BLUMEA 47 (2002) 363–383

SEED MORPHOLOGY OF SOME TRIBES OF BRASSICACEAE (IMPLICATIONS FOR TAXONOMY AND SPECIES IDENTIFICATION FOR THE FLORA OF EGYPT)

K. ABDEL KHALIK[1] & L.J.G. VAN DER MAESEN[2]

SUMMARY

Seed morphology of 45 taxa belonging to 23 genera of Brassicaceae were examined using light and scanning electron microscopy. The taxa included representatives of the tribes Arabideae, Euclideae, Hesperideae, Lunarieae, Matthioleae, and Sisymbrieae, which all occur in Egypt. Macro- and micromorphological characters, including seed shape, colour, size, the position of the radicle relative to the cotyledons, epidermal cell shape, anticlinal boundaries, outer periclinal cell wall and relief of outer cell walls, are presented. Three types of basic anticlinal cell wall boundaries are recognised and six different shapes of the outer periclinal cell wall are described. A key for the identification of the investigated taxa based on seed characters is provided.

Key words: Brassicaceae, SEM, seed coat.

INTRODUCTION

The Brassicaceae (Cruciferae) are one of the largest angiosperm families, comprising approximately 340 genera and more than 3350 species in 10 poorly defined tribes, distributed throughout the world, chiefly in temperate regions of the northern hemisphere (Al-Shehbaz, 1984). The major centres of distribution of the family are in the Irano-Turanian, Mediterranean, and Saharo-Sindian regions (Hedge, 1976).

In the flora of Egypt, Brassicaceae are one of the four largest plant families, represented by about 102 species belonging to 55 genera, assigned to 9 tribes (Schulz, 1936). Species of the tribes Lepideae, Brassiceae, and Alysseae (63 species belonging to 32 genera) have been the subject of an earlier study (El Naggar, 1987; El Naggar & El Hadidi, 1998). The remaining Brassicaceae, belonging to the tribes Arabideae, Euclideae, Hesperideae, Lunarieae, Matthioleae, and Sisymbrieae (Schulz, 1936) (39 species in 23 genera) exhibit great diversity, as shown in this revision. The members of these tribes are distributed over a wide range of habitats as weeds of farmland and waste places, desert land, Mediterranean coastal land, oases; mountains of Sinai and Elba, as well as inland flats and canal banks.

Most systematists agree that data concerning the macro- and microstructure of seeds are very significant for the classification of angiosperm taxa. Heywood (1971) drew attention to the importance and impact of scanning electron microscopy (SEM) in the study of systematic problems, as very valuable information has been provided

1) South Valley University, Faculty of Science, Botany Department, Sohag, Egypt.
2) Nationaal Herbarium Nederland, Wageningen University branch, Biosystematics Group, Generaal Foulkesweg 37, 6703 BL Wageningen, The Netherlands.

by using this technique. During the last decades, many scholars have applied SEM to morphological studies of seeds and small fruits. Micromorphology and ultrastructural data have contributed useful information for evolution and classification of seed plants and play an important role in the modern synthetic systems of angiosperms (Dahlgren, 1979–1980).

Most studies focused on intrageneric seed coat variation (Chuang & Heckard, 1972; Hill, 1976; Heyn & Herrnstadt, 1977; Clark & Jernstedt, 1978; Newell & Hymowitz, 1978; Canne, 1979; Crow, 1979; Wofford, 1981; Juan et al., 2000; Segarra & Mateu, 2001) or on variation among several closely related genera (Musselman & Mann, 1976; Seavey et al., 1977; Canne, 1980; Chance & Bacon, 1984; Matthews & Levins, 1986; Fayed & El Naggar, 1988, 1996; Haridasan & Mukherjee, 1993; Shanmukha & Leela, 1993; Kanak Sahai et al., 1997; Karam, 1997; Koul et al., 2000). Less commonly, SEM level variation was used to place taxa into tribes (Whiffin & Tomb, 1972).

For further information and references concerning seed forms and internal structures see Corner (1976). Seed appendages were studied by Kapil et al. (1980); for seed size and number see Aniszewski et al. (2001); for the colours of seeds refer to Berggren, 1962; Huber, 1969; Dahlgren & Clifford, 1982; Barthlott, 1984; while epidermal cell patterns and distribution of elements such as trichomes, glands, and stomata are given by Stace (1965). The distribution of epidermal cells is of importance between species and genus level (Barthlott, 1981, 1984; Haridasan & Mukherjee, 1993); while outer periclinal walls are also a good diagnostic character for the lowest taxonomic categories (Barthlott, 1981, 1984; Fayed & El Naggar, 1988, 1996).

In Brassicaceae, the external features of the seeds colour and shape are studied by Kondo (1917), McGugan (1948), Musil (1948), and Murley (1951). Berggren (1962) investigated the external morphology and anatomy of seeds testa of *Brassica.* Vaughan & Whitehouse (1971) studied the external morphology and anatomy of seeds of 90 genera and 200 species of the Cruciferae and paid special attention to the relationships between seed structure and the existing taxonomy. Prasad (1976) investigated the seed coat structure and development in certain species of Brassicaceae. Mulligan & Baily (1976) and Stork et al. (1980) studied some taxa of *Brassica* seeds with SEM and they suggested other data that help in the reclassification of the genus. Fayed & El Naggar (1988) investigated the seed coat sculpture in species of the tribe Brassiceae in Egypt by using SEM; several details offered taxonomic value at the generic and subtribal levels, such as the seed shape and size, epidermal cells pattern, anticlinal wall boundaries, and outer periclinal cell walls. Jonsell (1975) studied the seed coat of *Lepidium* in East tropical Africa; Fayed & El Naggar (1996) investigated the seed morphology and taxonomy with SEM in the tribe Lepidieae in Egypt.

Jonsell (1986) studied the seed coat of genus *Farsetia* by using SEM to distinguish between species. Stork (1971, 1972) and Stork & Wüest (1978) investigated the seed coats and development of epidermal slime bodies of *Malcolmia* and found large differences between the species. Jonsell (1979) used SEM on the seed surface to distinguish *Matthiola, Morettia,* and *Diceratella.* Stork & Wüest (1980) studied the seed coat morphology, particularly the epidermal slime structure of *Morettia.* Koul et al. (2000) investigated the seed coat microsculpturing in *Brassica* and allied genera and provided evidence for the close relationships among various genera within subtribe Brassicinae and of subtribes Raphaninae and Moricandiinae with the Brassicinae.

The present investigations deal with the macro- and micromorphological (LM & SEM) characters of seeds of 23 genera (39 species) of 6 tribes from the family Brassicaceae in Egypt, to decide on the importance of seed characters as a criterion for separating genera and species in this family. The terminology used here follows authors such as Barthlott (1981, 1984), Fayed & El Naggar (1988, 1996), Karam (1997), and Koul et al. (2000) with some modifications by the author.

MATERIAL AND METHODS

Some of the investigated seeds were collected from mature plants in Egypt during 1998–2000. The others were supplied by INIA, Madrid, Spain or taken from herbarium specimens (see Table 1).

Only mature seeds were taken for investigation. The dried seeds were first examined by light microscope (Carl Zeiss 475002), and 7–15 seeds for each taxon were chosen to cover the range of variation. Seeds were mounted on stubs with double adhesive tape. The stubs were sputter-coated with gold-palladium for 2–3 min. in a Polaron Equipment Ltd. SEM coating unit E 5100. After coating, the specimens were examined with a Jeol JSM 5200 scanning electron microscope, using accelerating voltages at 15–20 KV. All photomicrographs were taken at the department of Plant Cytology and Morphology, SEM laboratory, Wageningen University, The Netherlands.

RESULTS

Seed characters are very important to separate among genera and species levels in Brassicaceae. Seed shape varies from orbicular, suborbicular, oblong, ovoid, to oblong-ovoid. Seed size varies from large 3–8 by 2.5–7 mm to small 0.5–1 by 0.3–0.9 mm and helps to separate between species. Seed colour varies from brown, yellow-brownish to red-brownish. Radicle position relative to cotyledons varies from accumbent to incumbent. Epidermal cell shape varies from isodiametric, 4–5–6-polygonal to elongate in one direction. Anticlinal boundaries vary from raised to channelled and anticlinal walls from straight to sinuous or slightly sinuous; and the surface varies from smooth to fine or coarse folds. Periclinal cell walls showed a large variation among genera and species level, and can either be flat, concave, convex, or domate; smooth, micro- or macroreticulate, striate, and possess fine to coarse folds and papillae.

The seed shape, absence/presence of a wing, size, colour, radicle position relative to the cotyledons, epidermal cell shape, and the characters of anticlinal boundaries and periclinal cell walls of each taxon (39 species belong to 23 genera) are given in Table 2.

DISCUSSION OF SEED CHARACTERS

1. Seed shape

The shape of seeds among the investigated taxa showed a large variation. Most of the seeds vary from oblong or ovoid to oblong-ovoid or oblong-ellipsoidal (Table 2), however, they are orbicular in *Ricotia lunaria* (Fig. 11); sub-orbicular to sub-orbicular-ovoid in *Matthiola longipetala* subsp. *hirta*, *Arabis alpina* subsp. *caucasica*, *Neslia*

Table 1. List of Brassicaceae seed specimens used in Scanning Electron Microscope (SEM) studies.

taxon	collection no.	place of collections
1. Tribe Arabideae		
Arabis alpina L. subsp. *caucasica* (Willd.) Briq.	1313	Morocco, Taza, around gebel Tazzeka (NMGM)
Arabis nova Vill.	20273	Switzerland, Valois, Val de Bagnes (BR)
Nasturtium officinale R.Br.	415	
Rorippa indica (L.) Hiern	s.n.	Egypt, Qena, El Mahrosa island (SHG)
Rorippa integrifolia Boulos	9	Egypt, Middle of Sinai, about 5 km before Ras Sedr (SHG)
Rorippa palustris (L.) Besser	20	Egypt, along the canal of Ismailiya (SHG)
2. Tribe Euclidieae		
Anastatica hierochuntica L.	327	Egypt, Cairo-Suez road, 95 km from Cairo (CAI)
Neslia paniculata (L.) Desv.	64	Iran, near Gere between Abushir and Shiraz (WAG)
Ochthodium aegyptiacum (L.) DC.	129	Palestine, Jerusalem: Mt. Scopus (BM)
Schimpera arabica Hochst. & Steud.	3747-75	Spain, Madrid (INIA)
3. Tribe Hesperideae		
Eremobium aegyptiacum (Spreng.) Asch. & Schweinf. subsp. *aegyptiacum*	29	Egypt, El Arish area beside the airport, N Sinai (SHG)
Eremobium aegyptiacum subsp. *lineare* (Delile) Abdel Khalik	s.n.	Egypt, El Tor desert, Sinai (L)
Eremobium aegyptiacum subsp. *longisiliquum* (Coss.) Maire	s.n.	Egypt, in sands near Asswan (LY)
Erysimum repandum L.	1163-67	Spain, Madrid (INIA)
Leptaleum filifolium (Willd.) DC.	s.n.	Egypt, Wadi Chafura, north Galala (BR)
Malcolmia africana (L.) R.Br.	2	Egypt, Deir el Rahba, Wadi el Arbain, S Sinai (SHG)
Malcolmia nana (DC.) Boiss.	28	Egypt, El Arish-Rafah road, 23 km from El Arish (SHG)
Malcolmia pygmaea (Delile) Boiss.	22	Egypt, Alexandria-Matruh coastal road, 26 km, Sidi Krer, (SHG)
4. Tribe Lunarieae		
Ricotia lunaria (L.) DC.	45,004	Syria, Golan, Yahudiya forest (B)
5. Tribe Matthioleae		
Diceratella elliptica (DC.) Jonsell	17	Egypt, Gebel Elba, Wadi el Shallal (SHG)
Matthiola arabica Boiss.	12	Egypt, Wadi el Arbaien, S. Sinai (SHG)
Matthiola fruticulosa (L.) Maire	1221-66	Spain, Madrid (INIA)
Matthiola longipetala (Vent.) DC. subsp. *bicornis* (Sibth.) Ball	4379	Turkey, Tassia, in sands near Saban Dagi (BR)
Matthiola longipetala subsp. *hirta* (Conti) Greuter & Burdet	23	Egypt, Alexandria-Matruh coastal road, near Burg el Arab (SHG)
Matthiola longipetala subsp. *kralikii* (Pomel) Maire	7	Egypt, Cairo-Alexandria desert road, 100 km from Alexandria (SHG)
Matthiola longipetala subsp. *livida* (Delile) Maire	27	Egypt, Cairo-Ismailiya desert road, 23 km before Ismailiya (SHG)

Table 1 (*continued*)

taxon	collection no.	place of collections
Matthiola longipetala subsp. *longipetala* (Vent.) Boulos	25	Egypt, 28 km before Matruh, Alexandria-Matruh road (SHG)
Matthiola parviflora (Schousb.) R.Br.	0907-66	Spain, Madrid (INIA)
Morettia canescens Boiss.	1098-67	Spain, Madrid (INIA)
Morettia parviflora Boiss.	16984/2	Saudi Arabia, Wadi Harjab, rocky hillsides (BR)
Morettia philaeana (Delile) DC.	3	Egypt, 35 km from Qena on the road Qena-Safaga (SHG)
Notoceras bicorne (Aiton) Caruel	1052	Egypt, Gebel Elba, Saddle between Gebel Asotriba and Makin (CAI)
6. Tribe Sisymbrieae		
Crucihimalaya kneuckeri (Bornm.) Al-Shehbaz, O'Kane & R.A. Price	49785	Egypt, Sinai, E slopes of Gebel Catherine (CAI)
Descurainia sophia (L.) Webb & Berthold	1475	Jordan, El-Jubeiha, University campus (B)
Nasturtiopsis coronopifolia (Desf.) Boiss.	3663-76	Spain, Madrid (INIA)
Neotorularia aculeolata (Boiss.) Hedge & J. Léonard	5801	Iran, West of Jaz Murian (BR)
Neotorularia torulosa (Desf.) Hedge & J. Léonard	1461-68	Spain, Madrid (INIA)
Olimarabidopsis pumila (Stephan) Al-Shehbaz, O'Kane & R.A. Price	779	Syria, near Damascus, road of Zahroub to Merdj, Baustam el Mahar (L)
Robeschia schimperi (Boiss.) O.E. Schulz	170	Egypt, Sinai Mts, between granitic rocks (B)
Sisymbrium erysimoides Desf.	19	Egypt, Gebel Elba, Wadi Drawina (SHG)
Sisymbrium irio L.	31	Egypt, S Sinai, Deir el-Rahebat, Wadi Feiran, as weed in garden (SHG)
Sisymbrium orientale L.	11	Egypt, S Sinai, Deir Feiran, Wadi Feiran (SHG)
Sisymbrium polyceratum L.	6627-84	Spain, Madrid (INIA)
Sisymbrium runcinatum Lag. ex DC.	s.n.	Algeria, El Kantara, near Constantine (BR)
Sisymbrium septulatum DC.	3719-75	Spain, Madrid (INIA)

paniculata, *Eremobium aegyptiacum* subsp. *lineare* and *Diceratella elliptica* (Fig. 1, 7, 12). Seed shape was found useful to separate the closely allied genera *Matthiola* with oblong seeds; *Morettia* with ovoid seeds and *Diceratella* with suborbicular to elliptical and these results congruence with the results of Jonsell (1979). The shape of seeds showed a significant difference between the subspecies of *Eremobium aegyptiacum*: they are oblong in subsp. *aegyptiacum* and subsp. *longisiliquum* and sub-orbicular to ovoid in subsp. *lineare* (Fig. 7, 8).

Most of the seeds examined have no wings or only narrow wings, but in *Arabis alpina* subsp. *caucasica*, *Eremobium aegyptiacum* subsp. *lineare*, *Matthiola fruticulosa* and *Matthiola longipetala* subsp. *hirta* seeds have a broad wing (Fig. 1, 7).

(*text continued on page 376*)

Table 2. Seed descriptions of Brassicaceae.

taxon	seed shape	seed wing	seed size (mm)	seed colour	radicle	epidermal cell shape	anticlinal boundaries	periclinal cell wall
1. Tribe Arabideae								
Arabis alpina subsp. *caucasica*	sub-orbicular	wide	1.3–1.5 × 1.2–1.3	light brown	accumbent	isodiametric, polygonal	channelled, straight to slightly sinuous; smooth	domate with flat or concave central position; folds to smooth
Arabis nova	oblong-ovoid	none	0.7–1 × 0.3–0.4	light brown	accumbent	isodiametric, 5–6-polygonal	raised, straight to sinuous; coarse folds	domate with globular central papilla; radiate-striate
Nasturtium officinale	ovoid	narrow	0.9–1 × 0.75–0.9	brown	accumbent	4–5–6-gonal, elongate in one direction	raised, straight; folded	flat; macro-reticulate
Rorippa indica	ovoid	narrow	0.8–1 × 0.7–0.8	red-brown	accumbent	isodiametric, polygonal	raised, straight to slightly sinuous; smooth to medium folds	flat to concave; smooth to micro-reticulate
Rorippa integrifolia	ovoid to ellipsoid	none	0.8–1 × 0.5–0.75	orange-brown	accumbent	4–5-polygonal, elongate in one direction	raised, straight to slightly sinuous; smooth to fine folds	flat to slightly convex; striate
Rorippa palustris	cordiform to ovoid	none	0.5–0.9 × 0.3–0.6	brown	accumbent	isodiametric, 4–5-gonal	raised, straight to slightly sinuous; smooth to fine folds	flat to concave; smooth to micro-reticulate
2. Tribe Euclidieae								
Anastatica hierochuntica	ovoid	none	1–1.9 × 1–1.7	brown	accumbent	isodiametric	channelled, straight; smooth to fine folds	flat to convex with slightly sunken central papilla; smooth to fine folds
Neslia paniculata	ovoid to sub-orbicular	none	1.5 × 1.3	brown	incumbent	4-polygonal	raised-channelled, straight to sinuous; smooth to fine folds	concave; smooth to medium folds
Ochthodium aegyptiacum	ovoid-oblong	none	2.5–3 × 1.5–1.7	brown	incumbent	elongate in one direction, polygonal	slightly raised, sinuous; smooth to fine folds	flat to slightly concave; micro-reticulate
Schimpera arabica	oblong-ovoid	none	1.2–2.7 × 0.5–1.2	brown	incumbent	5–6-gonal, elongate in one direction	slightly raised-channelled, straight to slightly sinuous; smooth to fine folds	flat or slightly convex; micro-reticulate
3. Tribe Hesperideae								
Eremobium aegyptiacum subsp. *aegyptiacum*	oblong	narrow	2.2 × 1.2	yellow-brownish	accumbent	isodiametric, 4–5–6-gonal	slightly raised, straight; smooth	flat to convex; smooth to fine folds
Eremobium aegyptiacum subsp. *lineare*	sub-orbicular to ovoid	wide	2.1 × 1.6	red-brownish	accumbent	isodiametric, 5–6-gonal, elongate in one direction	slightly raised, straight; smooth	flat to convex; smooth to micro-papillate
Eremobium aegyptiacum subsp. *longisiliquum*	oblong	narrow	2.1 × 1	brown	accumbent	isodiametric, polygonal	raised, straight to slightly sinuous; smooth to fine folds	flat to concave; smooth to fine folds

Table 2 (*continued*)

taxon	seed shape	seed wing	seed size (mm)	seed colour	radicle	epidermal cell shape	anticlinal boundaries	periclinal cell wall
Erysimum repandum	oblong	none	1.6 × 0.7	yellow-brownish	incumbent	isodiametric, 5–6-gonal	raised, straight; smooth to fine folds	domate with globular central papilla; radiate-striate
Leptaleum filifolium	oblong-ovoid	none	0.6–0.7 × 0.4–0.5	yellow-brownish	incumbent	polygonal	channelled, sinuous to slightly straight; smooth	domate with flat or concave central position; striate
Malcolmia africana	oblong	none	1.2–1.7 × 0.5–0.8	brown	incumbent	isodiametric, polygonal	raised, straight to sinuous; smooth	flat to convex with flat central portion; fine to coarse folds
Malcolmia nana	oblong-ellipsoidal	none	0.6–0.8 × 0.3–0.4	yellow-brownish	incumbent	isodiametric, 4–5–6-gonal, elongate in one direction	raised, straight to slightly sinuous; smooth to fine folds	flat to convex; striate
Malcolmia pygmaea	ovoid	none	0.7–0.8 × 0.5–0.6	yellow-brownish	incumbent	isodiametric, 5–6-gonal, elongate in one direction	slightly raised, straight; smooth to fine folds	flat to convex; striate
4. Tribe Lunarieae								
Ricotia lunaria	orbicular	none	3–8 × 2.5–7	brown	accumbent	isodiametric, polygonal	channelled, straight to sinuous; smooth	flat to convex; smooth to micro-papillate
5. Tribe Matthioleae								
Diceratella elliptica	sub-orbicular to elliptic	narrow	1–1.1 × 0.8–1	light brown	accumbent	isodiametric, 4–5–6-gonal, elongate in one direction	raised, straight; smooth	flat to convex with sunken central papilla; smooth to fine folds
Matthiola arabica	oblong	narrow	1.1–1.3 × 0.7–0.8	brown	accumbent	4–5–6-gonal, elongate in one direction	raised, straight; smooth to fine folds	convex; smooth to fine folds
Matthiola fruticulosa	oblong	wide	2.2 × 1.2	brown	accumbent	isodiametric, 5–6-gonal, elongate in one direction	raised, straight; smooth to fine folds	flat to convex; fine to medium striate
Matthiola longipetala subsp. *bicornis*	oblong	wide	1.5–1.8 × 0.7–1	brown	accumbent	isodiametric, polygonal	raised, straight to sinuous; smooth to fine folds	flat to slightly concave; fine to coarse folds
Matthiola longipetala subsp. *hirta*	sub-orbicular	narrow	1–1.3 × 0.9–1.1	yellow-brownish	accumbent	isodiametric, 5–6-polygonal	raised, straight; smooth	flat to slightly convex; smooth to fine folds
Matthiola longipetala subsp. *kralikii*	oblong-ovoid	narrow	1–1.1 × 0.7–0.8	yellow-brownish	accumbent	isodiametric, 5–6-polygonal	raised, straight to slightly sinuous; smooth to fine folds	flat to slightly convex; smooth to fine folds
Matthiola longipetala subsp. *livida*	oblong	narrow	0.8–1 × 0.4–0.6	brown	accumbent	4–5-polygonal	slightly raised, straight to sinuous; smooth to fine folds	flat or slightly concave; coarse folds
Matthiola longipetala subsp. *longipetala*	oblong-ovoid	narrow	1–1.2 × 0.7–0.8	yellow-brownish	accumbent	isodiametric, 4–5–6-gonal	raised, straight to slightly sinuous; smooth to fine folds	flat; smooth to fine folds
Matthiola parviflora	oblong-ovoid	narrow	1.2–1.5 × 1–1.2	brown	accumbent	isodiametric, elongate in one direction, 4–5–6-gonal	slightly raised, straight; smooth	flat or slightly concave; micropapillate
Morettia canescens	ovoid	none	1–1.3 × 0.9–1.1	light brown	accumbent	isodiametric, 4–5-gonal	raised, straight; fine to coarse folds	convex; smooth

Table 2 (*continued*)

taxon	seed shape	seed wing	seed size (mm)	seed colour	radicle	epidermal cell shape	anticlinal boundaries	periclinal cell wall
Morettia parviflora	ovoid	none	1–1.2 × 0.8–1	light brown	accumbent	isodiametric, 4–5–6-gonal	raised, straight to slightly sinuous; smooth	domate with a globular central papillae; fine folds to radiate-striate
Morettia philaeana	ovoid	none	1.5–1.7 × 1.3–1.5	brown	accumbent	isodiametric, 5–6-gonal	raised, straight; smooth	convex; smooth
Notoceras bicorne	rounded	none	1–1.5 × 0.9–1.3	brown	accumbent	isodiametric, 5–6-gonal, elongate in one direction	raised, straight to slightly sinuous; smooth to fine folds	convex; medium striate
6. Tribe Sisymbrieae								
Crucihimalaya kneuckeri	oblong	none	0.8–1 × 0.3–0.4	brown	incumbent	isodiametric, polygonal	raised, straight to slightly sinuous; fine folds	flat to concave; folded to micro-reticulate
Descurainia sophia	oblong	none	1–1.3 × 0.6–0.8	red-brownish	incumbent	isodiametric, 4–5-poly-gonal	raised, straight; smooth to fine folds	flat to convex; smooth to fine folds
Nasturtiopsis coronopifolia	oblong-ellipsoidal	none	0.7–1 × 0.4–0.5	brown	incumbent	5–6-polygonal, elongate in one direction	raised, straight to sinuous; smooth to fine folds	flat to convex with sunken central papilla; fine to coarse folds
Neotorularia aculeolata	oblong	none	1.2–1.5 × 0.4–0.5	brown	incumbent	isodiametric, polygonal	channelled, sinuous; smooth	domate with sunken central portion; smooth to fine folds
Neotorularia torulosa	oblong-ellipsoidal	none	1–1.2 × 0.5–0.6	brown	incumbent	isodiametric, 5–6-gonal	slightly raised, straight; smooth	convex; smooth to fine folds
Olimarabidopsis pumila	oblong	none	0.9–1 × 0.4–0.5	brown	incumbent	isodiametric, polygonal	raised, straight; smooth to fine folds	domate with globular central papilla; smooth
Robeschia schimperi	oblong	none	1–1.3 × 0.5–0.6	brown	incumbent	isodiametric, 5–6-poly-gonal	raised, straight to slightly sinuous; smooth to deep folds	domate with globular central papilla; medium striate
Sisymbrium erysimoides	oblong	none	1–1.1 × 0.5	yellow-brownish	incumbent	isodiametric, polygonal	channelled, straight to sinuous; smooth to fine folds	domate with flat or concave central position; radiate-striate
Sisymbrium irio	oblong-ellipsoidal	none	0.7–1 × 0.4–0.5	yellow-brownish	incumbent	isodiametric, 4–5-gonal	slightly raised, straight; smooth	flat to slightly convex with flat or concave central portion; micro-reticulate
Sisymbrium orientale	oblong-ovoid	none	1.1–1.4 × 0.7–0.9	orange-brown	incumbent	isodiametric, 5-poly-gonal	raised, straight to slightly sinuous; smooth to fine folds	flat to slightly convex; micro-reticulate
Sisymbrium polyceratum	oblong	none	0.8–1 × 0.4–0.5	brown	incumbent	polygonal, elongate in one direction	channelled, sinuous to slightly straight; smooth	flat to convex; smooth to fine folds
Sisymbrium runcinatum	oblong	none	1–1.1 × 0.5–0.6	yellow-brownish	incumbent	polygonal	channelled, sinuous; smooth to fine folds	domate with sunken central portion; fine folds
Sisymbrium septulatum	oblong-ovoid	none	1–1.3 × 0.6–0.7	brown	incumbent	isodiametric, polygonal	raised-channelled, straight straight to slightly sinuous; smooth	domate with globular central papilla; smooth to fine folds

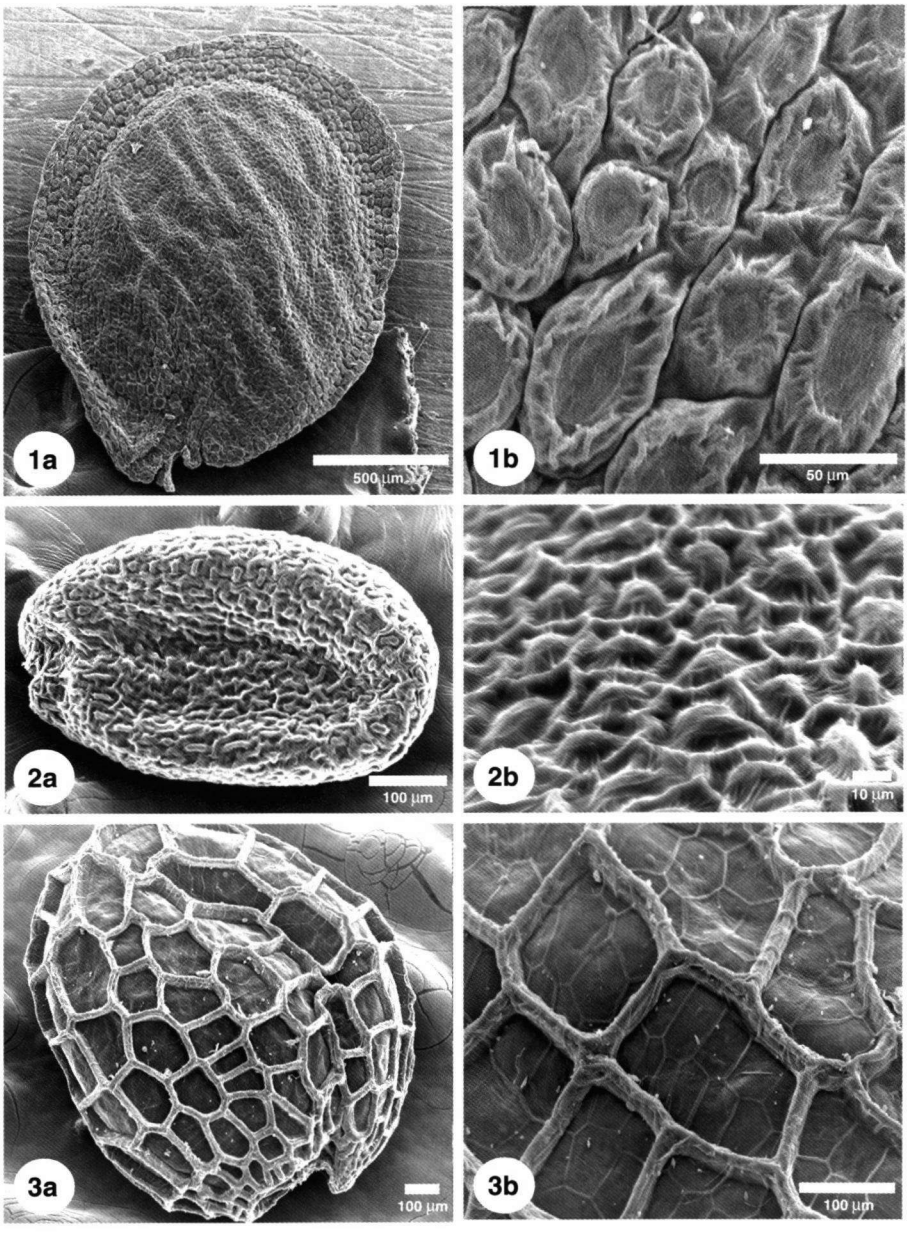
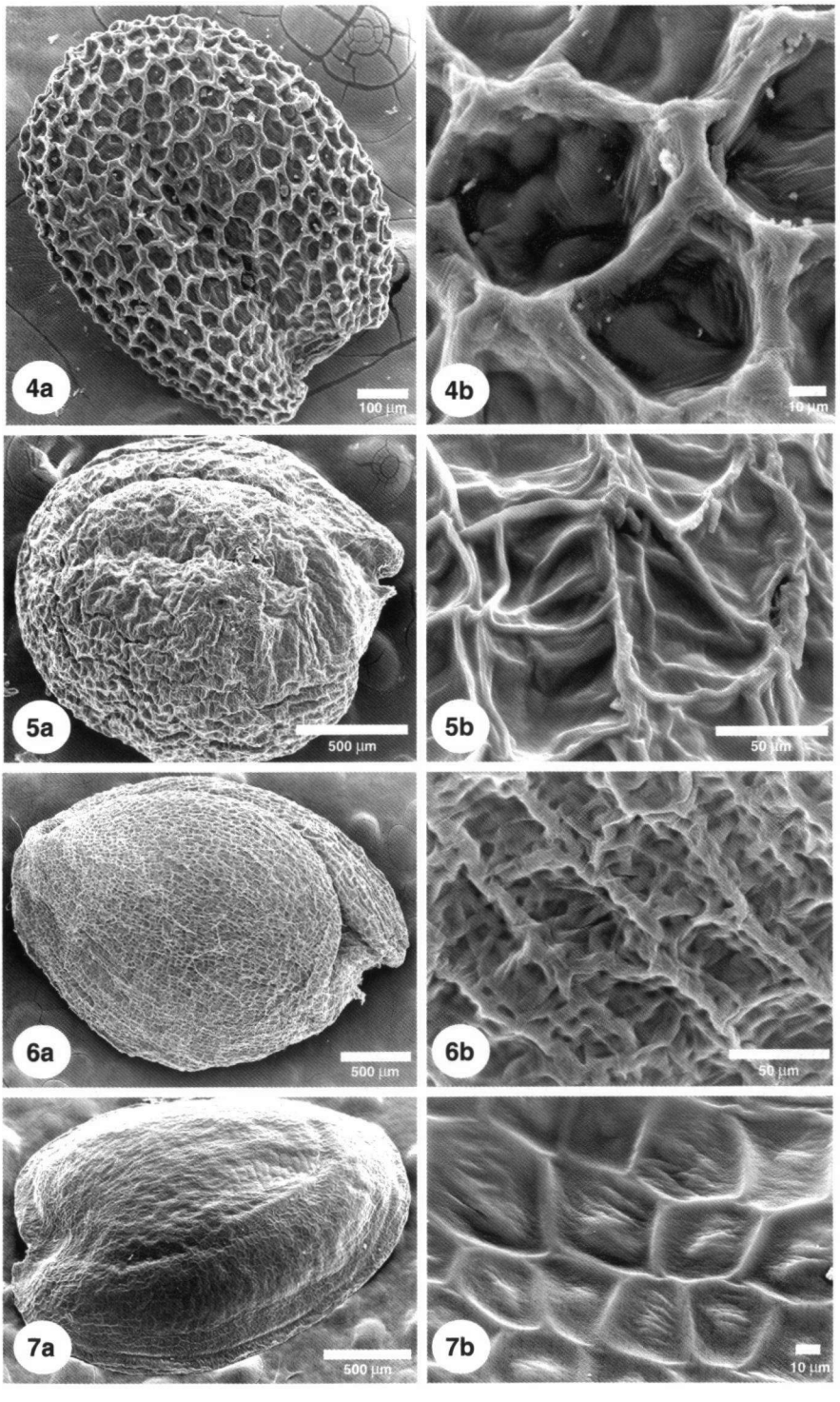


Fig. 1–3. SEM photographs of seeds. a. Entire seed; b. enlargement of seed coat. — 1. *Arabis alpina* L. subsp. *caucasica* (Willd.) Briq. — 2. *Arabis nova* Vill. — 3. *Nasturtium officinale* R. Br.


4a
100 µm
4b
10 µm
5a
500 µm
5b
50 µm
6a
500 µm
6b
50 µm
7a
500 µm
7b
10 µm

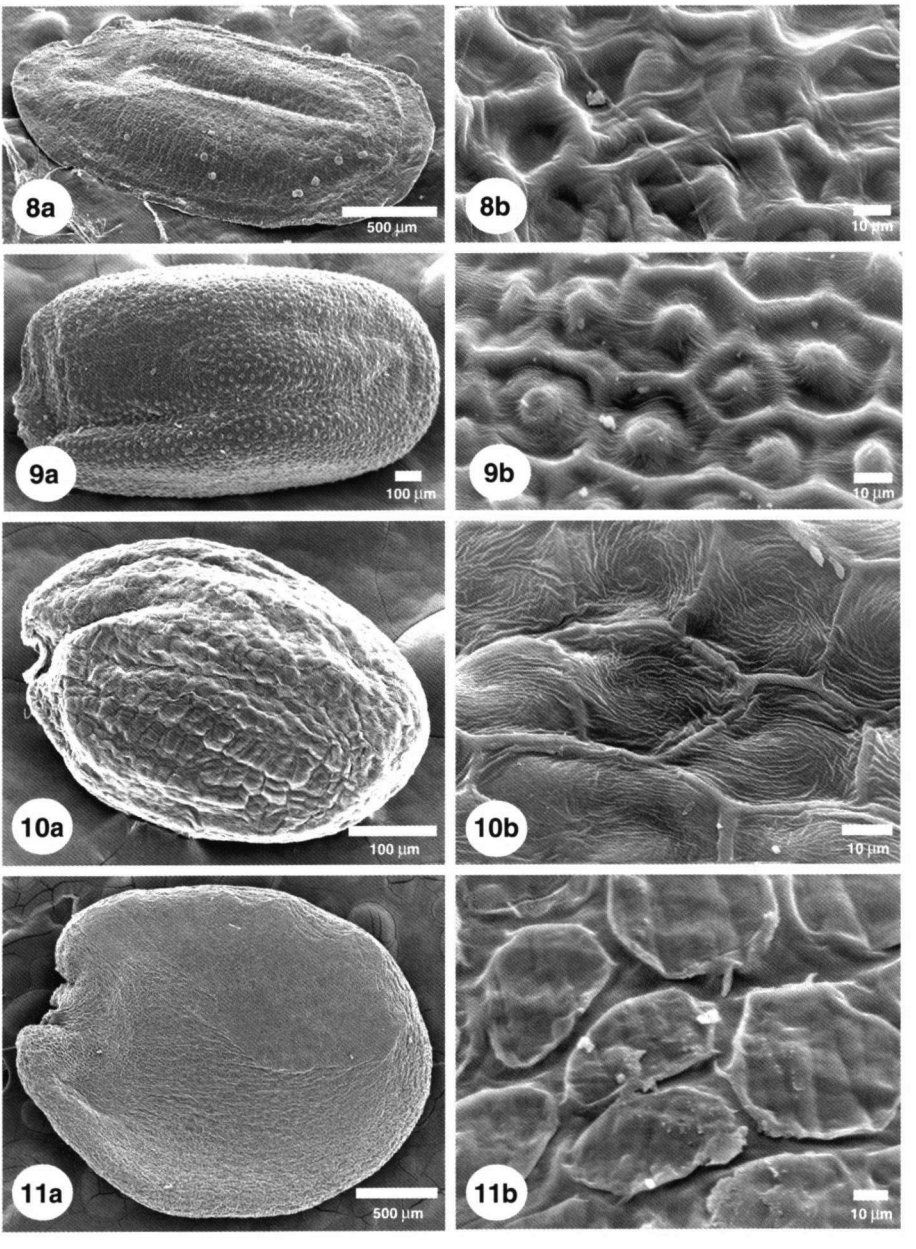


Fig. 4–11. SEM photographs of seeds. a. Entire seed; b. enlargement of seed coat. — 4. *Rorippa indica* (L.) Hiern. — 5. *Neslia paniculata* (L.) Desv. — 6. *Ochthodium aegyptiacum* (L.) DC. — 7. *Eremobium aegyptiacum* subsp. *lineare* (Delile) Abdel Khalik. — 8. *Eremobium aegyptiacum* subsp. *longisiliquum* (Coss.) Maire. — 9. *Erysimum repandum* L. — 10. *Malcolmia pygmaea* (Delile) Boiss. — 11. *Ricotia lunaria* (L.) DC.

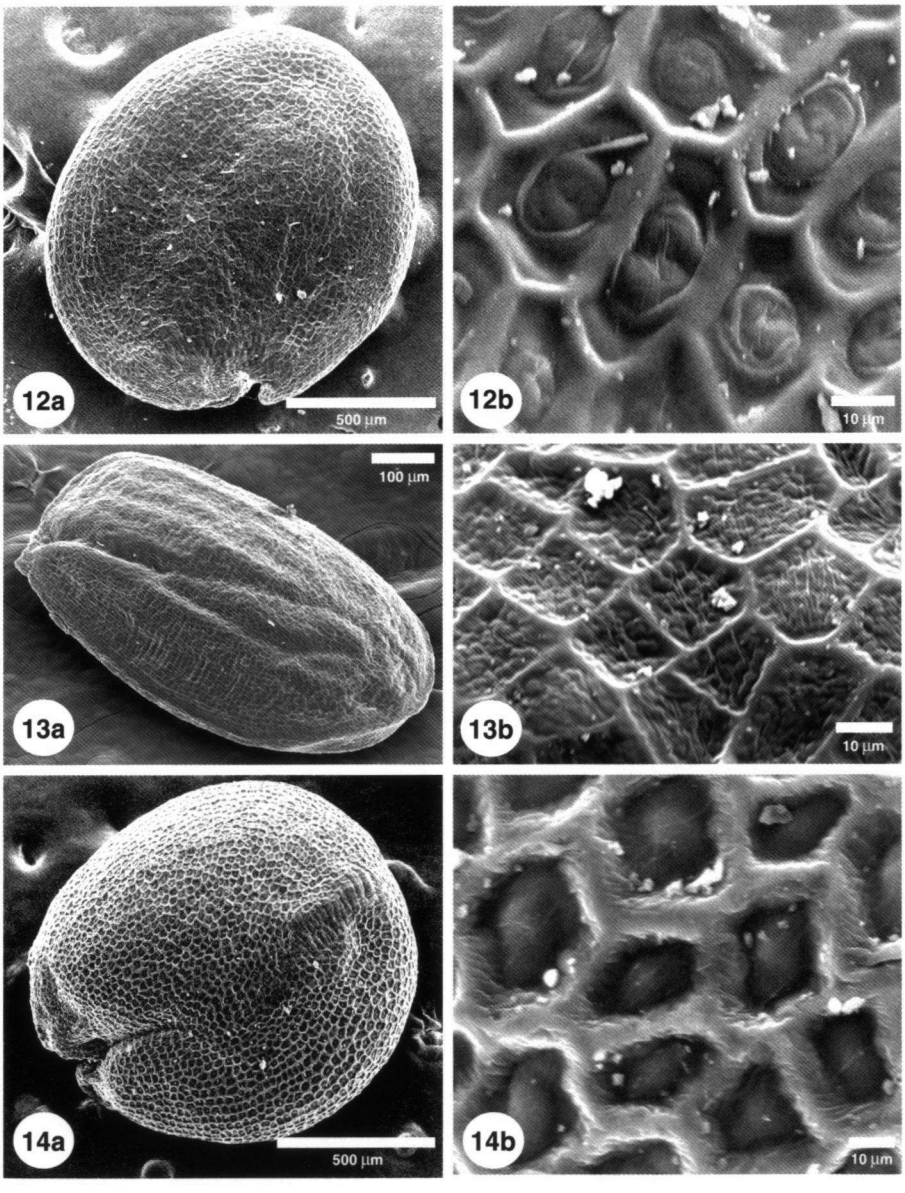


Fig. 12–14. SEM photographs of seeds. a. Entire seed; b. enlargement of seed coat. — 12. *Diceratella elliptica* (DC.) Jonsell. — 13. *Matthiola parviflora* (Schousb.) R.Br. — 14. *Morettia canescens* Boiss.

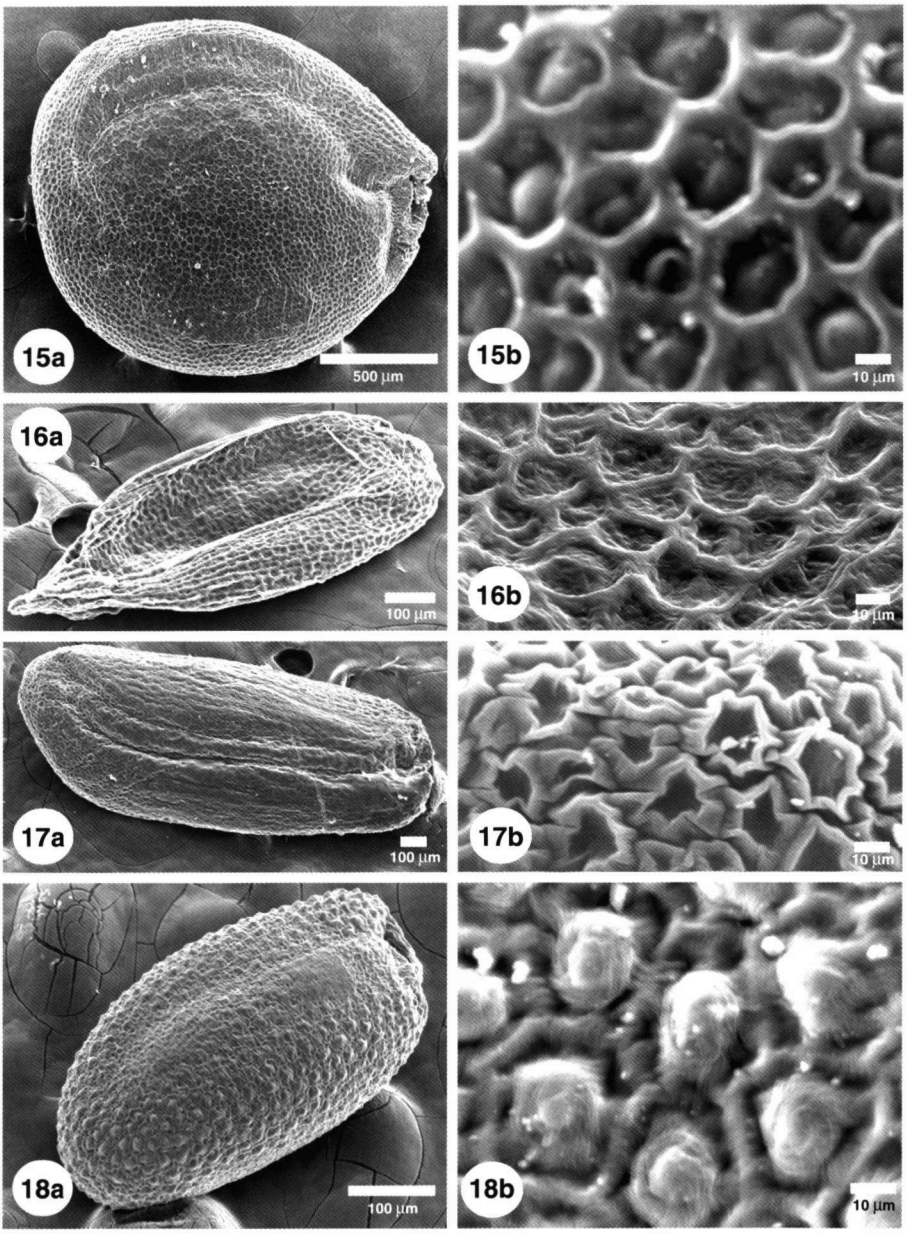


Fig. 15–18. SEM photographs of seeds. a. Entire seed; b. enlargement of seed coat. — 15. *Morettia philaeana* (Delile) DC. — 16. *Crucihimalaya kneuckeri* (Bornm.) Al-Shehbaz, O'Kane & R.A. Price. — 17. *Neotorularia aculeolata* (Boiss.) Hedge & J. Léonard. — 18. *Olimarabidopsis pumila* (Stephan) Al-Shehbaz, O'Kane & R.A. Price.

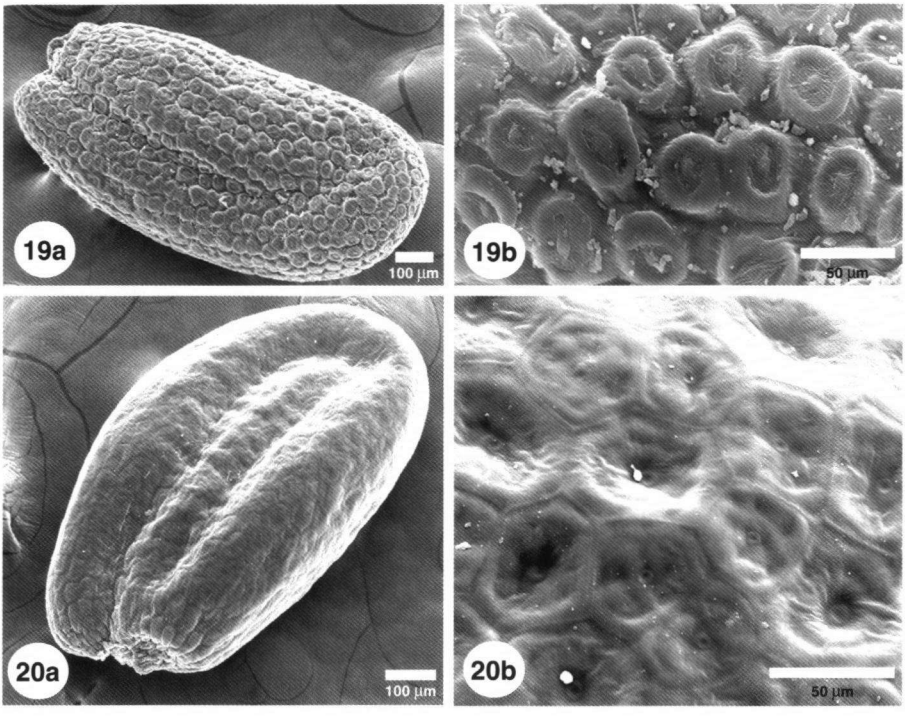


Fig. 19 & 20. SEM photographs of seeds. a. Enti_e seed; b. enlargement of seed coat. — 19. *Sisymbrium erysimoides* Desf. — 20. *Sisymbrium irio* L.

2. SEED SIZE

Seed dimensions vary greatly among the examined taxa, the largest orbicular seeds in *Ricotia lunaria* have a diameter of 3–8 by 2.5–7 mm, and the smallest seeds measure 0.5–1 by 0.3–0.9 mm in *Arabis nova, Nasturtium officinale, Rorippa, Leptaleum filifolium, Malcolmia nana, M. pygmaea, Nasturtiopsis, Crucihimalaya kneuckeri, Olimarabidopsis pumila, Sisymbrium irio,* and *S. polyceratum,* while the rest of the species have slightly larger seeds of 1–3 by 0.4–1.7 mm.

The seed size was found useful to separate between two species of *Arabis*, species of *Malcolmia,* and species of *Sisymbrium* (see Table 2).

3. SEED COLOUR

The colours of seeds are of high diagnostic and systematic interest among taxa. The colour of seeds varies from brown, yellow, red-brownish to orange-brownish. In the genus *Rorippa*, the colour varies from red-brown in *R. indica*, orange-brown in *R. integerifolia* to brown in *R. palustris*, but the colour in *Sisymbrium* varies from yellow-brownish in *S. erysimoides, S. irio*, and *S. runcinatum*; brown in *S. polyceratum* and *S. septulatum* to orange-brown in *S. orientale.* In *Malcolmia,* the colour is brown in *M. africana*; green-yellowish in *M. nana* and yellow-brown in *M. pygmaea.*

The colour is also used to distinguish between subspecies of *Eremobium aegyptiacum*; it is yellow-brownish in subsp. *aegyptiacum* and subsp. *longisiliquum* and red-brownish in subsp. *lineare.*

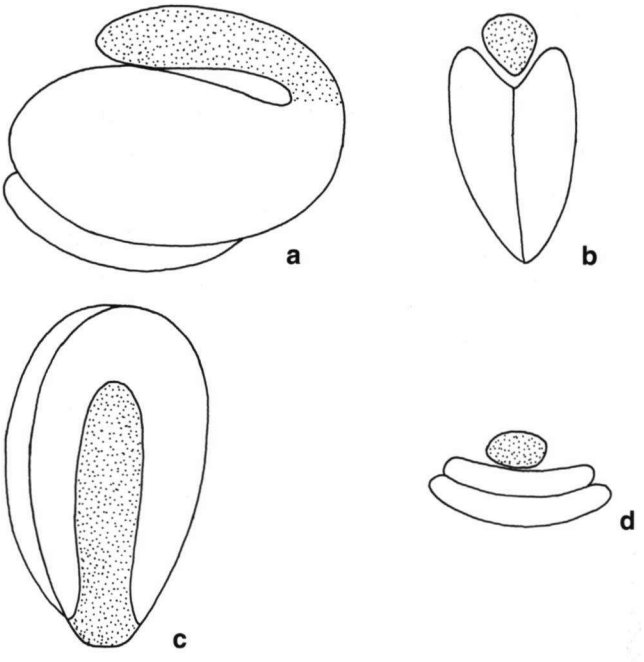


Fig. 21. Embryo shapes (radicle/cotyledons position). a & b. Radicle accumbent; c & d. radicle incumbent. — a & c. Face view; b & d. transverse section.

4. RADICLE/COTYLEDONS POSITION

Radicle/cotyledons position is a significant character to separate among tribes. In Brassicaceae there are 3 types of this position. Conduplicate is common in tribe Brassiceae (El Naggar, 1987); incumbent and accumbent are present throughout the rest of the family (Fig. 21). This character can vary within the tribe; in tribes Euclidieae and Hesperideae (accumbent and incumbent), in the tribe Euclideae, accumbent in *Anastatica hierochuntica* and incumbent in the rest of the tribe, and in the tribe Hesperideae accumbent in *Eremobium* and incumbent in the rest of the tribe.

5. EPIDERMAL CELLS

a. ***Shape***

The shape of epidermal cells can be of considerable diagnostic and systematic value. The cells are almost isodiametric to elongate in one direction, and usually 4–6-polygonal in most taxa. Epidermal cells of almost all seed coats are randomly arranged, but in *Nasturtiopsis coronopifolia, Crucihimalaya kneuckeri, Nasturtium officinale, Malcolmia nana*, and *Sisymbrium erysimoides* (Fig. 3, 16, 19) they are arranged in parallel rows. The cell shapes show significant variation between taxa of tribe Euclideae: isodiametric in *Anastatica hierochuntica*, 4-polygonal in *Neslia paniculata* (Fig. 5), polygonal to elongated in one direction in *Ochthodium aegyptiacum* (Fig. 6), and 5–6-gonal to elongated in one direction in *Schimpera arabica.*

b. ***Anticlinal cell wall boundaries***

These are generally well developed. There are three types of cell wall boundaries: 1) channelled, straight to sinuous; smooth or folded in *Arabis alpina* subsp. *caucasica* (Fig. 1), *Anastatica hierochuntica, Leptaleum filifolium, Ricotia lunaria* (Fig. 11), *Neotorularia aculeolata* (Fig. 17), *Sisymbrium erysimoides* (Fig. 19), *S. polyceratum*, and *S. runcinatum*; 2) raised-channelled, straight to sinuous; smooth to folds in *Neslia paniculata* (Fig. 5) and *Sisymbrium septulatum*; 3) raised, straight to sinuous; smooth to folds in the rest of the taxa (Fig. 2–4, 6–10, 12–16, 18, 20).

The anticlinal cell wall boundaries show a great variation between species and subspecies. In the genus *Arabis* they vary from channelled, straight to sinuous and smooth in *A. alpina* subsp. *caucasica* (Fig. 1), to raised, straight to sinuous and folded in *A. nova* (Fig. 2). In the genus *Sisymbrium* they vary from channelled, straight to sinuous and smooth to folded in *S. erysimoides* (Fig. 19), *S. polyceratum*, and *S. runcinatum*, from raised, straight to sinuous and smooth to folded in *S. orientale* and from slightly raised, straight and smooth in *S. irio* (Fig. 20), or raised-channelled, straight to sinuous and smooth in *S. septulatum*. In *Neotorularia* they vary from channelled, sinuous and smooth in *N. aculeolata* (Fig. 17), to slightly raised, straight and smooth in *N. torulosa*.

At subspecies level, this character separates between subspecies of *Eremobium aegyptiacum*: from slightly raised, straight and smooth in subsp. *aegyptiacum* and subsp. *lineare* to raised, straight to slightly sinuous and smooth to finely folded in subsp. *longisiliquum* (Fig. 7, 8).

c. ***Periclinal cell wall***

1. *Outer periclinal cell walls*

The curvature of outer walls can serve as a good diagnostic character for the lowest taxonomic categories. There are 6 different shapes for outer periclinal cell wall: domate (with a dome), concave, convex, flat, flat to convex, and flat to concave.

Shape 1: domate is divided into three types: 1) domate with flat or concave central portion in *Arabis alpina* subsp. *caucasica* (Fig. 1), *Leptaleum filifolium*, and *Sisymbrium erysimoides* (Fig. 19); 2) domate with globular central papillae in *Arabis nova, Erysimum repandum, Morettia parviflora, Olimarabidopsis pumila, Robeschia schimperi*, and *Sisymbrium septulatum* (Fig. 2, 9, 18); 3) domate with sunken central portion in *Neotorularia aculeolata* (Fig. 17) and *Sisymbrium runcinatum*.

Shape 2: convex in *Matthiola arabica, Morettia canescens* (Fig. 14), *M. philaeana* (Fig. 15), *Notoceras bicorne*, and *Neotorularia torulosa*.

Shape 3: flat in *Nasturtium officinale* (Fig. 3) and *Matthiola longipetala* subsp. *longipetala*.

Shape 4 is divided into three types: 1) normal flat to convex in *Rorippa integrifolia, Schimpera arabica, Eremobium aegyptiacum* subsp. *aegyptiacum, Eremobium aegyptiacum* subsp. *lineare, Malcolmia nana, M. pygmaea, Ricotia lunaria, Matthiola fruticulosa, Matthiola longipetala* subsp. *hirta*, and *Matthiola longipetala* subsp. *kralikii* (Fig. 7, 10, 11); 2) flat to convex with flat or concave central portion in *Malcolmia africana* and *Sisymbrium irio* (Fig. 20); 3) flat to convex with sunken central papillae in *Nasturtiopsis coronopifolia, Diceratella elliptica* (Fig. 12), and *Anastatica hierochuntica*.

Shape 5: flat to concave in *Rorippa indica, R. palustris, Ochthodium aegyptiacum, Eremobium aegyptiacum* subsp. *longisiliquum, Matthiola longipetala* subsp. *bicornis, Matthiola longipetala* subsp. *livida, Matthiola parviflora*, and *Crucihimalaya kneuckeri* (Fig. 4, 6, 8, 13, 16).
Shape 6: concave in *Neslia paniculata* (Fig. 5).

2. *Secondary cell wall sculpture*

The surface of the outer cell wall shows a great variation among taxa. It varies from radiate-striate in *Arabis nova, Erysimum repandum, Matthiola fruticulosa, Morettia parviflora, Notoceras bicorne*, and *Sisymbrium erysimoides* (Fig. 2, 9, 19), to striate in *Rorippa integrifolia, Leptaleum filifolium, Malcolmia nana*, and *Robeschia schimperi*; micro-papillate in *Eremobium aegyptiacum* subsp. *lineare, Ricotia lunaria*, and *Matthiola parviflora* (Fig. 7, 11, 13); micro-reticulate in *Rorippa indica, Ochthodium aegyptiacum, Schimpera arabica, Crucihimalaya kneuckeri, Sisymbrium irio*, and *S. orientale* (Fig. 4, 6, 16, 20); macro-reticulate in *Nasturtium officinale* (Fig. 3); smooth in *Morettia canescens* to smooth to folded in the rest of the taxa (Fig. 14).

KEY TO THE STUDIED TAXA BASED ON SEED CHARACTERS

1a. Seeds orbicular, 3–8 by 2.5–7 mm ..... **Ricotia lunaria**
b. Seeds suborbicular, ovoid, oblong or rounded, 0.6–2.2 by 0.3–1.5 mm 2
2a. Anticlinal boundaries channelled 3
b. Anticlinal boundaries raised or raised-channelled 9
3a. Seeds winged; periclinal cell wall domate with flat to concave central portion; folded to smooth ..... **Arabis alpina** subsp. **caucasica**
b. Seeds wingless; periclinal cell wall domate with sunken central portion or flat to convex; striate, radiate-striate, micro-reticulate or smooth to folded 4
4a. Periclinal cell wall domate with sunken central portion .....
..... **Neotorularia aculeolata, Sisymbrium runcinatum**
b. Periclinal cell wall flat to convex or domate with flat to concave central portion
..... 5
5a. Periclinal cell wall domate with flat to concave central portion 6
b. Periclinal cell wall flat to convex 7
6a. Seeds oblong-ovoid; the sculpture of periclinal cell wall striate .....
..... **Leptaleum filifolium**
b. Seeds oblong; the sculpture of periclinal cell wall radiate-striate .....
..... **Sisymbrium erysimoides**
7a. Seeds ovoid; periclinal cell wall with slightly sunken central papilla; smooth to folded ..... **Anastatica hierochuntica**
b. Seeds oblong-ellipsoidal or oblong; periclinal cell wall with flat or concave central portion; micro-reticulate or smooth to folded 8
8a. Seeds yellow-brownish; cell shapes isodiametric to 4–5-gonal; sculpture of periclinal cell wall micro-reticulate ..... **Sisymbrium irio**
b. Seeds brown; cell shapes polygonal, elongate in one direction; sculpture of periclinal cell wall smooth to folded ..... **Sisymbrium polyceratum**

9a. Anticlinal boundaries raised-channelled 10
b. Anticlinal boundaries raised without channels 12
10a. Periclinal cell wall concave; smooth to folded ..... **Neslia paniculata**
b. Periclinal cell wall domate or flat to slightly convex; smooth to folded or micro-reticulate 11
11a. Epidermal cell shapes isodiametric, polygonal; periclinal cell wall domate with globular central papillae; smooth to folded ..... **Sisymbrium septulatum**
b. Epidermal cell shapes 5–6-gonal and elongate in one direction; periclinal cell wall flat to slightly convex; micro-reticulate ..... **Schimpera arabica**
12a. Seeds winged 13
b. Seeds wingless 24
13a. Seeds with wide wings 14
b. Seeds with narrow wings 16
14a. Periclinal cell wall flat to slightly concave; folded .....
..... **Matthiola longipetala** subsp. **bicornis**
b. Periclinal cell wall flat to convex; striate or smooth to micropapillate 15
15a. Sculpture of periclinal cell wall smooth to micropapillate; seeds red-brownish
..... **Eremobium aegyptiacum** subsp. **lineare**
b. Sculpture of periclinal cell wall striate; seeds brown .. **Matthiola fruticulosa**
16a. Periclinal cell wall flat 17
b. Periclinal cell wall convex, flat to concave or flat to convex 18
17a. Sculpture of periclinal cell wall macro-reticulate; seeds ovoid .....
..... **Nasturtium officinale**
b. Sculpture of periclinal cell wall smooth to fine folds; seeds oblong-ovoid ...
..... **Matthiola longipetala** subsp. **longipetala**
18a. Periclinal cell wall convex ..... **Matthiola arabica**
b. Periclinal cell wall flat to convex or flat to concave 19
19a. Periclinal cell wall flat to convex 20
b. Periclinal cell wall flat to concave 22
20a. Periclinal cell wall with sunken central papilla; seeds sub-orbicular to elliptic
..... **Diceratella elliptica**
b. Periclinal cell wall with smooth to fine folds; seeds oblong, sub-orbicular or oblong-ovoid 21
21a. Seeds oblong; 2.2 by 1.2 mm **Eremobium aegyptiacum** subsp. **aegyptiacum**
b. Seeds sub-orbicular or oblong-ovoid; 1–1.3 by 0.7–1.1 mm .....
..... **Matthiola longipetala** subsp. **hirta**, subsp. **kralikii**
22a. Sculpture of periclinal cell wall smooth to micro-reticulate; seeds ovoid ....
..... **Rorippa indica**
b. Sculpture of periclinal cell wall smooth to folds or micro-papillate; seeds oblong or oblong-ovoid 23
23a. Sculpture of periclinal cell wall micro-papillate; seeds oblong-ovoid .....
..... **Matthiola parviflora**
b. Sculpture of periclinal cell wall smooth to folds; seeds oblong .....
..... **Matthiola longipetala** subsp. **livida**,
..... **Eremobium aegyptiacum** subsp. **longisiliquum**

24a. Periclinal cell wall convex 25
b. Periclinal cell wall domate, flat to concave or flat to convex 28
25a. Sculpture of periclinal cell wall striate; seeds rounded ... **Notoceras bicorne**
b. Sculpture of periclinal cell wall smooth or smooth to fine folds; seeds ovoid or oblong-ellipsoidal 26
26a. Radicle incumbent; seeds oblong-ellipsoidal ..... **Neotorularia torulosa**
b. Radicle accumbent; seeds ovoid 27
27a. Anticlinal boundaries folded ..... **Morettia canescens**
b. Anticlinal boundaries smooth ..... **Morettia philaeana**
28a. Periclinal cell wall domate with globular central papilla 29
b. Periclinal cell wall flat to concave or flat to convex 33
29a. Sculpture of periclinal cell wall smooth ..... **Olimarabidopsis pumila**
b. Sculpture of periclinal cell wall striate or radiate-striate 30
30a. Radicle incumbent; seeds oblong 31
b. Radicle accumbent; seeds oblong-ovoid or ovoid 32
31a. Sculpture of periclinal cell wall radiate-striate; anticlinal boundaries smooth to fine folds ..... **Erysimum repandum**
b. Sculpture of periclinal cell wall striate; anticlinal boundaries smooth to deep folds ..... **Robeschia schimperi**
32a. Anticlinal boundaries folds; seeds oblong-ovoid ..... **Arabis nova**
b. Anticlinal boundaries smooth; seeds ovoid ..... **Morettia parviflora**
33a. Periclinal cell wall flat to concave 34
b. Periclinal cell wall flat to convex 36
34a. Radicle accumbent; seeds cordiform to ovoid ..... **Rorippa palustris**
b. Radicle incumbent; seeds ovoid-oblong or oblong 35
35a. Seeds ovoid-oblong, 2.5–3 by 1.5–1.7 mm; shapes of cell elongate in one direction and polygonal; anticlinal walls sinuous ..... **Ochthodium aegyptiacum**
b. Seeds oblong, 0.8–1 by 0.3–0.4 mm; shapes of cell isodiametric and polygonal; anticlinal walls straight to slightly sinuous ..... **Crucihimalaya kneuckeri**
36a. Sculpture of periclinal cell wall striate, smooth to fine folds or micro-reticulate 37
b. Sculpture of periclinal cell wall fine to coarse folds 40
37a. Sculpture of periclinal cell wall micro-reticulate .... **Sisymbrium orientale**
b. Sculpture of periclinal cell wall striate or smooth to fine folds 38
38a. Sculpture of periclinal cell wall smooth to fine folds; seeds oblong; red-brownish ..... **Descurainia sophia**
b. Sculpture of periclinal cell wall striate; seeds ovoid, oblong-ellipsoidal or ovoid to ellipsoid; orange-brown or yellow-brownish 39
39a. Radicle accumbent; seeds ovoid to ellipsoid ..... **Rorippa integrifolia**
b. Radicle incumbent; seeds ovoid or oblong-ellipsoidal ..... **Malcolmia nana, Malcolmia pygmaea**
40a. Sculpture of periclinal cell wall with flat central portion; cell shapes isodiametric and polygonal; seeds oblong ..... **Malcolmia africana**
b. Sculpture of periclinal cell wall with sunken central papillae; cell patterns 5-6-polygonal and elongate in one direction; seeds oblong-ellipsoidal ..... **Nasturtiopsis coronopifolia**

REFERENCES

Al-Shehbaz, I.A. 1984. The tribes of Cruciferae (Brassicaceae) in the southeastern United States. J. Arnold Arbor. 65: 343–373.

Aniszewski, T., K.H. Mervi & A.J. Leinonen. 2001. Seed number, seed size and seed diversity in Washington Lupin (Lupinus polyphyllus Lindl.). Annals of Botany 87: 77–82.

Barthlott, W. 1981. Epidermal and seed surface characters of plants: Systematic applicability and some evolutionary aspects. Nord. J. Bot. 1: 345–355.

Barthlott, W. 1984. Microstructural features of seed surface. In: V.H. Heywood & D.C. Moore (eds.), Current concepts in plant taxonomy: 95–105. Academic Press, London.

Berggren, G. 1962. Reviews on the taxonomy of some species of the genus Brassica, based on their seeds. Svensk Bot. Tidskr. 56: 65–135.

Canne, J.M. 1979. A light and scanning electron microscope study of seed morphology in Agalinis (Scrophulariaceae) and its taxonomic significance. Syst. Bot. 4: 281–296.

Canne, J.M. 1980. Seed surface features in Aureolaria, Brachystigma, Tomanthera and certain South American Agalinis (Scrophulariaceae). Syst. Bot. 5: 241–152.

Chance, G.D. & J.D. Bacon. 1984. Systematic implications of seed coat morphology in Nama (Hydrophyllaceae). Amer. J. Bot. 71: 829–842.

Chuang, T.I. & L.R. Heckard. 1972. Seed coat morphology in Cordylanthus (Scrophulariaceae) and its taxonomic significance. Amer. J. Bot. 59: 258–265.

Clark, C. & J.A. Jernstedt. 1978. Systematic studies of Eschscholzia (Papaveraceae). II. Seed coat microsculpturing. Syst. Bot. 3: 386–402.

Corner, E.J.H. 1976. The seeds of Dicotyledons, 2 vols. Cambridge University Press, Cambridge.

Crow, G.E. 1979. The systematic significance of seed morphology in Sagina (Caryophyllaceae) under scanning electron microscopy. Brittonia 31: 52–63.

Dahlgren, R. 1979–1980. Angiospermernes taxonomi 1–3. Akademisk Forlag, Copenhagen.

Dahlgren, R.M. & H.T. Clifford. 1982. The monocotyledons. Academic Press, London.

El Naggar, S.M. 1987. Studies of the family Cruciferae in Egypt. PhD thesis, Assiut University.

El Naggar, S.M. & M.N. El Hadidi. 1998. The tribe Alysseae Hayek (Brassicaceae) in Egypt. J. Union Arab Biol. Cairo 6: 501–520.

Fayed, A.A. & S.M. El Naggar. 1988. Taxonomic studies on Cruciferae in Egypt 2. Taxonomic significance of the seed coat sculpture in species of tribe Brassiceae. Taeckholmia 11: 87–95.

Fayed, A.A. & S.M. El Naggar. 1996. Taxonomic studies on Cruciferae in Egypt 4. Seed morphology and taxonomy of the Egyptian species of Lepidieae. Bull. Fac. Sci. Assiut Univ. 25: 43–50.

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

Hedge, I.C. 1976. A systematic and geographical survey of Old World Cruciferae. In: J.G. Vaughan, A.J. Macleod & B.M.G. Jones (eds.), The biology and chemistry of the Cruciferae: 1–46. Academic Press, London.

Heyn, C.C. & I. Herrnstadt. 1977. Seed coat structure of Old World Lupinus species. Bot. Not. 130: 427–435.

Heywood, V.H. 1971. Scanning electron microscopy. Systematic and evolutionary applications. London.

Hill, R.J. 1976. Taxonomic and phylogenetic significance of seed microsculpturing in Mentzelia (Loasaceae) in Wyoming and adjacent Western states. Brittonia 28: 86–112.

Huber, H. 1969. Die Samenmerkmale und Verwandtschaftsverhältnisse der Liliiflorae. Mitteil. Bot. Staatssamml. München 8: 219–538.

Jonsell, B. 1975. Lepidium L. (Cruciferae) in tropical Africa. A morphological, taxonomical and phytogeographical study. Bot. Not. 128: 151–163.

Jonsell, B. 1979. New taxa of Cruciferae from East tropical Africa and Madagascar. Bot. Not. 132: 521–535.

Jonsell, B. 1986. A monograph of Farsetia (Cruciferae). Symb. Bot. Ups. 25: 1–106.

Juan, R., J. Pastor & I. Fernandez. 2000. SEM and light microscope observations on fruit and seeds in Scrophulariaceae from southwest Spain and their systematic significance. Annals of Botany 86: 323–338.

Kanak Sahai, K. Harbans & P. Aruna. 1997. Macro- and micromorphological seed characteristics of some Cassia species and their taxonomic significance. Phytomorphology 47: 273–279.

Kapil, R.N., J. Bor & F. Bouman. 1980. Seed appendages in Angiosperms. I. Introduction. Bot. Jahrb. Syst. 101: 555–573.

Karam, M.F. 1997. Scanning electron microscope studies of seed characters in Trifolium L. (Fabaceae). Phytomorphology 47: 51–56.

Kondo, M. 1917. Untersuchung der Samen der in Japan Vertretenen Brassica-Arten. Ein Beitrag zur genauen Feststellung der Sortenunterschiede. Berichte des Ohara Inst. F. Landw. Forschung, Bd. I: 123–150.

Koul, K.K., N. Ranjna & S.N. Raina. 2000. Seed coat microsculpturing in Brassica and allied genera (subtribes Brassicinae, Raphaninae, Moricandiinae). Annals of Botany 86: 385–397.

Matthews, J.F. & P.A. Levins. 1986. The systematic significance of seed morphology in Portulaca (Portulacaceae) under scanning electron microscopy. Syst. Bot. 11: 302–308.

McGugan, M. 1948. Seeds and seedlings of the genus Brassica. Canadian J. of Research 26: 520–587.

Mulligan, G.A. & L.G. Bailey. 1976. Seed coats of some Brassica and Sinapis weedy and cultivated in Canada. Econ. Bot. 30: 143–148.

Murley, M.R. 1951. Seeds of the Cruciferae of northeastern North America. The American Midland Naturalist 46: 1–81.

Musil, A.F. 1948. Distinguishing species of Brassica by their seeds. U.S. Dept. Agr. Washington, D.C. Misc. Pub. No. 643.

Musselman, L.J. & W.F. Mann. 1976. A survey of surface characteristics of seeds of Scrophulariaceae and Orobanchaceae using scanning electron microscopy. Phytomorphology 26: 370–378.

Newell, C.A. & T. Hymowitz. 1978. Seed coat variation in Glycine Wild. subgenus Glycine (Leguminosae) by SEM. Brittonia 30: 76–88.

Prasad, K. 1976. Seed coat structure and development in certain species of Cruciferae. New Botanist 3: 95–103.

Schulz, O.E. 1936. Cruciferae. In: A. Engler & K. Prantl (eds.), Die natürlichen Pflanzenfamilien 17B: 227–658. Engelmann, Leipzig.

Seavey, S.R., R.E. Magill & P.H. Raven. 1977. Evolution of seed size, shape and surface architecture in the tribe Epilobieae (Onagraceae). Ann. Missouri Bot. Gard. 64: 18–47.

Segarra, J.G. & I. Mateu. 2001. Seed morphology of Linaria species from eastern Spain: identification of species and taxonomic implications. Bot. J. Linn. Soc. 135: 375–389.

Shanmukha, S.R. & M. Leela. 1993. Seed morphology (LM and SEM) in some Ipomoea L. (Convolvulaceae). Feddes Repert. Spec. Nov. Regni Veg. 104: 209–213.

Stace, C.A. 1965. Cuticular studies as an aid to plant taxonomy. Bull. Brit. Mus. (Nat. Hist.) Bot. 4: 1–78.

Stork, A.L. 1971. Seed characters in European taxa of Malcolmia R.Br. Svensk Bot. Tidskr. 65: 283–292.

Stork, A.L. 1972. Seeds and seedlings of Malcolmia sens. lat. Svensk Bot. Tidskr. 66: 417–433.

Stork, A.L., S. Songerup & J. Wüest. 1980. Seed characters in Brassica section Brassica and some related groups. Candollea 35: 421–450.

Stork, A.L. & J. Wüest. 1978. SEM studies of seed coats in Malcolmia (Cruciferae). Arch. Sci. Phys. Nat. 31: 229–237.

Stork, A.L. & J. Wüest. 1980. Morettia DC. (Cruciferae): a morphological and taxonomical study. Bol. Soc. Brot. Ser. 2, 53: 241–273.

Vaughan, J.G. & J.M. Whitehouse. 1971. Seed structure and the taxonomy of the Cruciferae. Bot. J. Linn. Soc. 64: 383–409.

Whiffin, T. & A.S. Tomb. 1972. The systematic significance of seed morphology in the neotropical capsular-fruited Melastomataceae. Amer. J. Bot. 59: 411–422.

Wofford, B.E. 1981. External seed morphology of Arenaria (Caryophyllaceae) of the southeastern United States. Syst. Bot. 6: 126–135.