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Fruit and seed macro- and micromorphologies of the genus *Matthiola* (Brassicaceae) in Turkey and their taxonomic value

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Abstract: Macro- and micromorphological features of fruit and seeds belonging to 12 taxa genera of *Matthiola* W.T.Aiton were studied via stereomicroscope and scanning electron microscope. In macromorphological studies, the following variables were investigated: the shape, size, and color of fruit and seeds; the length of fruiting pedicel; the structure of the median vein; stigma (horns); and trichome properties and density in fruit. In micromorphological studies, the presence or absence of seed wings, seed coat pattern in disc and wing, and epidermal cell shape in disc and wing were determined. According to our findings, all characters of fruit and seeds are extremely variable and can be used as criteria to distinguish species of the genus.

Key words: Brassicaceae, fruit, Matthiola, morphology, seed, scanning electron microscopy, taxonomy

1. Introduction

The family Brassicaceae comprises 338 genera and 3709 species (Franzke et al., 2010) occurring mainly in the temperate regions of the northern hemisphere (Hedge, 1976). It is represented by 571 species in the flora of Turkey (Al-Shehbaz et al., 2007). *Matthiola* W.T.Aiton belongs to the family Brassicaceae and consists of about 50 species spread over various geographical areas (Appel and Al-Shehbaz, 2003). The genus *Matthiola* was previously represented by 10 taxa in the flora of Turkey (Cullen, 1965). Since then, two further taxa (*M. ovatifolia* (Boiss.) Boiss. and *Matthiola trojana* Dirmenci, Satıl & Tümen) have been described in Turkey and the current number is 12, of which four are endemic for Turkey (Davis et al., 1988; Dirmenci et al., 2006).

The systematic and phylogenetic significance of the fruit and seed morphology is well known in some members of Brassicaceae (Vaughan and Whitehouse, 1971; Fayed and El-Naggar, 1988, 1996; El-Naggar, 1996; El-Naggar and El-Hadidi, 1998; Koul et al., 2000; Abdel Khalik and Van Der Maesen, 2002; Tantawy et al., 2004; Zeng et al., 2004; Moazzeni et al., 2007; Kaya et al., 2011; Bona, 2013). In addition, the taxonomic importance of the trichome morphology is also well known in some members of Brassicaceae (Mulligan, 1995; Abdel Khalik, 2005; Beilstein et al., 2006). The purpose of all these studies was to solve taxonomic problems, to identify evolutionary relationships and to emphasize the adaptive importance. The use of the scanning electron microscope (SEM) technique in these investigations is also extremely effective and important.

Matthiola members are annual or perennial herbs that have furcate haired (branched) trichomes and glands. Sepals are saccate. Petals are purple, violet, whitish, or yellowish. Fruit is a terete or compressed siliqua. Stigma (horns) are absent or present (Cullen, 1965). There is little knowledge about the fruit and seed macromorphology of *Matthiola* taxa in the flora of Turkey. Moreover, the fruit and seed micromorphology of *Matthiola* taxa are also unknown in the flora of Turkey. Therefore, further research is needed to investigate the macro- and micromorphologies of the fruit and seed.

The main purpose of this work is to describe the fruit and seed macro- and micromorphological features of Turkish *Matthiola*, to evaluate the systematic significance of fruit and seed morphological characteristic variations between taxa of the genus, and to contribute to the flora of Turkey.

2. Materials and methods

Matthiola samples were collected from 12 different populations during 2012 and 2013 and specimens of the

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plants were deposited in the herbarium of Van Yüzüncü Yil University (VANF) (Table 1). For each taxon, at least 15 fruits and seeds were analyzed. The dry mature fruits and seeds were first examined by stereomicroscope (Wild M5). For SEM studies, clean and dry specimens were mounted on stubs with double adhesive tape and coated with gold for 5 min. The photomicrographs of examined specimens were taken with a Zeiss Ultra Plus FESEM scanning electron microscope at 5 kV and 5.6–7.4 mm working distance. The works of Koul et al. (2000) and Zeng et al. (2004) for the terminology of the fruit and seed characters and the work of Beilstein et al. (2006) for the terminology of the trichomes have been adopted.

3. Results

The comparative macro- and micromorphological features of the fruit and seeds of *Matthiola* taxa growing in Turkey were investigated and results are given in Tables 2 and 3. The representative patterns visible at lower and higher magnifications are shown in Figures 1–3.

3.1. General description of fruit features

Matthiola fruits are siliqua, compressed (*M. sinuata* (L.) W.T.Aiton, *M. incana* (L.) W.T.Aiton, *M. anchoniifolia* Hub.-Mor., *M. montana* Boiss., *M. odoratissima* (Pall. ex M.Bieb.) W.T.Aiton, *M. ovatifolia*) or terete (the other taxa). Siliquae are rigid and erect to ascending (Figure 1). The median vein is only observed in compressed siliquae. Stigma (horns) are absent or present. *M. incana* has the longest linear siliqua (120–130 mm) while *M. trojana* has the shortest fruit (25–50 mm). The pedicels of *M. incana* are the longest, at 15–23 mm, while they are the shortest in *M. trojana*, *M. longipetala* (Vent.) DC. subsp. *pumilio* (Sm.) P.W.Ball, and *M. fruticulosa* (L.) Maire, at 1.5–3 mm. The color of fruits varies from dark green in *M. fruticulosa* to green in *M. longipetala*, greenish-yellow in *M. sinuata* and *M. anchoniifolia*, pale yellow-black in *M. incana*, and pale yellow in the remainder of the taxa.

The surface of fruits has trichomes in all studied taxa, except *M. odoratissima*. Nonglandular trichomes are the furcate type that consist of a primary axis (greatly reduced stalk) and more (dendritic) branches. Cuticular micropapillae are observed on the hairs of all *Matthiola* taxa. However, they are more distinctive on hairs of *M. montana*, *M. longipetala*, and *M. trojana* than the others. Glands are only observed on fruits of *M. sinuata* and *M. trojana*. The surfaces of fruits of *M. montana* and *M. longipatala* (Vent.) DC. subsp. *bicornis* (Sm.) P.W.Ball have more trichomes than the rest of the taxa.

The horns are absent (*M. anchoniifolia*, *M. montana*, *M. ovatifolia*) or present and capitate type (*M. sinuata*, *M. incana*, *M. odoratissima*) or 2–3-partite. Horns in *M. trojana* are absent or capitate type (1 mm) while they are capitate or 3-partite (1–2 mm) in *M. fruticulosa*. Horns in *M. tricuspidata* (L.) W.T.Aiton are 3-partite, of equal size, and have a length of 2.5–5 mm. There are two equal parts, curved upwards, in *M. longipetala* subsp. *bicornis* and subsp. *longipetala*, having a length of 3–7 mm. However, horns are erect or slightly curved upwards and 2–5 mm in subsp. *pumilio* (Figures 1 and 2; Table 2).

3.2. General description of seed features

Seeds are orbicular-broadly oblong in *M. sinuata*, *M. incana*, and *M. ovatifolia*; broadly oblong in *M. tricuspidata*; narrowly oblong in *M. longipetala* subsp. *pumilio*; oblong in *M. trojana*, *M. longipetala* subsp. *longipetala*, and *M.*

Table 1. List of the examined *Matthiola* taxa.

Taxon	Locality	VANF
*1. *Matthiola anchoniifolia* Hub.-Mor.	Turkey, Sivas - 21.07.2013	164023
2. *Matthiola fruticulosa* (L.) Maire	Turkey, İstanbul - 18.06.2012	164024
3. *Matthiola incana* (L.) W.T.Aiton	Turkey, Sinop - 30.08.2013	164025
4. *Matthiola longipetala* (Vent.) DC. subsp. *longipetala*	Turkey, Niğde - 14.05.2013	164026
5. *Matthiola longipetala* (Vent.) DC. subsp. *bicornis* (Sm.) P.W.Ball	Turkey, Mardin - 15.05.2013	164027
*6. *Matthiola longipetala* (Vent.) DC. subsp. *pumilio* (Sm.) P.W.Ball	Turkey, Antalya - 06.04.2013	164028
*7. *Matthiola montana* Boiss.	Turkey, Bursa - 07.09.2012	164029
8. *Matthiola odoratissima* (Pall. ex M.Bieb.) W.T.Aiton	Turkey, Artvin - 31.08.2013	164030
9. *Matthiola ovatifolia* (Boiss.) Boiss.	Turkey, Sivas - 20.08.2013	164031
10. *Matthiola sinuata* (L.) W.T.Aiton	Turkey, Çanakkale 06.05.2012	164032
11. *Matthiola tricuspidata* (L.) W.T.Aiton	Turkey, İzmir - 10.04.2013	164033
*12. *Matthiola trojana* Dirmenci, Satıl & Tümen	Turkey, Balıkesir - 08.09.2012	164034

*Endemic taxon.

Table 2. Fruit morphology characters of the genus *Matthiola*

Taxon	Shape	Median vein	Horn (stigma)	Size (mm)	Color	Pedisel (mm)	Hair type	Hair density*
M. sinuata	compressed erect	present	capitate 2-3 mm	74-95 × 2.5-3	greenish-yellow	8-10	furcate with gland	++
M. incana	compressed erect-spreading	present	capitate 2-2.5 mm	120-130 × 3.5-4	pale yellow-black	15-23	furcate	++
M. anchoniifolia	compressed erect	present	absent	83-103 × 2.5-4.5	greenish-yellow	8-17	furcate	++
M. montana	compressed erect-spreading	present	absent	77-100 × 3-5	pale yellow	8-10	furcate	+++
M. odoratissima	compressed erect-spreading	present	capitate 2-3 mm	90-110 × 2.8-3.2	pale yellow	6-8	furcate	-
M. ovatifolia	compressed erect-spreading	present	absent	90-100 × 3.5-4.5	pale yellow	10-17	furcate	++
M. fruticulosa	terete erect-spreading	absent	capitate or 3-partite, 1-2 mm	54-110 × 2-2.8	dark green	1.5-3	furcate	++
M. tricuspidata	terete erect-spreading	absent	3-partite, 2.5-5 mm	50-70 × 2-2.4	pale yellow	3-5	furcate	++
M. longipetala* subsp. *pumilio	terete, erect-spreading	absent	2-partite, curved upwards , 2-5 mm	40-60 × 1-1.2	green	1.8-2	furcate	++
M. longipetala* subsp. *longipetala	terete, erect-spreading	absent	2-partite, curved upwards, 3-7 mm	75-95 × 1.3-1.5	green	2-4	furcate	++
M. longipetala* subsp. *bicornis	terete, erect-spreading	absent	2-partite, curved upwards, 3-7 mm	45-95 × 1.2-1.8	green	2-4	furcate	+++
M. trojana	terete, erect-spreading	absent	absent or capitate 1 mm	25-50 × 1.5-1.8	pale yellow	1.5-2	furcate, with gland	++

* Symbols: (-) not hairy, (+) less hairy, (++) hairy, (+++) densely hairy

Table 3. Seed morphology characters of the genus *Matthiola*

Species	Shape	Size (inc. wing)	Colour	Surface pattern in disc	Surface pattern in wing	Epidermal cell shape in disc	Epidermal cell shape in wing
M. sinuata	orbicular-broadly oblong	2.2-3 × 2-2.2	brown	ruminate	reticulate-foveate	irregular elevations	polygonal
M. incana	orbicular-broadly oblong	2.2-3 × 1.8-2.2	dark brown	reticulate-undulate	reticulate-undulate	polygonal	polygonal
M. anchoniifolia	oblong-elliptic	3-5 × 2-3	dark bown	weakly reticulate-ribbed	reticulate-striate	polygonal	polygonal
M. montana	oblong-elliptic	3-5 × 2-3	brown	reticulate	bireticulate	polygonal	polygonal
M. odoratissima	oblong-elliptic	3.5-5 × 2-3	brown	reticulate	reticulate-striate	polygonal	polygonal
M. fruticulosa	oblong-elliptic	2-4 × 1.5-1.8	brown	reticulate	reticulate-striate	polygonal	polygonal
M. tricuspidata	broadly oblong	1.5-1.8 × 1.2-1.5	pale brown	reticulate-verrucate	-	polygonal	-
M. longipetala subsp. ***pumilio***	narrowly oblong	1.2 × 0.4	brown	rugose-irregular reticulate	-	partly polygonal	-
M. longipetala subsp. ***longipetala***	oblong	1.8-2 × 0.5-0.8	brown	colliculate	-	weakly polygonal	-
M. longipetala subsp. ***bicornis***	oblong	1.8-2 × 0.8-1	brown	scalariform	-	elongated	-
M. ovatifolia	orbicular - broadly oblong	2.2-2.5 × 2.5	pale brown	ocellate	reticulate-striate	ovoid-orbicular	polygonal
M. trojana	oblong	1.8-2 × 1-1.2	brown	reticulate-foveate	reticulate-foveate	polygonal	polygonal

Figure 1. Siliquae shapes of *Matthiola* taxa. a- *M. sinuata*, b- *M. ovatifolia*, c- *M. incana*, d- *M. montana*, e- *M. anchoniifolia*, f- M. *odoratissima*, g- *M. longipetala* subsp. *longipetala*, h- *M. longipetala* subsp. *bicornis*, i- *M. longipetala* subsp. *pumilio*, j- *M. tricuspidata*, k- *M. trojana*, l- *M. fruticulosa*.

longipetala subsp. *bicornis*; and oblong-elliptic in the rest of the taxa. The largest and longest seeds in *M. anchoniifolia*, *M. montana*, and *M. odoratissima* have a diameter of 3–5 × 2–3 mm and the smallest seed size of 1.2 × 0.4 mm is seen in *M. longipetala* subsp. *pumilio*, as the rest of the taxa have slightly larger seeds. The color of the seed varies from pale brown in *M. tricuspidata* and *M. ovatifolia* to dark brown in *M. incana* and *M. anchoniifolia* and brown in the other *Matthiola* taxa.

Most of the investigated seeds have a wing, but it is absent in *M. tricuspidata* and three subspecies of *M. longipetala*. According to the results of the SEM studies, the seed surface pattern in the disc is ruminate in *M. sinuata*, reticulate-undulate in *M. incana*, weakly reticulate-ribbed in *M. anchoniifolia*, reticulate-verrucate in *M. tricuspidata*, rugose-irregular reticulate in *M. longipetala* subsp. *pumilio*, colliculate in *M. longipetala* subsp. *longipetala*, scalariform in *M. longipetala* subsp. *bicornis*, ocellate in *M ovatifolia*, reticulate-foveate in *M. trojana*, and reticulate in the other taxa. The wing sculpturing surface is reticulate-foveate in *M. sinuata*, reticulate-undulate in *M. incana*, bireticulate in *M. montana*, and reticulate-striate in *M. anchoniifolia*, *M. fruticulosa*, and *M. odoratissima*. The shapes of the epidermal cells in the disc consist of frequently 5–6

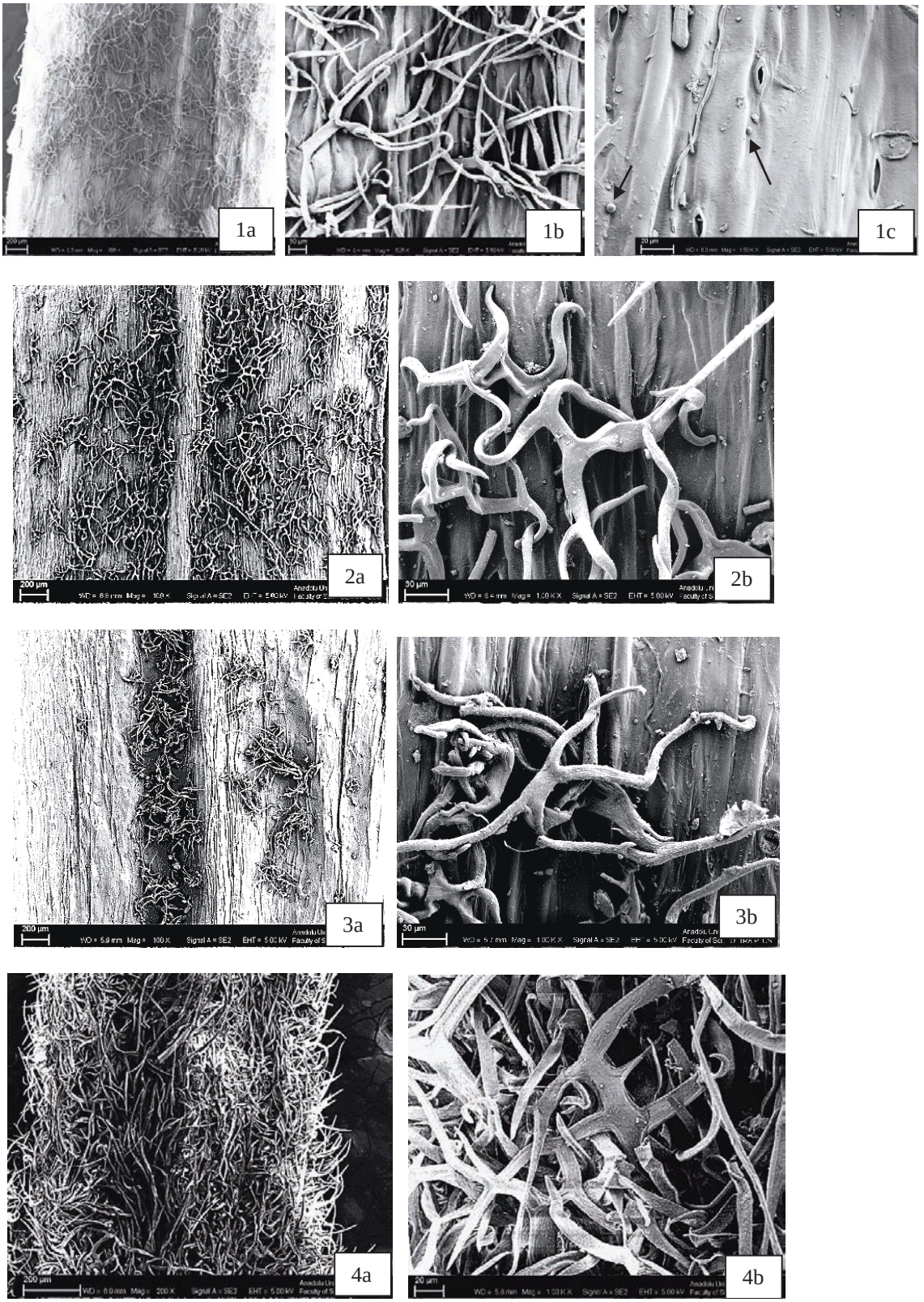
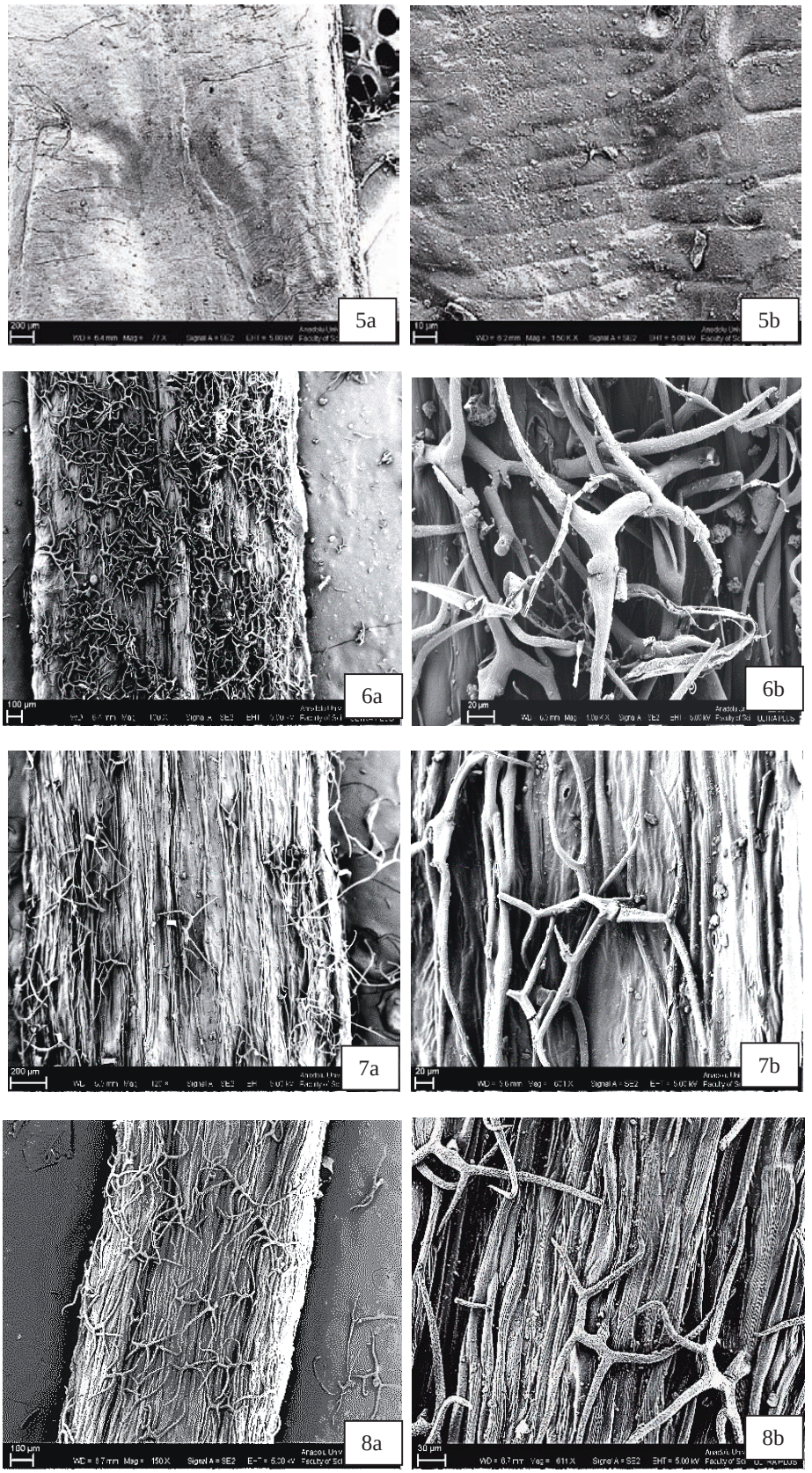


Figure 2. SEM photographs of *Matthiola* taxa. a- Fruits, b- Trichomes. 1- *M. sinuata*, 2- *M. incana*, 3- *M. anchoniifolia*, 4- *M. montana*, 5- M. *odoratissima*, 6- *M. fruticulosa*, 7- *M. tricuspidata*, 8- *M. longipetala* subsp. *pumilio*, 9- *M. longipetala* subsp. *longipetala*, 10- *M. longipetala* subsp. *bicornis*, 11- *M. ovatifolia*, 12- *M. trojana*.



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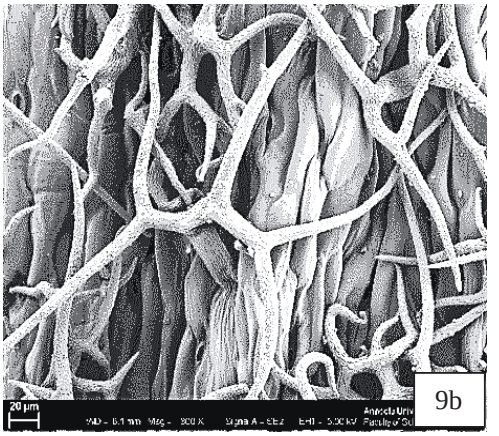

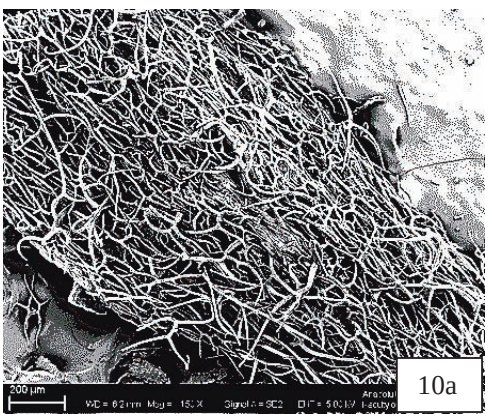

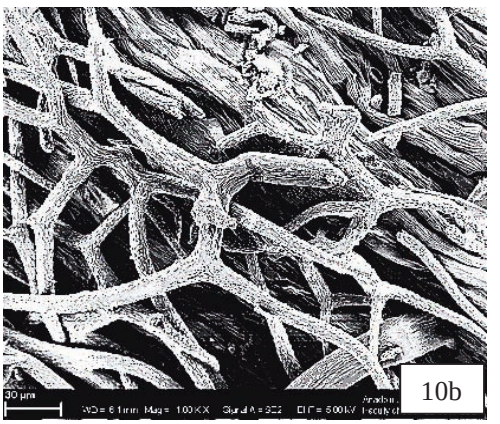

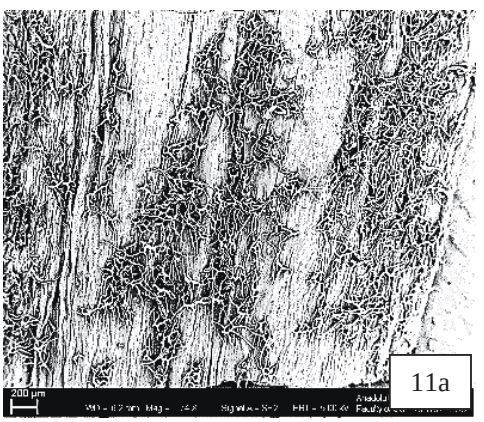

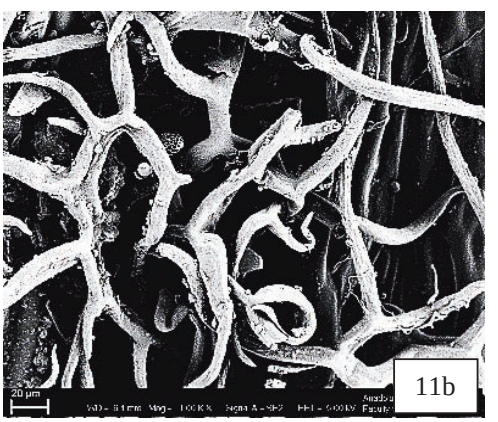

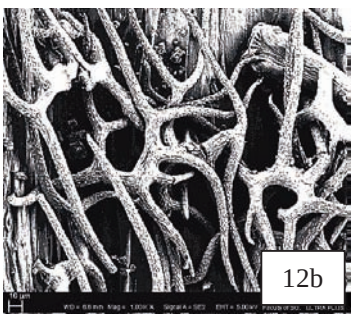

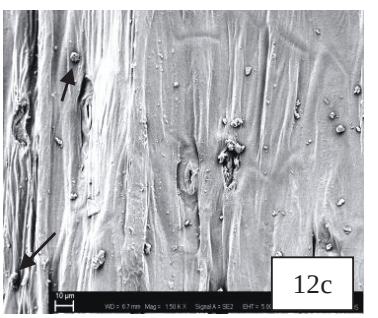

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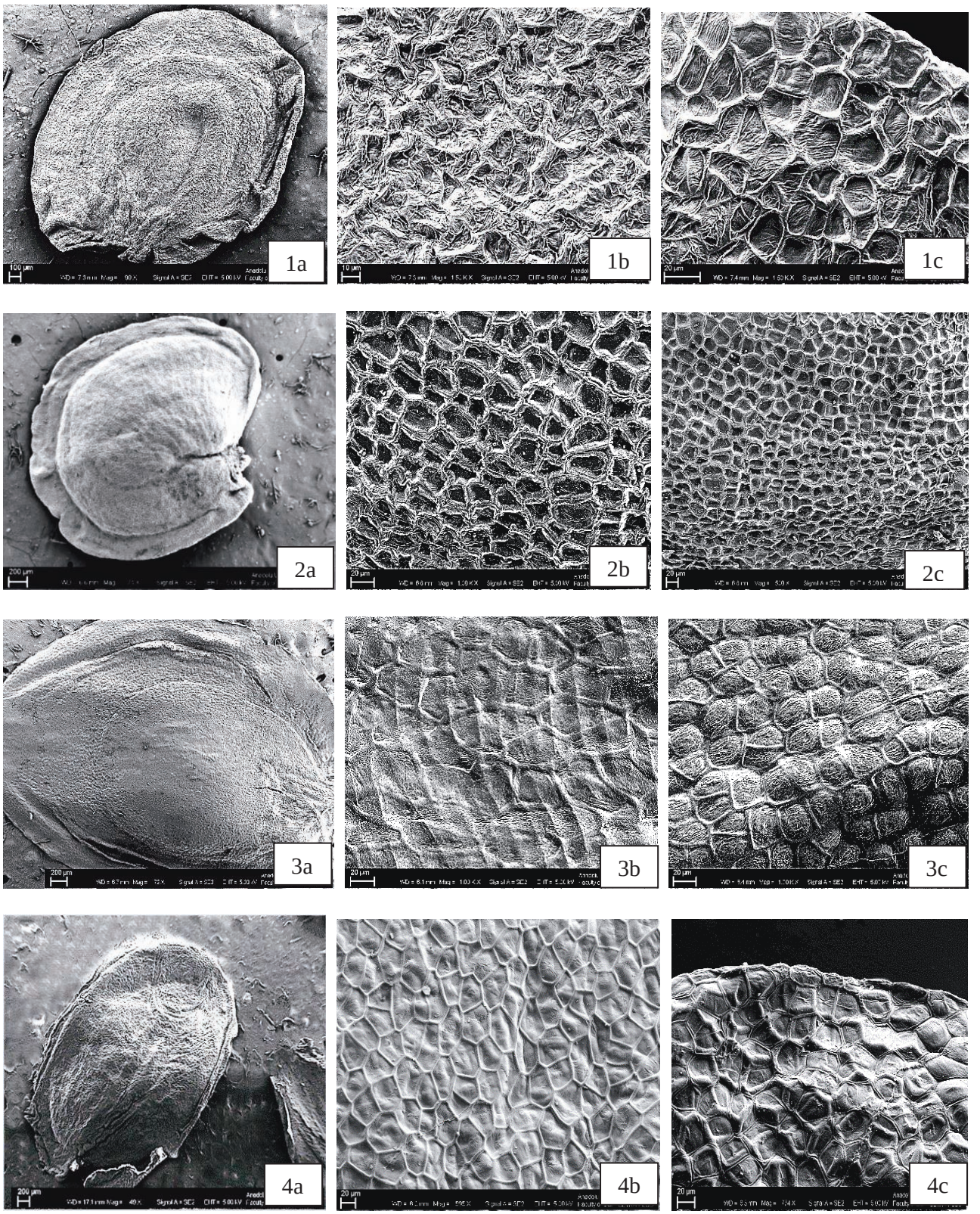
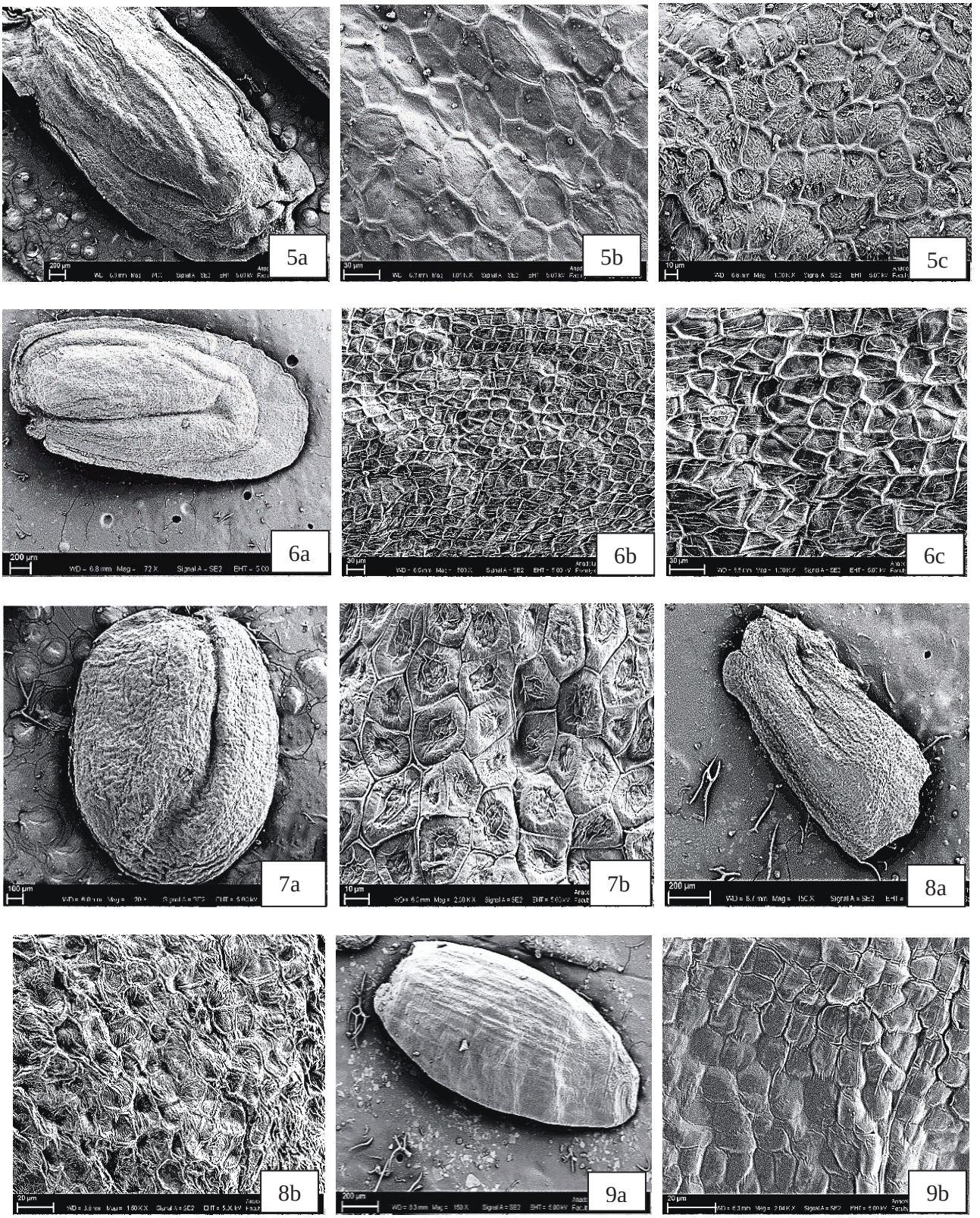


Figure 3. SEM photographs of *Matthiola* taxa. a- Seeds, b- Surface pattern in disc, c- Surface pattern in wing. 1- *M. sinuata*, 2- *M. incana*, 3- *M. anchoniifolia*, 4- *M. montana*, 5- *M. odoratissima*, 6- *M. fruticulosa*, 7- *M. tricuspidata*, 8- *M. longipetala* subsp. *pumilio*, 9- *M. longipetala* subsp. *longipetala*, 10- *M. longipetala* subsp. *bicornis*, 11- *M. ovatifolia*, 12-*M. trojana*.



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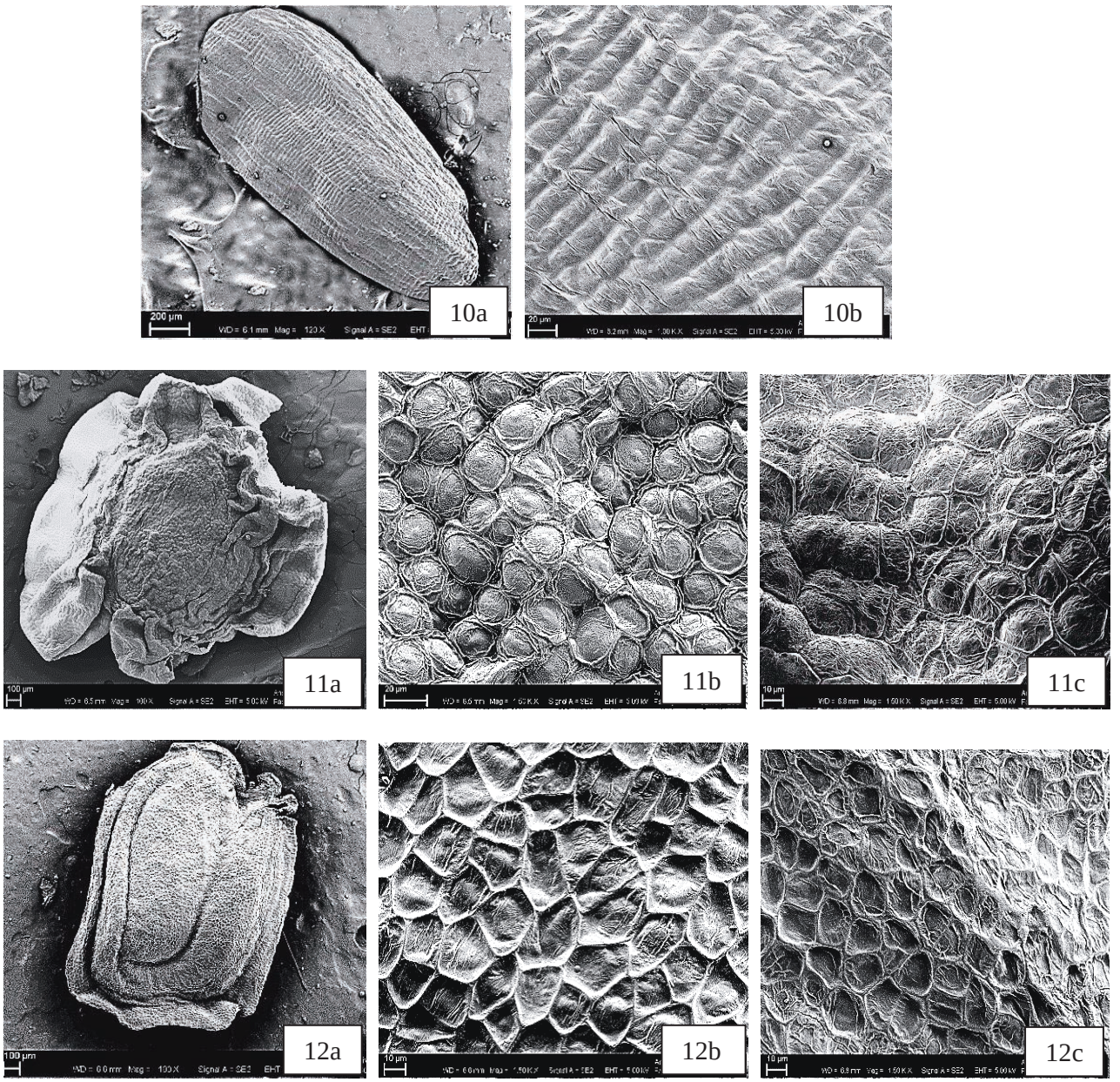

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polygonal cells in all taxa, except *M. sinuata*, *M. longipetala* subsp. *bicornis*, and *M. ovatifolia*, in which they have irregular elevations, are elongate, and are ovoid-orbicular, respectively (Table 3; Figure 3).

4. Discussion

The morphology of the fruit characteristics (size, color, presence or absence of trichomes and horns, trichome density, shape of horns) of *Matthiola* taxa has valuable taxonomic significance at the species level and these features can be used in genus taxonomy. Horn type and pedicel length were used to discriminate between *Matthiola* taxa in the *Flora of Turkey* (Cullen, 1965). According to the *Flora of Turkey*, fruits of *M. sinuata*, *M. incana*, and *M. odoratissima* are hornless or with short inconspicuous horns in *M. odoratissima,* but they have capitate type horns 2–3 mm in length according to our observations. Siliquae of *Matthiola* taxa are compressed or terete and erect or spreading. The length of the pedicel is 6–23 mm in compressed siliquae while it is 1.5–5 mm in terete siliquae. Minute yellow or black glands are only observed in the fruit of *M. sinuata* and *M. trojana* in our findings, which are similar to those of the *Flora of Turkey* (Cullen, 1965) and the study of Dirmenci et al. (2006). All

Matthiola taxa have more or less furcate trichomes with cuticular micropapillae, which are quite characteristic for Brassicaceae (Barthlott, 1981; Mulligan, 1995; Abdel Khalik, 2005; Beilstein et al., 2006).

Mulligan (1995) treated 30 species from *Arabis* L. in Canada, Alaska, and Greenland based on trichome morphology and cytological studies and described four types of trichomes (simple, once-forked, dendritic, stellate) on the undersurfaces of the leaves. Abdel Khalik (2005) studied the trichome morphology, structure, and taxonomic significance of 82 species belonging to 9 tribes (includes Matthioleae) of Brassicaceae from Egypt. He recognized twelve trichome types in total, with five trichome types (simple, branched, dendroid = furcate, stellate, and glandular) on the plant surfaces of *Matthiola* taxa. In another study, Beilstein et al. (2006) reported the forked/dendritic trichomes in the *Matthiola* species.

The lengths of fruits in the flora of Turkey are usually longer than our results. Zeraatkar et al. (2006) recorded the length of the fruit of *M. ovatifolia* as (2.5–)8–13(–17) cm. We know that many environmental factors, such as daily temperature differences, humidity, or the effects of wind, change due to changes in altitude. All these changes play an important role in morphological characteristics.

The morphology of seed characteristics in *Matthiola* taxa (size, shape, color, presence or absence of seed wing, surface patterns in disc and wing, and epidermal cell shapes) has valuable taxonomic significance according to our findings. The seed sculpturing surface of the studied *Matthiola* taxa has reticulate, varyingly reticulate, undulate-striate, colliculate, scalariform, and ocellate patterns. The reticulate type is more common among the Brassicaceae species (Vaughan and Whitehouse, 1971; Barthlott, 1981; Koul et al., 2000; Abdel Khalik and Van Der Maesen, 2002; Tantawy et al., 2004; Zeng et al., 2004; Kaya et al., 2011). Abdel Khalik and Van Der Maesen (2002) reported the seed morphology of 23 genera and 45 taxa of the family Brassicaceae. Eight taxa of *Matthiola* were investigated in that study and three of them are the same as in our *Matthiola* samples (*M. fruticulosa*, *M. longipetala* subsp. *bicornis*, and *M. longipetala* subsp. *longipetala*). Seed dimensions of Turkish *Matthiola* samples were found to be longer than in that study. In another study, the seed characters of 34 taxa of Brassicaceae were investigated by Tantawy et al. (2004). The three subspecies of *M. longipetala* were investigated in that study. According to their study, seeds are 1.5 × 2 mm, suborbicular, light brown, and winged in *M. longipetala* subsp. *bicornis*. They are 1.5 × 1 mm, suborbicular, and yellow-brownish in *M. longipetala* (Vent.) DC. subsp. *hirta* Conti. Seeds of *M. longipetala* (Vent.) DC. subsp. *incana* R.Br. are also 2 × 1.5 mm, elliptic-oblong, brownish, and winged. The seed surface patterns are of the reticulate type in subsp. *bicornis* and subsp. *incana*, while it is "domate" with cracks and flakes of epicuticular wax in subsp. *hirta*. However, our *M. longipetala* samples are brown, oblong or narrowly oblong-shaped, and wingless. The surface patterns of seeds are rugose-irregular reticulate in subsp. *pumilio*, colliculate in subsp. *longipetala*, and scalariform in subsp. *bicornis*. This is not in agreement with the study of Tantawy et al. (2004).

M. trojana is endemic and a new species for the flora of Turkey (Dirmenci et al., 2006). The closest species to *M. trojana* among *Matthiola* is *M. fruticulosa* according to Dirmenci et al. (2006). According to our findings, they can be easily separated, particularly with regard to characters such as the lengths of the siliquae, and color and seed surface pattern in disc and wing.

Key to *Matthiola* taxa

1. Siliquae compressed, median vein present, fruiting pedicels 6–23 mm long; seeds 2.2–5 mm 2
2. Siliquae to 103 mm long, horn absent 3
3. Seeds orbicular, 2.2–2.5 mm, surface pattern ocellate in disc ..... ***M. ovatifolia***
3. Seeds oblong-elliptic, 3–5 mm, surface pattern reticulate in disc 4
4. Siliquae greenish yellow, fruiting pedicels to 17 mm long; seeds dark brown, reticulate-striate pattern in wing ... . ***M. anchoniifolia***
4. Siliquae yellowish, fruiting pedicels to 10 mm long; seeds brown, bireticulate pattern in wing ..... ***M. montana***
2. Siliquae to 130 mm long, horn present 5
5. Siliquae with glandular, epidermal cell irregular elevations in disc ..... ***M. sinuata***
5. Siliquae without glandular, epidermal cell polygonal shaped in disc 6
6. Siliquae pale yellow-black, fruiting pedicels 15–23 mm long; seeds 2.2–3 mm ..... ***M. incana***
6. Siliquae pale yellow, fruiting pedicels 6–8 mm long; seeds 3.5–5 mm ..... ***M. odoratissima***
1. Siliquae terete, median vein absent, fruiting pedicels 1–5 mm long; seeds 1.2–2(–4) mm 7
7. Horn 3-partite; seeds broadly oblong, pale brown ... . ***M. tricuspidata***
7. Horn 2-partite or capitate; seeds oblong or narrowly oblong, brown 8
8. Horn 2-partite; seeds wingless 9
9. Fruiting pedicels 1.8–2 mm long; seeds narrowly oblong, 1.2 mm ..... ***M. longipetala* subsp. *pumilio***
9. Fruiting pedicels 2–4 mm long; seeds oblong, 1.8–2 mm 10
10. Siliquae least 45 mm, densely hairy; seed surface scalariform in disc ..... ***M. longipetala* subsp. *bicornis***
10. Siliquae least 75 mm, hairy; seed surface pattern colliculate in disc ..... ***M. longipetala* subsp. *longipetala***
8. Horn capitate; seeds winged 11

11. Siliquae 25–50 mm, pale yellow, with glandular; seeds 1.8–2 mm, surface pattern reticulate-foveate in disc ..... ***M. trojana***

11. Siliquae 54–110 mm, dark green, without glandular; seeds 2–4 mm, surface pattern reticulate in disc ..... ***M. fruticulosa***

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