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Seed coat micro-sculpturing and the systematic of the Egyptian *Brassicaceae* (*Magnoliopsida*)

Abstract

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Seed coat sculpture of 93 taxa belonging to 45 genera of the family *Brassicaceae* was examined using light and scanning electron microscope. Four basic epidermal cell patterns (types) with 7 subtypes were recognized. While one sub-type was represented by only one species, the remaining types and subtypes have more than one species and they either represent one genus or more. In most of the studied types and subtypes species could generally be distinguished from each other on the basis of differences in micro-sculpturing features of the outer periclinal cell walls. The results mostly support the traditional classification of *Brassicaceae* particularly at tribal and sub-tribal level with some modifications. The classification and phylogeny of the *Brassicaceae* are discussed together with recent molecular studies of the family.

Introduction

Brassicaceae is a large and natural family, well defined morphologically by an uniform flower architecture and fruit characters, with approximately 380 genera and about 3350 species. It has a cosmopolitan distribution especially in temperate regions of the north hemisphere (Hedge 1976; Al Shehbaz 1984; Judd & al. 1999; Koch & al. 2001; Appel & Al Shehbaz 2002; Koch & al. 2003). The *Brassicaceae* is economically important and include vegetable, oilseed, fodder, ornamental, and condiment plants plus the molecular model plant (*Arabidopsis thaliana*) (Crisp 1976; Gomez-Campo 1980, 1999; Simmond 1986; Gomez-Campo & Prakash 1999).

In spite of their remarkable constant floral structure; the members of the *Brassicaceae* exhibit a high morphological diversity. Morphological characters as those of habit, indumentum, flower, fruit, seed and embryo have been used in different systems of classification of the family (Schulz 1936; Al Shehbaz 1984; Appel & Al Shehbaz 2002). Generally, the *Brassicaceae* are divided into 3-19 tribes and 20-30 sub-tribes (Hayek 1911; Schulz 1936; Janchen 1942; Al Shehbaz 1973, 1984, 1995, 1987; Gomez-Campo 1980, 1999; Avetisian 1983, Gomez-Campo & Prakash 1999). The phylogeny and classification of the family at the generic and tribal level are still problematic (Koch & al. 2001; Koch & al.

2003; Hall & al. 2002; Appel & Al Shehbaz 2002).

As a consequence, several studies from different points of view have been carried out on both wild and cultivated members of this family, among them those of Warwick, & Aguinagalde (1992); Warwick & Black (1991, 1993, 1994, 1997); Pradhan & al. (1992); Al-Shehbaz & O'Kane (2002); Al-Shehbaz & al. (1999); Appel & Al-Shehbaz (2002); Koch & al. (1998); Koch & al. (2000); Warwick & al. (2002); Koch & Mummenhoff (2001); Mummenhoff (1995); Mummenhoff & Hurka (1990, 1991, 1994, 1995); Mummenhoff & Jentzsch (1994); Mummenhoff & Koch (1994); Mummenhoff & Zunk (1991); Mummenhoff & al. (1993); Mummenhoff & al. (1995); Mummenhoff, Franzke & Koch (1997a, 1997b); Mummenhoff & al. (2001); Zunk & al. (1993, 1999); Bleeker & al. (2002); Bleeker & al. (1999); Bowman, & Smyth (1998); Bowman & al. (1999); Bricker & al. (2000); Galloway& al. (1998) and Yang & al. (1999). Recent molecular systematic studies reveal that only tribes *Brassiceae* and *Lepidieae* may be considered to be natural assemblages (Zunk & al. 1999). Some other studies suggested that Lepidieae is a polyphyletic assemblage (Koch & al. 2001). On the other hand the family concept as a whole has also been discussed on the light of the molecular systematic studies. Some scholars considered *Brassicaceae* as a much larger family including *Capparaceae* and *Cleomaceae* (Judd & al. 1994, 1999). This idea was later rejected (Hall & al. 2002).

Usually seed coat structure and sculpture are considered to be conservative and stable characters and have been used successfully in the taxonomy and phylogeny of different taxa (Gunn 1981; Zeng & al. 2004). In the *Brassicaceae* several studies have been carried out on the seed coat and its taxonomic significance (Berggren 1962; Mulling & Baily 1976; Vaughan 1959; Vaughan & Whitehouse 1971; Bengoechea & Gómez-Campo 1975; Vaughan, Phelan & Denford 1976; Fayed & El Naggar 1988, 1996; El Naggar 1996; EL Naggar & El Hadidi 1998; Koul & al. 2000; Zeng & al. 2004).

The aim of the present study is to evaluate the taxonomic significance of the seed coat pattern as seen by SEM in some taxa of the *Brassicaceae* and to discuss the circumscription of genera, tribes and sub-tribes in addition to contribute to clear out the inter and intra-relationships of the studied different taxa within the family.

Material and Methods

This study is mainly based on herbarium specimens deposited in CAI, CAIM, (acronym according to Holmgren & al. 1990) and ASTUE (Assiut University herbarium, proposed acronym). Furthermore, fresh materials collected by the author were studied and original observations from several localities were used.

Scanning Electron Microscope (SEM) studies were carried out on mature seeds of 93 taxa of Brassicaceae. Three to seven seeds of each taxon were selected to cover the range of variation. These seeds were attached to SEM stubs by means of double-sided tape. The seeds were coated with gold using a JEOL JFC 1100E ion sputtering device to a thickness of approximately 50-700 μm. These were examined by a JEOL JSM 5400LV scanning electron microscope, operated at an accelerated voltage of 15 kv. The work was carried out in the Electron Microscope Unit, Assiut University. The terminology used here is that proposed by Cutler (1979) & Barthlott (1981, 1984) with some modifications.

Results

According to the epidermal cell patterns seen through SEM, seeds of the studied taxa can be divided into four basic types: undulate, reticulate papillate and domate (Table 2 and Figs.1-46).

In the undulate seed coat type, the anticlinal cell boundaries are not well developed while the outer periclinal cell walls are waved or folded irregularly, this giving the undulate appearance of the epidermal cells. This type is found in four species and two subspecies all belong to tribe *Brassiceae*: *Brassica rapa*, *Brassica tournefortii*, *Cakile maritima, Zilla spinosa* subsp. *spinosa* and *Zilla spinosa* subsp. *macroptera* (Figs.1 & 2).

The anticlinal cell boundaries are well developed in the rest three types: reticulate, domate and papillate. These anticlinal cell walls are raised in the reticulate type, while they are channeled in the domate and papillate types. The outer periclinal cell walls are flat, concave or slightly convex in the reticulate type while they are convex or raised in the the domate and papillate types.

The papillate seed coat pattern distinguishes all studied species of the genus *Alyssum: A. marginatum, A. homalocarpum, A. simplex* and *A. desertorum* (Figs. 41 & 42).

Using the micro-sculpture of the outer periclinal cell walls the reticulate type can be subdivided into five subtypes: normal reticulate, micro-reticulate reticulate-foveolate, double reticulate and reticulate with central structure. The domate type may be also subdivided into two subtypes: domate with striate periclinal cell wall (Fig., 36) and domate with central structure.

Double reticulate subtype is found only in the amphidiploid species: *Brassica junceae*, (Fig., 10). The microreticulate subtype distinguishes all studied taxa of subtribe *Raphaniniae* (*Raphanus raphanistrum* subsp. *raphanistrum*, *R. sativus*, *Enarthrocarpus lyratus*, *E. pterocarpus, E. strangulatus*, *Rapistrum rugosum, Didesmus aegyptius* and *Didesmus bipinnatus*) and subtribe *Cakilinae* (*Erucaria microcarpa, E. hispanica, E. pinnata* and *E. crassifolia*) (Fig., 3-9).

In the reticulate with central structure subtype, this structure may be a raised globular body as found in *Sinapis alba*, *S. arvensis, S. allionii*, (*Brassiceae*) *Anastatica hierochuntica, Camelina rumelica, C. hispida and Neslia apiculata* (*Euclideae*) or ocellate structure as in *Capsella bursa-pastoris, Isatis lusitanica* **(***Lepidieae*); *Nasturtium officinale* **(***Arabideae***)**, *Eremobium aegyptiacum*, *Malcolmia africana*, *Maresia nana, M. pgymaea*, *Diceratella elliptica, Matthiola arabica, M. longipetala, Morettia philaeana, M. canescens var. canescens , M. canescens var. parviflora, Notoceras bicorne, Leptaleum filifolium* (*Hesperideae*)*, Sisymbrium irio, S. orientale, S. erysimoides, S. runcinatum* and *Neotorularia torulosa* **(***Sisymbrieae***).**

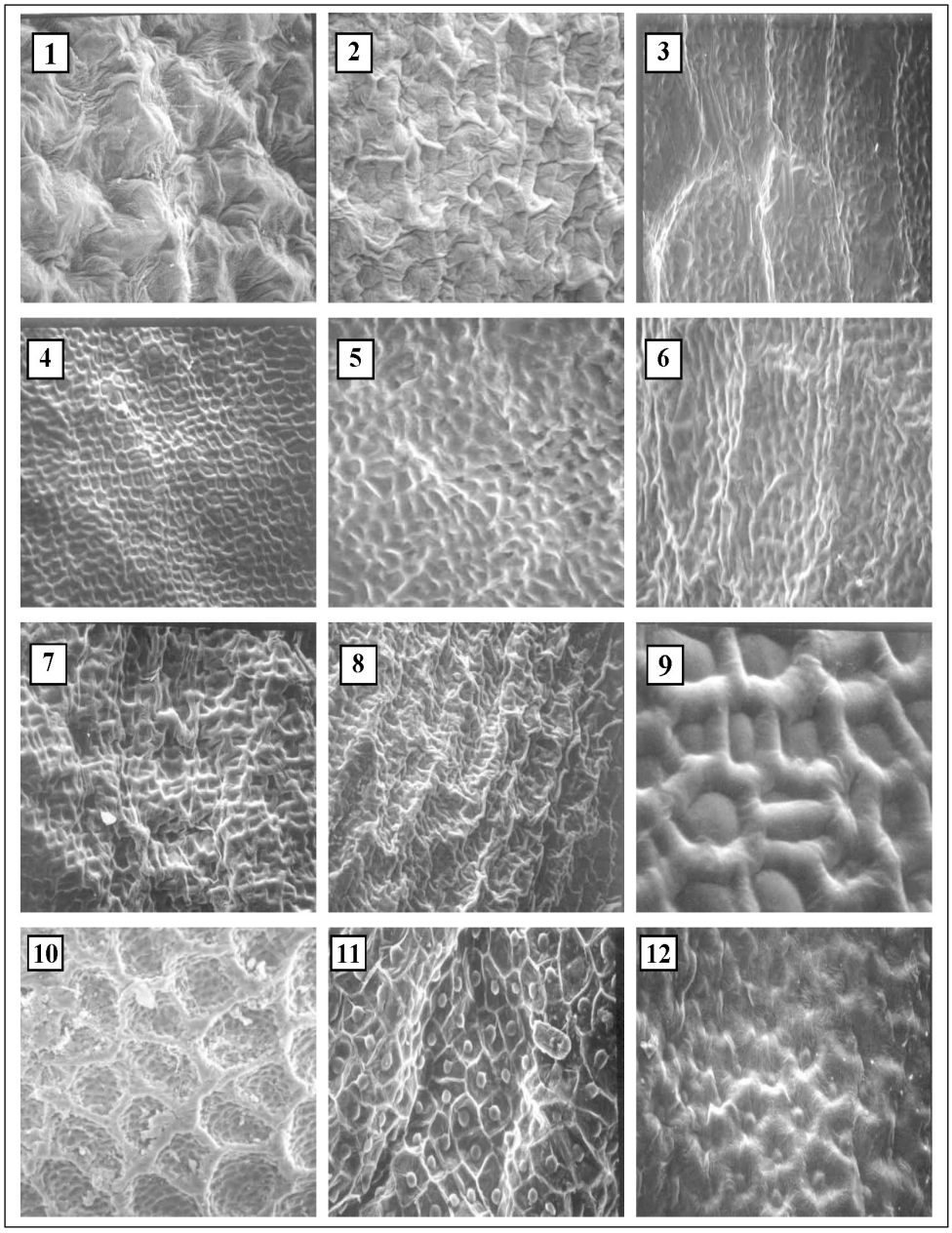
Domate with striate periclinal cell wall subtype (Fig.36) distinguishes *Savignya parviflora*, the only representative of sub-tribe Savignyinae in the flora of Egypt. Domate with central structure (Figs., 37-40) is found in three species of subtribe *Moricandiinae*: *Conringia orientalis*, *Moricandia nitens* and *M. sinaica*), and two species of subtribe *Vellinae*: (*Carrichtera annua* and *Schouwia purpurea*). The majority of studied seeds fall in the reticulate type with its different subtypes (Table, 2. Figs., 11-22).

Key for separation between the different types and subtypes of seed coat patterns

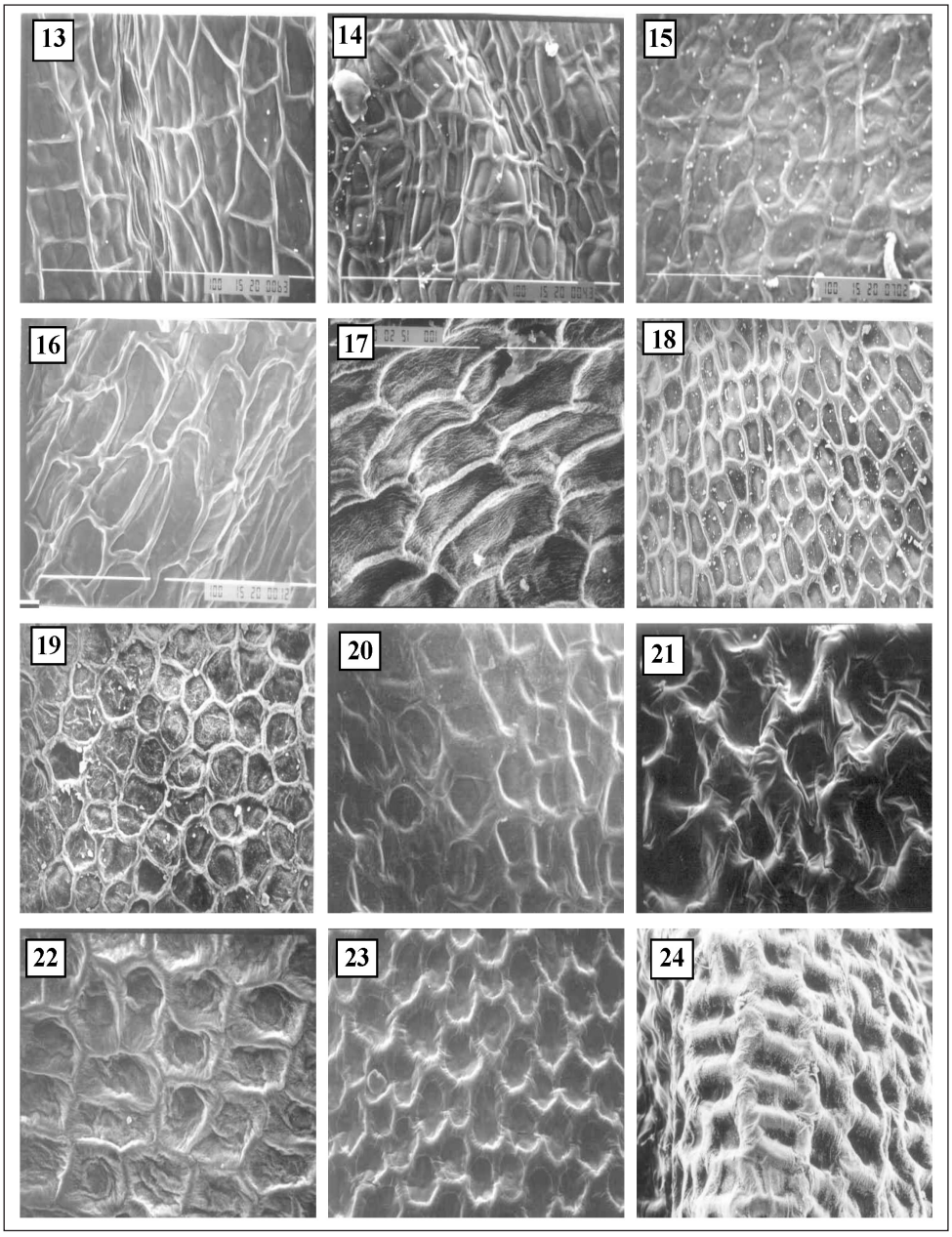
1.- Anticlinal cell boundaries are not well developed, epidermal cell pattern is not well defined……..……**Undulate**
1.-Anticlinal cell boundaries are well developed.,epidermal cell pattern are well defined ……..…….……**2**
2.- Anticlinal cell boundaries channeled, periclinal cell walls raised or convex.....**3**
2.- Anticlinal cell boundaries raised and periclinal cell walls flat, concave or slightly convex.....……..……**5**
3.- Periclinal cell walls raised as papillae.....……**Papillate**
3.- Periclinal cell walls domate .....……..…..**Domate 4**
4.- Periclinal cell walls with central structure.....…...**Central structrue**
4.- Periclinal cell walls radialy striated.....**Domate with striate periclnial**
5.- Periclinal cell walls with central structure.....……**6**
5.- Periclinal cell walls without central structure.....……**7**
6.- Central structure ocellate.....**Ocellate**
6.- Central structure globular body.....**Central globular body**
7.- Periclinal cell walls concave.....**Reticulate-foveolate**
7.- Periclinal cell walls flat .....……**8**
8.- Epidermal cells small .....…**Micro reticulate**
8.- Epidermal cells large.....……**9**
9.- Periclinal cell walls reticulate.....**Double reticulate**
9.- Periclinal cell walls not reticulate .....**Normal reticulate**

Discussion

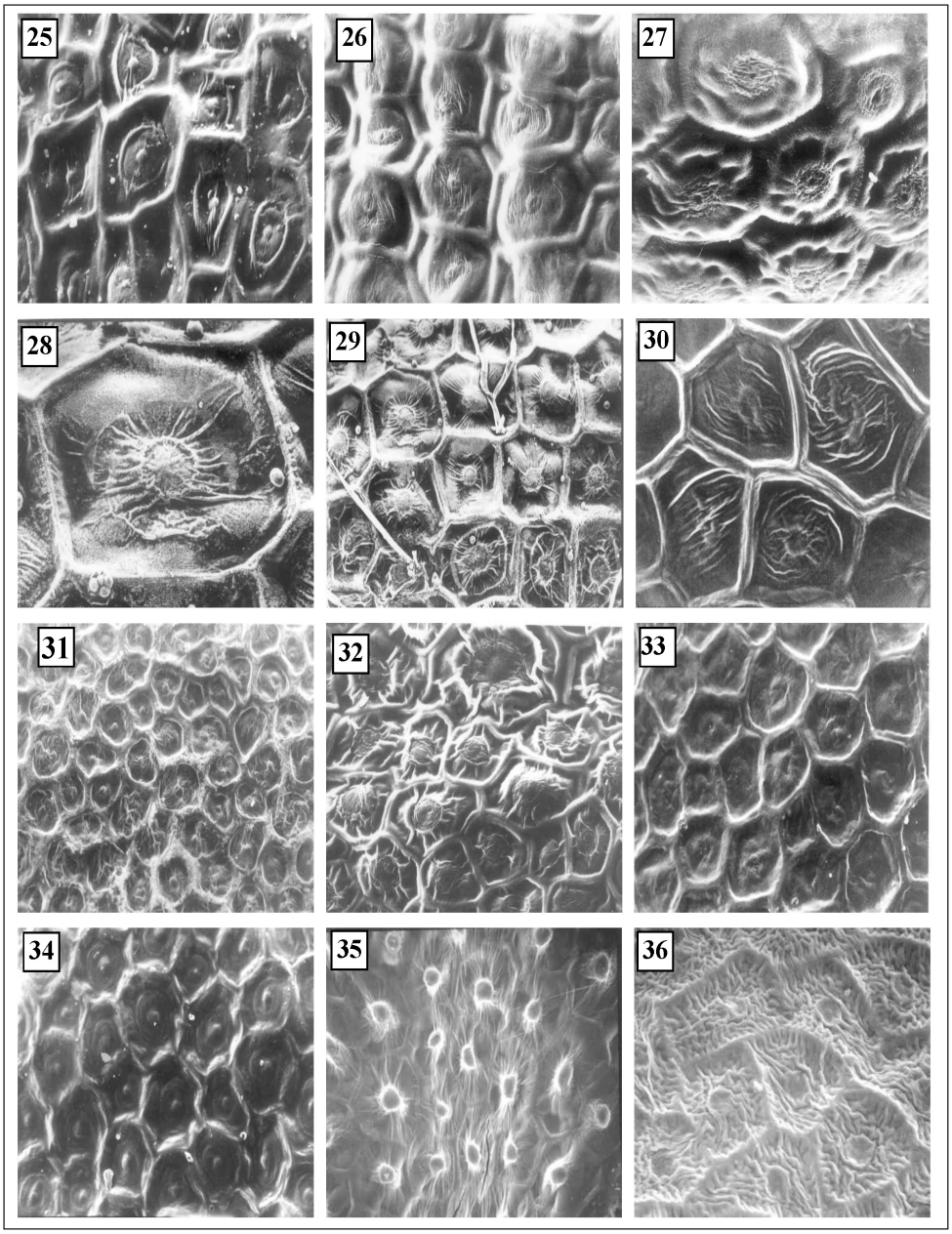
The grouping of the studied taxa according to the seed coat patterns as seen by SEM revealed two facts: On one hand, there are some types of seed coat pattern which conform, at least partially, to the traditional classification of the family at tribal and sub-tribal level. For example, most of studied taxa of sub-tribe *Moricandiinae* (*Moricandia nitens*, *Moricandia sinaica* and *Conringia orientalis*) and sub-tribe Vellinae (*Schouwia purpurea* and *Carrichtera annua*) are characterized by domate with central structure seed coat pattern. These results may support considering the above two sub-tribes as natural assemblages and may prove the close relationships between them in spite of the large diversity in fruit characters. In *Moricandiinae* fruit is long (siliqua) with a short and sterile beak while fruit in *Vellinae* is short (silicula) with spoon shape or spine-like sterile beak. Gomez-Campo (1980) considered the subtribe Moricandiinae to be a heterogeneous group. This idea has been recently, supported by in the molecular systematic studies based on chloroplast DNA restriction site variations, where it is suggested that some members of the subtribe Moricandiinae may be transferred to the other subtribe, *Brassicinae* (Warwick & Black 1994). The separation between *Brassicinae* and *Moricandiinae* is mainly based on two characters: the absence of median nectarines and seedless beak of the *Moricandiinae*,



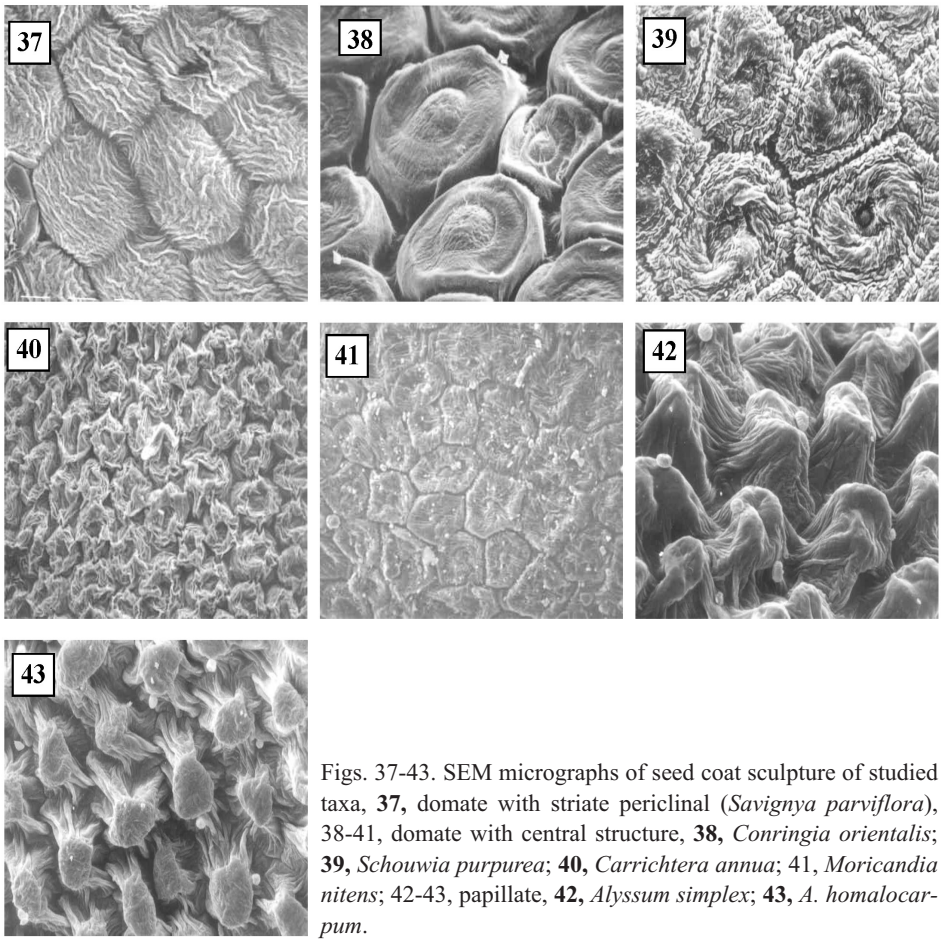
Figs. 1-12. SEM photomicrographs of seed coat patterns of the studied taxa, 1-2, undulate type **1,** *Brassica rapa*; **2,** *Brassica tournefortii*; 3-9, microreticulate: **3,** *Raphanus raphanistrum*; **4,** *Enarthrocarpus strangulatus*; **5,** *E. pterocarpus*; **6,** *Rapistrum rugosum*; **7,** *Didesmus bipinnatus*; **8,** *Enarthrocarpus lyratus*; **9,** *Erucaria pinnata*; **10,** Double reticulate, *Brassica juncea*; 11-12, reticulate with globular central body, **11,** *Neslia apiculata*; **12,** *Sinapis alba*.



Figs. 13-24. SEM microphotographs of seed coat of stusied taxa: 13-19, normal reticulate, **13,** *Lepidium aucheri*; **14,** *Coronopus niloticus*; **15,** *Biscutella didyma*; **16,** *Coronopus squamatus*; **17,** *Lepidium sativum*; **18,** *Farsetia aegyptia*; **19,** *Lobularia maritima*; 20-24, reticulate-foveolate: **20,** *Coronopus didymus*; **21,** *Brassica nigra*; **22,** *Cardaria draba*; **23,** *Eruca vesicaria* subsp. *sativa*; **24,** *Descurainia sophia.*



Figs. 25-36. SEM photomicrographs of seed coat of studied taxa, 25-33, reticulate with ocellate structure: **25,** *Diceratella elliptica*, **26,** *Sisymbrium orientale*; **27,** S. irio; 28- 29, *Capsella bursa-pastoris*; **30,** *Nasturtium officinale*; **31,** *Morettia philaeana*; **32,** *Neotorularia torulosa*; **33,** *Maresia nana*; 34-36, reticulate with globular central body: **34,** *Anastatica hierochuntica*; **35,** *Camelina hispida*; **36,** *Sinapis arvensis* var. *arvensis*.



Figs. 37-43. SEM micrographs of seed coat sculpture of studied taxa, **37,** domate with striate periclinal (*Savignya parviflora*), 38-41, domate with central structure, **38,** *Conringia orientalis*; **39,** *Schouwia purpurea*; **40,** *Carrichtera annua*; 41, *Moricandia nitens*; 42-43, papillate, **42,** *Alyssum simplex*; **43,** *A. homalocarpum*.

while the median nectarines are present and the beak is seeded in *Brassicinae* (Gomez-Campo 1980; Al Shehbaz 1985). Also seed coat characters of the present studies proved that *Pesuderucaria clavata* and *P. teretifolia* of *Moricandiinae* are characterized by reticulate-foveolate seed coat pattern. These characters are similar to those of different taxa such as*: Diplotaxis harra*, *D. acris* and *D. erucoides* of *Brassicinae*, which may support the transfer of *Pseuderucaria* to the *Brassicinae* (Warwick & Black 1994). According to the molecular studies, *Schouwia* (subtribe *Vellinae*) was formerly considered to be within another subtribe (*Zillinae*) which may prove that *Vellinae* might be a polyphyletic assemblage (Warwick & Black 1994: Crespo & al. 2000). Based on the morphological and seed protein characters this idea was suggested by El Naggar (2000).

Micro-reticulate seed coat pattern distinguishes all studied taxa represented in subtribes *Raphaninae* and *Cakilinae* except for *Cakile maritima* (*Cakilinae*), which has undulate seed coat pattern. Subtribe Raphaninae is considered to be unnatural group and its members should be separated. Some of these taxa have been suggested to be nested within

Tabe 1. Studied taxa of *Brassicaceae*, origin, date of collection, locality, collector and Herbarium.

Taxon	Locality, collector, Herbaria
Brassiceae	
Brassicinae	
1. *Brassica oleracea* L.	Egypt, Assiut University, Faculty of science farm, 25.3.2002, El Naggar, s.n. (ASTUE)
2. *Brassica juncea* (L.) Czern.	Egypt, El Minya, Maghaga, cultivated lands, 3.4.1999, El Naggar, s.n. (ASTUE)
3. *Brassica nigra* (L.) Koch	Egypt, El Dakhla Oasis, 103.1997, El Naggar, s.n. ASTUE).
4. *Brassica rapa* L.	Egypt, Assiut, March, 1985, El Naggar, s.n. (ASTUE)
5. *Brassica tournefortii* Gouan	Egypt, Banha, Kafr Mouas Jan., 1985, El Naggar, s.n. (ASTUE)
6. *Erucastrum arabicum* Fish. & M. C. Mey.	Egypt, Faruk's Garden, Inshaas, 2.1.1953, Abdel Fadel, s.n. (CAI)
7. *Sinapis alba* L.	Egypt, Assiut, reclamed area east of Assiut twon, 22.1.1999, El Naggar, s.n. (ASTUE)
8. *Sinapis allionii* Jacq.	Egypt, Assiut farmland north of Assiut twon, 11.1. 2000, El Naggar, s.n. (ASTUE)
9. *Sinapis arvensis* L. var. *arvensis*	Egypt, Assiut, cultivated lands, 17.3.1984. El Naggar, s.n. (ASTUE)
10. *Sinapis arvensis* var. *orientalis* (L.) Koch & Ziz	Egypt, Assiut, cultivated lands, 17.3.1984. El Naggar, s.n. (ASTUE)
11. *Diplotaxis acris* (Forssk.) Boiss.	Egypt, Wadi el Assiuty, 12.1.1999, El Naggar, s.n. (ASTUE)
12. *Diplotaxis erucoides* (L.) DC.	Palestine,1937, Dinsmore, s.n. (CAI)
13. *Diplotaxis harra* (Forssk.) Boiss.	Egypt, Cairo-Seuz desert road, Wadi Hagoul, 6.4.2004, El Naggar, s.n. (ASTUE)
14. *Diplotaxis muralis* (L.) DC. var. *muralis*	Tunisia, Davis & Lamond, D57311 (E)
15. *Diplotaxix muralis* var. *simplex* (Viv) El Naggar	Libya, Davis, 50348 (E)
16. *Eruca vesicaria* subsp. *sativa* (Miller) Thell.	Egypt, Assiut, Manfalot, 2.1999, El Naggar, s.n. (ASTUE)
Raphaininae	
17. *Raphanus raphanistrum* L.	Egypt, El Sharqia, Jan. 1985, El Naggar, s.n. (ASTUE)
18. *Raphanus sativus* L.	Egypt, Assiut University campus, 15.3.2003, El Naggar, s.n. (ASTUE)
19. *Enarthrocarpus lyratus* (Forssk.) DC.	Egypt, Mariut, Burg El Arab, 4.2001, El Naggar, s.n. (ASTUE)
20. *Enarthrocarpus pterocarpus* (Pers.) DC.	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
21. *Enarthrocarpus strangulates* Boiss	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
22. *Rapistrum rugosum* (L.) All.	Libya, El Beida, Gebl Akhdar, 9.2.1991, El Naggar,s.n. (ASTUE)
23. *Didesmus aegyptius,* (L.) Desv.	Libya, Benghazi, 23.3.1994, El Naggar, s.n. (ASTUE)
24. *Didesmus bipinnatus* (Desf.) DC.	Libya, Tuolmita, 6.5.1995, El Naggar, s.n. (ASTUE)
Cakilinae	
25. *Erucaria crassifolia* (Forssk.) Delile	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
26. *Erucaria hispanica* (L.) Druce	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
27. *Erucaria microcarpa* Boiss.	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
28. *Erucaria pinnata* (Viv.) El Naggar	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
29. *Cakile maritime* Scop.	Egypt, Abu Qir, 27.3.1984, El Naggar, s.n. (ASTUE)
Zillinae	
30. *Zilla spinosa* (Turra) Prantl subsp. *spinosa*	Egypt, Wadi Hof, 4. 2001. El Naggar, s.n. (ASTUE)
31. *Zilla spinosa* subsp. *macroptera* (Cosson) Maire & Weiller	Egypt, Mediterranean coast, Sallum area, 12.10.2002, El Naggar, s.n. (ASTUE)

Tabe 1. Continued.

Vellinae	
32. *Carrichtera annua* (L.) DC.	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
33. *Schouwia purpurea*	Egypt, Wadi el Assiuty, 15.1. 1999. El Naggar, s.n. (ASTUE)
Savignyniae	
34. *Savignya parviflora* (Delile) Webb	Egypt, Davis, 10529 (E)
Moricandiinae	
35. *Conrnigia orientalis* (L.) Andrs.	Turkey, Dudley, D35974 (E)
36. *Moricandia nitens* (Viv.) Dur. & Barr.	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
37. *Moricandia sinaica* (Boiss.) Boiss.	Egypt, S. Sinai, Wadi Feran, 20.5.1997, El Naggar, s.n. (ASTUE)
38. *Pesuderucaria clavata* (Boiss & Reut.) O. E. Schulz	Egypt, Wadi Digla, Maadi, 30.5.1965, Holmen, s.n. (CAI)
39. *Pseuderucaria teretifolia* (Desf.) O. E. Schulz	Algeria, Davis,52399, (E)
Lepidieae	
Lepidinae	
40. *Lepidium aucheri* Boiss.	Iraq, Edgar Evans, N/219, (E)
41. *Lepidium latifolium* L.	Iran, Sistan, 1965, Ayazi, 5860 (E)
42. *Lepidium sativum* L.	Egypt, Assiut, farmland, 14.3.1996. El Naggar, s.n. (ASTUE)
43. *Lepidium virginicum* L.	Egypt, Assiut public garden, 25.5.1996, El Naggar, s.n. (ASTUE)
44. *Coronopus didymus* (L.) Sm.	Egypt, Cairo, 4.4.2001, El Naggar, s.n. (ASTUE)
45. *Coronopus niloticus* (Delile) Spreng.	Egypt, Assiut Manfalot, 11.5.1999. El Naggar, s.n. (ASTUE)
46. *Coronopus squamatus* (Forssk.) Asch.	Egypt, Assiut Manfalot, 11.5.1999. El Naggar, s.n. (ASTUE)
47. *Cardaria draba* subsp, *chalpensis* (L.) O. E. Schulz	Egypt, Sinai El Ribbah, Aprile,1961, El Hadidi, s.n. (CAI)
48. *Cardaria draba* (L.) Desv. subsp. *draba*	Egypt, south Sinai, Wadi Feran, 20.5. 1997, El Naggar, s.n. (ASTUE)
Iberinae	
49. *Isatis lusitanica* L.	Turkey, Davis 41163 (E)
50. *Biscutella didyma* L. var. *didyma*	Egypt, Burg El Arab, 22.3.1956, El Hadidi,s.n. (CAI)
51. *Biscutella didyma* var. *depressa* (Willd) El Naggar	Egypt,On the road Burg el Arab to El Alamein, 16.2.1965, Tackholm, s.n. (CAI)
52. *Biscutella didyma* var. *elbensis* (Chrtek) El Naggar	Egypt, Khor across Gebel Shallal, Expedition to Gebel Elba district , 1962, Tackholm et al. (CAI)
53. *Capsella bursa-pastoris* (L.) Medic.	Egypt, Assiut, March,1998. El Naggar, s.n. (ASTUE)
54. *Hymenolobus procumbens* (L.) Fourr.	Egypt, Alexandria, 4 March,1909. Maire, 62. (CAI)
Euclideae	
55. *Anastatica hierochuntica* L.	Egypt, Cairo-Seuz desert road, Wadi Hagoul, 6.4.2004, El Naggar, s.n. (ASTUE)
56. *Neslia apiculata* Fisch., C. A. Mey & Avel-Lall.	Turkey, Van, 14.6,2002, El Naggar, s.n. (ASTUE)
57. *Camelina hispida* Boiss.	Turkey, Van, 13.6.2002, El Naggar, s.n. (ASTUE)
58. *Camelina rumelica* Velen.	Jordan, 15 km south east Jerash on Aloub road, 29 March 1974 W. Jallad, s.n. (CAI)
59. *Schimpera arabica* Hochst. & Steud.	Saudi Arabia , El Kharag road, Jan. 1969. A.M. Migahid, 58 (CAI)
Alysseae	
60. *Farsetia aegyptia* Turra	Egypt, Cairo-Seuz desert road, Wadi Hagoul, 6.4.2004, El Naggar, s.n. (ASTUE)
61. *Farsetia longisiliquaI* Decne	Egypt,Wadi Khudaa, Eastern desert, 24.5.1998, El Naggar, s.n. (ASTUE)
62. *Farsetia stylosa* R. Br.	Egypt, Assiut-Dakhla road, March, 1997, El Naggar, s.n. (ASTUE)
63. *Alyssum desertorum* Stapf	Romania-Distr. Caras-Severin, 24.VI.1967, I Moraria & M. Danciu (CAI)
64. *Alyssum homalocarpum* (Fish. & C.A. Mey.) Boiss.	From G. Schweinfurth's Herbarium, Berlin, Now burnt (CAI)
65. *Alyssum marginatum* Stued. ex Boiss.	Egypt, Sinai, Gabel Catherin, 20.5.1997,El Naggar, s.n. (ASTUE)
66. *Alyssum simplex* Rudolphi	Libya,El Beida Gebel el Akhdar, 24.3.1992, El Naggar, s.n. (ASTUE)
67. *Lobularia arabica* (Boiss.) Muschl.	Egypt, North Sinai, El Arish, May.2001, El Naggar, s.n. (ASTUE)
68. *Lobularia libyca* (Viv.) Meissn.	Egypt, Mariut, Burg El Arab, April, 2002, El Naggar, s.n. (ASTUE)
69. *Lobularia maritima* (L.) Desv.	Egypt, Cairo, Madinet Nasr behind Al Azhar University, May 1972, Adel El Gazzar,s.n. (CAI)
70. *Clypeola jonthlaspi* L.	Egypt, Sinai Wadi el Raha, Bedwins garden, Safsafa, 9.4.1967, Kosinova & Chrtek (CAI)

Table 1. Continued.

Arabideae		
71.	*Nasturtium officinale* R. Br.	Libya, Wadi Derna, 14.3.1968, L. Boulos, s.n. (CAI)
72.	*Rorippa palustris* (L.) Besser	Egypt, Kafr Mouas on canal Bank 4.2000 El Naggar, s.n. (ASTUE)
73.	*Rorippa indica* (L.) Hiern	From G. Schweinfurth's Herbarium, Berlin, Now burnt (CAI)
Hesperideae		
74.	*Notoceras bicorne* (Aiton) Amo	Egypt,Wadi Mawaw, Gebel Elba, April 1962, Tackholm et al. s.n. (CAI)
75.	*Diceratella elliptica* (DC.) Jonsell	Egypt, Gebl Elba, 20.5.1998, El Naggar, s.n. (ASTUE)
76.	*Matthiola arabica* Boiss.	Egypt, Sinai, Gebel el Deir outside the monastry of St. Catherin, 11.5.1956, Tackholm, s.n. (CAI)
77.	*Matthiola longipetala* (Vent.) DC.	Egypt, Matruh, El Obied, June, 2001, El Naggar, s.n. (ASTUE)
78.	*Morettia canescens* var. *parviflora* Boiss.	Saudi Arabia, Al Hail, 2.5.1976, A.M. Migahid,578-A (CAI)
79.	*Matthiola canescens* Boiss. var. *canescens*	Egypt, Sinai, Naqb el Hawa, April 1940, M. Hassib, s.n. (CAI)
80.	*Morettia philaeana* (Delile) DC.	Egypt, Qift-El Qusir desert road, Eastern desert, 11.3.1999, El Naggar, s.n. (ASTUE)
81.	*Malcolmia africana* (L.) R. Br.	Egypt, S. Sinai, Wadi Al Ribba, 21.5.1997, El Naggar, s.n. (ASTUE)
82.	*Eremobium aegyptiacum* (Spreng.) Asch. & Schweinf.	Egypt,Wadi el Assuity, 25.2. 2003, El Naggar, s.n. (ASTUE)
83.	*Maresia pygmaa* (DC.) O. E. Schulz	Egypt, Mariut, Burg el Arab, 3. 1980, El Naggar,s.n. (ASTUE)
84.	*Maresia nana* (DC.) Batt.	Egypt, Mariut, Sidi Karer, March 1988, El Naggar, s.n. (ASTUE)
85.	*Leptaleum filifolium* (Willd) DC.	To of Az Zor Hills23.3.1965, Riad Halwagy & A. Maksod, s.n. (CAI)
Sisymbrieae		
86.	*Sisymbrium erysimoides* Desf.	Egypt, El Sharqia,Jan. 1985, El Naggar, s.n. (ASTUE)
87.	*Sisymbrium orientale* L.	Egypt, Wadi el Assiuty, 11.1.1999, El Naggar, s.n. (ASTUE)
88.	*Sisymbrium runcinatum* L.	Libya, El Mekhaly, 10,3,1993, El Naggar, s.n. (ASTUE)
89.	*Sisymbrium irio* L.	Egypt, Assiut University compus, March, 1997, El Naggar, s.n. (ASTUE)
90.	*Neotorularia torulosa* Hedge & Leonard	Egypt, Mediterranean coast, Sallum- Barani area, 11.4.2003. El Naggar, s.n. (ASTUE)
91.	*Descurainia sophia* (L.) Webb & Berth.	Kalmar, Sweden, 7.8.1943, Torvard Laurent (CAI)
92.	*Arabidopsis pumila* (Stephan ex Willd.) N. Busch.	Wadi El Hankalia near the gold mines Red Sea coast, 14.2.1961, Tackhol et al. (CAI)
93.	*Nasturtiopsis coronopifolia* subsp. *arabica* (Boiss) Greuter & Burdet	Sinai Bir Lehfen South of El Arish, 21.3.1928, G. Tackholm, s.n. (CAI)

Table 2. Seed coat characters of the investigated taxa of *Brassicaceae*.

Taxon	**Anticlinal cell boundaries**	**Periclinal cell wall**	**Epidermal cell pattern**	**subtype**
Brassica rapa	not well developed	waved	undulate	-
Brassica tournefortii	not well developed	waved	undulate	-
Cakile maritima	not well developed	waved	undulate	-
Zilla spinosa subsp. spinosa	not well developed	waved	undulate	-
Zilla spinosa subsp. macroptera	not well developed	waved	undulate	-
Alyssum desertorum	channeled	raised	papillate	-
Alyssum homalocharpum	channeled	raised	papillate	-
Alyssum marginatum	channeled	raised	papillate	-
Alyssum simplex	channeled	raised	papillate	-
Savignya parviflora	channeled	raised	domate	striate
Conringia orientalis	channeled	raised	domate	central structure
Carrichtera annua	channeled	raised	domate	central structure
Schouwia purpurea	channeled	raised	domate	central structure
Moricandia nitens	channeled	raised	domate	central structure
Moricandia sinaica	channeled	raised	domate	central structure
Diplotaxis harra	raised	flat	reticulate	normal reticulate
Diplotaxis erucoides	raised	flat	reticulate	normal reticulate
Lepidium aucheri	raised	flat	reticulate	normal reticulate

Table 2. Continued.

Lepidium latifolium	raised	flat	reticulate	normal reticulate
Lepidium sativum	raised	flat	reticulate	normal reticulate
Lepidium virginicum	raised	flat	reticulate	normal reticulate
Coronopus didymus	raised	flat	reticulate	normal reticulate
Coronopus niloticus	raised	flat	reticulate	normal reticulate
Biscutella didyma var. *didyma*	raised	flat	reticulate	normal reticulate
Biscutella didyma var. *depressa*	raised	flat	reticulate	normal reticulate
Biscutella didyma var. *elbensis*	raised	flat	reticulate	normal reticulate
Arabidopsis pumila	raised	flat	reticulate	normal reticulate
Lobularia arabica	raised	flat	reticulate	normal reticulate
Lobularia libyca	raised	flat	reticulate	normal reticulate
Lobularia maritima	raised	flat	reticulate	normal reticulate
Farsetia aegyptia	raised	flat	reticulate	normal reticulate
Farsetia longisiliqua	raised	flat	reticulate	normal reticulate
Farsetia stylosa	raised	flat	reticulate	normal reticulate
Clypeola jonthlaspi	raised	flat	reticulate	normal reticulate
Rorippa palustris	raised	flat	reticulate	normal reticulate
Rorippa indica	raised	flat	reticulate	normal reticulate
Schimpera arabica	raised	flat	reticulate	normal reticulate
Diplotaxis acris	raised	concave	reticulate	normal reticulate
Diplotaxis muralis var. muralis	raised	concave	reticulate	normal reticulate
Diplotaxix muralis var. simplex	raised	concave	reticulate	normal reticulate
Eruca vesicaria subsp. *sativa*	raised	concave	reticulate	reticulate foveolate
Brassica nigra	raised	concave	reticulate	reticulate foveolate
Erucastrum arabicum	raised	concave	reticulate	reticulate foveolate
Pesuderucaria clavata	raised	concave	reticulate	reticulate foveolate
Pseuderucaria teretifolia	raised	concave	reticulate	reticulate foveolate
Cardaria draba subsp. *draba*	raised	concave	reticulate	reticulate foveolate
Coronopus squamatus	raised	flat	reticulate	reticulate foveolate
Hymenolobus procumbens	raised	flat	reticulate	reticulate foveolate
Nasturtiopsis coronopifolia subsp. *arabica*	raised	concave	reticulate	reticulate foveolate
Descurainia sophia	raised	concave	reticulate	reticulate foveolate
Cardaria draba subsp. *chelepensis*	raised	concave	reticulate	reticulate foveolate
Brassica oleracea	raised	concave	reticulate	reticulate foveolate
Raphanus raphanistrum	raised	flat	reticulate	microreticulate
Raphanus sativus	raised	flat	reticulate	microreticulate
Rapistrum rugosum	raised	flat	reticulate	microreticulate
Enarthrocarpus lyratus	raised	flat	reticulate	microreticulate
Enarthrocarpus pterocarpus	raised	flat	reticulate	microreticulate
Enarthrocarpus strangulatus	raised	flat	reticulate	microreticulate
Erucaria crassifolia	raised	flat	reticulate	microreticulate
Erucaria hispanica	raised	flat	reticulate	microreticulate
Erucaria microcarpa	raised	flat	reticulate	microreticulate
Erucaria pinnata	raised	flat	reticulate	microreticulate
Didesmus aegyptius	raised	flat	reticulate	microreticulate
Didesmus bipinnatus	raised	flat	reticulate	microreticulate
Brassica juncea	raised	flat	reticulate	double reticulate
Sinapis alba	raised	concave	reticulate	globular central body
Sinapis allonii	raised	concave	reticulate	globular central body
Sinapis arvensis var. *arvensis*	raised	concave	reticulate	globular central body
Sinapis arvensis var. *orientalis*	raised	concave	reticulate	globular central body
Anastatica hierochuntica	raised	flat	reticulate	globular central body
Camelina hispida	raised	flat	reticulate	globular central body
Camelina rumelica	raised	flat	reticulate	globular central body
Neslia apiculata	raised	flat	reticulate	globular central body
Isatis lusitanica	raised	flat	reticulate	ocellate
Capsella bursa-pastoris	raised	flat	reticulate	ocellate
Nasturtium officinale	raised	flat	reticulate	ocellate
Eremobium aegyptiacum	raised	flat	reticulate	ocellate
Malcolmia africana	raised	flat	reticulate	ocellate

Table 2. Continued.

Maresia nana	raised	flat	reticulate	ocellate
Maresia pygmaea	raised	flat	reticulate	ocellate
Matthiola longipetala	raised	flat	reticulate	ocellate
Diceratella elliptica	raised	flat	reticulate	ocellate
Matthiola arabica	raised	flat	reticulate	ocellate
Morettia canescens var. *canescens*	raised	flat	reticulate	ocellate
Morettia canescens var. *parviflora*	raised	flat	reticulate	ocellate
Morettia philaeana	raised	flat	reticulate	ocellate
Notoceras bicorne	raised	flat	reticulate	ocellate
Leptaleum filifolium	raised	flat	reticulate	ocellate
Sisymbrium irio	raised	flat	reticulate	ocellate
Sisymbrium erysimoides	raised	flat	reticulate	ocellate
Sisymbrium orientale	raised	flat	reticulate	ocellate
Sisymbrium runcinatum	raised	flat	reticulate	ocellate
Neotorularia torulosa	raised	flat	reticulate	ocellate

Brassicinae (Warwick and Black 1991; Warwick and Aguinagalde 1992). The present results may support the close relationships between *Brassicinae* and *Raphaninae* but not considering them as one assemblage. *Raphanus* and its allied genera (*Enarthrocarpus*, and *Rapistrum*) have been considered to belong to the "Rapa" lineage, while *Didesmus* would belong to the "Nigra" lineage, if we follow the scheme of Warwick & Black 1994, while Yang & al. (1998) based on 5S rRNA spacer sequence considered *Raphanus* among "Nigra" lineage.

Subtribe *Cakilinae* is usually considered to be a natural group (Gomez-Campo 1980; Al Shehbaz 1985) and more related to *Raphaninae* morphologically (Schulz 1936). This fact has been supported by the present results since *Erucaria* (*Cakilinae*) and all representatives of *Raphaninae* have the same seed coat pattern (microreticulate).

The only representative of subtype Savignyniae, *Savignya parviflora*, is characterized domate striate seed coat pattern. Our seed coat results with *Savignya parviflora* (*Savignyniae*) may support considering this taxon as a distinct taxon. This is also supported by its unique morphological characters (Fayed & El Naggar 1988; Crespo & al. 2000). On the other hand the present results support the close relationships between *Savignyniae* and *Vellinae* which agrees with those of Warwick & Black (1994) but not including *Savignyniae* in *Vellinae* as suggested by Gomez-Campo (1980).

On an other hand, there are some other types of seed coat pattern which do not conform to the traditional classification of the family Brassicaceae. For example, reticulate with central globular body seed coat pattern distinguishes different species belonging to different genera and different tribes: *Sinapis alba, S. arvensis* and *S. allionii* (Brassiceae**)**, *Anastatica hierochuntica, Neslia apiculata, Camelina rumelica* and *Camelina hispida* (Euclideae**)**. The reticulate with ocellate structure seed coat pattern is also found in different species and genera belonging to different tribes: *Capsella bursa-pastoris and Isatis lusitanica* (*Lepidieae***),** *Nasturtium officinale* **(***Arabideae***);** *Eremobium aegyptiacum*, *Malcolmia africana*, *Maresia nana, M. pgymaea Matthiola longipetala, M. arabica , Diceratella elliptica, Morettia philaeana M. canescens var. canescens M. canescens var. parviflora, Notoceras bicorne, Leptaelum filifolium* (*Hesperideae*), *Sisymbrium irio, S.*

orientale, S. erysimoides, S. runcinatum and *Neotorularia torulosa* (*Sisymbrieae*). These results may suggest the idea that the boundaries between the above tribes are highly artificial (Zunk & al. 1993; Price & al. 1994).

Tribe Alysseae comprises 4 genera in Egypt: *Alyssum, Farsetia, Lobularia* and *Clypeola.* These genera are characterized by different types of seed coat patterns, i.e. papillate in *Alyssum,* and reticulate in *Lobularia*, *Farsetia* and *Clypeola.* These results support the idea that the tribe *Alysseae* is a polyphyletic grouping (El Naggar & El Hadidi 1998).

The tribe Lepidieae was morphologically considered to be a natural group (El Naggar 1992, 2000: Zunck & al., 1999). Seed coat characters of most of studied taxa of *Lepidieae* are characterized by reticulate or reticulate-foveolate seed coat pattern except in *Capsella bursa-pastrois and Isatis lusitanica* (reticulate with ocellate structure). Recently this assemblage has been considered to be an unnatural group (Koch, Haubold & Mitchell-Olds 2000; Koch & Mummenhoff 2001). Seed coat pattern of *Capsella bursa pastoris* may support the close relationships between this taxon and some other taxa belonging to the *Arabideae*. These results agree with those of Koch, Weisshaar, Kroymann, Haubold & Mitchell-Olds (2001).

Sisymbrieae is usually considered to be an unnatural group (El Naggar 2000; Koch, Haubold & Mitchell-Olds 2001; Warwick, Al-Shehbaz, Price & Sauder 2002). Seed coat characters of the present paper support this idea wherever different genera of *Sisymbrieae* have different types of seed coat pattern. For example *Sisymbrium* and *Neotorularia* have reticulate with ocellate structure seed coat pattern while *Nastrutiopsis* and *Descurainia* have reticulate pattern.

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