

ARTICLE

The leaf architecture and its taxonomic significance in Capparaceae from Egypt

Monier M Abd El-Ghani^{1*}, Wafaa Kamel², Mona El-Bous²

¹The Herbarium, Faculty of Science, Cairo University, Giza, Egypt, ²Botany Department, Faculty of Science, Suez Canal University, Ismailia, Egypt

ABSTRACT The paper deals with the leaf architecture of 19 species belonging to 7 genera (*Capparis*, *Cadaba*, *Boscia*, *Maerua*, *Dipterygium*, *Cleome* and *Gynandropsis*) of the family Capparaceae *sensu lato* (including Cleomaceae) from Egypt. A comprehensive description of leaf architecture for the studied taxa was provided, including venation pattern, areolation, and marginal ultimate venation. The venation pattern showed mostly pinnate brochidodromous or craspidodromous. Aeroles may be well or poorly developed. Taxonomically significant leaf features of the examined taxa showed great diversity in leaf or leaflet form, leaf surface, leaf base, leaf persistence, main venation pattern, secondary vein angle, inter secondary veins, number of veins on either side of midrib, free ending ultimate veins and marginal ultimate venation. A new free ending ultimate venation (F.E.V.S) branched with swollen ends was reported. On the basis of leaf architecture, we advocate the recognition of two separate families Capparaceae *sensu lato* and Cleomaceae. Multivariate analysis was carried out with the aim of solving some of the taxonomic problems existing in the family using 21 characters including 74 character states. Based on the comparison of leaf architecture, we supported the taxonomic treatment of the family Capparaceae. We supported retaining *Gynandropsis gynandra* as *Cleome gynandra* of the family Capparaceae, as it clearly nested within *Cleome*. Leaf architecture helped to distinguish all the species investigated and accordingly a key was provided for this purpose.

Acta Biol Szeged 51(2):125-136 (2007)

KEY WORDS

Dicotyledons
Capparaceae
Cleomaceae
leaf architecture
leaf venation
flora of Egypt
taxonomy

Family Capparaceae *sensu lato* is a fairly large (45 genera and 675 species), mainly subtropical being most conspicuous in tropical seasonally dry habitats with diversity in floral structure (Mabberley 1987). Except in some species of *Capparis*, it has a great constancy in the number and position of sepals and carpels (Pax and Hoffmann 1936; Jacobs 1965). It also shows great diversity in the morphology and number of petals and stamens (Endress 1992). Many genera that were considered in Capparaceae by Pax and Hoffmann (1936) have been elevated to familial level or included in unrelated families. The two major subfamilies of Capparaceae: Cleomoideae (about 8 genera and 275 species) and Capparoidae (about 25 genera and 440 species) are quite distinct, and have been elevated to familial status by some authors (e.g., Airy Shaw 1965; Hutchinson 1967). In both subfamilies the type genus is by far the largest and houses the majority of the species: *Cleome* (200 species) for the former and *Capparis* (150-200 species) for the latter. However, Pax and Hoffman (1936) described the most comprehensive taxonomic treatment of *Capparis* to date in which they recognized 45 genera (20 monotypic) to be included in eight subfamilies.

Capparaceae are represented in the Egyptian flora by 7 genera, 21 species and 4 varieties of wide ecological and geographical range of distribution (Boulos 1999). They vary considerably in their growth forms from small trees (e.g. *Boscia*) or shrubs (e.g. *Capparis*) to annual (e.g. *Gynandropsis gynandra*) or perennial herbs (e.g. *Cleome*). Therefore, their vegetative characters range from woody perennials to annual herbs. The Egyptian taxa of Capparaceae belong to the xerophytic communities (Zahran and Willis 1992; Abd El-Ghani and Marei 2006), except for *Gynandropsis gynandra* that is common among the weed flora of the arable fields (Boulos and El-Hadidi 1984). The taxonomic treatment of the family in Egypt focused mainly on seed morphology (Al-Gohary 1997), leaf anatomy (Al-Gohary 1982) and pollen morphology (Khafagi and Al-Gohary 1998). The systematic revision of the native species of Capparaceae (excluding *Cleome*) revealed the uncertain occurrence of *Boscia angustifolia*, while *Capparis spinosa* is represented by 3 varieties viz.: *spinosa*, *inermis* and *deserti* (El-Karemy 2001). Separation from Cleomaceae may be unsustainable, since difficulties are encountered in assigning the genera. Precise comparative data on gynoecium and fruit structure are elusive or non-existent. Actually, the taxonomic affinities between Capparaceae and Cleomaceae are still of debate. Täckholm (1974) distinguished between the two families according to gland struc-

Accepted Nov 28, 2007

*Corresponding author. E-mail: elghani@yahoo.com

Table 1. List of the studied Egyptian taxa arranged into subfamilies and tribes according to Pax and Hoffman (1936).

No	Taxon	Subfamily	Tribe	Number of examined individuals
1	<i>Capparis decidua</i> Edgew.	Capparoideae	Capparideae	20
2	<i>Capparis sinaica</i> Veill.	Capparoideae	Capparideae	30
3	<i>Capparis spinosa</i> L. var. <i>spinosa</i>	Capparoideae	Capparideae	30
4	<i>Capparis spinosa</i> L. var. <i>canescens</i> Coss.	Capparoideae	Capparideae	15
5	<i>Capparis spinosa</i> L. var. <i>inermis</i> Turra	Capparoideae	Capparideae	20
6	<i>Capparis spinosa</i> L. var. <i>deserti</i> Zohari	Capparoideae	Capparideae	25
7	<i>Cadaba glandulosa</i> Forssk.	Capparoideae	Capparideae	5
8	<i>Cadaba farinosa</i> Forssk.	Capparoideae	Capparideae	7
9	<i>Cadaba rotundifolia</i> (Forssk.) Delile	Capparoideae	Capparideae	10
10	<i>Boscia senegalensis</i> Poir.	Capparoideae	Capparideae	8
11	<i>Boscia angustifolia</i> A. Rich.	Capparoideae	Capparideae	7
12	<i>Maerua oblongifolia</i> (Forssk.) A. Rich.	Capparoideae	Maerueae	5
13	<i>Maerua crassifolia</i> Forssk.	Capparoideae	Maerueae	5
14	<i>Dipterygium glaucum</i> Decne.	Dipterygioideae		10
15	<i>Cleome droserifolia</i> (Forssk.) Delile	Cleomoideae		30
16	<i>Cleome chrysantha</i> Decne	Cleomoideae		12
17	<i>Cleome arabica</i> L.	Cleomoideae		15
18	<i>Cleome brachycarpa</i> DC.	Cleomoideae		5
19	<i>Cleome hanburyana</i> Penz.	Cleomoideae		10
20	<i>Cleome paradoxa</i> R. Br. ex DC.	Cleomoideae		10
21	<i>Cleome amblyocarpa</i> Barratte & Murb.	Cleomoideae		40
22	<i>Gynandropsis gynandra</i> (L.) Briq.	Cleomoideae		20

ture, fruit type, and development of a gynophore, whereas Zohary (1966) included the intriguing genus *Cleome* in the subfamily Cleomoideae of Capparaceae. The Capparaceae in Boulos (1999), however, included both Cleomaceae and Capparaceae. On the species level, Täckholm (1974) recognized 8 species of *Capparis*, whereas Boulos (1999) classified the genus as 3 species and 4 varieties.

Although flower and fruit characters have proved very useful in identification and delimitation of the genera and species, there are situations in which these organs are not available for study as in Capparaceae. The study of the reproductive characters of this group is problematic for different reasons, amongst others; the difficulty of preserving the flowers in some genera as in *Capparis* (Hedge and Lamond 1970), the striking variability in their size and shape at the individual level species (Mabberley 1987), and many long-lived tropical plant flowers are infrequent and irregular (LAWG 1999). So, there is a great need to identify and classify plants using vegetative characters.

Ettingshausen (1861) made the first comprehensive effort to systematize the description of the vegetative leaf architecture with his classification of venation patterns. Leaf architectural characters have proved valuable taxonomic and systematic data both in fossil and living plants (Hickey 1973; Dilcher 1974; Hickey and Wolfe 1975). Leaf architecture and venation pattern studied in different families of dicotyledons; amongst others, Compositae (Banerjee and Deshpande 1973), Solanaceae (Inamdar and Murthy 1978), Bignoniaceae (Jain 1978), Hamamelidaceae *sensu lato* (Li and Hickey 1988),

Leguminosae (Sun et al. 1991), Amaranthaceae (Shanmuka et al. 1994), Ulmaceae (Wang et al. 2001), Fagaceae (Luo and Zhou 2002), and in some monocots (Inamdar et al. 1983). The present work was undertaken to give comprehensive account of the venation pattern and leaf architecture in 7 genera and 19 species of the Capparaceae (including Cleomaceae) as no report exists on the subject. It is a contribution towards better understanding the systematic treatment of the Egyptian Capparaceae verifying the role of leaf architecture, assessing the range of variation among species by applying multivariate analysis.

Materials and Methods

During the growing seasons in 2005-2006, fresh material of 7 genera (*Capparis*, *Cadaba*, *Boscia*, *Maerua*, *Dipterygium*, *Cleome* and *Gynandropsis*) and 19 species were collected from their natural habitats and field observations were made from several localities of the Mediterranean region, and in the western Desert, Eastern Desert, Mountains of Sinai and Elba (Fig. 1). In addition, leaves were obtained from herbarium specimens in Cairo University (CAI), Ministry of Agriculture (CAIM) and National Research Centre (CAIRC). In order to broadly sample the variation, the studied taxa were represented by a number of collections (herbarium specimens or fresh material or both) from different localities in Egypt (Table 1). Plant identifications were according to Zohary (1966), Täckholm (1974), Thulin (1993) and Boulos (1999).

Mature leaves were cleared following Thakur (1988), but with modified procedure to suit investigation. Accord-

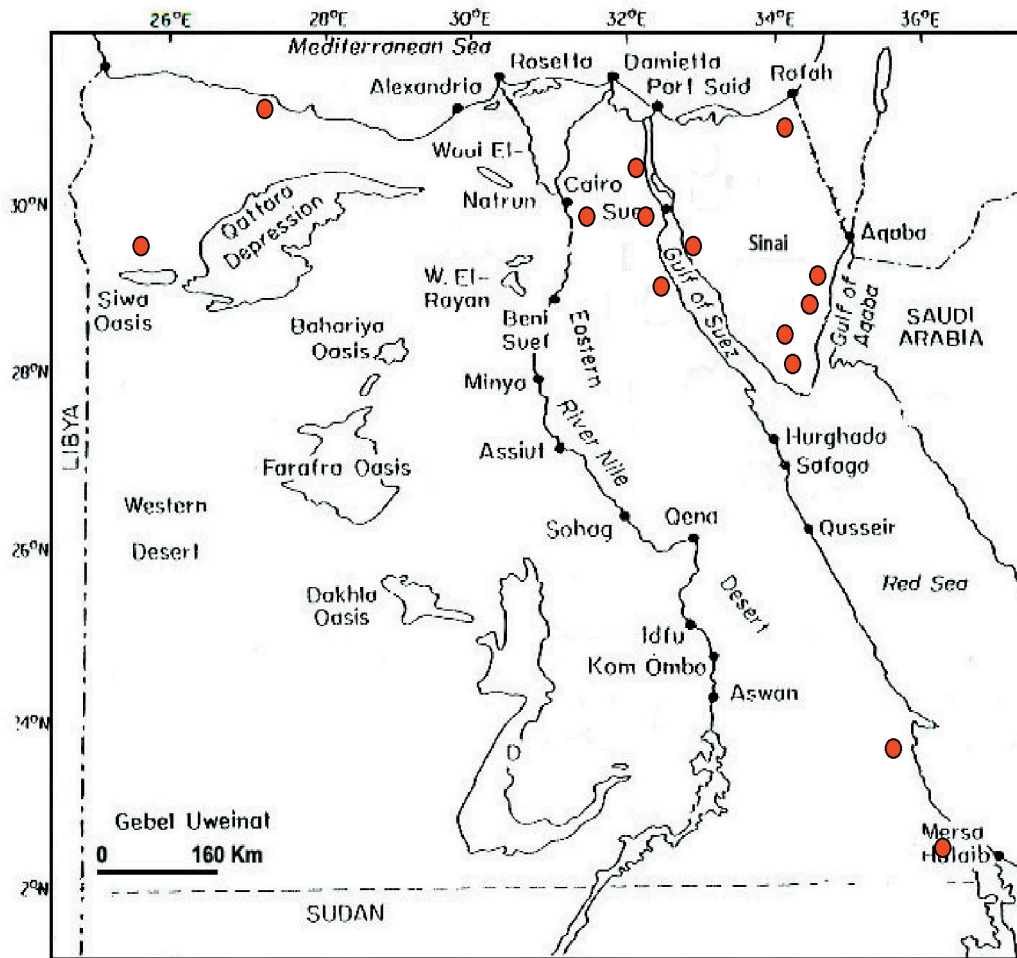


Figure 1. Location map showing the collecting sites.

ingly, the mature leaves were cleared by keeping them in 5% NaOH solution at 25°C for two or three days, rinsed in water and transferred to acetic acid, hydrogen peroxide and lactophenol (Subrahmanyam 1999) in 1:1:1 ratio for three or four days. The cleared leaves were stained with 1% safranin, and mounted on slides with glycerine (Plates 1-3). A total of 21 characters were measured in each studied specimen, comprising 3 quantitative and 18 qualitative characters. Seven of the qualitative characters were scored as binary and the rest were scored as multistate characters (Table 2). The measurements for all specimens of a taxon were averaged into one score for each of the characters. Scores for quantitative characters were averages of measurements of at least 20 specimens (where possible). Because herbarium specimens cannot be considered to be a random sample of the species, we followed Wieringa (1999) by calculating the mean of the minimum and maximum measurement. When some of the characters for a certain species were lacked, these omissions were coded as missing data (-999). The complete data matrix

is available upon request from the first author. Leaf architectural terminology was largely from Hickey (1973, 1977 and 1991), Levin (1986) and Leaf Architecture Working Group (LAWG 1999).

To avoid the effects of different scales of measurement for different characters, the values for each character were standardized prior to analysis using the default option in SYSTAT version 5.02 for Windows software (SYSTAT Inc, USA). Two types of analyses were performed with Community Analysis Package (CAP version 1.2, Pisces Conservation Ltd, UK). Firstly, we performed three different procedures of agglomerative cluster analysis (complete linkage, average linkage and minimum variance) using Euclidean distance to a data matrix of 22 taxa and 21 characters. Secondly, we performed a principal components analysis (PCA).

Results

Leaf was persistent in most of the studied species, but it was deciduous in only two species; *Capparis decidua* and *Dip-*

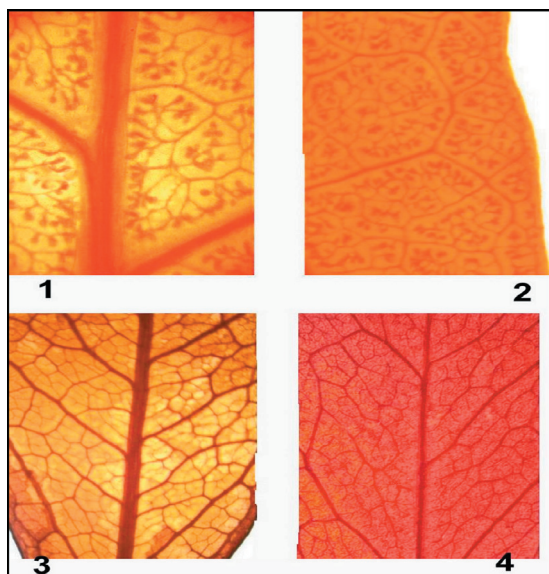


Plate (1). Figure 1: *Capparis spinosa* var. *inermis* (x40), pinnate venation pattern, F.E.V.S free ending ultimate veins three branched with swollen dots; Figure 2: *Capparis sinaica* (x40) brochidodromous, incomplete margin; Figure 3: *Boscia senegalensis* (x40), absence of F.E.V.S, random reticulate of third and fourth vein category, prismatic attached vein angle; Figure 4: *Maerua crassifolia* (x40), five or more sided aeroles, tapering branched F.E.V.S.

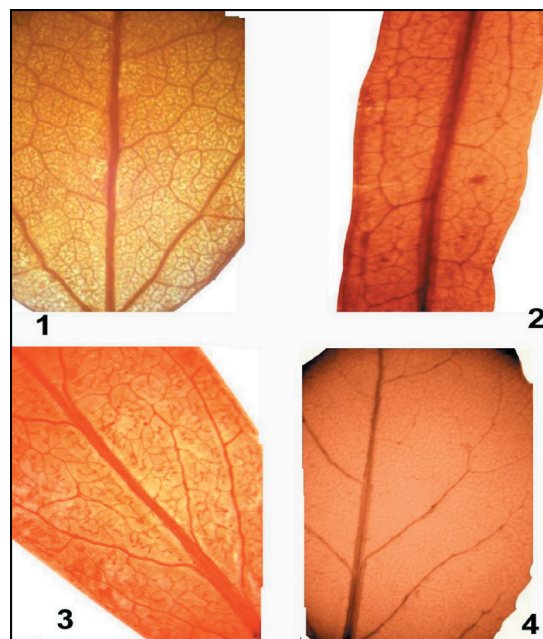


Plate (3). Figure 1: *Boscia angustifolia* (x40), one acute pair secondaries, random reticulate fourth vein category, no F.E.V.S.; Figure 2: *Capparis decidua* (x25), marginal arcuate venations looped arcuate, perpendicular third vein angle to the primary; Figure 3: *Dipterygium glaucum* (x 40) poorly developed aerolation. Figure 4: *Gynandropsis gynandra*, cladododromous, excurrent vein branched.

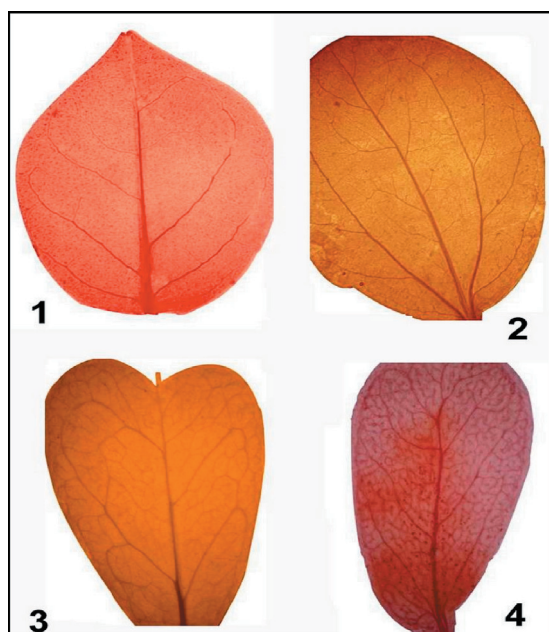


Plate (2). Figure 1: *Capparis spinosa* (x 40), brochidodromous, 4 veins on either side of midrib; Figure 2: *Cleome arabica*, actinododromous, one vein on either side of midrib, cladododromous; Figure 3: *Maerua crassifolia* (x25), secondary vein spacing increasing toward base, secondary vein angle decreasing toward base, marginal ultimate venation of incomplete loops. Figure 4: *Dipterygium glaucum* (x25), cladododromous, agrophic, excurrent vein branched.

terygium glaucum. Taxonomically significant leaf features of the examined taxa showed great diversity in leaf or leaflet form, leaf surface, leaf base, leaf persistence, main venation pattern, secondary vein angle, inter-secondary veins, number of veins on either side of midrib, free ending ultimate veins and marginal ultimate venation. As in the case with other taxonomic characters, great care must be taken when using leaf venation.

A survey of venation of Egyptian Capparaceae (Plates 1-3) showed that venation pattern is mostly pinnate, but it was actinododromous in *Cleome arabica* and *C. droserifolia*. Secondary vein category was brochidodromous in the majority of the studied taxa, while it was cladododromous in *Cleome arabica*, *Dipterygium glaucum* and *Gynandropsis gynandra*; craspedodromous secondary vein were present in four species of *Cleome* viz., *Cleome brachycarpa*, *C. droserifolia*, *C. chrysantha* and *C. hanburyana*; semicraspidodromous was restricted only to *Cleome amblyocarpa*. Most taxa had irregular vein spacing and rarely regular, e.g. *Cleome paradoxa*, or increasing towards base as in *Cleome droserifolia*. The second vein angle varied greatly between the studied taxa, so it has no taxonomic value to differentiate between rare taxa. The number of veins on either side of midrib had a significant taxonomic value among different taxa; where *Capparis decidua* was characterized by 7-8 veins on either

Table 2. Characters and character states used in morphometric analysis of Capparaceae.

Character	Character state	Code
1. Leaf or leaflet form	Obovate	1
	Narrow oblong	2
	Orbicular	3
	Ovate	4
	Oblanceolate	5
	Elliptic	6
	Linear	7
2. Leaf apex	Mucronate spiny	1
	Mucronulate	2
	Obtuse	3
	Acute	4
	Retuse	5
	Accuminate	6
3. Leaf margin	Entire	1
4. Leaf composition	Denticulate	2
	Simple	1
5. Leaf surface	Trifoliate	2
	Petafoliate	3
	Glabrous or pubescent	1
	Glandular hairy	2
	Farinose	3
6. Leaf base	Scabrous	4
	Pilose	5
	Viscid	6
	Cuneate	1
	Acute	2
	Obtuse	3
7. Leaf persistence	Subcordate	4
	Decurrent	5
	Deciduous	1
	Persistent	2
8. Venation pattern	Pinnate	1
	Actinododromous	2
9. Secondary vein category	Brochidodromous	1
	Cladododromous	2
	Craspedodromous	3
	Semicraspedodromous	4
	Irregular	1
10. Secondary vein spacing	Regular	2
	Increasing toward base	3
	Uniform	1
	Increasing toward base	2
	Decreasing toward base	3
11. Secondary vein angle	One pair acute secondaries	4
	Two pair acute secondaries	5
	Present	1
	Absent	2
	1	1
12. Inter-secondary veins	4 – 6	2
	7 – 8	3
	Random reticulate	1
13. Number of veins on either side of midrib	Dichotomous	2
	Acute	1
14. Third vein category	Perpendicular	2
	Random reticulate	1
15. Third vein angle to the primary	Dichotomously branched	2
	Absent	1
16. Fourth vein category	Random reticulate	2
	Dichotomously branched	3
	Absent	1
17. Fifth vein category	Random reticulate	2
	Dichotomously branched	3

Table 2. Continued.

Character	Character state	Code
18. Areolation	5 – or more sided	1
	Poorly or moderately developed	2
19. Free Ending Ultimate Veins of the leaf (F.E.V.S)	Three branched with swollen dots	1
	One branched tapering	2
	Three branched diffuse	3
	Three branched tapering	4
	Absent	5
20. Attached vein angle	Prismatic	1
	Truncate triangle	2
21. Marginal ultimate venation	Incomplete loops	1
	Fimbrial arcuate	2
	Fimbrial simple	3
	Excurrent vein branched	4

side of midrib, *Cleome arabica* and *C. droserifolia* were characterized by one vein on either side of midrib. The third vein category was reticulate and mostly meets the primary veins at acute angles. Quaternary venation was mostly dichotomized branching, while fifth vein category is mostly absent, and, if present, it may be random or dichotomizing branched.

Areolation were usually well developed. In addition, the free ending ultimate veins of the leaf (F.E.V.S.) could be

distinguished by having one, two or three branched tapering or swollen ends. Marginal ultimate venation had incomplete loops in genera of *Capparis* (except *Capparis decidua*) and *Maerua*; while fimbrial arcuate was characterized to *Cadaba* and *Boscia*. Branched excurrent vein was characteristic to genus *Cleome*, except *Cleome chrysantha*, which had fimbrial arcuate marginal vein.

Analysis of venation in the Capparaceae indicated that the

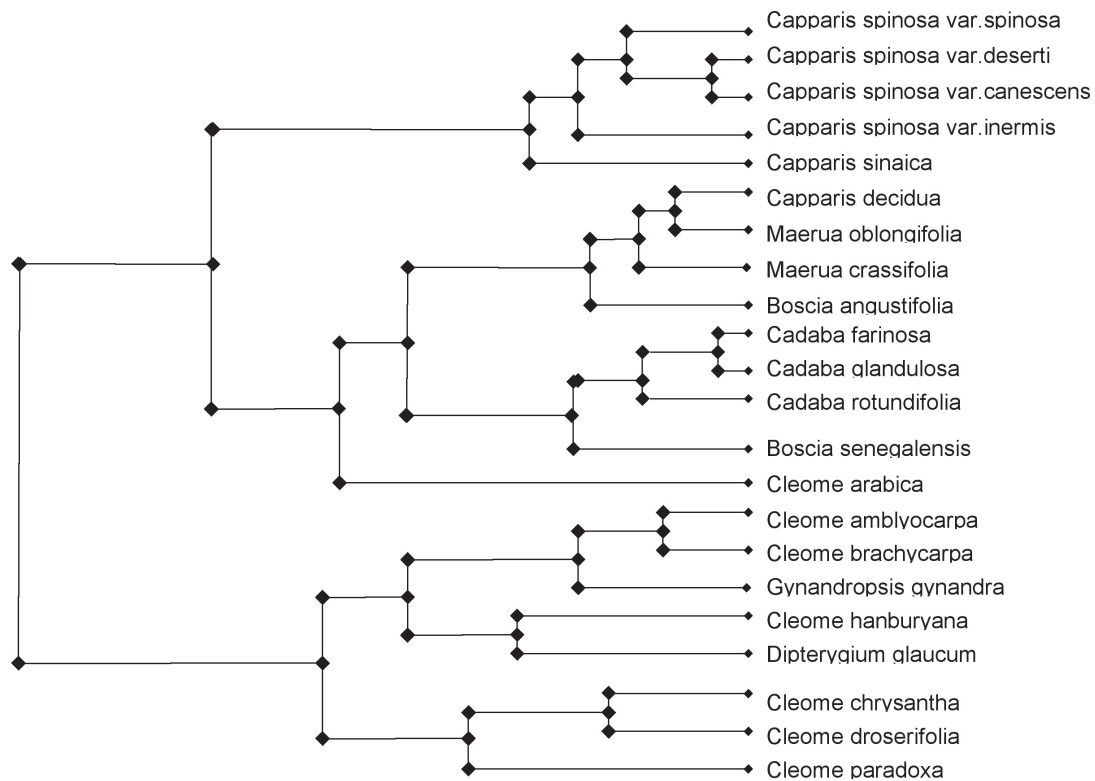


Figure 2. Complete linkage

following characteristics were helpful in the identification of the studied taxa: leaf composition, leaf surface, major venation pattern, secondary vein category, number of veins on either side of midrib, areolation, free ending ultimate veins and marginal ultimate venation. Therefore, based on the aforementioned results, the following key can be presented for the identification of the Capparaceae:

1. Venation pattern actinododromous
2. Marginal ultimate venation is incomplete loop *Cleome arabica*
2. Marginal ultimate venation is branched excurrent vein..... *Cleome droserifolia*
1. Venation pattern pinnate
3. Number of veins on either side of midrib 7-8..... *Capparis decidua*
3. Number of veins on either side of midrib otherwise 4
4. Marginal ultimate venation with excurrent vein branched5
5. Secondary vein category brochidodromous.....
- *Cleome paradoxa*
5. Secondary vein category semi-craspedodromous
.....*Cleome amblyocarpa*
5. Secondary vein category cladododromous6
6. Secondary vein angle decreasing toward base and areolation poorly developed..... *Dipterygium glaucum*
6. Secondary vein angle uniform, areolation well developed 5 or more sided*Gynandropsis gynandra*
5. Secondary vein category craspedodoromous7
7. Marginal ultimate venation fimbrial arcuate and secondary vein spacing increasing toward base.....
..... *Cleome chrysantha*
7. Marginal ultimate venation with excurrent vein branched and irregular secondary vein spacing8
8. Secondary vein angle with one pair acute secondaries*Cleome hanburyana*
8. Secondary vein angle decreasing towards base *Cleome brachycarpa*
4. Marginal ultimate venation with fimrial arcuate 9
9. Free ending ultimate veins (F.E.V.S.) absent

-10
10. Secondary vein spacing increasing toward base and secondary vein angle with one pair acute secondaries*Boscia angustifolia*
10. Secondary vein angle with two pair acute secondaries and irregular vein spacing
..... *Boscia senegalensis*
9. Free ending ultimate veins with three branched and tapering 11
11. Secondary vein angle decreasing towards base *Cadaba farinosa*
11. Secondary vein angle with one pair acute secondaries*Cadaba glandulosa*
11. Secondary vein angle with two pair acute secondaries *Cadaba rotundifolia*
4. Marginal ultimate venation with incomplete loops12
12. Free ending ultimate veins with three branched diffuse13
13. Leaf oblanceolate*Maerua crassifolia*
13. Leaf narrow oblong *Maerua oblongifolia*
12. Free ending ultimate veins with three branched and swollen dots
..... 14
14. Inter-secondary veins absent 15
15. Secondary vein angle uniform
.....*Capparis spinosa* var. *deserti*
15. Secondary vein angle increase towards base
.....*Capparis spinosa* var. *inermis*
14. Inter-secondary vein present16
16. Third vein angle to the primary is perpendicular*Capparis spinosa* var. *spinosa*
16. Third vein angle to the primary is acute17
17. Secondary vein angle increasing towards base
.....*Capparis spinosa* var. *canescens*
17. Secondary vein angle with two pair acute secondaries..... *Capparis sinaica*

On the basis of leaf architecture, cluster analysis was used to solve some of the problems met within this family such as: (a) the segregation of *Cleome* species from the *Capparis* group, i.e., into two distinct families or not, (b) whether *Dipterygium* is better placed in Capparaceae than Brassicaceae (Hedge et al. 1980), and (c) the treatment of *Gynandropsis* as separate genus or its restoration as *Cleome gynandra*.

The dendrograms resulted from the cluster analysis are shown in Figures (2-4). Differences between methods arose

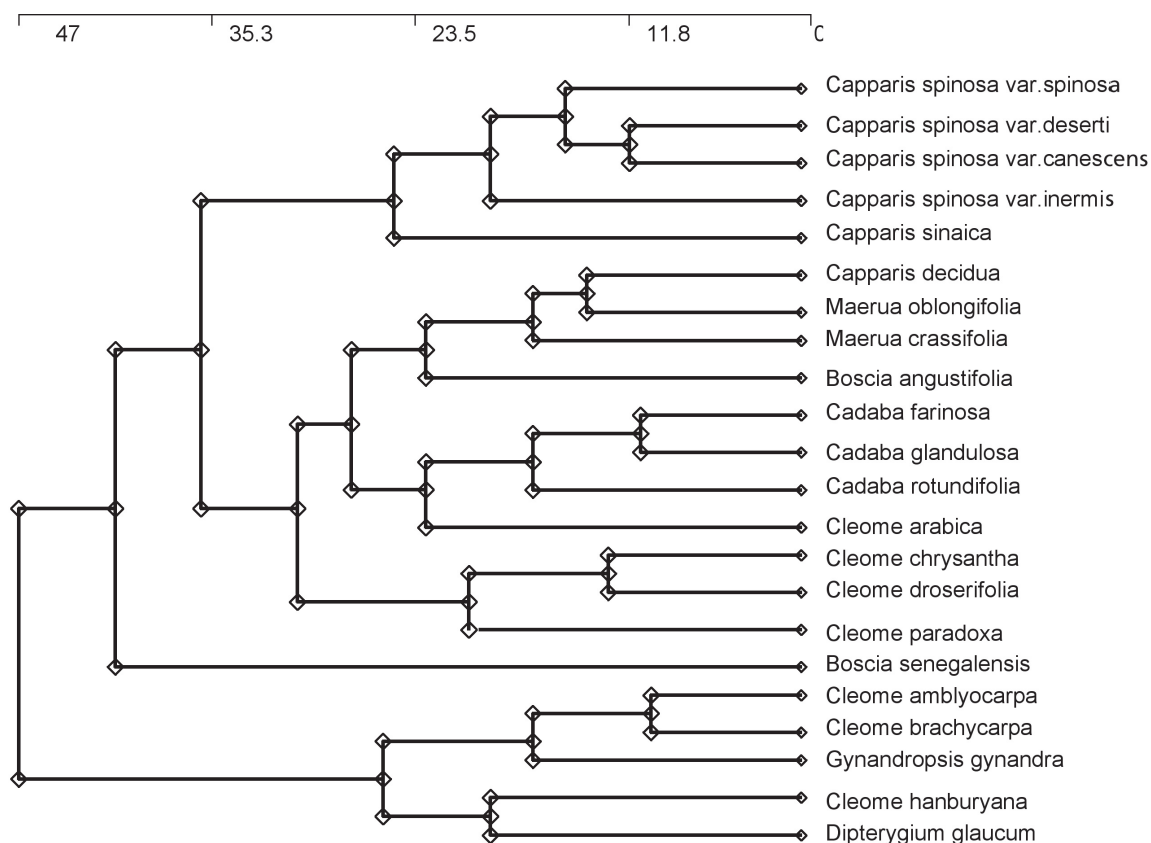


Figure 3. Average linkage

because of the differences in the ways of defining distance (or similarity) between individuals, and a group containing several individuals. All the dendrograms showed that three main clusters can be distinguished: (1) a cluster comprised most of the *Capparis* species; (2) a cluster divided into three subgroups: the first comprises all *Maerua* species, *Capparis decidua* and *Boscia angustifolia*, the second comprises *Cadaba* species and *Boscia senegalensis*, and the third with *Cleome arabica*; and (3) a cluster comprises most of *Cleome* species, *Gynandropsis gynandra* and *Dipterygium glaucum*.

Principal Components Analysis (PCA) reflected which characters were important on the axes; and indicated the significant characters based on the highest factor loading (Table 3). Therefore, it becomes clear which characters caused the separation between groups and can be useful to distinguish taxa. Generally, the results showed congruence between classification and ordination analyses in suggesting the following groups:

1- *Capparis* group (Tribe Capparideae): On the basis of leaf and venation characters, results of PCA confirmed that the studied taxa of *Capparis* formed a well-distinguished group characterized by: (a) simple ovate leaf, (b) irregular secondary vein spacing, (c) random reticulate third vein

category and (d) branched free ending ultimate veins with swollen dots.

2- *Boscia* group (Tribe Capparideae): This group characterized by the absence of free ending ultimate veins. Phylogenetically and based on morphological and molecular data, Hall et al. (2002) revealed that there was less supported resolution within the terminal clades of Capparoideae, and still unresolved but comprise five well supported clades.

3- *Cadaba* group (Tribe Capparideae): This group is characterized by: (a) three branched with tapering end of free ending ultimate ends and (b) absence of intersecondary veins. Hall et al. (2002) indicated that genus *Cadaba* is well supported as a natural genus based upon the presence of large adaxial glands in flowers, and thus it can be supported as monophyletic group.

4- *Maerua* group (Tribe Maerueae): This group included the taxa of genus *Maerua*. It is differentiated on the basis of: (a) simple leaf, (b) pinnate venation pattern and (c) three branched diffuse of free ending ultimate veins of the leaf.

5- The mixed group: which included *Cleome* species, *Dipterygium glaucum* and *Gynandropsis gynandra* that characterized by their leaf margin and leaf persistence.

The present results showed some degree of similarity

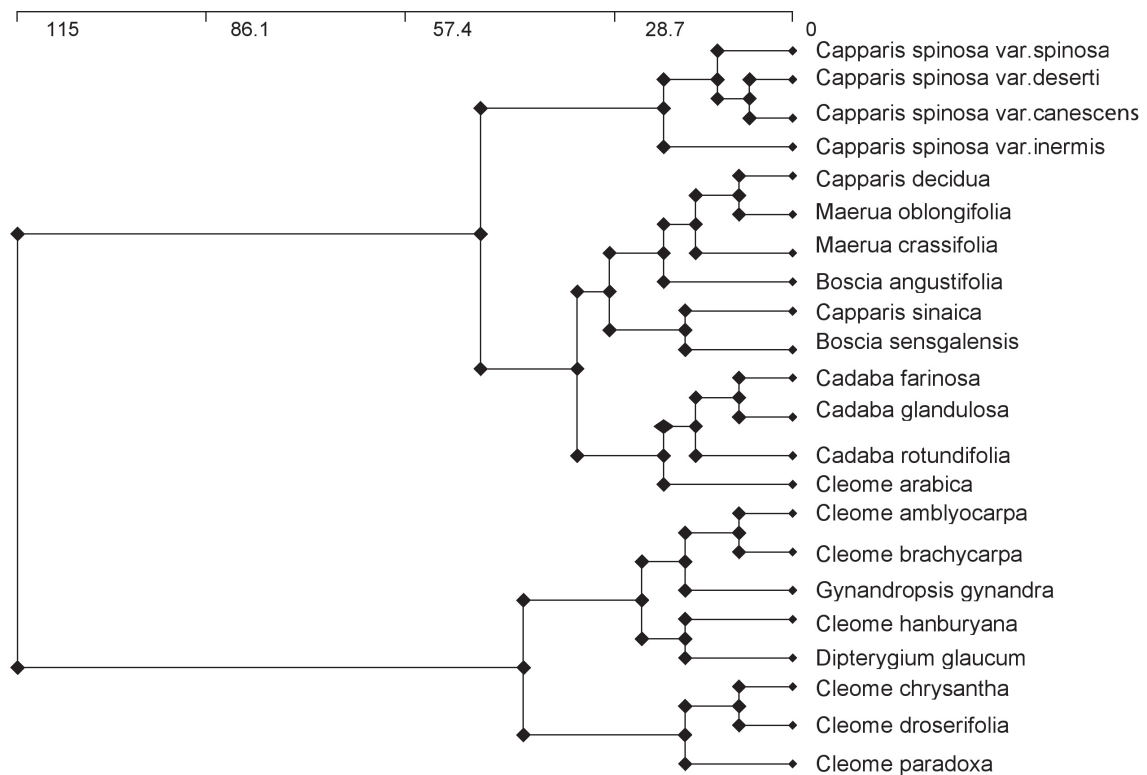


Figure 4. Minimum variance

among the taxa of Dipterygioideae and Cleomoideae based on: (a) the number of veins on either side of midrib and (b) secondary vein category (either cladodromous or craspidodromous).

Table 3 and Figure 5 showed that the main characters explaining this separation were leaf or leaflet form (1), leaf surface (5), leaf base (6), leaf persistence (7), main venation pattern (8), secondary vein angle (11), inter-secondary veins (12), number of veins on either side of midrib (13), free ending ultimate veins (19) and marginal ultimate venation (21).

Discussion

Leaf venation in angiosperm varies both in pattern (Hickey 1973) and regularity (Hickey and Doyle 1972). According to Pray (1954), the veins of first, second and third order form major venation pattern and those of subsequent orders constitute minor venation patterns. Hickey and Wolf (1975) based most of their conclusions on a survey of dicotyledonous leaf architecture made in the course of over ten years' study. They established the first framework for a systematic summary of dicotyledonous leaf architectural features. Because most taxa of dicots possess consistent patterns of leaf architecture, this rigorous method of describing the features of leaves is of immediate usefulness in both modern and fossil taxonomic studies. In addition as a result of this method, it is anticipated

that leaves will play an increasingly important part in phylogenetic and ecological studies.

Based on the present study the Capparaceae *sensu lato* manifest two principal types of venation pattern: pinnate and actinododromous. According to Hickey and Wolf (1975), leaves (or leaflets) of the studied taxa of Capparaceae were basically simple, margin entire, venation pinnate, secondary veins were strongly brochidodromous. The free ending ultimate veins of the leaf (F.E.V.S) are a diagnostic character in the Capparaceae. The present observations were in accordance with those of Hickey and Wolf (1975) except the formation of a three-branched free ending ultimate vein with swollen dots (in *Capparis* species, except *C. decidua*), which was not recorded earlier. Whereas it was absent in the studied species of *Boscia*, three branched tapering or diffuse ending was recorded in genera of *Maerua*, and *Cleome arabica*. The remaining *Cleome* species were characterized by one-branched tapering endings.

Cleomoideae and Capparoideae were previously included in Capparaceae (Cronquist 1981, 1988; Thorne 1976, 1983; Dahlgren 1975; Takhtajan 1980, 1976). However, the two subfamilies of Capparaceae (Cleomoideae and Capparoideae) have already been elevated to familial status by some taxonomists (Airy Shaw 1965; Hutchinson 1967). Morphological and molecular studies (Radman 1991a, 1991b; Radman

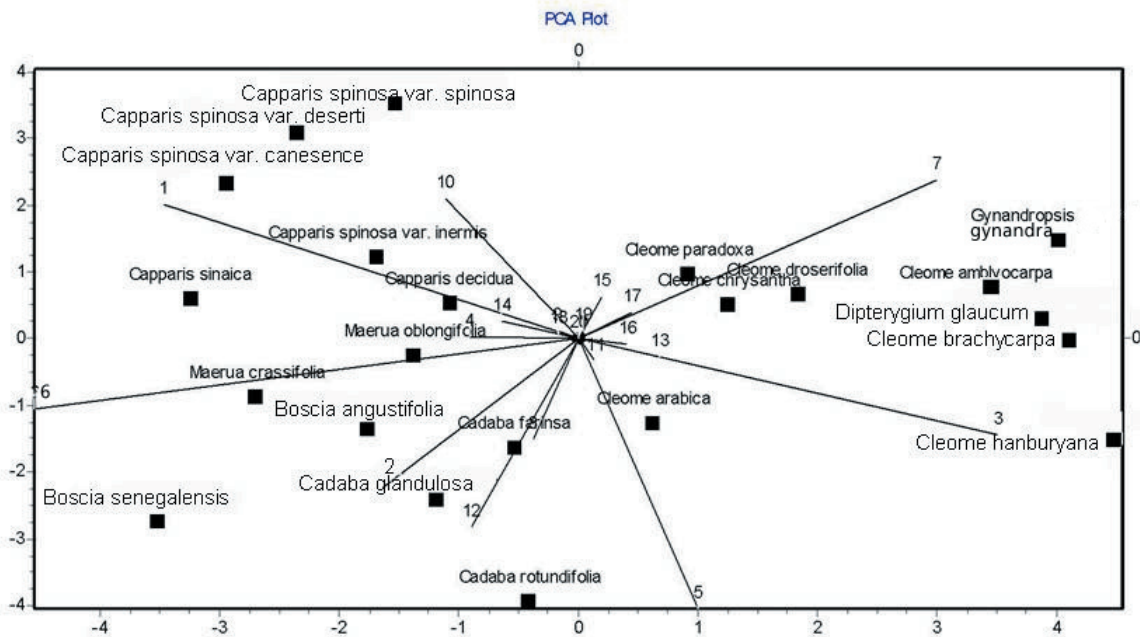


Figure 5. Principal Components Analysis (PCA) biplot showing characters (arrows) and species (dark squares). For character numbers, see Table 2.

et al. 1993; Judd et al. 1994) suggested that Capparoideae form a paraphyletic grade sister to a monophyletic Cleomoideae plus Brassicaceae. Based on these analyses, the two families have been merged into one family: the Brassicaceae *sensu lato* (APG 1998). However; based on molecular data; Cleomoideae, Capparoideae and Brassicaceae all form three well-supported monophyletic clades (Hall and Sytsma 2000; Hall et al. 2002) and could be recognized as three separate families, the Capparaceae, Cleomaceae, and Brassicaceae, a course of action recommended by some recent authors (Hall et al. 2002). On the basis of leaf architecture study, we advocate the recognition of two separate families Capparaceae and Cleomaceae. In this investigation most vein orders of leaf architecture were shown to be of great importance in the taxonomy of Capparaceae and Cleomaceae. They allowed in many instances clear separation between various taxa even at the very lower levels (species level) of the taxonomic hierarchy. Thus, their use to complement macro characters for taxonomic purposes is highly advisable. So for, there is no study devoted to the minor venation pattern, in the Capparaceae and Cleomaceae, the major and minor venation patterns are useful for the identification of the species. Our result revealed that leaf architecture has a significant value in differentiation between species; however, there is no differentiation at the variety level. We will investigate these tribes and genera with both morphological and molecular data in a separate account.

The present numerical analysis generally in agreement with earlier classification though it has suggested some

amendments on generic level. Iltis (1960), De Wolf (1962), Ernst (1963) and Al-Gohary (1997) adopted the treatment of *Gynandropsis* as separate genus, but this had been contradicted with Täckholm (1974) and Boulos (1999). The cladistic

Table 3. Morphological characters showing highest factor loadings on the first three axes of PCA. For character numbers, see Table 2.

Character Number	Axis 1	Axis 2	Axis 3
1	-1.44	6.25	-1.60
2	-4.36	-2.48	0.058
3	3.28	-0.20	0.61
4	2.12	-1.37	-0.05
5	-0.46	-4.89	-3.07
6	-2.88	-0.61	-0.04
7	-0.45	1.13	-1.31
8	2.88	-0.27	0.95
9	0.56	-2.96	-0.79
10	-0.11	0.42	2.72
11	-5.87	2.21	0.34
12	0.09	0.09	0.24
13	-0.56	1.58	-0.94
14	3.37	0.05	0.83
15	3.02	0.48	0.98
16	-0.21	-0.92	1.04
17	2.55	3.79	-3.68
18	3.00	0.02	0.97
19	-4.52	1.14	248
20	1.94	0.39	1.56
21	-1.92	-3.90	-1.31

analysis of leaf architecture presented in this study supported the concept adopted by some authors as El Hadidi and Fayed (1994/95) and Boulos (1995) who retained *Gynandropsis gynandra* as *Cleome gynandra* of the family Capparaceae, as it clearly nested within *Cleome* (Figures 2-4). Corner (1976) also stated that the seeds of some species of *Cleome* seem to be resemble those of *Gynandropsis* e.g. *Cleome chelidonii*. Our results also added further evidence for the suggestion of Pax and Hoffman (1936), Ernst (1963) and Khafagi and Al-Gohary (1998) that *Gynandropsis gynandra* is closely related to *Cleome hanburyana*.

Although, Täckholm (1974) maintained *Dipterygium* in Cruciferae (Brassicaceae), yet Hedge et al. (1980) and Boulos (1999) favoured better placement in Capparaceae *sensu lato* than in the Cruciferae. This investigation had reinforced evidence for the suggestion of Hedge et al. (1980) for maintaining *Dipterygium* in Cleomaceae. Based on molecular and morphological data, Hall et al. (2002) demonstrated also a strong relationship within the clade including *Cleome* spp., *Dipterygium glaucum* and *Gynandropsis gynandra*.

References

- Abd El-Ghani MM, Marei AH (2006) Vegetation associates of the endangered *Randonia africana* Coss. and its soil characteristics in an arid desert ecosystems of western Egypt. *Acta Bot Croat* 65(1):83-99.
- Airy Shaw HK (1965) Diagnoses of new families, new names, etc. for the seventh edition of Willis (Dictionary). *Kew Bulletin* 18:249-273.
- Al Gohary IH (1982) Morphological studies on the Capparidaceae in Egypt. M.Sc. Thesis Botany Department, Faculty of Science, Ain Shams University.
- Al Gohary IH (1997) Biosystematic studied of Cleomaceae in Egypt. 1. The seed morphology and its taxonomic significance. *Desert Institute Bulletin Egypt* 47 (2):423-440.
- APG (Angiosperm Phylogeny Group) (1998) An ordinal classification for the families of flowering plants. *Annals of the Missouri Botanical Garden* 85: 531-553.
- APG (2003) An update of the angiosperm phylogeny group classification for the orders and families of the flowering plants. APG II. *Botanical Journal of the Linnean Society* 141:399-439.
- Banerjee G, Deshpande BD (1973) Foliar venation and leaf histology of certain members of Compositae. *Flora* 162:529-532.
- Boulos L (1999) *Flora of Egypt*. Vol. 1 (Azollaceae-Oxalidaceae). Al Hadra Publishing, Cairo.
- Boulos L, El-Hadidi MM (1984) *The Weed Flora of Egypt*. The American university in Cairo Press, Cairo.
- Corner EJH (1976) *The Seeds of Dicotyledons*. Vol.1. Cambridge Univ. Press, Cambridge.
- Cronquist A (1981) *An integrated system of classification of flowering plants*. Columbia University Press, New York, USA.
- Cronquist A (1988) *The evolution and classification of flowering plants*. 2nd Ed. The New York Botanical Garden, New York.
- Dalhgren R (1975) A system of classification of the Angiosperms to be used to demonstrate the distribution of characters. *Botaniska Notiser* 128:119-147.
- De Wolf GP (1962) Notes on African Capparidaceae III. *Kew Bulletin* 16 (1):75-83.
- Dilchler DL (1974) Approach to the identification of Angiosperm leaf remains. *Bot Rev* 40:1-157.
- El Hadidi MN, Fayed A (1994/1995) Materials for Excursion Flora of Egypt. *Taeckholmia* 15:1-233.
- El-Karemy ZAR (2001) Capparaceae in the flora of Egypt. *Taeckholmia* 21(2):257-267.
- Endress PK (1992) Evolution and floral diversity: the phylogenetic surroundings of *Arabidopsis* and *Antirrhinum*. *Int J Plant Sci* 153:106-122.
- Ernst WR (1963) The genera of Capparaceae and Moringaceae in the south-eastern United States. *Journal of the Arnold Arboretum* 44:1-81.
- Etingshausen C von (1861) *Die Blattsklete des Dicotyledonen*. K.K. Hof. Staatsruckeri, Wien.
- Hall JC, Sytsma KJ (2000) Solving the riddle of California cuisine: phylogenetic relationships of Capers and Mustards. *Am J Bot* 87(6, Suppl.):132.
- Hall JC, Kenneth J, Iltis HH (2002) Phylogeny of Capparaceae and Brassicaceae based on chloroplast sequence data. *Am J Bot* 89(11): 1826-1842.
- Hedge IC, Lamond J (1970) Capparidaceae. In Rechinger K.H. ed., *Flora Iranica* 68:1-9, Graz.
- Hedge IC, Kjaer A, Malver O (1980) *Dipterygium*: Cruciferae or Capparaceae. *Notes from Royal Botanic Gardens Edinburgh* 38(2):247-250.
- Hickey L (1973) Classification of the architecture of dicotyledonous leaves. *Am J Bot* 60:17-35.
- Hickey L (1977) Stratigraphy and paleobotany of the Golden Valley Formation (Early Tertiary) of western North Dakota. *Memoirs of the Geological Society of America* 150: 1-183.
- Hickey LJ, Doyle JA (1972) Fossile evidence in the evolution of Angiosperm leaf venation. *Am J Bot* 59:661 (Abstract).
- Hickey LJ, Taylor DW (1991) The leaf architecture of *Ticodendron* and the application of foliar character in discerning its relationships. *Ann Mo Bot Gard* 78:105-130.
- Hickey LJ, Wolf JA (1975) The bases of Angiosperm phylogeny: vegetative morphology. *Ann Mo Bot Gard* 62:538-589.
- Hutchinson J (1967) *The Genera of Flowering Plants*. Univ. Press, Oxford, UK.
- Iltis HH (1960) Studies in Capparidaceae VII. Old world Cleomes adventive in the New World. *Brittonia* 12:279-294.
- Inamdar JA, Murthy GSR (1978) Leaf architecture in some Solanaceae. *Flora* 176:269-272.
- Inamdar JA, Shenoy KN, Rao NV (1983) Leaf architecture of some monocotyledons with reticulate venation. *Ann Bot* 52:725-735.
- Jacobs M (1965) The genus *Capparis* (Capparaceae) from the Indus to the Pacific. *Blumea* 12:385-541.
- Jain DK (1978) Studies in Bignoniaceae. III. Leaf architecture. *J Indian Bot Soc* 57:369-386.
- Judd WS, Sanders RW, Donghue MJ (1994) Angiosperm pairs: preliminary phylogenetic analyses. *Harv Pap Bot* 5:1-51.
- Khafagi A, Al-Gohary IH (1998) Biosystematic studies of Cleomaceae in Egypt. II. Taxonomic significance of some micromorphological characters of the leaf and pollen grains. *Al-Azhar Bulletin of Science* 19(2):1027-1036.
- LAWG (1999) *Manual of Leaf Architecture- morphological description and categorization of dicotylenous and net-veined monocotylenous angiosperms*. Leaf Architecture Working Group, Washington.
- Levin GA (1986) Systematic foliar morphology of Phyllanthoideae (Euphorbiaceae). 1. Conspectus. *Ann Mo Bot Gard* 73:29-85.
- Li HM, Hickey LJ (1988) Leaf architecture and systematics of the Hamamelidaceae *sensu lato*. *Acta Phytotaxonomica Sinica* 26:96-110.
- Luo Y, Zhou Z-K (2002) Leaf architecture in *Quercus* subgenus *Cyclobalanopsis* (Fagaceae) from China. *Bot J Linn Soc* 140:283-295.
- Mabberley DJ (1987) *The plant book*. Cambridge University Press, Cambridge, New York.
- Mabberley DJ (1997) *The plant book: a portable dictionary of the higher plants*. Univ. Press, Cambridge, UK.
- Pax F, Hoffmann K (1936) Capparidaceae. In Engler and Prantl, eds., *Natürlichen Pflanzenfamilien* 17(b):146-233.
- Pray TR (1954) Foliar venation of Angiosperms. I. Mature venation of *Liriodendron*. *Am J Bot* 41:663-670.
- Rodman JE (1991a) A taxonomic analysis of glucosinolate-producing plants. 1: Phenetics. *Syst Bot* 16:598-618.

- Rodman JE (1991b) A taxonomic analysis of glucosinolate-producing plants. 2: Cladistics. Syst Bot 16:619-629.
- Rodman JE, Price RA, Karole K, Conti E, Sytsma KJ, Palmer JD (1993) Nucleotide sequences of the *rbcL* gene indicate monophyly of mustard oil plants. Ann Mo Bot Gard 80:686-699.
- Shammuka R, Narmada K (1994) Leaf Architecture in some Amaranthaceae. Feddes Repertorium 105(1-2):37-44.
- Subrahmanyam NS (1999) Laboratory of Plant Taxonomy. Delhi.
- Sun H, Chen J, Zhou ZK, Fei Y (1991) The leaf architecture and its taxonomic significance in the genera *Albizia* and *Cylindrokelupha* from China. Acta Botanica Yunnanica 13:241-253.
- Täckholm V (1974) Students' Flora of Egypt. Cairo University, Cairo.
- Tackhtajan AL (1980) Outline of classification of flowering plants. Bot Rev 46:225-359.
- Thakur C (1988) Leaf architecture in Cassia. Acta Botanica Indica 16: 63-72.
- Thorn RE (1976) A phylogenetic classification of the Angiospermae. In Hecht MK, Steere WC and Wallace B, eds., Evolutionary Biology 9: 35-106, New York.
- Thorn RF (1983) Proposal new realignment in the Angiospermae. Nord J Bot 3: 85-117.
- Thulin M (1993) Flora of Somalia. Vol. 1. Royal Botanic Gardens, Kew.
- Wang YF, Ferguson DK, Zetter R, Denk T, Garfi G (2001) Leaf architecture and epidermal characters in *Zelkova* (Ulmaceae). Bot J Linn Soc 136: 255-265.
- Wieringa JJ (1999) Monopetalanthus exit. A systematic study of *Aphanocalyx*, *Bikinia*, *Icuria*, *Michelsonia* and *Tetraberlinia* (Leguminosae, Caesalpinioideae). Wageningen Agriculture University Papers 99(4):1-320.
- Zahran MA, Willis AJ (1992) The Vegetation of Egypt. Chapman and Hall, London, UK.
- Zohary M (1966) Flora Palestina. Vol.1, Israel Academy of Sciences and Humanities, Jerusalem.