moltkiopsis ciliata (Forssk.) I. M. Johns.	Borag.	+	+	+	M + IT
Convolvulus siculus L.	Conv.	+	+	+	M + IT
Mentha longifolia (L.) Huds. subsp *typhoides* (Briq) Harley	Lami.	+	+	+	M + IT
Salvia lanigera Poir.	Lami.	+	+	+	M + IT
Cistanche tubulosa (Schenk) Wight	Orob.	+	+	+	M + IT
Orobanche mutelii F. W. Schultz	Orob.	+	+	+	M + IT
Veronica polita Fr.	Scro.	+	+	+	M + IT
Heliotropium ovalifolium Forssk.	Borag.	+	+	+	SA + SZ
Salvia aegyptiaca L.	Lami.	+	+	+	SA + SZ
Kickxia acerbiana (Boiss.) Täckh.& Boulos	Scro.	+	+	+	SA + SZ
Lycium shawii Roem. & Shult.	Solan.	+	+	+	SA + SZ
Heliotropium lasiocarpum Fisch. & C. A. Mey.	Borag.	+	+	+	SA + IT
Heliotropium ramosissimum (Lehm.) Sieb. *ex* A. DC.	Borag.	+	+	+	SA + IT
Convolvulus fatmensis Kunze	Conv.	+	+	+	SA + IT
Verbascum sinuatum L.	Scro.	+	+	+	SA + IT
Hyoscyamus muticus L.	Solan.	+	+	+	SA + IT
Heliotropium bacciferum Forssk. var. *bacciferum*	Borag.	+	+	+	M + SA + SZ
Heliotropium supinum L.	Borag.	+	+	+	M + SA + SZ
Anchusa aegyptiaca (L.) A. DC.	Borag.	+	+	+	M + SA + IT
Anchusa hispida Forssk.	Borag.	+	+	+	M + SA + IT
Arnebia linearifolia A. DC.	Borag.	+	+	+	M + SA + IT
Cuscuta planiflora Ten.	Conv.	+	+	+	M + SA + IT
Veronica persica Poir.	Scro.	+	+	+	M + SA + IT
Withania somnifera (L.) Dunal	Solan.	+	+	+	M + SA + IT
Orobanche ramosa L.	Orob.	+	+	+	M + SA + ES
Asperugo procumbens L.	Borag.	+	+	+	M + IT + ES
Marrubium vulgare L.	Lami.	+	+	+	M + IT + ES
Datura innoxia Mill.	Solan.	+	+	+	Nat.
Total number of species		152	260	141	

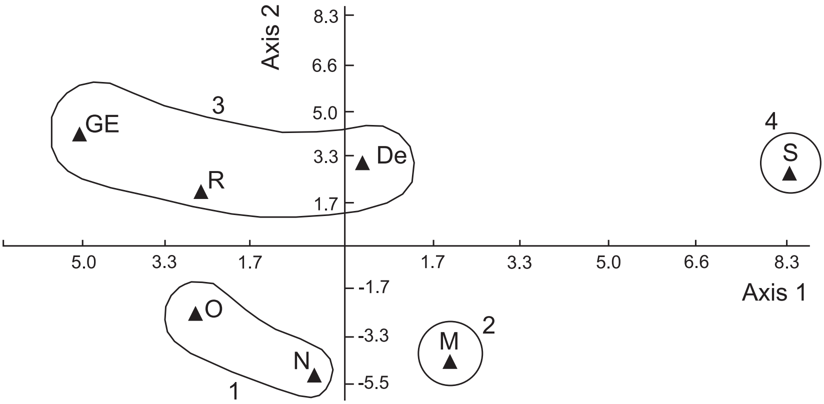

Fig. 6. Scatterplot of the studied biogeographic zones as analyzed by PCoA. 1–4 – floristic groups (for abbreviations of zones see Fig. 3).

together with their chorology, are shown in Table 7. The total number of species varied from 260 in Egypt to 152 in Libya and 141 in Saudi Arabia. Boraginaceae, Labiatae and Scrophulariaceae were the species-rich families, while Orobanchaceae was the poorest. Thirty-nine species were confined to Libya, 61 to Egypt and 2 to Saudi Arabia. The prevalence of the Mediterranean geoelement in the Libyan Tubiflorae was noticeable: 73 species representing different Mediterranean chorotypes (mono, bi- and multiregional) were recognized. The pure Mediterranean geoelement was best represented in Libya (29), decreasing eastwards in Egypt (6) and Saudi Arabia (2). Generally there was a remarkable west-east decrease in the number of Mediterranean taxa: 65 in Egypt and 38 in Saudi Arabia. Although the presence of a Mediterranean zone in Egypt has been well documented since Engler (1882), several authors (Zohary 1973; Boulos 1975) have stated that such zone is absent due to the lack of any arboreal Mediterranean species in Egypt. The annual rainfall (*ca* 200 mm) can hardly support the growth of such species characteristic of the Mediterranean biome. Wickens (1977) maintained that there was ample evidence to suggest that the apparent increase in desert conditions since Roman times is due to human activities. The Saharo-Arabian geoelement, on the other hand, attained its highest number of species in Egypt (28), with fewer in Libya and Saudi Arabia (18 each). Recently, Salama *et al.* (2003) reviewed the chorology of the Sallum area (at the Egyptian-Libyan border) on the western Mediterranean coast of Egypt. They concluded that despite its occurrence within the Mediterranean phytogeographic zone of Egypt, the monoregional Saharo-Arabian chorotype overrides the pure Mediterranean. This may be attributed to the fact that plants of the Saharo-Arabian geoelement are good indicators of harsh desert environmental conditions, while Mediterranean species indicate more mesic conditions.

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