FLORAL TAXONOMICAL INVESTIGATION WITHIN PAPAVERACEAE S.L.

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ABSTRACT

Twenty seven species belonging to eight genera have been investigated in this study. These species covered the three restricted families, Papaveraceae, Fumariaceae and Hypecoaceae. The floral characters have been examined carefully, and the herbarium sheets, flowers, stigma, fruits and pollen grains have been photographed. The results indicated that the flower arrangement and symmetry, stamen number, presence of style, shape of stigma, and type of fruits as well as pollen grain characters all together proved new taxonomic division of the Papaveraceae s.l.. This investigation supports the separation of the Fumariaceae with two tribes from both the papaveraceae and Hypecoaceae. Meanwhile, the position of the Hypecoaceae, as subfamily level, under the Papaveraceae is more acceptable. Floral morphological key has been constructed as well as phenogram show the relations between these taxa using SYSTAT12 program. A correlation analysis of nineteen most important characters has been investigated using SPSS program and three identification keys have been constructed.

Key words: Fagoniaceae-Floral-Hypecoaceae-Papaveraceae-Taxonomy
Introduction

Floral characters have been used in many systems of classification since Tournefort (1656-1708). Tournefort recognized two grades of genera based on the form and size of flowers and fruits. This view has been accepted by Linnaeus (1737), but he used the androecium characters to construct his sexual system of angiosperm classification. Stearn (1961b) arranged the plant characters in a priori consideration as follows: embryo, stamens and pistils, followed by the perianth and fruits. The flowers exhibit an amazing variety of sizes, shapes, colors, arrangements, scents, rewards, and sexual systems. Small et al. (1981) used the petal arrangement, venation and staminal tube variations in distinguishing members of tribe Trigonelleae, Medicago, Trigonella, and Melilotus. They referred these variations as an adaptation to outcross pollinations. A recent opinion by Kay et al. (2006) concerning the importance of floral characters is their influence in speciation and extinction of many species. Thus floral morphology recently applied in the taxonomic decisions in many taxa (ex. Kong and Hong, 2018; Nam and Chung, 2018; Vasconcelos et al., 2019 & Taia et al., 2020).

Dahlgren (1980), Kadereit (1993) and Lidén (1993a) recognized Papaveraceae s. s. with the combination of Fumariaceae including Hypecoum L. and Fumariaceae including Pteridophyllum Siebold & Zucc., and Hypecoum. Hutchinson (1921), Cronquist (1981) and Wang et. al. (2009) recognized two subfamilies within Papaveraceae s. l.: Fumarioideae (DC) Endl. (including Pteridophyllum and Hypecoum) and Papaveroideae Eaton. Cronquist (1981), Takhtajan (1987), Dahlgren (1989) and Kubitzki (1993) suggested major segregation of Fumariaceae from Papaveraceae.

Members of family Papaveraceae s.l. have great variations in their floral characters. These variations have been used in their segregation and identifications of certain taxa by Günther (1975a). He found two types of inflorescence; monotelic or amphitelic synflorescences; within the papaveraceae s.s. which are of important value in the classification of the genera. Xuan and Chuang (1993) considered the papaveraceae from the most primitive families within the Angiosperm. They used the floral characters, especially the number of carpels and their status in dividing the family into three subfamilies and eight tribes and their importance in the phylogenetic trend. Molecular investigations done by Cronquist (1981) recognized the Fumariaceae as a separate family, despite their close phylogenetic relationship to the Papaveraceae s.s. The three families may be treated as subfamilies. The Angiosperm Phylogeny Group II (2003) and III (2009) favor the recognition of Papaveraceae s. l., but retain the option of recognizing Pteridophyllaceae and Fumariaceae (including Hypecoum) as separate families. In APG III (2009) the Papaveraceae has three taxa, these taxa have been separated into different families: the Papaveraceae s. s., the Fumariaceae and the Pteridophyllaceae. While the APG IV (2016) treated the
Papaveroideae and Fumarioideae (including Hypecoum) as a subfamilies under family Papaveraceae in order Ranunculales. Nowadays most of the authors are treating Fumariaceae as a subfamily of Papaveraceae.

The Papaveraceae s.s. comprises 43 genera and 820 species worldwide, mostly distributed in north temperate and tropical regions (Mabberley, 2008). Fumariaceae s.s. family previously treated as a small family of about 19 genus and 400 species (Lidén, 1986) occurring mainly in North America, Europe, Asia and Africa. The family Hypecoaceae includes the single genus Hypecoum with about 15 living species distributed from the Mediterranean region through central Asia to northern China (Mabberley, 1987).

In Egypt the family Papaveraceae s.s. is represented by 13 species classified under four genera; Papaver L., Argemone L., Roemeria Medik. And Glaucium Mill. (Täckholm, 1974 and Boulos, 1999). According to Täckholm (1974), the family Fumariaceae represented by one genus Fumaria L. containing 8 species, while according to Boulos (1999) the Fumariaceae merged with Hypecoaceae and represented by 15 species distributed in two genera, Fumaria L. and Hypecoum L. This work aims to clarify the relationship between the three closely related families; Papaveraceae, Fumariaceae and Hypecoaceae; by investigating the floral characters within 24 species.

Materials and Methods

This work has been done on 27 species representing eight genera collected from field trips and different herbaria in Egypt (table 1). From three to ten sheets or fresh individuals were examined in each species, as availability. Fresh specimens collected from Borg El Arab, King Mariut and Al Omayed region in the western Mediterranean coastal strips during March and April 2017, 2018 by the author, have been subjected in this study. The flowers have been examined and dissected by Stereomicroscope. The specimens were identified by the aid of student’s flora of Egypt Täckholm (1974) and Boulos (1999) and confirmation of nomenclature has been done according to the sites indicated in table 1. All the information about the studied taxa is summarized in table 1, abbreviation of the herbaria in which the specimens located are as follows: Alexandria (ALEX) and Cairo (CAI).

Data analyses

The studied characters have been subjected to data analyses using SPSS program to investigate nineteen, most variable characters (Appendix 1) have been subjected to SYSTAT13 program to evaluate the relations between the studied taxa, as well as correlation analysis between these characters have been investigated using SPSS program.

Results

The results of the studied taxa summarized in tables 2, 3, 4 & 5. The flowers of the studied species are either solitary in Papaveraceae s.s. and Hypecoum species, or aggregated in definite inflorescences in Fumaria species. The length of the inflorescences within the Fumaria species varied from 1.3 cm in F. bracteosa to 3.4 cm in F.judaica, with different width from 1 mm in both F.
gaillardotii and F.microstachys to 6 mm in F. bracteosa, F.judaica and F.parviflora. All the flowers are bracteated and pedicellated with bracts either shorter or longer than the pedicels (table 2). The calyx in all the studied species consists of two sepals, which are deciduous in the Papaveraceae s.s species. The sepal surface is enriched by sharp spines in Argemone Mexicana only, while they are hairy in all the other species belonging to Papaveraceae s.s except P.decaisnei the sepals are glabrous. In both the Fumariaceae and Hypecoaceae the sepals are glabrous, except F.microstachys they are hairy. The corolla consists of four delicate and colorful petals, which are actinomorphic in the papaveraceae taxa and zygomorphic in both Fumariaceae and Hypecoaceae (table 2).

The gynaeicum within the studied species varied greatly in their characters. The number of united carpels differs within the Papaveraceae taxa, they are 5 in Argemone Mexicana, 2 in Eschscholzia sp., from 5-12 in Papaver sp. and 4 in Roemeria hybrida. In both the Fumariaceae and Hypecoaceae there are two united carpels only. The style absent in the Papaveraceae species, except in Eschscholzia species, while in both the Fumariaceae and the Hypecoaceae the style present. The stigmas are mostly sessile, with rounded lobes or disc- shape in the Papaveraceae, except Eschscholzia and Glaucium they are either lobed or biforked. The ovary takes different shapes between the studied species. It is globose in both Aragemone and Glaucium with spiny wall in the former and glabrous in the later. The ovary is linear and glabrous in Eschscholzia species. In Papaver sp. it is rectangular and glabrous, while in Roemeria it is rectangular and enriched by multicellular uniseriate hairs (table 3). In both Fumariaceae and Hypecoaceae taxa, the ovary is globose and glabrous, except in F.gaillardotii, the wall covered by multicellular uniseriate hairs, and F.microstachys, the wall covered by multicellular glandular hairs. In F.parviflora, the ovary is globose and ridged (table 3).

The fruit characters are more obvious within the studied taxa. Mostly the capsules are dry dehiscent capsules opened by either valves or pores within the Papaveraceae species. In the Fumariaceae, only the genus Dicentra has Capsule fruits opened by valves, while in the genus Fumaria the fruits are dry indehiscent nuts. In Hypecoum species, the fruits are siliquose articulated. The fruit shape varied according to the ovary shape, from linear, slightly elongated, oblong or globose with different lengths and widths (table 4). The fruit surfaces are either spiny in A.mexicana, mostly glabrous or ornamented with multicellular uniseriate hairs in moderate density except in F. microstachys they are woolly (table 4).

The androecium has great variations in both stamen number and pollen grain characters as viewed in table 5. In Papaveraceae taxa the number of stamens varied from 10 to numerous, while in the Fumariaceae they are six only and three in the Hypecoaceae. The pollen morphological characters show great variation between the three restricted families. They are stenopalynous within the Papaveraceae and Fumariaceae species i.e. have different shapes, aperture number and type as well as exine ornamentations.
They are varied from the suboblate, peroblate, spheroidal to the subprolate with three, four to six apertures. The apertures are colporate, colporoidate or colporate and in some Fumaria species the pollen grains have porate aperture. Their exine ornamentation varied from the reticulate to the tectate echinate or scabrate (table 5). The pollen grains of the Hypecoaceae; are eurypalynous i.e. having more similar characters. They are spheroidal, with one or two colpi and tectate echinate exine (table 5).

Data analyses
The results of the data analyses have been summarized in tables 6 and 7. Table 6 shows the mean, standard error, standard deviation, sample variance, range (19-2=17), minimum reading, maximum reading, summation of the data and count of the studied taxa (=27 investigated species) of the nineteen most variable characters. While table 7 shows the correlation between these characters. The most obvious results obtained are the number of flower per inflorescence is highly correlated with the symmetry of the flowers, presence of style and fruit shape. The symmetry of the flowers is positively correlated with type of fruits and pollen grain characters and negatively correlated with the number of stamen, in the same time the number of stamens is negatively correlated with the presence of style. In the same time the stigma shape is highly correlated with the fruit shape, and the fruit shape is highly correlated with both ovary shape and pollen aperture type as well as the ovary shape is highly correlated with the fruit surface.

The clustering analysis of the nineteen most variable characters (Apendix 1) grouped that the studied taxa into two categories, I & II. The first category (I) include all the Fumariaceae and Hypecoaceae species, while the second category (II) include all the Papaveraceae species. Each of these two categories is subdivided into two divisions within the first category (A & B) and three divisions in the second category (A, B & C). Group I A has all the Fagonia species, except F.microstachys which came in group I B with the Dicentra and Hypecoum species. Group II A has the Eshscholzia species only, while group II B has the two Glaucium species and finally group II C gather the Argemone with the Papaver and Romeria species (Fig.1).
A-Key to the three families Papaveraceae, Fumariaceae & Hypecoaceae

1-Flowers solitary
   1.1-Flowers actinomorphic Papaveraceae
   1.2-Flowers zygomorphic Hypecoaceae

1-Flowers arranged in inflorescences Fumariaceae

B-Key to the studied genera

1-Flowers solitary
   1.2.1-Bract spiny Argemone mexicana
   1.2.2-Bract glabrous Papaver & Eschscholzia
   1.2.3-Bract hairy
      1.2.3.1-Flowers actinomorphic Roemeria & Glaucium
      1.2.3.2-Flowers zygomorphic Hypecoum

1-Flowers in inflorescences composed from 5-7 flowers
   1.2.1-Bract glabrous Dicentra formosa
   1.2.2-Bract hairy Fagonia microstachys

1-Flowers in inflorescences composed from 8-18 flowers
   1.2.1-Bract glabrous, Bract/pedicel shorter
      Fagonia galilordii, F.judaica, F.officinalis
   1.2.2-Bract glabrous, Bract/pedicel longer
      F.bracteosa, F.densiflora, F.parviflora

C-Key to the nearby genera and species

1-Flowers solitary actinomorphic, bract glabrous
   1.2-Stigma sessile Papaver sp.
      1.2.1-Stigma discoid, 5 in number
         1.2.1.1-Fruit obovate P.argemone
         1.2.1.2-Fruit oblong P.decaiseneii
      1.2.2-Stigma discoid, 7 in number
         1.2.1-Fruit glabrous P.pumile
         1.2.2-Fruit hairy P.hybridum
      1.2.3-Stigma discoid, 10 in number P.dubium
      1.2.4-Stigma discoid, 12 in number P.rhoeas
   1.2-Stigma subtended by long style Eschscholzia sp.
      1.2.1-Stamens 10-12
         1.2.1.1-Calyx sparsely hairy E.lobii
         1.2.1.2-Calyx densely hairy E.minutifolia
      1.2.2-Stamens 12
         1.2.2.1-Calyx hairy E.caespitosa
         1.2.2.2-Calyx glabrous E.californica & E.glyptosperma
      1.2.3-Stamen 12-16 E.lemmonii

1-Flowers solitary actinomorphic, bract hairy
   1.2-Fruit length from 65-13 cm. Glaucium sp.
   1.2-Fruit length never exceed 5.8 cm Roemeria hybrid
1-Flower solitary, zygomorphic  

*Hypecoum Sp.*

1-Flowers aggregated in cyme inflorescences

1.2-Number of flowers 5-7

1.2.1-Bract glabrous  
*Dicentra Formosa*

1.2.2-Bract hairy  
*Fagonia microstachys*

1.2-Number of flowers 8-18

1.2.1-Bract/pedicel shorter

1.2.1.1-Pollen aperture tricolpate  
*F.gaillordii*

1.2.1.2-Pollen aperture pentaporate  
*F.judaica*

1.2.1.3-Pollen aperture hexaporate  
*F.officinalis*

1.2.2-Bract/pedicel longer

1.2.2.1-Pollen aperture hexaporate

1.2.2.1.1-Pollen grain spherical  
*F.densiflora*

1.2.2.1.2-Pollen grain spherical  
*F.bracteosa & F.parviflora*
Discussion

The flower, which is the basic reproductive organ of all angiosperms, is incomparably more diverse than equivalent structures found in any other group of organisms (Barrett 2002). Accordingly, flowers give the taxonomic key to all groups of angiosperm. Floral characters are the most important tool in taxonomic decisions since Linnaeus (1737). Floral characters such as the type and position of inflorescence, flowers and associated structures such as structure of perianth, floral symmetry, the number, size, shape and union of floral leaves in each whorl, types of androecium, stamens numbers and pollen grains, gynoecium and carpel characters, fruits and ovules, beside characters of bracts, bracteoles and pedicels are very important from the taxonomic point of view. These characters are more stable than the external vegetative ones and considered from the most important characters in taxonomic decisions.

The Papaveraceae senso lato comprise the three families, Papaveraceae, Fumariaceae and Hypecoaceae, has diverse floral features which make it interesting to reevaluate it and considered in the taxonomy of the group. For that, this work has been done in order to clarify the relations between the studied taxa according to their variations in floral characters. Hidalgo and Gleisberg (2010) gave clear description of the Papaveraceae floral structures which varied between the main divisions of the three restricted families and even between the genera. From the result obtained the Papaveraceae s.s. is the only ones with actinomorphic flowers emerged solely and not aggregated in inflorescences. The symmetry of the flowers is the first observable character to recognize members of the papaveraceae from the two other families. From the correlation analyses of the obtained characters, the number of flower per inflorescence is highly correlated with the symmetry of the flowers as well as the presence of style and fruit shape. Meanwhile the symmetry of the flowers is positively correlated with type of fruits and pollen grain characters and negatively correlated with the number of stamen. These characters are obviously identified members of the Fumariaceae. The number of flowers / inflorescence divided the Fumariaceae into two categories; F.microstachys and Dicentra Formosa having from 5 to 7 flowers, and the rest of the studied taxa have from 8 to 18 flowers. This division coincides with Lidén (1986) who proposed two tribes within the Fumariaceae, Corydaleae Rchb. and Fumarieae.

The position of the Hypecoaceae as separate family is confusing, Lidén (1986) considered the genus Hypecoum L. at subfamily level within family Papaveraceae s.l. but in his later work (1993) he treated Fumariaceae as an separate family and maintained Hypecoum as a subfamily within Fumariaceae ( Lidén, 1993 ). The result obtained shows that the Hypecoum species have floral characters similar to those within Papaveraceae members, the only things share the Fumariaceae on are the zygomorphic flowers and the number of stamens. Thus it is logic to put
the Hypecoaceae as subfamily level under the Papaveraceae. Wang et al. (2009) found that Hypecoum was a sister clade of Pteridophyllum Siebold & Zucc. which had been considered the earliest-diverging lineage of Papaveraceae s.l., and that both genera were related to the Fumarioideae taxa. Our results prefer the separation of the Fumariaceae as separate family as mentioned before by Cronquist (1981).

The floral characters of the studied taxa within the Papaveraceae s.s support the position of genus Eschscholzia has its characteristic features which might enables it to be upgraded to the subfamily level; Eschscholzioidea; as mentioned by Ernst (1962a & b), Layka (1976), Heslop-Harrison & Shivana (1977), Mabry (1973), Kadereit (1993), Kadereit et al. (1994), Bruckner (2000) and Taia (2008 & 2009). The data obtained from the fruit characters support the separation of the Eschscholzia from both the Papaver and Hypecoum and each of them will be in separate subfamily, Eschscholzioidea, Papaveroideae and Hypecoideae. This classification support that obtained by Hoot et al. (1997). While the separation of the genus Hypecoum, as proposed by Hoot et al. (2015), in another family is not supported as all the studied genera form related groups.

Palynological results show that the Papaveroideae taxa have either echinate or reticulate exine sculpture, while those belonging to the Fumarioideae have scabrate or smooth exine sculpture. Shapes of the pollen grains differs between the Papaveroideae and Fumarioidea as well, in addition to the type of aperture which varied from the colpate to colporoidate to the porate with different numbers (table 5). 

From this results, we can construct phylogenetic trend within the studied taxa as the Papaveroideae considered the most primitive, then the Hypecoideae and last with the Fumarioideae. Within the Papaveroideae Roemeria is the most primitive genus, then Glaucium and Papaver and the Argemone is the most advanced one. Within the three families genus Dicentra considered the more advanced one, as it has zygomorphic flowers arranged in inflorescences with closed corolla, capsule fruits and scabrate exine surface and this coincide Berg (1969) and Stern (1970).

![Diagram showing the classification of Papaveraceae subfamilies](image-url)

**Scheme towards the advanced taxa**

- Papaveraceae
- Hypecoa
- Fagonia
- Dicentra
- Roemeria
- Glaucium
- Papaver
- Argemone

![Diagram showing the classification of Papaveraceae subfamilies](image-url)
| No. | Family | Genus            | Species                          | Localities                  | Source                                      | Confirmation of nomenclature                                                                 |
|-----|--------|------------------|----------------------------------|------------------------------|---------------------------------------------|------------------------------------------------------------------------------------------------|
| 1   | Papaveraceae A.Juss. | Argemone L. | A.mexicana. L. | Sinai (Saint cartein) The road of Nile, Helwan | CAI                                         | -- Sp. Pl. 2 1753 (IPNI). -- Sp. Pl. 1: 508. 1753 [1 May 1753] (GCI). -- Sp. Pl. 1: 508. 1753 [1 May 1753] (IK). |
| 2   | Eschscholzia Cham | E. caespitosa Benth. | Napa County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 3   | Eschscholzia Cham | E. californica Cham | Solano, Yolo, Marin Counties, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 4   | Eschscholzia Cham | E. glyptosperma Greene | Inyo County, California | ALEX                          | WCSP, 2012, 23-3. Bull. Calif. Acad. Sci. 1(3): 70 1885. IPNI: http://ipni.org/urn:lsid:ipni.org:names:672773. |
| 5   | Eschscholzia Cham | E. lemmonii Greene | San Luis Obispo County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 6   | Eschscholzia Cham | E. lobii Greene | Solano County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 7   | Eschscholzia Cham | E. minutifolia S.Watts | Inyo County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 8   | Glaucium Adams | G.arabicum Pres. | Sinai | ALEX                          | WCSP, 2012, 23-3.                             |
| 9   | G. corniculatum. (L.) Rudolph. | G. corniculatum. (L.) Rudolph. | King maruit (Fresh Sp.) | ALEX                          | Fl. Londin. (Curtis) vi. t. 32. (IK). -- Florae Jenensis Plantas 1781 (APNI). |
| 10  | Papaver L. | P.argemone L. | Borg El Arab (Fresh Sp.) | ALEX                          | WCSP, 2012, 23-3.                             |
| 11  | Papaver L. | P.decaisneii. Hochst & Steud. | Borg El Arab (Fresh Sp.) | ALEX                          | -- Bull. Herb. Boissier Ser. II. v. 446. (IK). |
| 12  | Fumariaceae | Dicentra Benth. | D.formosa (Haw)Walp. | Placer County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 13  | Fumariaceae | F. bracteosa. Pomel. | Borg El Arab (Fresh Sp.) | ALEX                          | -- Catalogus Plantarum Horti Botanici Monseliniensis 1813 (APNI). -- Cat. Pl. Horti Monsp. 113. 1813 [Feb-Mar |
| 14  | Fumariaceae | F. densiflora. Dc. | Borg El Arab (Fresh Sp.) | ALEX                          | -- Regni Vegetabilis Systema Naturale 2 1821 (IPNI). -- Abh. Königl. Böhm. Ges. Wiss. ser. 5, 3: 438. 1845 [Jul-Dec 1845] ; Bot. Bemerk. (C. Presl): 8. [Jan-Apr 1846] (IK). -- Regni Vegetabilis Systema Naturale 2 1821 (IK). -- Yst. Nat. [Candolle] 2: 92. 1821 [late May 1821] (IK). |
| 15  | Fumariaceae | F. bulbosa | Borg El Arab (Fresh Sp.) | ALEX                          | -- Species Plantarum 2 1753 (APNI). -- Sp. Pl. 2: 1196. 1753 [1 May 1753] (IK). -- Deutschl. Fl. (Sturm), ed. 2. 6: 12. 1902 (IK). |
| 16  | Roemeria Medic. | R. hybrida. (L.) Dc. | Baheig Borg El Arab road (Fresh Sp.) | ALEX                          | -- Species Plantarum 2 1753 (APNI). -- Spe. Pl. 2: 1196. 1753 [1 May 1753] (IK). -- Deutschl. Fl. (Sturm), ed. 2. 6: 12. 1902 (IK). |
| 17  | Fumariaceae | Dicentra Benth. | D.formosa (Haw)Walp. | Placer County, California | ALEX                          | WCSP, 2012, 23-3.                             |
| 18  | Fumariaceae | F. bracteosa. Pomel. | Borg El Arab (Fresh Sp.) | ALEX                          | -- Catalogus Plantarum Horti Botanici Monseliniensis 1813 (APNI). -- Cat. Pl. Horti Monsp. 113. 1813 [Feb-Mar |
| 19  | Fumariaceae | F. densiflora. Dc. | Borg El Arab (Fresh Sp.) | ALEX                          | -- Catalogus Plantarum Horti Botanici Monseliniensis 1813 (APNI). -- Cat. Pl. Horti Monsp. 113. 1813 [Feb-Mar |
| No. | Character Species | No. of flowers | Infl L. (cm) | Infl W. (cm) | Bract /Pedicel | Calyx | Corolla |
|-----|-------------------|---------------|-------------|-------------|----------------|-------|---------|
| 1   | A. mexicana.      | 1             | ___         | ___         | Shorter         | Gr    | Spiny   | Yellow | Act.. |
| 2   | E. caespitosa     | 1             | ___         | ___         | Shorter         | Gr    | Hairy   | Yellow | Act.. |
| 3   | E. californica    | 1             | ___         | ___         | Shorter         | Gr    | Gl      | Yellow | Act.. |
| 4   | E. glyptosperma   | 1             | ___         | ___         | Shorter         | Gr    | Gl      | Yellow | Act.. |
| 5   | E. lemmonii       | 1             | ___         | ___         | Shorter         | Gr    | Hairy   | Yellow | Act.. |
| 6   | E. lobii          | 1             | ___         | ___         | Shorter         | Gr    | Hairy   | Yellow | Act.. |
| 7   | E. minutifolia    | 1             | ___         | ___         | Shorter         | Gr    | Densely hairy | Red     | Act.. |
| 8   | G. arabicum       | 1             | ___         | ___         | Shorter         | Gr    | Hairy   | Red     | Act.. |

Table 2 Flower characters within the studied taxa

Abreviations: Infl.=Inflorescence, L.=Length, W.=Width, Col.=Colour, Gl=Glabrous, Sym.=Symmetry, Act.=Actinomorphic, Zyg=Zygomorphic
| No. | Character  | Species       | Style   | Stigma | Shape | Surface  | Trichome type |
|-----|------------|---------------|---------|--------|-------|----------|---------------|
| 1   | Character  | Species       | Style   | Stigma | Shape | Surface  | Trichome type |
| 1   | A. mexicana. | | Absent | 5 | Lobed | Globose | Spiny | Spines |
| 2   | E. caespitosa | | Present | 2 | Lobed | Linear | Gl. |... |
| 3   | E. californica | | Present | 2 | Lobed | Linear | Gl. |... |
| 4   | E. glyptosperma | | Present | 2 | Lobed | Linear | Gl. |... |
| 5   | E. lemmii | | Present | 2 | Lobed | Linear | Gl. |... |
| 6   | E. lobii | | Present | 2 | Lobed | Linear | Gl. |... |
| 7   | E. minutifolia | | Present | 2 | Lobed | Linear | Gl. |... |
| 8   | G.arabicum | | Absent | 2 | Lobed | Linear | Hairy | MU |
| 9   | G.corniculatum | | Absent | 2 | Lobed | Linear | Hairy | MU |
| 10  | P.argemone | | Absent | 5 | Discoid | Rectangular | Gl. |... |
| No. | Character Species | Fruit Type | Fruit shape | Fruit surface | Fruit length (cm) | Fruit width (cm) |
|-----|------------------|------------|-------------|---------------|------------------|-----------------|
| 1   | A. mexicana.     | Capsule op. by valve | Oblong | Spiny | 2.5 – 5.2 (3.8 ± 1.11) | 1.1-2.0 (1.5 ± 0.11) |
| 2   | E. caespitosa    | Capsule op. by valve | Linear | Glabrous | 3.8-5.2 4.6±0.87( | 0.8-1.4 (1.1±0.33) |
| 3   | E. californica   | Capsule op. by valve | Linear | Glabrous | 4.8-6.2 5.2±0.82( | 0.5-1.1 (0.6±0.21) |
| 4   | E. glyptosperma  | Capsule op. by valve | Linear | Glabrous | 4.8-5.4 5.1±0.62( | 0.5-1.0 (0.9±0.33) |
| 5   | E. lemmonii      | Capsule op. by valve | Linear | Glabrous | 3.8-4.8 4.5±0.62( | 0.6-1.0 (0.9±0.33) |
| 6   | E. lobii         | Capsule op. by valve | Linear | Glabrous | 4.6-5.6 5.1±0.62( | 0.5-1.0 (0.9±0.33) |
| 7   | E. minutifolia   | Capsule op. by valve | Linear | Glabrous | 4.8-5.4 4.9±0.62( | 0.5-1.0 (0.9±0.33) |
| 8   | G arabicum.      | Capsule op. by valve | Linear | Hairy | 8.5-12.5 (11.5±1.5) | 0.25 – 0.4 (0.32 ± 0.07) |
| 9   | G.corniculatum   | Capsule op. by valve | Linear | Hairy | 5.9 – 13.3 (8.32 ± 3) | 0.2 – 0.4 (0.28 ± 0.07) |
| 10  | P.argemone       | Capsule op. by pores | obovate | Glabrous | 1.2-2.2 (1.82 ± 0.13) | 0.3-0.8 (0.45 ± 0.016) |
| No. | Species            | Capsule op. by pores | Oblong     | Glabrous | 0.4 – 0.8 (0.6 ± 0.15) | 0.8 – 1.8 (1.36 ± 0.43) | 0.8 – 1.1 (0.93 ± 0.12) | 0.4 – 0.5 (0.45 ± 0.036) |
|-----|--------------------|----------------------|------------|----------|------------------------|--------------------------|--------------------------|--------------------------|
| 11  | *P.decaisneii.*    |                      |            |          |                        |                          |                          |                          |
| 12  | *P.dubium.*        |                      |            |          |                        |                          |                          |                          |
| 13  | *P.humile.*        |                      |            |          |                        |                          |                          |                          |
| 14  | *P.hybridum.*      |                      |            |          |                        |                          |                          |                          |
| 15  | *P.rhoeas.*        |                      |            |          |                        |                          |                          |                          |
| 16  | *R.hybrida.*       |                      |            |          |                        |                          |                          |                          |
| 17  | *D.Formosa.*       |                      |            |          |                        |                          |                          |                          |
| 18  | *F.bracteosa.*     |                      |            |          |                        |                          |                          |                          |
| 19  | *F.densiflora.*    |                      |            |          |                        |                          |                          |                          |
| 20  | *F.gaillardotii.*  |                      |            |          |                        |                          |                          |                          |
| 21  | *F.judaica.*       |                      |            |          |                        |                          |                          |                          |
| 22  | *F.microstachys.*  |                      |            |          |                        |                          |                          |                          |
| 23  | *F.officinalis.*   |                      |            |          |                        |                          |                          |                          |
| 24  | *F.parviflora.*    |                      |            |          |                        |                          |                          |                          |
| 25  | *H.aegyptiacum*    | Siliquose, articulated | Linear   | Glabrous | 1.2 – 4.2 (2.52 ± 1.08) |                          |                          |                          |
|     | *H.parviflorum*    | Siliquose, articulated | Linear   | Glabrous | 1.8-3.7 (2.8± 1.37)    | 1.2-2.8 (2.5 ± 0.14)    |                          |                          |
|     | *H.pendulum.*      | Siliquose, articulated | Linear   | Glabrous | 2 – 5.6 (3.6 ± 1.37)   | 1.2 – 3.3 (2.25 ± 0.14) |                          |                          |

Table 5 Stamen and pollen grain characters of the studied taxa
|   | Species          | Number | Type     | Shape    | Value |
|---|------------------|--------|----------|----------|-------|
| 1 | A. mexicana      | Many   | Peroblate| Colporate| 3     |
| 2 | E. caespitosa    | 12     | Peroblate| Colpate  | 4-6   |
| 3 | E. californica   | 12     | Peroblate| Colpate  | 4-6   |
| 4 | E. glyptosperma  | 12     | Peroblate| Colpate  | 4-6   |
| 5 | E. lemmonii      | 12-16  | Peroblate| Colpate  | 4-6   |
| 6 | E. lobii         | 10-12  | Peroblate| Colpate  | 4-6   |
| 7 | E. minutifolia   | 10-12  | Peroblate| Colpate  | 4-6   |
| 8 | G. arabicum      | Many   | Subprolate| Subprolate| 3     |
| 9 | G. corniculatum  | Many   | Subprolate| Subprolate| 3     |
|10 | P. argemone      | Many   | Perprolate| Colpate  | 3     |
|11 | P. decaisneii    | Many   | Perprolate| Colpate  | 3     |
|12 | P. dubium        | Many   | Perprolate| Colpate  | 3     |
|13 | P. humile        | Many   | Perprolate| Colpate  | 3     |
|14 | P. hybridum      | Many   | Subprolate| Subprolate| 3     |
|15 | P. rhoeas        | Many   | Perprolate| Colpate  | 3     |
|16 | R. hybrida       | Many   | Spheroidal| Spheroidal| 4     |
|17 | D. Formosa       | 6      | Subprolate| Colpate  | 3     |
|18 | F. bracteosa     | 6      | Subprolate| Porate   | 6     |
|19 | F. densiflora    | 6      | Spheroidal| Porate   | 6     |
|20 | F. gaillardottii  | 6      | Subprolate| Colpate  | 3     |
|21 | F. judaica       | 6      | Spheroidal| Porate   | 8     |
|22 | F. microstachys   | 6      | Spheroidal| Colporate| 3     |
|23 | F. officinalis    | 6      | Peroblate| Porate   | 6     |
|24 | F. parviflora    | 6      | Subprolate| Porate   | 6     |
|25 | H. aegypticum    | 3      | Spheroidal| Colpate  | 3     |
|26 | H. parviflorum   | 3      | Spheroidal| Colpate  | 3     |
|27 | H. pendulum      | 3      | Spheroidal| Colpate  | 3     |

Table 6 Statistical values of the nineteen most variable characters mentioned below

1= No.of flowers/Inflorescence  2= Flower symmetry  3= Bract/Pedicel  4= Calyx surface
5=Style presence  6=Number of stigma  7=Stigma shape  8=Ovary shape
9=Ovary surface  10=Fruit type  11=Fruit shape  12=Fruit surface
13=Fruit length  14=Fruit width  15=Stamen number  16=Pollen shape
Table 7 Correlation between the nineteen most variable characters, grey cells= highly +ve correlated, blue cells=+ve correlation, pink cells=-ve correlation, red cells= highly –ve correlation, white cells=no correlation

|   | Mean | Standard error | Standard deviation | Sample variance | Range | Min. | Max. | Sum  | Count |
|---|------|---------------|-------------------|----------------|-------|------|------|------|-------|
| 1 | 4.52 | 1.16          | 6.03              | 36.34          | 17    | 1    | 18   | 122  | 27    |
| 2 | 1.41 | 0.09          | 0.50              | 0.25           | 1     | 1    | 2    | 38   | 27    |
| 3 | 1.85 | 0.08          | 0.40              | 0.16           | 1     | 1    | 2    | 32   | 27    |
| 4 | 1.96 | 0.21          | 1.09              | 1.20           | 3     | 1    | 4    | 53   | 27    |
| 5 | 1.59 | 0.09          | 0.50              | 0.25           | 1     | 1    | 2    | 43   | 27    |
| 6 | 3.44 | 0.52          | 2.69              | 7.26           | 10    | 2    | 12   | 93   | 27    |
| 7 | 2.60 | 0.15          | 0.8               | 0.64           | 3     | 1    | 4    | 70   | 27    |
| 8 | 1.96 | 0.18          | 0.94              | 0.88           | 3     | 1    | 4    | 53   | 27    |
| 9 | 1.4  | 0.15          | 0.80              | 0.64           | 2     | 1    | 3    | 38   | 27    |
| 10| 2.11 | 0.20          | 1.05              | 1.10           | 3     | 1    | 4    | 57   | 27    |
| 11| 2.26 | 0.25          | 1.32              | 1.74           | 3     | 1    | 4    | 61   | 27    |
| 12| 1.56 | 0.17          | 0.89              | 0.79           | 2     | 1    | 3    | 42   | 27    |
| 13| 2.96 | 0.53          | 2.74              | 7.51           | 11.3  | 0.2 | 11.5 | 79.8 | 27    |
| 14| 0.7  | 0.12          | 0.60              | 0.34           | 2.3   | 0.2 | 2.5  | 18.8 | 27    |
| 15| 12.12| 1.29          | 6.71              | 45.00          | 17    | 3   | 20   | 329  | 27    |
| 16| 3.41 | 0.21          | 1.08              | 1.17           | 3     | 2   | 5    | 92   | 27    |
| 17| 1.93 | 0.23          | 1.21              | 1.46           | 3     | 1   | 4    | 52   | 27    |
| 18| 4.33 | 0.31          | 1.61              | 2.62           | 5     | 3   | 8    | 117  | 27    |
| 19| 3.00 | 0.33          | 1.71              | 2.92           | 4     | 1   | 5    | 81   | 27    |

17=Aperture type  18=Aperture number  19=Exine ornamentation
Photographs of herbarium sheets show general appearance and fruits. Arrows indicate to fruit.

Photographs of selected flowers showing different stigma and fruit types
### Appendix 1

Characters subjected to SYSTAT 13 clustering analysis

| No. | Character                          | State                        | Possibilities                                      |
|-----|-----------------------------------|------------------------------|----------------------------------------------------|
| 1   | No. of flowers/Inflorescence      | Continuous                   |                                                    |
| 2   | Flower symmetry                   | Binary                       | 1=Actinomorphic, 2=Zygomorphic                      |
| 3   | Bract/Pedicel                     | Binary                       | 1=shorter, 2=Longer                                |
| 4   | Calyx surface                     | Multistate qualitative       | 1=Glabrous, 2=Spiny, 3=Hairy, 4=Densely hairy      |
|     |                                  | ordered (MQO)                |                                                    |
| 5   | Style                             | Binary                       | 1=Absent, 2=Present                                |
| 6   | Stigma number                     | Continuous                   |                                                    |
| 7   | Stigma shape                      | Multistate qualitative       | 1=Pointed, 2=lobed, 3=Biforked, 4=Discoid          |
|     |                                  | unordered (MQUO)             |                                                    |
| 8   | Ovary shape                       | Multistate qualitative       | 1=Linear, 2=Rectangular, 3=Globose, 4=Riged        |
|     |                                  | unordered (MQUO)             |                                                    |
| 9   | Ovary surface                     | Multistate qualitative       | 1=Glabrous, 2=Spiny, 3=Hairy                       |
|     |                                  | ordered (MQO)                |                                                    |
|   | Feature                        | Type and Details                                                                 |
|---|--------------------------------|----------------------------------------------------------------------------------|
| 10| Fruit type                     | Multistate qualitative unordered (MQUO)                                          |
|   |                                | 1=Capsule opened by valves, 2=Capsule opened by pores, 3=Nut, 4=Soliquose        |
| 11| Fruit shape                    | Multistate qualitative unordered (MQUO)                                          |
|   |                                | 1=Linear, 2=Obovate, 3=Oblong, 4=Globose                                         |
| 12| Fruit surface                  | Multistate qualitative ordered (MQO)                                             |
|   |                                | 1=Glabrous, 2=Spiny, 3=Hairy                                                     |
| 13| Fruit length                   | Continuous                                                                       |
| 14| Fruit width                    | Continuous                                                                       |
| 15| Stamen number                  | Continuous                                                                       |
| 16| Pollen grain shape             | Multistate qualitative ordered (MQO)                                             |
|   |                                | 1=Suboblate, 2=Peroblate, 3=Spheroidal, 4=Subprolate, 5=Prolate                  |
| 17| Aperture type                  | Multistate qualitative ordered (MQO)                                             |
|   |                                | 1=Colporate, 2=Colporoidate, 3=Colporate, 4=Porate                              |
| 18| Aperture number                | Continuous                                                                       |
| 19| Exine ornamentation            | Multistate qualitative ordered (MQO)                                             |
|   |                                | 1=Reticulate, 2=Psilate, 3=Rugate, 4=Scabrate, 5=Echinate.                       |

Cluster Tree

Phenogram showing the grouping of the studied taxa

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