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A phenetic study of *Convolvulaceae* from Egypt based on analysis of morphological characters

Abstract

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A systematic study of 44 taxa belonging to 10 genera of tribes *Convolvuleae*, *Cuscuteae*, *Cresseae*, *Dichondreae*, *Ipomoeeae* and *Merremieae* of the *Convolvulaceae* from Egypt was carried out by means of a phenetic analysis based on seventy one morphological characters, including vegetative parts, pollen grains and seeds. Based on UPGMA clustering and PCO analysis, five main groups are recognized: *Convolvuleae*, *Cuscuteae*, *Cresseae*, *Dichondreae* and a mixed group from Ipomoeeae and Merremieae. OUT's of these groups are clustered together based on characters with high factor loading >0.60 in the PCO analysis. Our results indicate that the tribe *Convolvuleae* is heterogeneous and the *Cuscuteae* is homogeneous, and there is some degree of similarity between taxa of *Merremieae* and *Ipomoeeae*, and those *Cresseae* and *Dichondreae*.

Key words: *Convolvuleae*, *Cuscuteae*, *Cresseae*, *Dichondreae*, *Ipomoeae*, *Merremieae*, taxonomy, morphology, UPGMA, PCO.

Introduction

The *Convolvulaceae* (morning glory family) is a family of herbaceous, twining, or woody, climbing or trailing vines, shrubs or trees. It is almost cosmopolitan in distribution, but primarily tropical, with many genera endemic to individual continents (Austin 1998). The family is, however, the best known in temperate regions for its weedy representatives (e.g., *Convolvulus, Calystegia*). A traditional placement for the *Convolvulaceae* is in the order *Solanales* (Cronquist 1988, Dahlgren 1989, Thorne 1992). Takhtajan (1997) placed this family in its own order, *Convolvulales*, due to a number of characteristics, such as presence of articulate latex canals, latex cells, intraxylary phloem position, seed and pollen morphology, not shared with other *Solanales*. Based on molecular phylogenetic studies for the *Convolvulaceae* suggested that the family is closely related to the *Solanaceae* and *Montiniaceae* (Olmstead & Palmer 1992, Olmstead & al. 1992, 1993, 2000, Soltis & al. 2000, Stefanovic & al. 2002, 2003). Tiagi (1951) and Johri & Tiagi (1952) compared the embryological features of *Cuscuta* with those of the *Convolvulaceae* and suggested the placement of *Cuscuta* into a distinct family:

Cuscutaceae. Austin (1973) divided *Convolvulaceae* into different tribes based mainly on chromosome numbers. Täckholm (1974) placed the parasitic genus *Cuscuta* in a separate family *Cuscutaceae* and non-parasitic taxa under family *Convolvulaceae*; Takhtajan (1997) also placed the genus *Cuscuta* in a separate family, based on embryology and floral anatomy. Manos & Miller (2001) tested the phylogenetic hypothesis of the genus *Ipomoea* with other genera from the tribe Ipomoeae based on morphology and phylogeny and found that *Ipomoea* is paraphyletic. Stefanovic & al. 2002; Stefanovic & Olmstead 2004, 2005 placed the genus *Cuscuta* within *Convolvulaceae* based on DNA sequences of chloroplast gene regions rbcL, atpB, psbE-J and trnL-trnF intron/spacer. *Convolvulaceae* was studied by several authors. Hallier (1893) recognized the usefulness of pollen characters and divided the family into subfamily *Echinoconiae* on the basis of distinct spiny pollen and put *Ipomoea, Argyreia, Exogonium* and *Calonyction* under *Echinoconiae* and he placed *Cuscuteae, Dichondreae, Poraneae, Erycibeae* and *Convolvuleae* under subfamily *Psiloconiae*, based on psilate or granulated surface pollen. Sengupta (1972) studied the pollen of 170 species in 30 genera, and described four pollen types, each with several subtypes. Tellera & Daners (2003) studied the pollen of 75 species belonging to 11 genera, and described three main pollen types; in two of these some subtypes were recognized. Osman & Abdel Khalik (2005) studied the pollen morphology of Convolvulaceae in Egypt and recognized three main pollen types. Sampathkumar & Agyangar (1978) studied the seed coat anatomy and morphology of the family *Convolvulaceae* and separated *Cuscuta* from other genera of the family. Abdel Khalik & Osman (2007) investigated the seed morphology of 31 taxa belong to six genera of *Convolvulaceae* from Egypt, Three types of basic anticlinal cell wall boundaries and four different shapes of the outer periclinal cell wall were described.

In the flora of Egypt, *Convolvulaceae* is represented by 47 species belonging to 10 genera, assigned to 6 tribes (Austin's system 1973, 1998), (Boulos 2000). Members of these tribes are distributed over a wide range of habitats: weeds of farmland and waste places, desert herbs, subshrubs or shrubs in the Mediterranean coastal land, the oases, and the mountains of Sinai and Elba; as well as inland salt marshes. The family *Convolvulaceae* is distinctive as a whole, but division into subfamilies, tribes and genera may be difficult because the characters traditionally used at this rank are few, usually only one or two morphological characters are adapted. These characters are variable even within genera, or conflict with one another in their distribution patterns among genera and tribes and may not reflect natural groups.

The main goal of this study is to use numerical taxonomy to delimit genera within the tribes of the family in Egypt (Table 1) and to find out the position of *Cuscuta*, the only parasitic genus related to *Convolvulaceae*. This study is based on 71 characters of vegetative parts, pollen grains and seed morphology, using UPGMA clustering and PCO analysis.

Materials and Methods

Plant material

The present study is largely based on herbarium material kept in the following herbaria: CAI, CAIM, L, SHG, and WAG. In addition, fresh material of most of the taxa was studied, and field observations were made from several localities in Egypt.

Table1. List of taxa used for the study (Boulos 2000), a comparison of most recent traditional (Austin 1973, 1998) and newly phylogenetic classification (Stefanovic & al. 2003).

No	Taxon	Austin (1973, 1998) **Tribe**	Stefanovic & al. (2003). **Tribe**	**No. of individuals**
1	*Calystegia silvatica* (Kit.) Griseb.	*Convolvuleae*	*Convolvuleae*	2
2	*C. althaeoides* L.	*Convolvuleae*	*Convolvuleae*	30
3	*C. arvensis* L.	*Convolvuleae*	*Convolvuleae*	30
4	*C. dorycnium* L	*Convolvuleae*	*Convolvuleae*	4
5	*C. fatmensis* Kunze	*Convolvuleae*	*Convolvuleae*	20
6	*C. glomeratus* Choisy	*Convolvuleae*	*Convolvuleae*	5
7	*C. humilis* Jacq.	*Convolvuleae*	*Convolvuleae*	4
8	*C. hystrix* Vahl	*Convolvuleae*	*Convolvuleae*	15
9	*C. lanatus* Vahl	*Convolvuleae*	*Convolvuleae*	24
10	*C. lineatus* L.	*Convolvuleae*	*Convolvuleae*	4
11	*C. oleifolius* Desr.	*Convolvuleae*	*Convolvuleae*	4
12	*C. pilosellifolius* Desr.	*Convolvuleae*	*Convolvuleae*	6
13	*C. prostratus* Forssk.	*Convolvuleae*	*Convolvuleae*	8
14	*C. rhyniospermus* Choisy	*Convolvuleae*	*Convolvuleae*	20
15	*C. scammonia* L.	*Convolvuleae*	*Convolvuleae*	7
16	*C. schimperi* Boiss.	*Convolvuleae*	*Convolvuleae*	4
17	*C. secundus* Desr.	*Convolvuleae*	*Convolvuleae*	4
18	*C. siculus* subsp. *agrestis* (Schweinf.) Verdc.	*Convolvuleae*	*Convolvuleae*	15
19	*C. stachydifolius* Choisy	*Convolvuleae*	*Convolvuleae*	4
20	*Cressa cretica* L.	*Cresseae*	*Cresseae*	14
21	*Cuscuta brevistylosa* R. Br.	*Cuscuteae*	*Cuscuteae*	4
22	*C. campestris* Yunck.	*Cuscuteae*	*Cuscuteae*	5
23	*C. chinensis* Lam.	*Cuscuteae*	*Cuscuteae*	5
24	*C. epilinum* Weihe	*Cuscuteae*	*Cuscuteae*	4
25	*C. monogyna* Vahl	*Cuscuteae*	*Cuscuteae*	7
26	*C. palaestina* Boiss.	*Cuscuteae*	*Cuscuteae*	8
27	*C. pedicellata* Ledeb.	*Cuscuteae*	*Cuscuteae*	7
28	*C. planiflora* Ten.	*Cuscuteae*	*Cuscuteae*	8
29	*Dichondra micrantha* Urb.	*Dichondreae*	*Dichondreae*	7
30	*Evolvulus alsinoides* (L.) L.	*Cresseae*	*Cresseae*	8
31	*E. nummularius* (L.) L.	*Cresseae*	*Cresseae*	5
32	*Ipomoea cairica* (L.) Sweet	*Ipomoeeae*	*Ipomoeeae*	3
33	*I. carnea* Jacq.	*Ipomoeeae*	*Ipomoeeae*	11
34	*I. eriocarpa* R. Br.	*Ipomoeeae*	*Ipomoeeae*	7
35	*I. obscura* (L.) Ker-Gawl.	*Ipomoeeae*	*Ipomoeeae*	10
36	*I. pes-caprae* (L.) R. Br.	*Ipomoeeae*	*Ipomoeeae*	7
37	*I. purpurea* (L.) Roth	*Ipomoeeae*	*Ipomoeeae*	8
38	*I. sinensis* (Desr.) Choisy	*Ipomoeeae*	*Ipomoeeae*	8
39	*I. stolonifera* (Cyr.) Gmel.	*Ipomoeeae*	*Ipomoeeae*	6
40	*Jacquemontia tamnifolia* (L.) Griseb.	*Convolvuleae*	*Jacquemontieae*	2
41	*Merremia aegyptia* (L.) Urb.	*Merremieae*	*Merremieae*	9
42	*M. semisagitta* (Peter) Dandy	*Merremieae*	*Merremieae*	2
43	*Seddera arabica* (Forssk.) Choisy	*Cresseae*	*Cresseae*	5
44	*S. latifolia* Hochst. & Steud.	*Cresseae*	*Cresseae*	5

In the analyses, species constituted the OTU (Operational Taxonomic Unit) see Appendix1. In order to broadly sample the variation, the OTU's consist of a number of collections (either herbarium specimens or fresh material or both) from different localities in Egypt. For some specimens from Egypt were not available or few were available, when specimens from other countries were used (OUT 7, 17, 20, 29, and 31).

MORPHOLOGICAL CHARACTERS OBSERVATIONS

Table 2 shows the characters and character states scored for plant, seed, and pollen morphology, averaged for each OTU.

A total of 71 characters were measured on each specimen, comprising 8 quantitative and 63 qualitative characters. Twenty one of the qualitative characters were scored as binary and the rest were scored as multi-state characters.

VEGETATIVE PARTS, FLOWER AND FRUIT CHARACTERS

The measurements for all specimens of a taxon were averaged into one OTU score for each of the characters. OTU scores for quantitative characters were averages of measurements of at least 20 specimens (whenever possible). Because herbarium specimens can not be considered to be a random sample of the species, we followed Wieringa (1999: 62-65) by calculating the mean of the minimum and maximum measurement. For some of the OTU's observations for some of the characters were not available, and these omissions were coded as missing data (-999). The complete data matrix is available on request at the Botany Department, Faculty of Science, Sohag University, Egypt.

POLLEN GRAIN AND SEED CHARACTERS

Pollen samples of each studied species were taken from herbarium specimens or from fresh material. Material for light microscopy (LM) observations were carried out on acetolyzed pollen and prepared according to Erdtman (1960). The acetolyzed pollen grains were mounted on glycerin jelly onto glass slides.

Material for scanning electron microscopy (SEM) observations was prepared by mounting acetolyzed pollen and coated with a thin layer of gold/palladium for 3 minutes using a EMITECH K550 sputter according to the Erdtman (1969).

Dried mature seeds were first examined by light microscope (Olympus type BH-2), and 10-15 seeds for each taxon were selected to cover the range of variation. Seeds were mounted on stubs with double adhesive tape. The stubs were sputter-coated with gold/palladium for 3 min. in a EMITECH K550. After coating, the specimens were examined with a Jeol - 6300 scanning electron microscope, using accelerating voltages at 15-20 KV.

Data analysis

Two types of analyses were performed with NTSYS-pc 2.02k software (Applied Biostatistics Inc., Setauket, New York, USA). Firstly, we performed a cluster analysis using average taxonomic distance and UPGMA clustering (procedures SIMINT, SAHN, and TREE). To reduce the effects of different scales of measurement for different characters, the values for each character were standardized with procedure STAND, according to

Table 2. Characters and character states used in morphometric analysis of the *Convolvulaceae.*

N	Character	Character state	Code
1	Plant life	Parasite	1
		Not parasitic	2
2	Plant colour	Colourless	1
		Green	2
3	Habit	Annual	1
		Annual or short-lived perennial	2
		Perennial	3
		Subshrubs	4
		Shrubs	5
4	Stem nature	Herbaceous	1
		Woody	2
5	Plant height (mean length in cm)		
6	Stem shape	Prostrate	1
		Prostrate to twining	2
		Twining	3
		Climbing	4
		Prostrate to ascending	5
		Ascending	6
		Ascending to erect	7
		Erect	8
7	Mode of perennation	Rhizomatous	1
		Not rhizomatous	2
8	Nature of branches	Spinescent	1
		Not spinescent	2
9	Plant surface	Glabrous	1
		Glabrous to sparsely hairs	2
		Hairy	3
10	Hairs patent	Spreading	1
		Appressd	2
11	Hair shape	Simple	1
		Simple and glandular	2
		Simple and vasculate	3
Leaf character			
12	Lower leaves arrangement	Rosette-forming	1
		No rosette	2
13	Green leaves	Present	1
		Absent	2
14	Leaf petiole	Sessile	1
		Sessile to short-petiolate	2
		Petiolate	3
15	Leaf petiole measurements (mean length in cm)		
16	Leaf venation	Pinnate	1
		Palmate	2
17	Leaf shapes	Linear to lanceolate	1
		Oblong to lanceolate	2
		Ovate to lanceolate	3
		Spathulate to oblanceolate	4
		Sagittate to hastate	5
		Cordate to sagittate	6
		Cordate to ovate	7
		Reniform to elliptical	8
		Reniform	9
		Orbicular	10
18	Leaf apex	Mucronate	1
		Acuminate	2
		Apiculate	3
		Acute to acuminate	4
		Acute	5
		Obtuse to acute	6
		Obtuse	7
		Retuse	8

Table 2. continued.

		Emarginate	9
19	Leaf margin	Entire	1
		Crenate	2
		Dentate to crenate	3
		Undulate	4
		Crenate to lobed	5
		Dissected or divided	6
20	Inflorescence characters	Bracts present	1
		Bracts absent	2
21	Inflorescence position	Terminal	1
		Terminal and axillary	2
		Axillary	3
22	Peduncle measurements (mean length in cm)		
Flower characters			
23	Flower number	Solitary	1
		Solitary or in pairs	2
		2 to 10	3
		Many	4
24	Flower pedicel	Sessile	1
		Sessile to short pedicellate	2
		Pedicellate	3
25	Flower bract	Present	1
		Absent	2
26	Sepal length (mean length in mm)		
27	Sepal shape	Lanceolate	1
		Lanceolate to oblong	2
		Oblong	3
		Oblong to obovate	4
		Obovate	5
		Ovate	6
		Cordate to ovate	7
		Orbicular to ovate	8
28	Sepal apex	Acuminate	1
		Apiculate	2
		Acute	3
		Obtuse to acute to mucronate	4
		Obtuse	5
29	Sepal surface	Glabrous	1
		Glabrous to sparsely hairy	2
		Hairy	3
30	Sepals patent at fruit maturity	Erect	1
		Erect to spreading	2
		Spreading	3
31	Corolla shape	Funnel-shaped	1
		Campanulate	2
		Tubular shaped	3
32	Corolla margin	Deeply lobed	1
		Shallow lobed or bifid	2
33	Corolla length (mean length in mm)		
34	Corolla colour	White	1
		Yellow to white	2
		Yellow	3
		Yellow to brown	4
		Pink	5
		Pink to white	6
		Violet	7
		Violet to pink	8
		Blue	9
		Blue to pink or white	10
35	Corolla surface	Glabrous	1
		Glabrous with hairy bands	2
		outside	3
		Hairy	
36	Filament length (mean length in mm)		
37	Filament surface	Glabrous	1
		With sessile glands at the base	2
		Hairy	3

Table 2. continued.

38	Anther shape	Globose	1
		Sagittate	2
		Oblong to sagittate	3
		Oblong	4
39	Stamens and styles	Included	1
		Exserted	2
40	Style number	One	1
		Two	2
41	Style shape	Filiform	1
		Stout	2
42	Style surface	Glabrous	1
		Hairy	2
43	Style length	Shorter than the stigma	1
		Equal to the stigma	2
		Longer than the stigma	3
44	Style branching	Forked	1
		Not forked	2
45	Stigma number	One or bi-lobed	1
		2	2
		4	3
46	Stigma shape	Filiform	1
		Cylindrical	2
		Clavate to cylindrical	3
		Clavate	4
		Globose	5
		Capitate	6
		Peltate	7
Pollen grain characters			
47	Pollen surface	Smooth to micro-granulate	1
		Spinulose	2
48	Pollen shape	Oblate spheroidal P/E = .88-1 μ	1
		Spheroidal P/E = 1 μ	2
		Prolate spheroidal P/E = 1-	3
		1.14μ	4
		Subprolate P/E = 1.14-1.33	5
		μ	
		Prolate P/E = 1.33-2	
		μ	
49	Pollen types	Tricolpate	1
		Pantocolpate	2
		Pantoporate	3
50	Exine sculpture	Tectate, punctuate, micro-	1
		granulate	2
		Semitectate, reticulate-	3
		microgranulate	4
		Tectate, punctuate,	
		microechinate	
		Semitectate, microreticulate-	
		echinate-microgranulate	
Fruit characters			
51	Fruit length (mean length in mm)		
52	Fruit width (mean length in mm)		
53	Fruit dehiscence	Dehiscent	1
		Indehiscent	2
54	Fruit shape	Globose	1
		Subglobose	2
		Ovoid	3
		Oblong	4
		Conical	5
55	Number of fruit locules	1	1
		2	2
		2-3	3
		3	4
56	Number of seeds in fruit	1	1
		2	2
		2-4	3
		4	4

Table 2. continued.

		6	5
57	Fruit patent	Appressed	1
		Erect	2
		Erect to spreading	3
		Spreading	4
		Recurved	5
58	Fruit surface	Glabrous	1
		Glabrous to sparsely hairy	2
		Hairy	3
		Papillate	4
59	Fruit pedicel (mean length in mm)		
60	Surface of fruit pedicel	Glabrous	1
		Hairy	2
Seed characters			
61	Seed shape	Oblong	1
		Obovoid	2
		Ovoid	3
		Pyramidal	4
62	Seed surface	Glabrous	1
		Short-hairy	2
		Long-hairy	3
63	Seed architecture	Smooth	1
		Tuberculate	2
64	Seed size(mm) (length x width)	0.6-1.5 x 0.4-1.3	1
		1.5-4 x 1.3-3.7	2
		4-9 x 3.8-8	3
65	Seed colour	Black	1
		Black to brown	2
		Brown	3
		Yellow to brown	4
		Orange	5
66	Epidermal cell patterns	Isodiametric or 4-5-6 polygonal	1
		Irregular or 4-5-6 polygonal	2
		Irregular or polygonal cells	3
		4-5 gonal or elongate in one	4
		direction	5
		Isodiametric, 4-5-6 polygonal or	
		elongate in one direction	
67	Anticlinal walls	Straight	1
		Straight to slightly sinuous	2
		Undulate	3
68	Relief of cell wall boundaries	Raised	1
		Raised-channeled	2
		Channeled	3
69	Sculpture of anticlinal boundaries	Smooth	1
		Smooth to fine-folded	2
		Folded	3
70	Curvature of outer periclinal cell wall	Flat	1
		Flat to concave	2
		Concave	3
		Flat to convex	4
		Rugulate	5
71	Secondary cell wall sculpture	Smooth	1
		Smooth to fine-folded	2
		Folded	3
		Striate	4
		Microreticulate	5

the formula: yI,STD = (yi- AVGyi) / STDyi), Where the default value in NTSYS-pc (STAND) for yi = the value to be standardized, AVGyi= the average of all values for the character, and STDyi = the standard deviation. The cophenetic correlation coefficient between the distance matrix and the tree matrix was calculated to examine the goodness of fit of the cluster analysis to the distance matrix (procedures COPH and MXCOMP).

Secondly, a principal coordinates analysis (PCO) was performed, using the product-moment correlation as a coefficient. The procedure SIMINT was used to calculate the distance matrix based on STAND data, the procedures EIGEN, PROJ, and MXPLOT to perform the PCO. A PCO was preferred rather than a PCA (Principal Components Analysis), because a PCO performs better on data sets with missing data (Rohlf 1972).

Results

Cluster analysis. Figure 1 shows the UPGMA phenogram comprising all OUT's in the present work. The cophenetic correlation of distance matrix and tree matrix was 0.80, indicating a good fit of the phenogram to the distance matrix (see Rohlf 1993).

Five branches and clusters may be distinguished: (1) A cluster with all species (21-28) of the genus *Cuscuta* (tribe *Cuscuteae*). (2) A cluster with *Convolvulus lineatus* and *C. oleifolius* (tribe *Convolvuleae*). (3) A cluster divided into two subgroups: *Dichondra micrantha* (tribe Dichondreae) subgroup, and a subgroup with *Evolvulus alsinoides, E. nummularius, Seddera arabica, S. latifolia* and *Cressa cretica* (tribe *Cresseae*). (4) A cluster consisting of two subgroups: *C. hystrix* and *C. lanatus* subgroup (tribe *Convolvuleae*), and subgroup with the rest of the species of *Convolvulus* and *Jacquemontia tamnifolia* (tribe *Convolvuleae*). (5) A cluster with two subgroups: subgroup with *Merremia aegyptia* and *M. semisagitta* (tribe *Merremieae*), and a subgroup with all species (32-39) of *Ipomoea* (tribe *Ipomoeeae*) and *Calystegia silvatica* (tribe *Convolvuleae*).

Principal coordinates analysis (PCO). The plot of 44 OUT's on the first three principal coordinate's axes is shown in Figs. 2, 3, & 4. These axes explain 38.34% of the total observed variation. Plots 1/2, 1/3, 2/3 and 1/2/3 together show five groups.

On the first axis (19.30 % of the total variation, Figs. 2, 3) a separation is demonstrated between two groups. 1) Group of 32. *Ipomoea cairica*, 33. *I. carnea*, 34. *I. eriocarpa*, 35. *I. obscura*, 36. *I. pes-caprae,* 37. *I. purpurea*, 38. *I. sinensis*, 39. *I. stolonifera* (tribe *Ipomoeae*), 41. *Merremia aegyptia*, 42. *M. semisagitta* (tribe *Merremieae*) and 1. *Calystegia silvatica* (tribe *Convolvuleae*). 2) Group of all species of the tribe *Cuscuteae* (21-28). The main characters explaining this separation (characters with high factor loading > 0.62) are (1) lower leaves arrangement, (2) fruit length, (3) fruit width, (4) fruit patent, (5) plant height, (6) filament length, (7) Corolla length, (8) fruit pedicel length, (9) seed shape, (10) seed architecture, (11) leaf petiole length, (12) pollen type, (13) pollen surface, (14) exine sculpture of pollen grains, (15) seed size, (16) stigma number, (17) peduncle length (Table 3).

The second principal coordinate axis (11.94 % of the total variation, Figs. 2 & 3) reveals a split between four groups. 1) Group of all species (2-19) of the genus *Convolvulus* (tribe *Convolvuleae*). 2) Group of 20. *Cressa cretica,* 30. *Evolvulus alsinoides*, 31. *E. nummularius,* 43. *Seddera arabica* and 44. *S. latifolia* (tribe *Cresseae*). 3) Group of 29. *Dichondra*

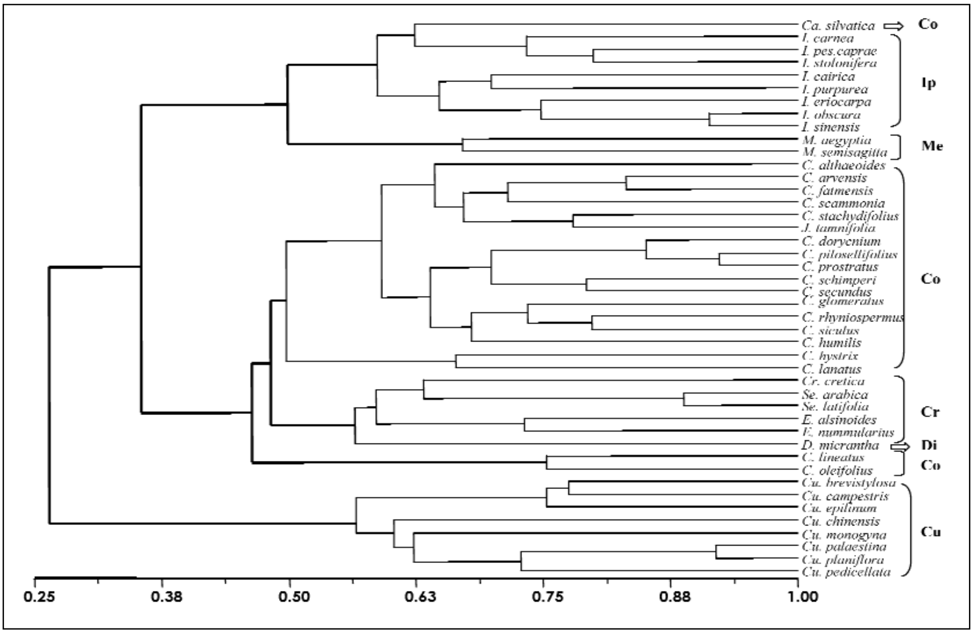

Fig. 1. Phenogram of the 44 studied taxa, clustering with UPGMA method: Co, *Convolvuleae*; Cr, *Cresseae*; Cu, *Cuscuteae*; Di, *Dichondreae*; Ip, *Ipomoeeae*; Me, *Merremieae*.

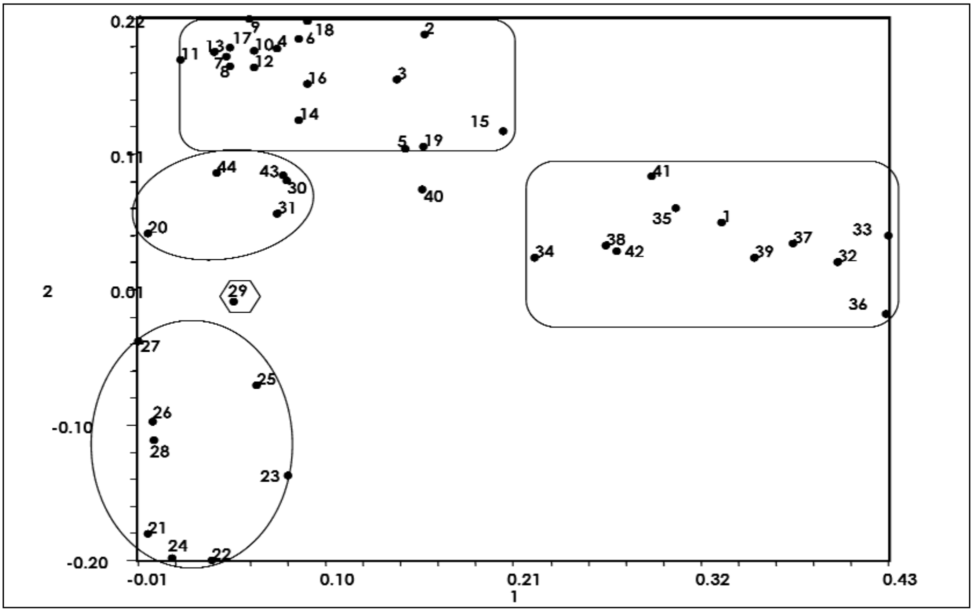

Fig. 2. Scatterplot of the 44 OUTs plotted against the first principal coordinate by the second principal coordinate.

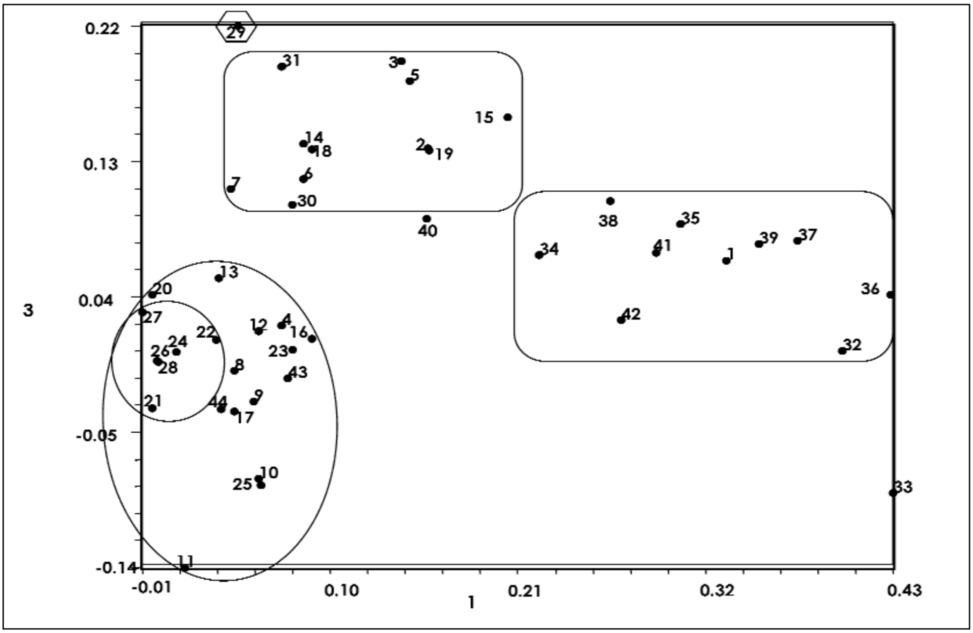

Fig. 3. Scatterplot of the 44 OUTs plotted against the first principal coordinate by the third principal coordinate.

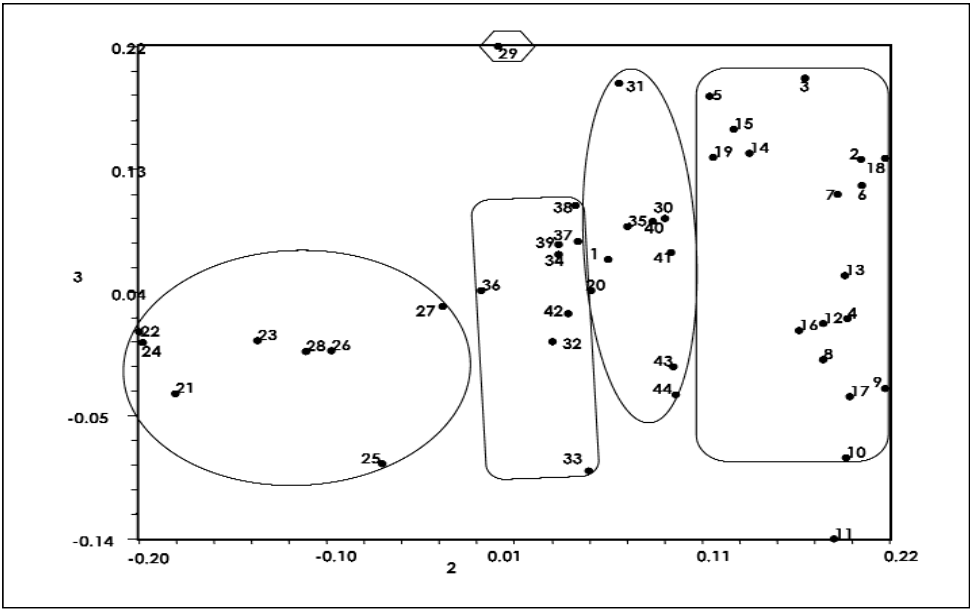

Fig. 4. Scatterplot of the 44 OUTs plotted against the second principal coordinate by the third principal coordinate.

Table 3. Morphological characters and their factor loading on the first three principal coordinates axes; shading indicates highest loadings.

N	Characters	Principal coordinates		
		1	2	3
		Factors loading		
1	Plant life	0.35	0.82	0.15
2	Plant colour	0.35	0.82	0.15
3	Habit	0.12	0.54	-0.26
4	Stem nature	-0.15	0.34	-0.56
5	Plant height (mean length in cm)	0.87	-0.29	-0.23
6	Stem shapes	-0.16	0.33	-0.72
7	Mode of perennation	-0.25	-0.86	-0.12
8	Nature of branches	0.17	-0.27	0.20
9	Plant surface	-0.47	0.62	0.39
10	Hairs patent	-0.39	0.38	-0.21
11	Hair shape	-0.25	0.22	-0.21
12	Lower leaves arrangement	0.96	-0.33	0.18
13	Green leaves	-0.35	-0.82	-0.15
14	Leaf petiole	0.54	-0.20	0.40
15	Leaf petiole measurements (mean length in cm)	0.76	-0.24	-0.36
16	Leaf venation	0.38	-0.13	-0.14
17	Leaf shape	0.36	-0.26	0.63
18	Leaf apex	-0.23	-0.11	0.27
19	Leaf margin	0.41	-0.69	-0.22
20	Inflorescence characters	0.17	-0.56	-0.21
21	Inflorescence position	0.35	0.45	0.24
22	Peduncle measurements (mean length in cm)	0.71	0.96	-0.16
23	Flower number	-0.51	-0.29	-0.38
24	Flower pedicle	0.52	0.31	0.16
25	Flower bract	0.18	-0.29	0.18
26	Sepal length (mean length in mm)	0.54	0.39	-0.37
27	Sepal shape	0.18	-0.44	-0.15
28	Sepal apex	0.15	-0.49	-0.96
29	Sepal surface	-0.44	0.39	-0.63
30	Sepals patent at fruit maturity	0.26	0.22	0.24
31	Corolla shape	-0.34	-0.72	0.10
32	Corolla margin	0.19	0.13	-0.26
33	Corolla length (mean length in mm)	0.84	0.24	-0.20
34	Corolla color	0.23	0.24	0.10
35	Corolla surface	-0.42	0.67	-0.14
36	Filament length (mean length in mm)	0.87	0.18	-0.17
37	Filament surface	-0.12	0.39	0.44
38	Anther shape	-0.30	0.16	-0.80
39	Stamens and styles	-0.32	-0.57	0.13
40	Style number	-0.50	-0.65	0.996
41	Style shape	-0.14	0.55	-0.36
42	Style surface	-0.15	0.22	-0.47
43	Style length	0.46	-0.15	0.27
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table 3. continued.

44	Style branching	0.12	-0.89	-0.25
45	Stigma number	-0.72	0.57	0.31
46	Stigma shape	0.35	-0.43	-0.68
47	Pollen surface	0.75	-0.13	-0.94
48	Pollen shape	-0.19	0.30	0.27
49	Pollen types	0.76	-0.18	-0.30
50	Exine sculpture	0.74	-0.16	-0.99
51	Fruit length (mean length in mm)	0.91	0.14	-0.95
52	Fruit width (mean length in mm)	0.91	0.10	-0.99
53	Fruit dehiscence	-0.10	-0.17	0.38
54	Fruit shape	-0.13	0.25	-0.40
55	Number of fruit locules	0.34	-0.22	0.26
56	Number of seeds in fruit	0.32	-0.19	0.21
57	Fruit patent	0.91	0.52	0.45
58	Fruit surface	-0.27	-0.94	-0.37
59	Fruit pedicel (mean length in mm)	0.82	0.51	0.93
60	Surface of fruit pedicel	-0.57	0.49	0.32
61	Seed shape	0.80	-0.24	0.56
62	Seed surface	0.52	0.94	-0.37
63	Seed architecture	-0.78	0.41	0.44
64	Seed size(mm) (Length x width)	0.73	0.91	-0.38
65	Seed colour	-0.12	-0.57	0.25
66	Epidermal cell paterns	0.25	0.16	0.28
67	Anticlinal walls	0.18	-0.14	0.26
68	Relief of cell wall boundaries	-0.19	-0.13	-0.60
69	Sculpture of anticlinal boundaries	0.51	-0.95	0.10
70	Curvature of outer periclinal cell wall	-0.11	-0.13	-0.13
71	Secondary cell wall sculpture	0.30	0.31	0.26
Percentage per **PCO**		19.30	11.94	7.10
Percentage total variation for the first three principal coordinates amount 38.34%				

micrantha (tribe *Dichondreae*). 4) Group of all species (21-28) of the genus *Cuscuta* (tribe *Cuscuteae*). This separation is based on mainly (1) peduncle length, (2) Sculpture of anticlinal boundaries, (3) fruit surface, (4) seed surface, (5) seed size, (6) style branching, (7) mode of perennation, (8) plant life, (9) plant colour, (10) green leaves, (11) corolla shape, (12) leaf margin, (13) corolla surface, (14) style number, (15) plant surface (table 3).

Along the third axis (7.1 % of the total variation, Figs. 3 & 4) a segregation between. 1) Group of 29. *Dichondra micrantha* (tribe *Dichondreae*). 2) Group of most taxa (2, 3, 5, 6, 7, 14, 15, 18, and 19) from the genus *Convolvulus* (tribe *Convolvuleae*) and 30. *Evolvulus alsinoides* and 31. *E. nummularius* (tribe *Cresseae*). 3) Group of the genus *Cuscuta* (tribe *Cuscuteae*) nested within of genera from the tribes Cresseae (20, 43, and 44) and *Convolvuleae* (4, 8, 9, 10, 11, 12, 13, 16, and 17). The main characters explaining this separation are (1) style number, (2) exine sculpture of pollen grain, (3) fruit width, (4) sepal apex, (5) fruit length, (6) pollen surface, (7) fruit pedicel length, (8) anther shape, (9) stem shapes, (10) stigma shape, (11) leaf shapes, (12) sepal surface, (13) relief of cell wall boundaries.

Discussion

Taxonomy largely rely on morphological characters to define taxa. Problems in classification arise when taxa display a large number of variability, due to phenotypic plasticity (van den Berg and Groendijk-Wilders 1999, Abdel Khalik & al. 2002).

Many authors have tried to present a natural system to subdivide *Convolvulaceae* into subfamilies and tribes (Peter 1891, Hallier 1893, Peter 1897, Roberty 1952, 1964, Ooststroom 1953, Sengupta 1972, Austin 1973, 1979, Sampathkumar & Agyangar 1978, Carlquist & Hanson 1991, Tellera & Daners 2003). These studies were based on a few morphological characters. In the present study a large number of characters were scored and numerical methods (UPGMA and PCO) were applied to elucidate the relationships among genera within a tribe and tribes within the family and to find out the position of *Cuscuta*, the only parasitic genus related to *Convolvulaceae*.

UPGMA gives insight into degree of similarity among the OUT's and whether they form groups/ clusters, and gives an indication of the rank of variation within and among tribes.

PCO reflects which characters are important on the axes, and indicates the significant characters based on the highest factor loading (Table 3). For that reason it becomes clear which characters cause the separation between groups and can be useful to distinguish taxa.

Generally, our results confirm congruence between the UPGMA clustering and PCO analyses, in suggesting five groups:

TRIBE *CONVOLVULEAE* GROUP

Ooststroom (1953) placed *Convolvulus* with *Calystegia, Jacquemontia* and *Merremia* in tribe *Convolvuleae*. Austin (1998) sited *Convolvulus, Calystegia* and *Jacquemontia* under tribe *Convolvuleae* based on morphological and cytological characters (table 1).

Stefanovic & al. (2002) presented phylogenetic relationships of some *Convolvulaceae* species (rbcL, atpB, psbE-J operon, and trnL-trnF intron/spacer) and indicated that *Convolvulus* and *Jacquemontia* are distantly related in the family. This result contrasts markedly with earlier taxonomic treatments which have considered the two genera closely related in the tribe *Convolvuleae*. However, they indicated that the genus *Calystigia,* according to the molecular data, is nested within the larger genus *Convolvulus*, rendering this taxon paraphyletic.

Althought the genus *Calystegia* is well distinguished morphologically from *Convolvulus* by the two large bracts subtending the calyx and enveloping it, the generally larger flowers, the 1-locular ovary, the oblong or cylindrical stigmas, the inflorescences having solitary flowers and the spheroidal, pantoporate pollen. The bracts in most species of *Convolvulus* are much smaller, leaf- like and do not closely subtend the calyx, the inflorescences have many and smaller flowers, ovary 2-locular, the linear, filiform stigma, the prolate to subspheroidal, tri- or rarely tetra-colpate pollen grain.

The present results show some degree of similarity among the OTU's of this group based on pollen surface, exine sculpture of pollen grain, style number, fruit pedicel, fruit surface, peduncle length, seed surface, sculpture of anticlinal boundaries of seeds and stigma shape, and there is a close relationship between these OTU's. The genus *Convolvulus* were divided by Sa'ad (1967) into three sections, twelve subsections and four series and she placed *C. hystrix* and *C. lanatus* in section *Acanthocladi*, *C. arvensis, C. fatmensis, C. althaeoides, C. scammonia*, and *C. stachydifolius* in section Convolvulus, and placed *C. dorycnium* (subsection *Inermes*), *C. schimperi* and *C. secundus* (subsection *Pannosi*), *C. glomeratus, C. humilis, C. prostratus, C. pilosellifolius, C. siculus* and *C.rhyniospermus* (subsection *Diffusi*), *C. lineatus* and *C. oleifolius* (subsection *Oleifolii*) in section *Inermes*.

Our UPGMA results show that the tribe *Convolvuleae* is distinguished into five branches: (1) *Calystegia silvatica* which differs from the species of the genus *Convolvulus* based on pollen, seed and stigma characters. Telleria & Daners (2003) investigated the pollen morphology of *Convolvulaceae* and found that the *Calystegia* is characterized by the unique type that includes the presence of both elliptic and circular pores, and they suggested that the *Calystegia* apertures seem to be an intermediate stage between pores of *Ipomoea* and colpi of *Convolvulus.* (2) a branch with *C. arvensis, C. fatmensis, C. althaeoides, C. scammonia*, *C. stachydifolius* and *Jacquemontia tamnifolia* based on the pollen surface, ovary with 2-locules, style shape and fruit characters; this result agrees with that of Sa'ad (1967) in putting these species of the genus *Convolvulus* in the section *Convolvulus*. (3) a branch combining *C. dorycnium*, *C. schimperi, C. secundus*, *C. glomeratus, C. humilis, C. prostratus, C. pilosellifolius, C. siculus* and *C. rhyniospermus,* based on the inflorescense, pollen and seed characters. This result congruent with those of Saad. (4) *C. hystrix* and *C. lanatus* based on the spiny branches, plant surface, pollen and seed characters. This result agrees with Sa'ad (1967). (5) a branch with *C. lineatus* and *C. oleifolius* based on the habit, seed, style surfaces, and inflorescense position. This result is in agreement with the studies of Cronk & Clarke (1981), who separate *C. lineatus* from other species due to the presence of irregularly shaped luminae formed by the fusion of tectal punctae. They also report 6- zonocolpate grains in *C. lineatus* from North European species while the remaining species have normal trizonocolpate grains. The results from previous studies of phylogenetic relationships by Stefanovic & al. (2002) demonstrated that the tribe *Convolvuleae* is polyphyletic. Our results consider the tribe Convolvuleae is the most heterogeneous of the tribes because we found the taxa from this tribe interspersed with taxa from other tribes.

Tribe *Cuscuteae* group

Cuscuteae is a monogeneric tribe, comprising the genus *Cuscuta*. Most classifications recognize a separate tribe (Choisy 1845, Bentham & Hooker 1873, Hallier 1893, Austin 1998) or subfamily (Peter 1891, Melchior 1964) within *Convolvulaceae*. However, some botanists accepted that the genus should be recognized as a separate family (Roberty 1952, 1964, Wettstein 1962, Austin 1973, Täckholm 1974, Cronquist 1988, Takhtajan 1997). Recently phylogenetic results indicate it belongs within *Convolvulaceae* (Stefanovic & al. 2002, Stefanovic & Olmstead 2004). The results of both cluster and principal coordinates analysis confirmed that the tribe *Cuscuteae* is a well distinguishable group characterized by: (1) plant life cycle, (2) plant colour, (3) seed size, (4) style branching, (5) green leaves (with out chlorophyll), (6) style number. Our results identify four branches that are congruent with the subgenera proposed by Engelmann (1859) and Yuncker (1932). The subgenus with united styles, *Monogyna* (*C. monogyna*), is the sister to the rest of the genus. The bifid stylar structure provides a uniting character for subgenera *Grammica* (*C. compestris*) and *Cuscuta* (the rest of *Cuscuta* species). These taxa of the two subgenera can be distinguished by capitated and elongated stigmas respectively.

TRIBE *CRESSEAE* GROUP

Austin (1973, 1998) placed *Cressa, Evolvulus* and *Seddera* within tribe *Cresseae*. Stefanovic & al. (2002, 2003) treated these genera under one tribe based on molecular data (Table 1). The results of both cluster and principal coordinated analysis confirmed that the tribe *Cresseae* as a well- distinguished group, characterized by: (1) style bifid, branched or free (2) fruit glabrous, (3) sculpture of anticlinal boundaries of seed is smooth to fine folded, (4) leaf margin entire, (5) seed size is varies from 0.6-4 mm in length to 0.4-3.7 mm in width. Results presented here strongly congruence with the results of Austin (1998) and Stefanovic & al. (2002, 2003).

TRIBE *DICHONDREAE* GROUP

Hallier (1893) removed *Dichondreae* from the family *Convolvulaceae* due to its deeply divided ovary and gynobasic styles, but is found to be a well-supported monophyletic group included within the family.

Morphologically, the tribe *Dichondreae* (*Dichondra micrantha*) is quite distinct and easily identifiable. It seems to be a homogenous tribe and is distinguished from other *Convolvulaceae* tribes by the indehiscent, one-seeded fruit, gamosepalous, bilobulate ovary, and reniform leaves. It is shared with genera of tribe *Cresseae* in the bifid style. According to cluster analysis and principal coordinate analysis, *Dichondra micrantha* (*Dichondreae*) is distinct from the others by the characters of indehiscent, one-seeded fruit, gamosepalous and bilobulate ovary, and it shares the bifid style with genera of tribe *Cresseae*. This result agrees with those of Johnston (1941) and Stefanovic & al. (2002, 2003).

THE MIXED GROUP.

Sampathkumar (1970) investigated chromosome morphology in the family *Convolvulaceae* and concluded that the chromosomes of the genus *Merremia* much resemble those of *Ipomoea.* A survey of records of chromosome numbers yields a fairly consistent number in several genera (*Ipomoea* and *Merremia*). *Ipomoea* has $2n$=30, occasionally $2n$=28. *Merremia* has $2n$=28 or 30.

The results from previous studies of phylogenetic relationships (Stefanovic & al. 2002, 2003) demonstrated a close relationship between the tribes *Merremieae* and *Ipomoeeae*. Wilkin (1999) presented cladistic analysis of the tribe *Ipomoeeae* based on 45 morphological and palynological characters, and suggested that the *Ipomoeeae* is a monophyletic tribe. Stefanovic & al. (2002) distinguished tribe *Ipomoeeae* by large, pantoporate pollen with spinous supratectal processes.

The present results show some degree of similarity between the taxa of tribes *Merremieae* and *Ipomoeeae* based on fruit characters, plant height, filament length, corolla length, seed shape, seed size, seed architecture, pollen type, pollen surface, exine sculpture of pollen grain, stigma number and there is a close relationship between tribes.

Manos & Miller (2001) investigated the genus *Ipomoea* and all members of Hillier's historical taxon, subfamily *Echinoconiae* based on the phylogenetic analysis of DNA sequences (ITS region). They found the *Ipomoea* species placed within two clades.

Our UPGMA results show that the tribe *Ipomoeeae* is separated from *Merremieae* based on leaf venation, echinate pollen surface, pantoporate, exine sculpture semitectate, microreticulate-echinate-microgranulate, four seeded fruit, and undulate anticlinal boundaries of the seed (Fig. 1), however the second branch with species of *Merremia* (*Merremieae*). This group is characterized by compound leaves, small petals, globose stigma, and pollen grain with smooth to micro-granulate, tricolpate, exine sculpture tectate, punctuate, micro-granulate, and folded curvature of outer periclinal cell wall. These results agree with those of Sampathkumar (1970), Manos & Miller (2001).

Conclusion

UPGMA and PCO analysis can be used to study the morphological variation within the tribe and the tribes within the family to determine the discontinuities among genera and tribes. Our analyses have shown that *Convolvulaceae* are homogenous, including the species of *Cuscuta* which have been proposed in a separate family. There are many separations between tribes *Cuscuteae*, *Cresseae* and all mixed group of tribes *Merremieae* and *Ipomoeeae*, which seem to be distinct groups. However there is some degree of similarity between taxa of the tribes *Merremieae* and *Ipomoeeae*, and those of *Cresseae* and *Dichondreae*. We consider *Convolvuleae* the most heterogeneous of the tribes because we found that the taxa from this tribe interspersed with taxa from *Ipomoeeae*.

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References

Abdel khalik, K. & Osman, K. A. 2007: Seed morphology of some species of *Convolvulaceae* from Egypt (Identification of species and systematic significance). – Feddes Repert. **1-2:** 27-34.

—, van der Maesen, L.J.G., Koopman, W.J.M. & Van den Berg, R. G. 2002. Numerical taxonomic study of some tribes of *Brassicaceae* from Egypt. – Plat Syst. Evol. **233:** 207-221.

Austin, D. F. 1973: American *Erycibeae* (*Convolvulaceae*): *Maripa, Dicranostyles*, and *Lysiostyles* I: Systematics. – Ann. Missouri Bot. Gard. **60:** 306-412.

— 1979: An infrageneric classification of *Ipomoea* (*Convolvulaceae*). – Taxon **28:** 359-361.

— 1998: Parallel and convergent evolution in the family *Convolvulaceae*. Pp. 201-234. – in Sivadasan, M. & Mathew P., Biodiversity and taxonomy of tropical flowering plants. – Calcutta.

— 1999. Guide to the Vascular Plants of Florida. by Richard P. Wunderlin. – Florida Sci. **62:** 87-88.

Bentham, G. & J.D. Hooker 1873: *Convolvulaceae*. – Pp. 865-881 in: Genera plantarum, **2.** – London.

Boulos, L. 2000: Flora of Egypt, **2.** – Cairo.

Carine, M.A., Russell, S.J., Santos-Guerra, A., & Francisco-Ortega, J. 2004: Relationships of the Macronesian and Mediterranean floras: Molecular evidence for multiple colonization of the continent in *Convolvulus* (*Convolvulaceae*). – Amer. J. Bot. **91(7):** 1070-1085.

Carlquist, S. & Hanson, M. A. 1991: Wood and stem anatomy of *Convolvulaceae*: a survey. – Aliso **13:** 51-94.

Choisy, J. D. 1845: *Convolvulaceae*. Pp. 323-465. – in De Candolle, A. (ed.) Prodromus systematis naturalis regni vegetabilis, **9. –** Paris.

Cronk, Q. C. B. & Clarke G. C. S. 1981: The Northwest European pollen Flora, 28. *Convolvulaceae*. – Rev. Palyobot. Palynology **33:**117-135.

Cronquist, A. 1988: The evolution and classification of flowering plants. – New York.

Dahlgren, G. 1989: The last Dahlgrenogram: system of classification of the Dicotyledones. Pp. 249-260. – in Tann, K., Mill, R. R. & Elias T. S. (eds.): Plant taxonomy, phytogeography, and related subjects. – Edinburgh.

Engelmann, G. 1895. Systematic arrangement of the species of the genus *Cuscuta* with critical remarks on old species and descriptions of new ones. – Trans. Acad. Sci., St. Louis **1:** 453-523.

Erdtman, G. 1960: The acetolysis method, a revised description. – Svensk Bot. Tidskr. **54(4):** 561-464

— 1969: Handbook of Palynology, An introduction to the study of pollen grains and Spores. – Copenhagen.

Hallier, H. 1893: *Convolvulaceae* Africanae. – Bot. Jahrb. Syst. **18:** 81-160.

Haridasan, V. K. & Mukherjee, P. K. 1993: Seed surface features in Indian *Lobeliaceae*. –Phytomorphology **43:** 287-294.

Johri, B. M. & Tiagi, B. 1952. Floral morphology and seed formation in *Cuscuta reflexa* Roxb. – Phytomorphology **2:** 126.

Manos, P. S. & Miller, R. E. 2001: Phylogenetic analysis of *Ipomoea, Argyreia, Stictocardia*, and *Turbina* suggests a generalized model of morphological evolution in morning glories. –Syst. Bot. **26(3):** 585-602.

Melchior, H. 1964: *Convolvulaceae*. –Pp. 427-429, in: Engler's Syllabus der Pflanzenfamilien, **12.** – Berlin.

Olmstead, R. G. & Palmer, J. D. 1992:. A chloroplast DNA phylogeny of the *Solanaceae*: subfamilial relationships and characters evolution. – Ann. Missouri Bot. Gard. **79:** 346-360.

—, Bremer, B., Scott, K. M., & Palmer, J. D. 1993: A parsimony analysis of the *Asteridae* sensu lato based on *rbcL* sequences. – Ann. Missouri Bot. Garden **80:** 700-722.

—, Kim, K. J., Jansen, R. K. & Wagstaff, S. J. 2000: The phylogeny of the *Asteridae sensu lato* based on chloroplast *ndhF* gene sequences. – Molec. Phylogen. Evol. **16:** 96-112.

—, Michaels, H. J., Scott, K. M. & Palmer, J. D. 1992. Monophyly of the *Asteridae* and identification of their major lineages inferred from DNA sequences of *rbcL*. – Ann. Missouri Bot. Garden **79:** 249-265.

Ooststroom, S. J. van. 1953: *Convolvulaceae*. Pp. 388-512. – in van Steenis. D. G. G. J. Flora Malesiana, ser I, **4.** – The Netherlands.

Osman, K. A. & Abdel Khalik, K. 2005: A Palynological Study on some Egyptian species of *Convolvulaceae* and its taxonomic significance. – Tackholmia**18:** 57-69.

Peter, A. 1891: *Convolvulaceae*. Pp. 1-40 – in Engler A. & Prantl K. (eds.) Die Natürlichen Pflanzenfamilien, **4.** – Leipzig.

— 1897: *Convolvulaceae*. Pp. 375-377 – in Engler A.& Prantl K. (eds.), Die Natürlichen Pflanzenfamilien, **4.** – Leipzig.

Roberty, G. 1952. Genera *Convolvulacearum*. – Candollea **14:** 11-60.

— 1964. Les genres des *Convolvulacées* (esquisse). – Boissiera **10:** 129-156.
Sa'ad, F. 1967: The *Convolvulus* species of the Canary Isles, the Mediterranean region and the Near and Middle East. – Meded. Bot. Lab. Rijksuniv. Utrecht: 1-281.
Sampathkumar, R. & Ayyangar, K. R. 1978. Seed morphology of *Convolvulaceae*. – J. Ind. Bot. Soc. **57:** 28.
— 1970. Karyotype analysis in some South Indian *Convolvulaceae*. – J. Annamalai Uni. Sci. **28:** 39-55.
Sengupta, S. 1972: On the pollen morphology of *Convolvulaceae* with special reference to taxonomy. – Rev. Palaeobot. Palynol. **13:** 157-212.
Sharma, A. & Datta, P. C. 1958. Cytological investigation on the genus *Ipomoea* and its importance in the study of phylogeny. – Nucleus **1(1):** 89-122.
Soltis, D. E., Soltis, P. S., Chase, N. M.W., Mort, M. E., Al-Bach, D. C., Zanis, M., Savolainen, V., Hahn, W. H., Hoot, S. B., Fay, M. F., Axtell, M., Swensen, S. M., Prince, L. M., Kress, W. J., Nixon, K. C., & Farris, J. S. 2000: Angiosperm phylogeny inferred from 18S rDNA*, rbcL*, and *atpB* sequences. – Bot. J. Linn. Soc. **133:** 381-461.
Stefanovic, S. & Olmstead R. G. 2004. Testing the phylogenetic position of a parasitic plant (*Cuscuta, Convolvulaceae, Asteridae*): Bayesian inference and the parametric bootstrap on data drawn from three genomes. – Syst. Biol. **53 (3):** 384-399.
— & — 2005: Down the Slippery slope: Plastid genome evolution in *Convolvulaceae*. – J. Mol. Evol. **61:** 292-305.
—, Austin, D.F., & Olmstead, R.G. 2003. Classification of *Convolvulaceae*: A phylogenetic Approach. – Syst. Bot. **28(4):** 791-806.
—, Krueger, L. & Olmstead, R.G. 2002. Monophyly of the *Convolvulaceae* and circumscription of their major lineages based on DNA sequences of multiple chloroplast loci. – Amer. J. Bot. **89(9):** 1510-1522.
Táckholm, V. 1974: Students' Flora of Egypt. – Beirut.
Takhtajan, A. L. 1997: Diversity and classification of flowering plants. – New York.
Telleria, M. C., & Daners, G. 2003: Pollen types in Southern New World *Convolvulaceae* and their taxonomic significance. – Plant Syst. Evol. **243:** 99-118.
Thorne, R. F. 1992. An updated phylogenetic classification of flowering plants. – Aliso **13:** 365-389.
Tiagi, B. 1951: A contribution to the morphology and embryology of *Cuscuta hyaline* Roth. and *C. planiflora* Tenore. – Phytomorphology **1:** 9.
Van den Berg, R. G. & Groendijk-Wilders, N. 1999: Numerical analysis of the taxa of series *Circaefolia* (*Solanum* sect. *Petota*). Pp. 213-226. – in: Nee, M., Symon, D., Lester, R., Jessop, J. (eds.) *Solanaceae* IV. – Kew.
Wettstein, R. 1962: Handbuch der Systematischen Botanik. – Leipzig-Wien.
Wieringa, J. J. 1990: Monopetalanthus exit. A systematic study of *Aphanocalyx, Bikinia, Icuria, Michelsonia* and *Tetraberlinia* (*Leguminosae*, *Caesalpinioideae*). – Wageningen Agric. Univ. Papers **99-4:** 1-320.
Wilkin, P. 1999: A morphological cladistic analysis of the *Ipomoeeae* (*Convolvulaceae*). – Kew Bull. **54:** 853-876.
Yuncker, T. G. 1932: The genus *Cuscuta.* – Mem. Torrey Bot. Club **18:** 113-331.

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Appendix 1

List of specimens used for the study; species arranged alphabetically within tribes according to Austin (1973, modified 1998).

Tribe *Convolvuleae*

1. *Calystegia silvatica* (Kit.) Griseb.

EGYPT: Gebel Elba, Wadi Yahameib, Abdel Khalik s.n. (SHG); without location, herb de Heldreich 5/1843 (WAG).

2. *Convolvulus althaeoides* L.

EGYPT: Burg El Arab, Abdel Khalik 585 (SHG); Mariut, Abdel Khalik 600 (SHG); Sidi Abdel Rahman, Abdel khalik 605 (SHG); Mersa Matrouh, Abdel Khalik 650 (SHG); Abu Sir, Mariut, Sand dunes, Täckholm s.n. (CAI). ISRAEL: Shefela, Masmiyeh to Gedera, S. Leinkram, A. Grizi 457 (WAG).

3. *C. arvensis* L.

EGYPT: Burg El Arab, Abdel Khalik 588 (SHG); Mariut, Abdel Khalik 602 (SHG); Sohag, El Kola, Abdel Khalik 114 (SHG); El Maragha, Abdel Khalik 139 (SHG); Sagholta, Abdel Khalik 145 (SHG); Assiut University garden, N. El Hadidi s.n. (CAI).

4. *C. dorycnium* L.

EGYPT: Sallum, Matrouh, Abdel Khalik s.n. (SHG). PALAESTINE: Foot of Mt. Carmel, near Zichron-Yaacov, A. Grizi 560 (WAG). IRAN: Schiraz, in arid area, T. Kotschy 436 (WAG). TURKEY: Anatolica, C5 Adana, Pozanti-Camardi, Max Nydegger 15446 (WAG).

5. *C. fatmensis* Kunze

EGYPT: Dakhla Oasis, Bed Kulo, Abdel Khalik 441 (SHG); Dakhla Oasis, Mout, Abdel Khalik 445 (SHG); Wadi Daeeb, Abdel Khalik s.n. (SHG); without location, in cultivated land, L. Kralik s.n. (WAG).

6. *C. glomeratus* Choisy

EGYPT: Gebel Elba, Wadi Mawaw, Täckholm & al. s.n. (CAI); Wadi Yahameib, Abdel Khalik s.n. (SHG); Wadi Abo Saafa, Wadi Hodeein , Abdel Khalik & al. s.n. (SHG); Wadi Daeeb, Alt. 205 m, Abdel Khalik et al. S.n. (SHG): SAUDI ARABIA: Jiddah, Dscheddan, Schimper, W. 784 (WAG). SUDAN: Kassala province, Jebel Qeili, Osman Abdel-Rhim 168 (WAG).

7. *C. humilis* Jacq.

ALGERIA: Saida, cultivated land, B. Balansa 357 (WAG): MOROCCO: Forest between Al-Hajeh and Ifrane, 18 km from NW. Ifrane, P. A. de Wilde & al. 2562 (WAG).

8. *C. hystrix* Vahl

EGYPT: Wadi Wizr, 42 Km from Qusser, Abdel Khalik 329 (SHG); Gebel Elba, Wadi Sermatii, Abdel Khalik s.n. (SHG); Wadi Allaqi, 20 km North East of Darahib, M. Abdallah & al. 1444 (WAG); Wadi Allaqi, at the entrance of Wadi Mitikwan, M. Abdallah & al. 1286 (WAG).

9. *C. lanatus* Vahl

EGYPT: Cairo-Suez desert road, 52 Km from Cairo, Abdel Khalik 547 (SHG); El Arish, Bir Lehfin, Abdel Khalik 640 (SHG); Cairo-Alexandria desert road, 100 km from Cairo, Abdel Khalik s.n. (SHG); Mariut, Burgel Arab M. Zareh s.n. (CAI); near Cairo L. Kralik s.n. (WAG).

10. *C. lineatus* L.

EGYPT: Dakhla Oasis, Mout, Abdel Khalik s.n. (SHG). SYRIA: Damascus, without collector April 1846 (WAG). IRAN: Schiras, Mt. Sabst-Buschom, T. Kotschy 371 (WAG). LIBYA: Gebel Akhdar, Wadi El Teir, Boulos 1178 (CAI);

11. *C. oleifolius* Desr.

EGYPT: Ras El Hekma, Täckholm s.n. (CAI). GREECE: Attica, De Heldreich 1158 (WAG); near Megara, Theodorus 481(WAG).

12. ***C. pilosellifolius*** **Desr.**

EGYPT: Siwa, Een El Saghier road, Fahmy, G. 191 (CAI); Wadi Abraq, around Bir El Sonta, Abdel Khalik et al. s.n. (SHG).

13. ***C. prostratus*** **Forssk.**

EGYPT: Gebel Elba, Karam Elba, Abdel Khalik s.n. (SHG); Wadi Daeeb, Abdel Khalik s.n. (SHG); Aswan, Kralik s.n. (L); Wadi Allaqi, Umm Qureiyat, Saad & Mahdi 1187 (WAG).

14. ***C. rhyniospermus*** **Choisy**

EGYPT: Gebel Elba, Wadi Yahameib, Abdel Khalik s.n. (SHG); Shalateen area, Wadi Baaneed, Abdel Khalik et al. s.n. (SHG); Gebl karm Elba, Abdel Khalik s.n. (SHG). SUDAN: N. Sudan, Nubia, M. Kohn, Kotschy 235 (WAG).

15. ***C. scammonia*** **L.**

EGYPT: Alexandria-Matrouh coastal road, 7 km east of Al- Hemma, Täckholm 8934 (CAI). LEBANON: Beyrut, Hohenack 630 (WAG); TURKEY: Prov. Seyhan, 3 km S. of Haruniye, 100 km NE of Adana, E. Hennipman & al. 1345 (WAG).

16. ***C. schimperi*** **Boiss.**

EGYPT: Gebel El Asfar, Täckholm & al. s.n. (CAI); Sinai, Wadi Fayran, Schimper s.n. (WAG).

17. ***C. secundus*** **Desr.**

PALESTINE: Gaza, Boissier s.n. (L); ISRAEL: Tel-Aviv, sandy soil, A. Eig, A. Grizi 369 (L). LEBANON: Saida, Blanche 1457 (L).

18. ***C. siculus*** subsp. ***agrestis*** **(Schweinf.) Verdc.**

EGYPT: Gebel Elba, Karam Elba, Abdel khalik s.n. (SHG); Wadi Yahameb, 500-600 m, Abdel Khalik s.n. (SHG).

19. ***C. stachydifolius*** **Choisy**

EGYPT: Wadi Asharcoan, affluent from Wadi Aideep, Abdel Khalik & al. s.n. (SHG). TURKEY: Prov. Diyarbakir, between Elazig and Diyabakir, 20 km SE Ergani, E. Hennipman & al. 1500 (WAG).

20. ***Jacquemontia tamnifolia*** **(L.) Griseb.**

SUDAN: Kordofan, J. R. Shabetai. (CAIM).

Tribe *Cresseae*

21. ***Cressa cretica*** **L.**

EGYPT: El-Faiyum, El-Roda, Monier Abdel Ghani s. n. (CAI); El Dekhela-Alexandria coastal road, Abdel Khalik s. n. (SHG); Dakhla Oasis, Bed Kulo, Abdel Khalik 449 (SHG); Without location, Schimper 720 (WAG).

22. ***Evolvulus alsinoides*** **(L.) L.**

EGYPT: Gebel Elba, Wadi Merakwan, Hassib s. n. (CAI); Wadi Yahameib, Abdel Khalik s.n. (SHG).

23. ***E. nummularius*** **(L.) L.**

EGYPT: Gebel Elba, Karam Elba, Abdel Khalik 700 (SHG). CAMERON: Ngouama, 20 km S. Fort-Foureau, R. Letouzey 7128 (WAG).

24. ***Seddera arabica*** **(Forssk.) Choisy**

EGYPT: Gebel Elba, Wadi Yahameb, Abdel Khalik s.n. (SHG); Wadi Asharcoan, affluent from Wadi Aideep, Abdel Khalik & al. s.n. (SHG).

25. ***S. latifolia*** **Hochst. & Steud.**

EGYPT: Gebel Elba, Wadi Yahameib, M. Hassib s. n. (CAIM); Gebel Elba, Wadi Yahameib, Abdel Khalik 750 (SHG). ETHIOPIA: Shoa region, 7 km W of Awash station, M. G. Gillbert & M. Thulin 175 (WAG); 2 km of Dire Dawa, on the road to the Harar, J. J. F. E. De Wilde 4810 (WAG).

Tribe *Cuscuteae*

26. ***Cuscuta brevistylosa*** **R. Br.**

EGYPT: Gebel Elba, Wadi Mawaw, Täckholm 930 (CAI). MOROCCO: Mt. Atlas, road Taroudant-

Asni, 20 km to Tizi-n-Teste, J. J. F. E. de Wilde & al. 1995 (WAG).

27. *C. campestris* Yunck.

EGYPT: Siwa Oasis, Tegzerti Farm, Täckholm & al. s.n. (CAI); Gabal Serbal, S. Sinai, Fayed & al. s.n. (SHG).

28. *C. chinensis* Lam.

EGYPT: Gebel Elba, Wadi Yahameb,Abdel Khalik s.n. (SHG); Wadi Aideeb, Abdel Khalik s.n. (SHG); Wadi Sarara, affluent from Wadi Sermataii, Abdel Khalik s.n. (SHG).

29. *C. epilinum* Weihe

EGYPT: Bahtim near Cairo, Hadidi s.n. (CAI); Fayum, field of linseed, L. Kralik 69 (WAG).

30. *C. monogyna* Vahl

EGYPT: without location, Täckholm & al. s. n. (CAI). ISRAEL: Hulleh plain, near the Barid river, M. Zohary 562 (WAG). MOROCCO: Near Boulemane, P.A.W. De Wide & al. 2728 (WAG); Agadir district, P.A.W. De Wide & al. 1853 (WAG).

31. *C. palaestina* Boiss.

EGYPT: S. Sinai, Gabal Serbal, Fayed & al. s. n. (SHG); S. Sinai, Wadi Gebaal, Fayed & al. s. n. (SHG).

32. *C. pedicellata* Ledeb

EGYPT: Giza, Kirdasa, Hadidi s. n. (SHG); Gebel Elba, Wadi Drawina, abdel Khalik s.n. (SHG); Cairo, field of Vicia, L. Kralik s. n. (WAG).

33. *C. planiflora* Ten

EGYPT: Shalateen area, Wadi Baaneed, Abdel Khalik & al. s. n. (SHG). SUDAN: Topolin plateau, Gebel Marra, 120 km E. of Zalingeri, J.J. E. de Wilde & al. 5539 (WAG). ISRAEL: Sharon plain, Kefar Vitkin, near Alexander River, N. Feinbrun & M. Zohary 758 (WAG).

Tribe *Dichondreae*

34. *Dichondra micrantha* Urb.

ETHIOPIA: Wollega region, 25 km on Ghimbi-Dembidolo, M. Gillbert & M. Thulin 760 (WAG). CAMEROON: Meaudji, 600 m alt., R. Schlechter 12857 (WAG); road Yaounde- Bafussam, km 26, S. Lisowski B-3129 (WAG).

Tribe *Ipomoeeae*

35. *Ipomoea cairica* (L.) Sweet

EGYPT: Ismailia canal at Abu Zaabal, Hadidi & al. s. n. (CAI); Alexandria, L. Kralik s. n. (WAG).

36. *I. carnea* Jacq.

EGYPT: Giza, University garden, V. Täckholm s. n. (CAI); Sohag, El Kola, canal bank, Abdel Khalik s. n. (SHG); Assuit-Sohag agricultural road, Abdel Khalik s. n. (SHG).

37. *I. eriocarpa* R. Br.

EGYPT: El Khanka, W. Amer 1075 (CAI); Behiera, Abu Qir, Alaa Amer s. n. (CAI). SUDAN: 4 km east of border Savana, H.J. Road 100 (WAG).

38. *I. obscura* (L.) Ker-Gawl.

EGYPT: Wadi Akaw, Gebel Elba, Abdel Khalik s. n. (SHG); Mouth of Wadi Aideep, Abdel Khalik s. n. (SHG); Wadi Yahameb, Abdel Khalik s. n. (SHG); Gebl Karm Elba, Abdel Khalik s. n. (SHG).

39. *I. pes-caprae* (L.) R. Br.

EGYPT: Ismailia, Täckholm, G. 4780 (CAI); Giza, V. Täckholm s. n. (CAI). ETHIOPIA: Red sea coast, Assab, J.J.E.F. de Wilde & al. 7300 (WAG).

40. *I. purpurea* (L.) Roth

EGYPT: Idku, A. Amer 9720 (CAI). ETHIOPIA: 3 km from road Alemaya, Harar, side road from Hamaressa, E. Westphal & J.M.C. Westphal Stevels 636 (WAG).

41. *I. sinensis* (Desr.) Choisy

EGYPT: Gebel Elba, Wadi Yahameib, Täckholm & al. s.n. (CAI). SUDAN: near Khartoum, in *Accacia nilotica* forest, J.J.E. de Wilde & al. 5774 (WAG); 30 km SE of Khartoum, on the river bank, J.J.E. de Wilde & al. 5821 (WAG).

42. *I. stolonifera* (Cyr.) Gmel.

EGYPT: N. Sinai, Rafah, Täckholm et al. s.n. (CAIM). ISRAEL: Acre plain, S. of Acre, sands of the beach, M. Zohary & I. Amdursky 458 (WAG); At lit, P. Terpstra 36 (WAG).

Tribe *Merremieae*

43. *Merremia aegyptia* (L.) Urb.

EGYPT: Gebel Elba, Wadi Yahameib, Abdel Khalik, s. n. (SHG)**;** Gebel Elba, Wadi Shallal V. Täckholm & al. s. n. (CAI).

44. *M. semisagitta* (Peter) Dandy

SAUDI ARABIA: Gedda, A. Khattab, s. n. (CAI). KENYA: 43 km on the Wajir, El-Wak road, Commiphora, M. Gillbert & M. Thulin 1161 (WAG).