Research Article

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Pollen morphology of six *Achillea* L. sect. *Achillea* (Asteraceae) species in Turkey

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Abstract: The pollen morphology of 48 specimens of 6 species (9 taxa) of the genus *Achillea* L. sect. *Achillea* (Asteraceae), *A. nobilis* L. subsp. *neilreichii* (A.Kern.) Formánek, *A. nobilis* subsp. *densissima* (O.Schwarz ex Bässler) Hub.-Mor., *A. nobilis* subsp. *sipylea* (O.Schwarz) Bässler, *A. nobilis* subsp. *kurdica* Hub.-Mor., *A. filipendulina* Lam., *A. clypeolata* Sm., *A. coarctata* Poir., *A. biebersteinii* Afan., and *A. cappadocica* Hausskn. & Bornm. distributed in Turkey were investigated using light (LM) and scanning electron microscopy (SEM). The pollen grains were oblate-spheroidal, prolate-spheroidal, subprolate and generally tricolporate, though at times tetracolporate or even pentacolporate. The size of the grains varied, ranging from 17.6 to 57.5 µm on the polar axis mean and from 19.7 to 55.2 µm on the equatorial axis mean. Their outline is oval, compressed oval, or circular in the meridional optical section and trilobulate or sometimes tetralobullate in the polar optical section. The structure of the exine is double tectate and mean exine thickness varied from 3 to 8.5 µm. The pollen ornamentations are echinate in LM and echinate-microperforate and echinate-rugulate-microperforate in SEM. In conclusion, the species examined showed substantial variation in pollen characteristics, at both the interspecific and intraspecific levels.

Key words: *Achillea,* Compositae, LM, pollen morphology, SEM, taxonomy

Türkiye'deki altı *Achillea* L. cinsi, *Achillea* seksiyonu (Asteraceae) türünün polen morfolojisi

Özet: Bu çalışmada, *Achillea* L. cinsi *Achillea* seksiyonunun (Asteraceae) Türkiye'de yayılış gösteren 6 türü (9 takson) *A. nobilis* L. subsp. *neilreichii* (A.Kern.) Formánek, *A. nobilis* subsp. *densissima* (O.Schwarz ex Bässler) Hub.-Mor., *A. nobilis* subsp. *sipylea* (O.Schwarz) Bässler, *A. nobilis* subsp. *kurdica* Hub.-Mor., *A. filipendulina* Lam., *A. clypeolata* Sm., *A. coarctata* Poir., *A. biebersteinii* Afan. ve *A. cappadocica* Hausskn. & Bornm.'ya ait 48 örneğin polen morfolojisi ışık (LM) ve elektron mikroskobu kullanılarak (SEM) incelenmiştir. Polenler oblat-sferiodal, prolat-sferiodal, subprolat ve genellikle trikolporat bazen tetrakolporat hatta pentakolporatdır. Polen boyutlarının polar eksen ortalamaları 17,6-57,5 µm ve ekvatoral eksen ortalamaları 19,7-55,2 µm arasında değişmektedir. Şekli, meridional optik bölgede oval yada dairemsi ve polar optik bölgede trilobulat bazen tetralobulattır. Ekzin yapısı doubletektat ve ortalama kalınlığı 3-8,5 µm arasında değişmektedir. Polen ornementasyonları LM'de ekinat, SEM'de ekinat-mikroperforat ve ekinat-rugulat-mikroperforatdır. Sonuç olarak, incelenen türlerin polen özellikleri hem türler arası hem de tür içi düzeyde önemli değişkenlikler göstermektedir.

Anahtar sözcükler: *Achillea,* Compositae, LM, polen morfolojisi, SEM, taksonomi

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Introduction

The genus *Achillea* L. is a member of the Asteraceae, subfamily Asteroideae, tribe *Anthemideae. Anthemideae* contains 109 genera and about 1740 species (Bremer, 1994). *Achillea* comprises some 110-140 species, which are centred in SW Asia and SE Europe, with extensions through Eurasia to North America. The genus exhibits a high level of ecological adaptability (Ehrendorfer & Guo, 2006).

According to recent studies, the genus *Achillea* is represented in Turkey by 48 species (54 taxa), including *Otanthus* Hoffmanns. & Link and *Leucocyclus* Boiss., 24 of which are endemic to Anatolia. The endemism ratio is 50%. The species are classified into 5 sections: sect**.** *Othantus* (Hoffmanns. & Link) Ehrend. & Y.-P.Guo (one species), sect**.** *Babounya* (DC.) O.Hoffm. (30 species), sect. *Ptarmica* (Mill.) W.D.J.Koch. (2 species), sect. *Anthemoideae* (DC.) Heimerl (2 species), and sect. *Achillea* (13 species) (Huber-Morath, 1975; Duman, 2000; Danihelka, 2001; Ehrendorfer & Guo, 2005, 2006; Arabacı & Yıldız, 2006a, 2006b; Çelik & Akpulat, 2008; Arabacı & Budak, 2009).

The pollen morphology of some *Achillea* species has been previously studied (Wodehouse, 1935; Erdtman, 1943; Meo & Khan, 2003). Punt and Hoen (2009) used the name *Anthemis arvensis* type instead of *Achillea* type. According to their study, the *Anthemis arvensis* type pollen grains are 3-zonocolporate, oblate spheroidal to prolate spheroidal and the ornamentations are echinate with small puncta between the echinae. Furthermore, 10 species of the genus *Achillea* were examined by Yang and Ai (2002) and found some differences in size, colpae, and exine ornamentation.

As an initial part of a study of the pollen morphology of Turkish *Achillea* species, the present study examined 48 specimens from 6 species (9 taxa) of sect. *Achillea*: *Achillea nobilis* L. subsp. *neilreichii* (A.Kern.) Formánek, *A. nobilis* subsp. *densissima* (O.Schwarz ex Bässler) Hub.-Mor., *A. nobilis* subsp. *sipylea* (O.Schwarz) Bässler, *A. nobilis* subsp. *kurdica* Hub.-Mor., *A. filipendulina* Lam., *A. clypeolata* Sm., *A. coarctata* Poir., *A. biebersteinii* Afan., and *A. cappadocica* Hausskn. & Bornm. using light and scanning electron microscopy. Due to extensive ecological adaptability and high polyploidy levels, more specimens from different localities were chosen to determine the palynological features of the species (Ehrendorfer & Guo, 2006; Sahin et al., 2006; Kıran et al., 2008).

Materials and methods

The materials of this study were collected during field studies conducted in Turkey between 2002 and 2008. The specimens were identified using regional Floras and published papers (Boissier, 1875; Post, 1933; Huber-Morath, 1975; Richardson, 1976; Duman, 2000; Danihelka, 2001; Ehrendorfer & Guo, 2005, 2006). The voucher specimens are kept in the Herbarium of İnönü University (INU), in Malatya, Turkey.

The pollen grains were prepared following Erdtman (1960) and examined by light microscope (LM) and scanning electron microscope (SEM). A Leica DM 2500 microscope and DFC 280 camera were used for measurements and LM micrographs. All measurements were based on ca. 50 pollen grains for each specimen. The spine lengths were excluded from the measurements. The polar and equatorial axis**,** mesocolpium, distances between the colpus apices, colpus length, amb, exine, ectexine, and endexine thickness, number of apertures, and the length of the spines were measured on the pollen grains. Also, the shape classifications based on P/E ratios were given following the method of Erdtman (1969). Pollen grains were directly mounted on stubs using double-sided adhesive tape, coated with gold and examined using a JEOL JSM-6335F scanning electron microscope. SPSS (ver. 13.0) was used to calculate the mean (M), standard deviation (S), and variation (V) of LM measurements. The pollen terminology follows mainly Erdtman (1943, 1960, 1969), Faegri and Iversen (1992), and Skvarla and Turner (1966, 1971). The pollen slides were deposited in the Palynology Laboratory of Çanakkale Onsekiz Mart University, in Turkey.

Specimens examined

Achillea nobilis subsp. *neilreichii* -A1(E) Kırklareli: 10 km from Kırklareli to Dereköy, 200 m, 18.07.2005, *Arabacı* 2129; A5 Amasya: Between Osmancık and

Merzifon, Ulubey pass, forest openings, 900 m, 17.07.2004, *Arabacı* 1912; B3 Eskişehir: Between Eskişehir and Sarıcakaya, Hekimdağı pass, open places in *Quercus* L. scrubs, 1100 m, 16.07.2004, *Arabacı* 1899. Afyon: Between Afyon and Konya, around Dereçine, 16.07.2005, *Arabacı* 2110; B10 Iğdır: 10 km from Iğdır to Tuzluca, steppe, 900 m, 13.06.2002, *Arabacı* 1430a; C4 Karaman: 37 km from Mut to Karaman, Sertavul pass, 1350 m, 04.07.2000, *Arabacı* 1573.

Achillea nobilis subsp. *densissima* -B3 Konya: Akşehir, Sultandağı, above Cankurtaran, subalpine meadows, 1700 m, 15.07.2004, *Arabacı* 1893; C2 Denizli/Muğla: 35 km from Fethiye to Çameli, Mount Çal, around Kırkpınar, serpentine, 1600 m, 13.07.2005, *Arabacı* 2062 & *Dirmenci*.

Achillea nobilis subsp. *sipylea* -B1 Manisa: Mount Sipil, Atalanı, *Pinus nigra* J.F.Arnold openings, 1200 m, 05.07.2004, *Yıldız* 15751.

Achillea nobilis subsp. *kurdica* -A9 Kars: 7 km from Kağızman to Tuzluca, 1750 m, 13.06.2002, *Yıldız* & *Arabacı* 1428; B9 Van: Çavuştepe, 1800 m, 09.06.2002, *Yıldız* & *Arabacı* 1417a; C10 Hakkari: 31 km from Yüksekova to Şemdinli, steppe, 1700 m, 09.06.2002, *Yıldız* & *Arabacı* 1409.

Achillea filipendulina -A5 Amasya: around Gümüşhacı village, steppe, 850 m, 10.06.2008, *Arabacı* 2656; B9 Muş: 2 km from Güloymak to Muş, field sides, 1600 m, 02.08.2003, *Arabacı* 1625; C9 Hakkari: 90 km from Hakkari to Şırnak, streamside, 1000 m, 08.06.2002, *Yıldız* & *Arabacı* 1397b.

Achillea clypeolata -A1(E) Kırklareli: 21 km from Kırklareli to Dereköy, forest openings, 480 m, 19.06.2003, *Arabacı* 1546.

Achillea coarctata -A1(E) Kırklareli: 23 km from Kırklareli to Dereköy, forest openings, 500 m, 09.06.2008, *Yıldız* & *Arabacı* 2647; A4 Çankırı: Between Kalecik and Kırıkkale, slopes, 700 m, 20.06.2003, *Arabacı* 1563; A5 Kastamonu: Tosya, Mount Ilgaz pass, forest openings, 1200 m, 17.07.2004, *Arabacı* 1907; A8 Rize: 10 km from İkizdere to İspir, forest openings, 1600 m, 27.06.2008, *Yıldız* & *Arabacı* 2671; A9 Kars: 46 km from Sarıkamış to Karaurgan and Horosan, rocky slopes, 1950 m, 14.07.2007, *Arabacı* 2568; B3 Bilecik: 2-3 km from Bayırlar village to Yenişehir, 350 m, 30.05.2002, *Dirmenci* 1733; Eskişehir: Around Çifteler field sides, 1150 m, 15.07.2004, *Arabacı* 1898; B5 Kayseri: 38 km from Kayseri to Avanos, steppe, 900 m, 04.06.2008, *Arabacı* 2622; B9 Van: 10 km from Ahlat to Adilcevaz, steppe, 1700 m, 02.08.2003, *Arabacı* 1622; C5 Niğde: 40 km from Çamardı to Niğde, field sides, 1400 m, 05.06.2003, *Arabacı* 1589.

Achillea biebersteinii -A2(A) Bursa: Uludağ, 1500 m, 24.07.2002, *Arabacı* 1496; B5 Yozgat: 80 km from Yozgat to Kayseri, field sides, 06.06.2007, *Arabacı* 2226; B6 Sivas: Junction of Sivas, Kangal, and Gürün road, 3 km south of Halep bridge, 15.06.2003, *Arabacı* 1521; Malatya: 35 km from Malatya to Darende, 950 m, 17.06.2002, *Arabacı* 1440; B7 Erzincan: 30 km from Kemaliye to Arapkir, Fırat valley, rocky slopes, 850 m, 09.06.2007, *Arabacı* 2245; Malatya: 14 km from Hekimhan to Hasançelebi, calcareous slopes, 1100 m, 09.06.2004, *Arabacı* 1750. Around Kale, 800 m, 13.05.2006, *Arabacı* 2182; Elazığ: 3 km from Harput to Serince, 23.06.2002, *Arabacı* 1454; B9 Van: 38 km from Van to Erciş, 1850 m, 12.06.2002, *Yıldız* & *Arabacı* 1424; C5 Niğde: 16 km from Çamardı to Niğde, field sides, 1650 m, 05.06.2003, *Arabacı* 1588. 1 km from Yeşilhisar to Kayseri, 1150 m, 05.06.2003, *Arabacı* 1590. Adana: Pozantı, west of Eski Anahsa castle, 1250 m, 27.05.2006, *Arabacı* 2185; C6 Gaziantep: 15 km from Gaziantep to Adana, 900 m, 06.06.2002, *Arabacı* 1382; C7 Şanlıurfa: 1 km from Birecik to Şanlıurfa, field sides, 350 m, 06.06.2002, *Yıldız* & *Arabacı* 1386; C9 Şırnak: 73 km from Şırnak to Hakkari, 1300 m, 08.06.2002, *Yıldız* & *Arabacı* 1402; C9/10 Hakkari: 29 km from Çukurca to Hakkari, 1300 m, 08.06.2002, *Yıldız* & *Arabacı* 1399; C10 Hakkari: 31 km from Yüksekova to Şemdinli, steppe, 1700 m, 09.06.2002, *Yıldız* & *Arabacı* 1410.

Achillea cappadocica -A4 Çankırı: 60 km from Çankırı to Kalecik, *Amygdalus* L. scrubs, 800 m, 20.06.2003, *Arabacı* 1562b; B5 Yozgat: Akdağmadeni, above Kızılcaova village, Nalbant hill, alpine meadows, 2000 m, 17.07.2004, *Arabacı* 1913a; C4 Karaman: Between Gülnar and Ermenek, around Bereketli village, forest openings, 1100 m, 03.07.2003, *Arabacı* 1567a. Ibid., 20 km from Gülnar to Ermenek, rocks, 1180 m, *Arabacı* 1568a; C5 Adana: Pozantı, west of Eski Anahsa castle, 1250 m, 27.05.2006, *Arabacı* 2186.

Results

The main palynological features of the species examined in this study are summarised in Tables 1 and 2 and shown in Figures 1-11.

Symmetry and shape

The pollen grains of the sect. *Achillea* species investigated in this study are radially symmetrical and isopolar. Pollens are oblate-spheroidal, prolate-

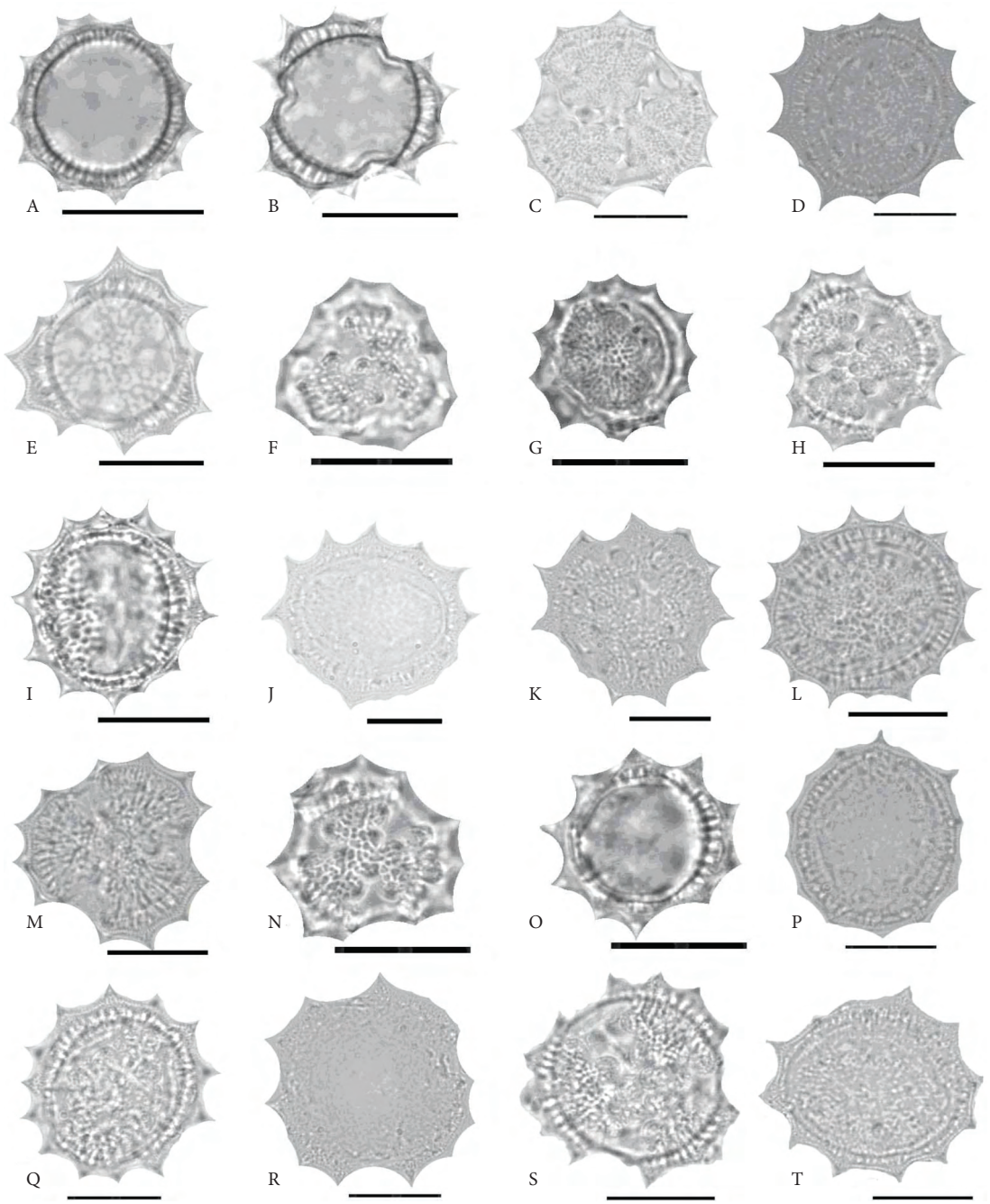

Figure 1. Light micrographs of pollen grains. *Achillea nobilis* subsp. *neilreichii*: A-B (Arabacı 2129), C-D (Arabacı 1573), E (Arabacı 1912), F-G (Arabacı 1899), H-I (Arabacı 2110), J-K (Arabacı 1430a); *A. nobilis* subsp. *densissima*: L-M (Arabacı 2062), N-O (Arabacı 1893); *A. nobilis* subsp. *sipylea*: P-R (Yıldız 15751); *A. nobilis* subsp. *kurdica*: S-T (Arabacı 1428). Scale bars: 20 μm.

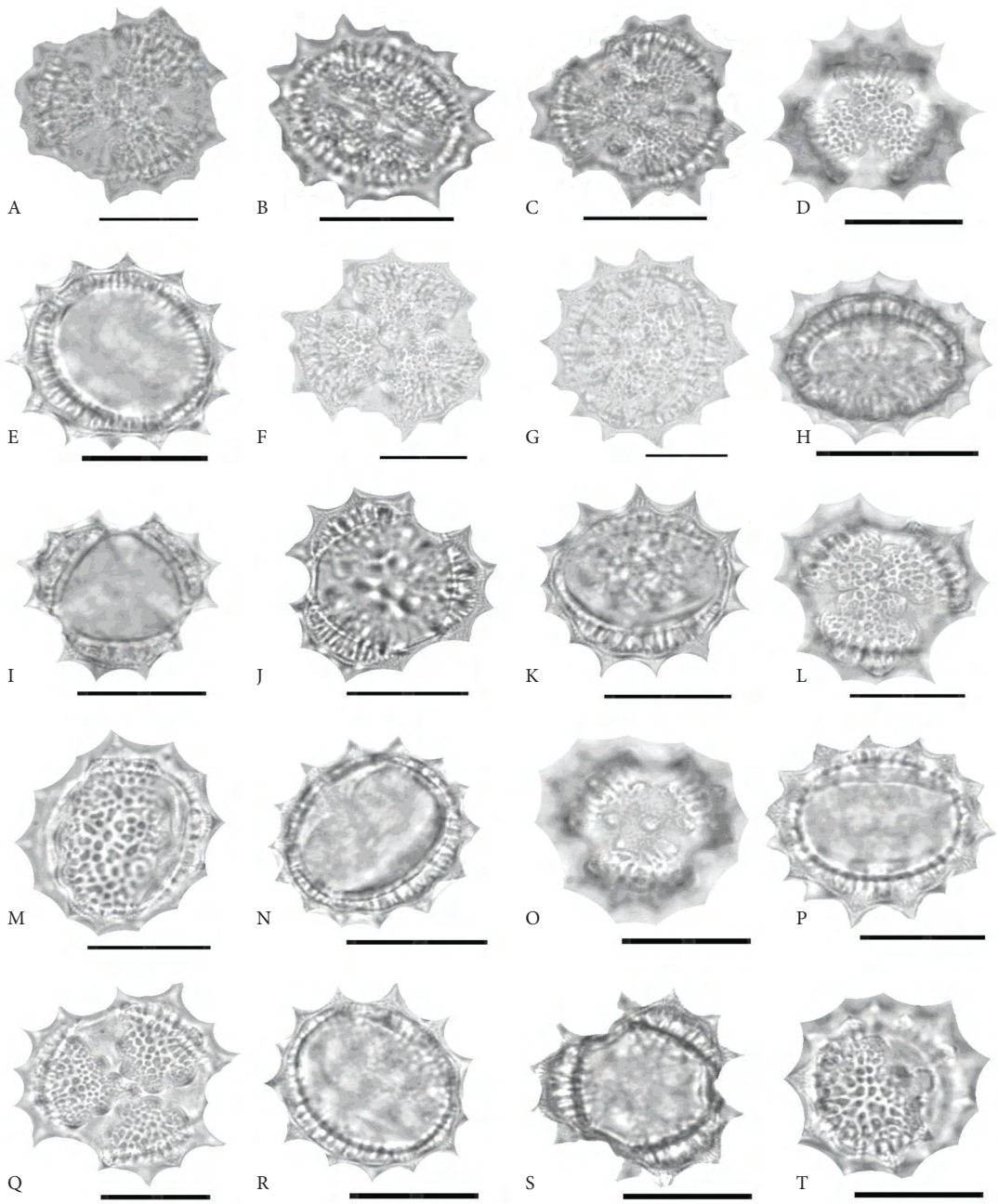

Figure 2. Light micrographs of pollen grains. *Achillea nobilis* subsp. *kurdica*: A (Arabaci 1417a), B-C (Arabacı 1409); *A. filipendulina*: D-E (Arabacı 1625), F-G (Arabacı 1397b), H-I (Arabacı 2656); *A. clypeolata*: J-K (Arabacı 1546); *A. coarctata*: L-M (Arabacı 1563), N-O (Arabacı 1907), P- (Dirmenci 1733), Q-R (Arabacı 1898), S-T (Arabacı 1622). Scale bars: 20 μm.

spheroidal, and subprolate. The size of grains varies, with the mean of polar axis ranging from 17.6 to 57.5 μm and the mean equatorial axis ranging from 19.7 to 55.2 μm (Table 1). Amb shape is intersemiangular. The outline is oval, compressed oval, or circular in the meridional section and trilobulate (Figures 1-5) or sometimes tetralobullate (Figures 5, 10) in the polar optical section.

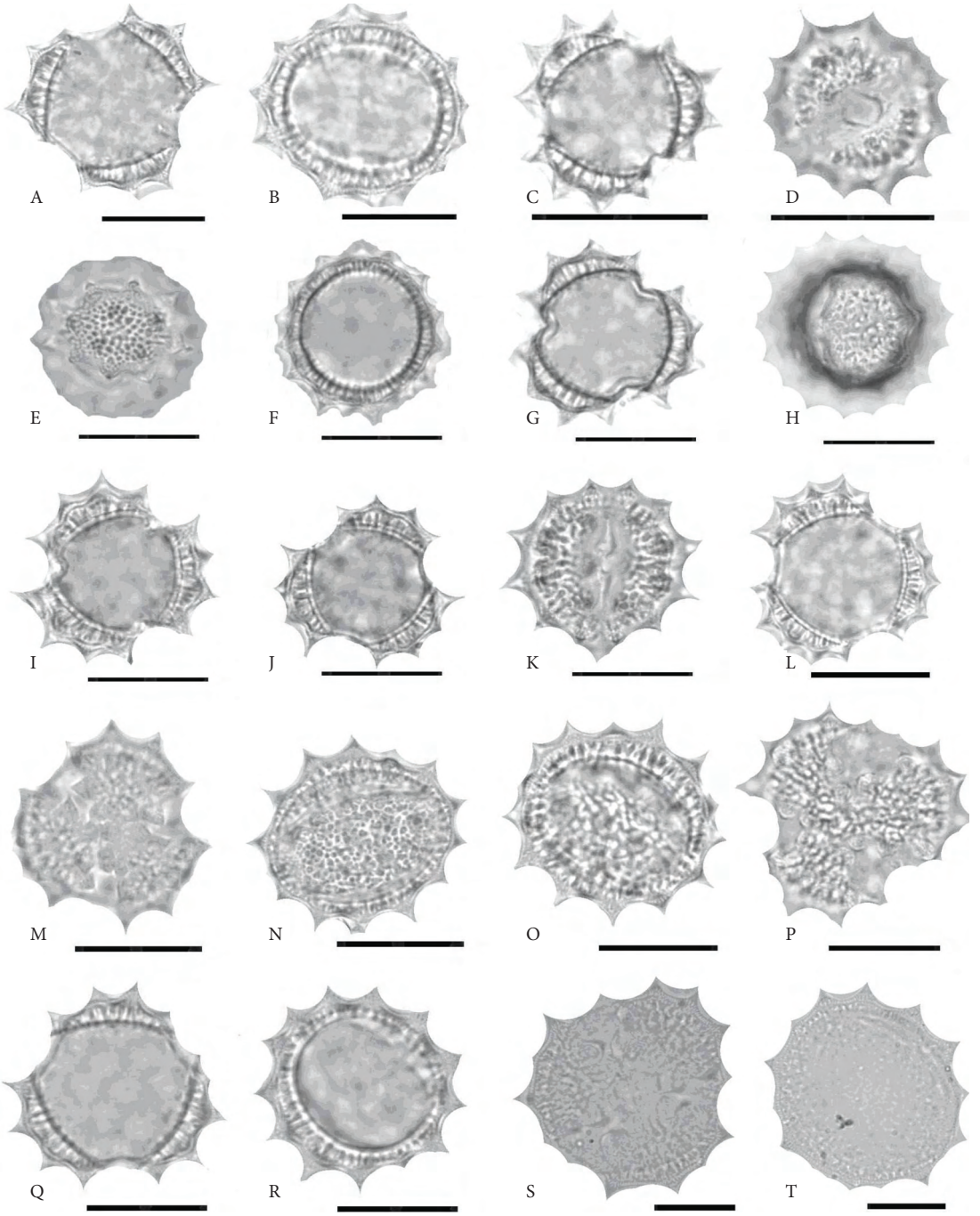

Figure 3. Light micrographs of pollen grains. *Achillea coarctata*: A-B (Arabacı 1589), C-D (Arabacı 2671), E-G (Arabacı 2568), H-I (Arabacı 2647), J-K (Arabacı 2622); *A. biebersteinii*: L (Arabacı 1496), M-N (Arabacı 1440), O-P (Arabacı 1521), Q-R (Arabacı 1454), S-T (Arabacı 1750). Scale bars: 20 µm.

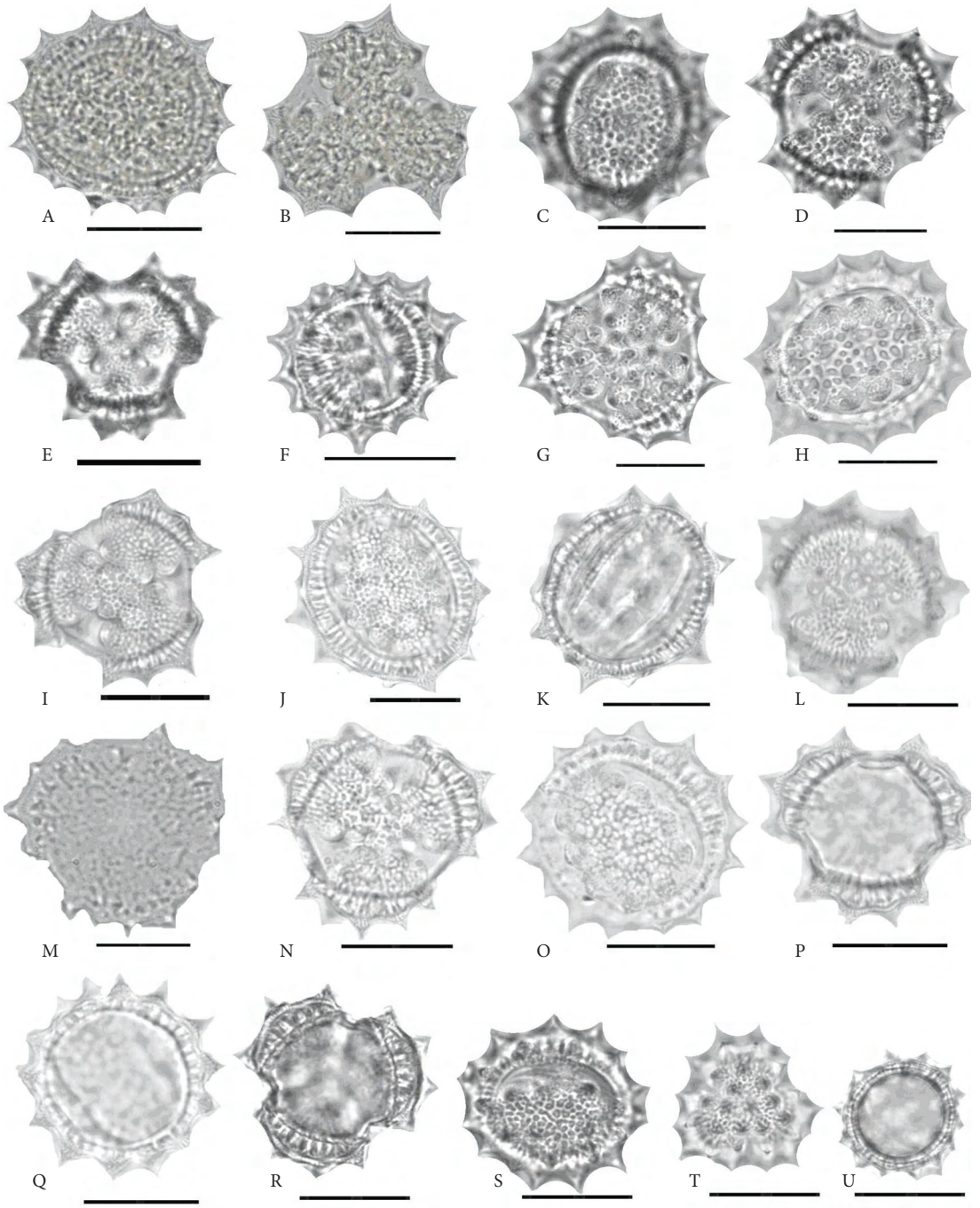

Figure 4. Light micrographs of pollen grains. *Achillea biebersteinii:* A-B (Arabacı 2182), C-D (Arabacı 1588), E- F (Arabacı 1590), G-H (Arabacı 2185), I-J (Arabacı 1382), K-L (Arabacı 1386), M (Arabacı 1402), N-O (Arabacı 1399), P-Q (Arabacı 1410), R-S (Arabacı 2245), T-U (Arabacı 2226). Scale bars: 20 μm.

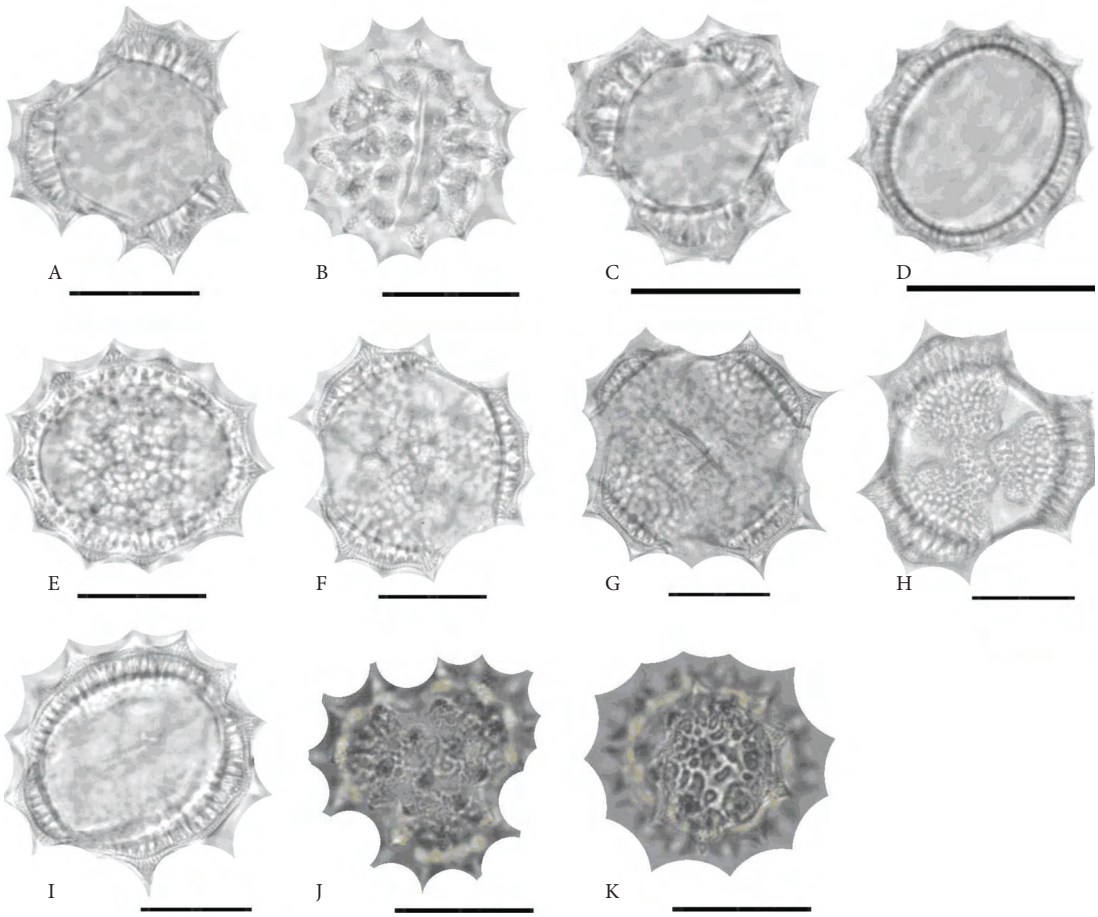

Figure 5. Light micrographs of pollen grains. *Achillea cappadocica*: A-B (Arabacı 1562b), C-D (Arabacı 1913a), E-F (Arabacı 1567a), G-I (Arabacı 1568a), J-K (Arabacı 2186). Scale bars: 20 µm.

Apertures

The pollen grains are usually tricolporate, though tetracolporate grains are also observed in some taxa (Figures 5, 10). Some specimens of *A. nobilis* subsp. *densissima*, *A. nobilis* subsp. *sipylea*, *A. filipendulina*, *A. biebersteinii*, and *A. cappadocica* have both tricolporate and tetracolporate grains (Figures 1-2, 4-5). The mean length of colpi varied from 11.2 to 35.3 µm, acute at apices, and margins are distinct. The mean distances between the colpus apices (t) varied from 4.7 to 12.3 µm. The apocolpium is angular. The aperture membrane is scabrous (Figure 8). The endoaperture is lalongate or elongate. In SEM analyses, the operculum is observed on the pores in the specimens that were treated with alcohol (Figures 6, 8, 10).

Exine

The structure of the exine is double tectate and mean exine thickness varies from 3 to 8.5 µm. Mean ectexine thickness is between 2 and 6.3 µm and is 3.7 times that of the endexine. The endexine is thin and the mean of length varies between 0.6 and 1.7 µm. The columellae in the ectexine are thick or thin, distinctly branched and "Y" shaped at the apices, terminating with a layer that consists of uniform bacula (Figure 9). Sculpturing is echinate in LM and usually echinate-microperforate in SEM. Perforations are elliptical or circular. The ornamentation is echinate-rugulate-microperforate in *A. clypeolata* and some specimens of *A. coarctata*, *A. biebersteinii,* and *A. cappadocica* (Figures 3-5). The perforations are few, amorphous, or elliptic-circular in these specimens.

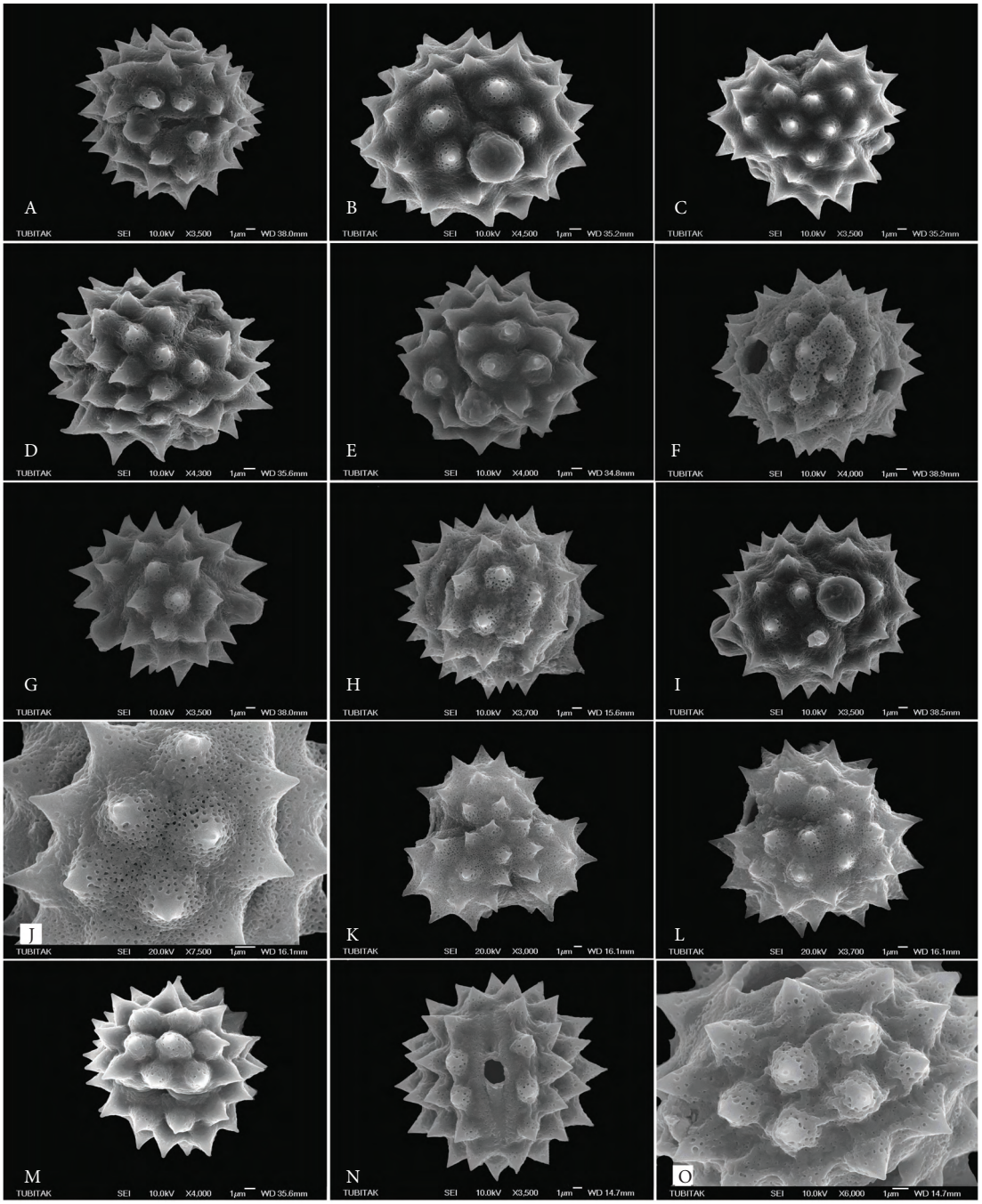

Figure 6. Scanning electron micrographs of pollen grains. *Achillea nobilis* subsp. *neilreichii*: A (Arabacı 2129), B-C (Arabacı 1573), D (Arabacı 1912), E (Arabacı 1899), F (Arabacı 2110), G (Arabacı 1430a); *A. nobilis* subsp. *densissima*: H (Arabacı 2062), I (Arabacı 1893); *A. nobilis* subsp. *sipylea*: J-K (Yıldız 15751); *A. nobilis* subsp. *kurdica* L (Arabacı 1428), M (Arabacı 1417a); *A. filipendulina* N-O (Arabacı 1625).

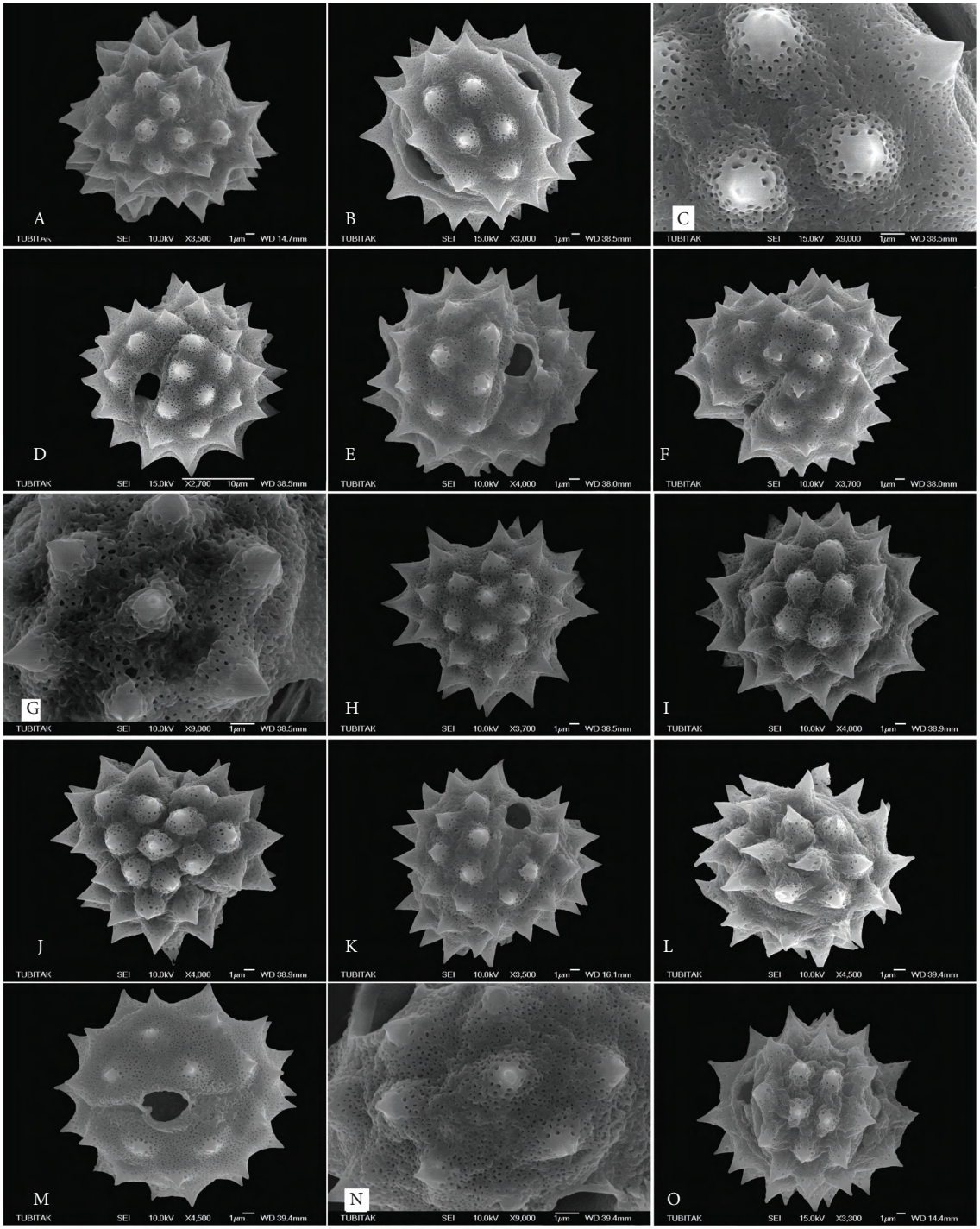

Figure 7. Scanning electron micrographs of pollen grains. *Achillea filipendulina*: A (Arabacı 1625), B-D (Arabacı 1397b), E-F (Arabacı 2656); *A. clypeolata* G-H (Arabacı 1546); *A. coarctata*: I-J (Arabacı 1563), K (Dirmenci 1733), L (Arabacı 1898), M-N (Arabacı 1622), O (Arabacı 1589).

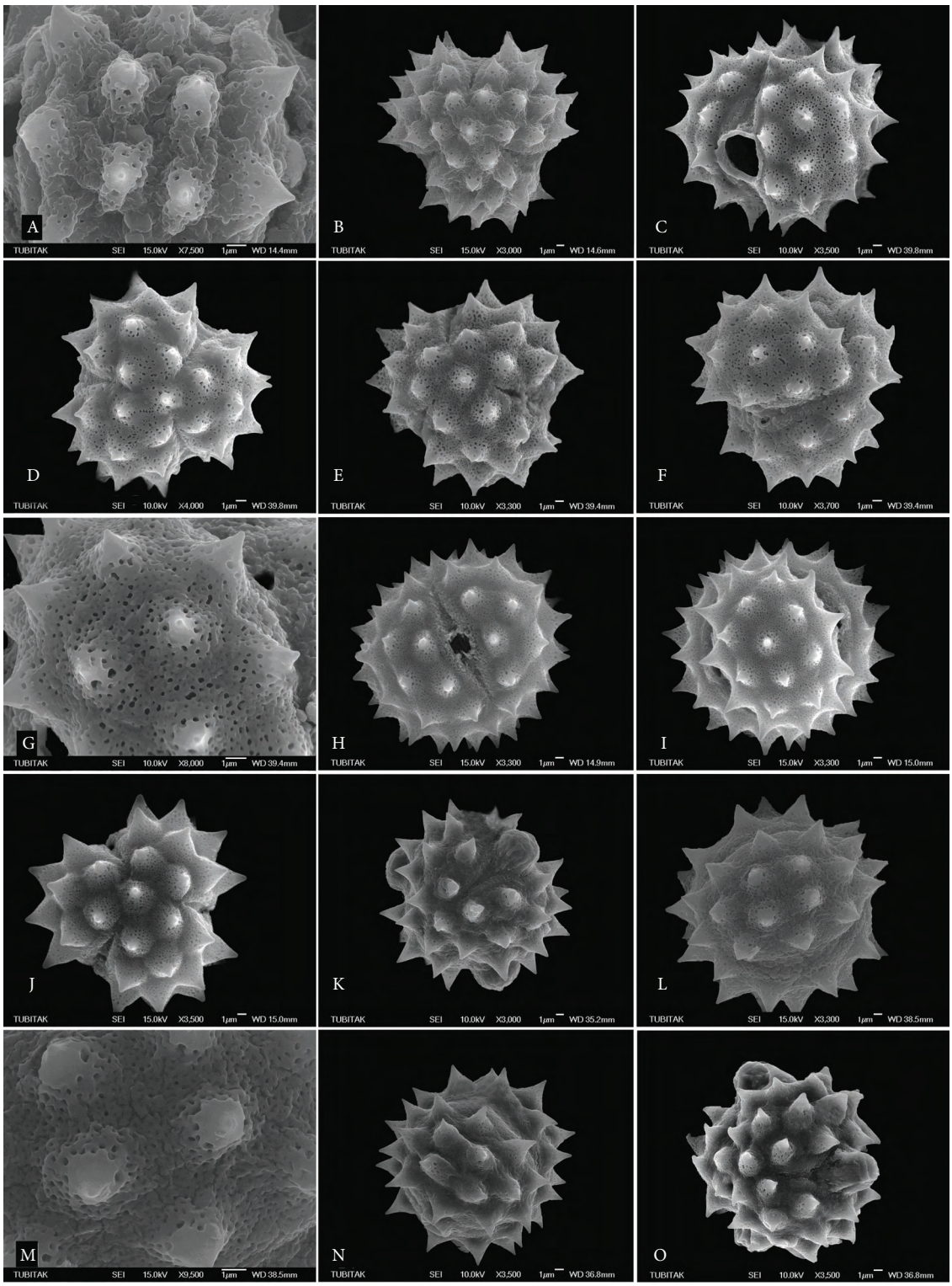

Figure 8. Scanning electron micrographs of pollen grains. *Achillea coarctata*: A-B (Arabacı 1589), C-D (Arabacı 2671), E (Arabacı 2647), F-G (Arabacı 2622); *A. biebersteinii*: H-J (Arabacı 1496), K (Arabacı 1440), L-M (Arabacı 1521), N (Arabacı 1454), O (Arabacı 1750).

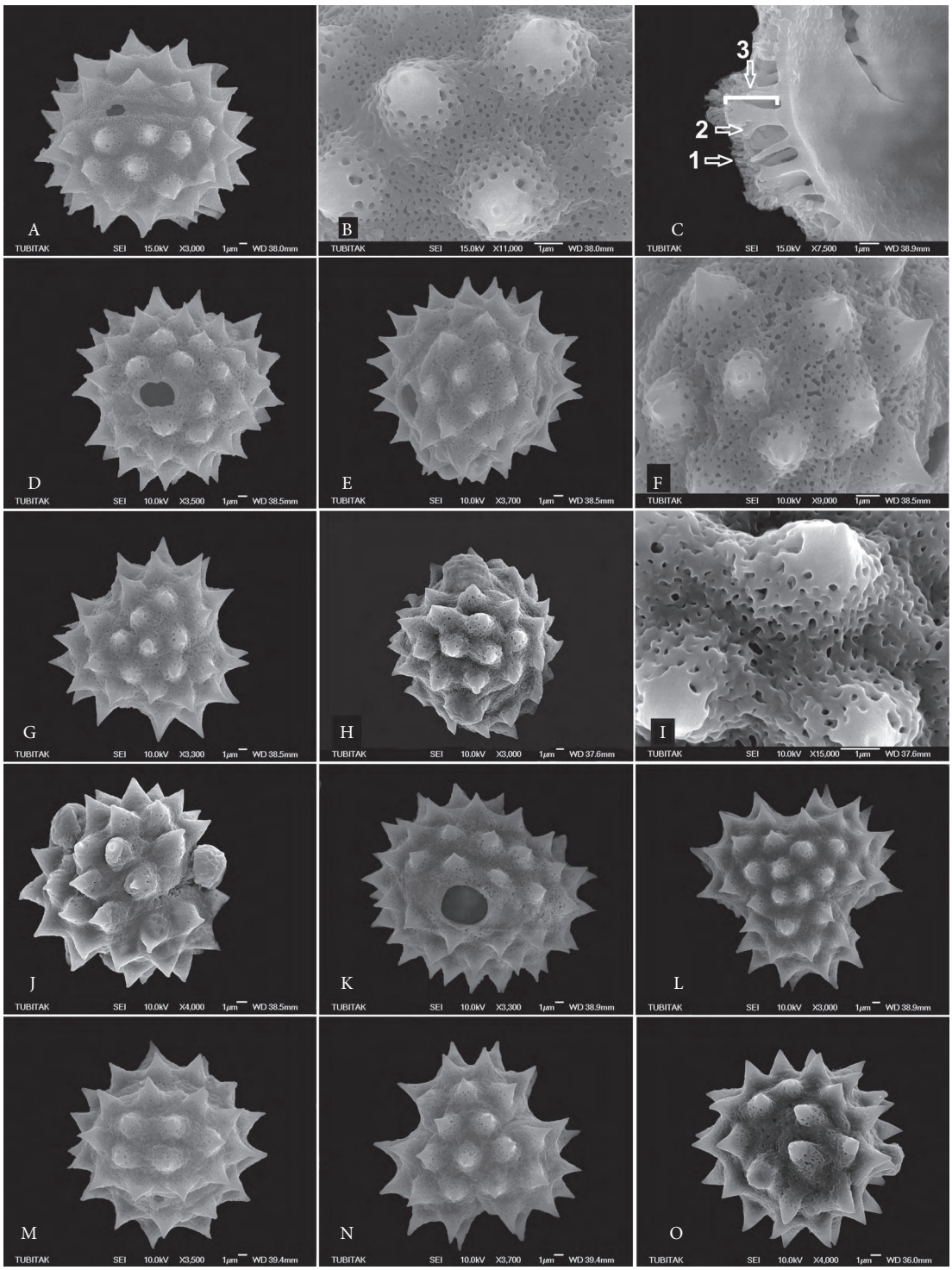

Figure 9. Scanning electron micrographs of pollen grains. *Achillea biebersteinii*: A-C (1- double tectum: columellae of uniform length, 2- branching columellae, 3- basal columellae: extending between double tectum and foot layer) (Arabacı 2182), D-G (Arabacı 1424), H-I (Arabacı 1588), J (Arabacı 1590), K-L (Arabacı 2185), M-N (Arabacı 1382), O (Arabacı 1386).

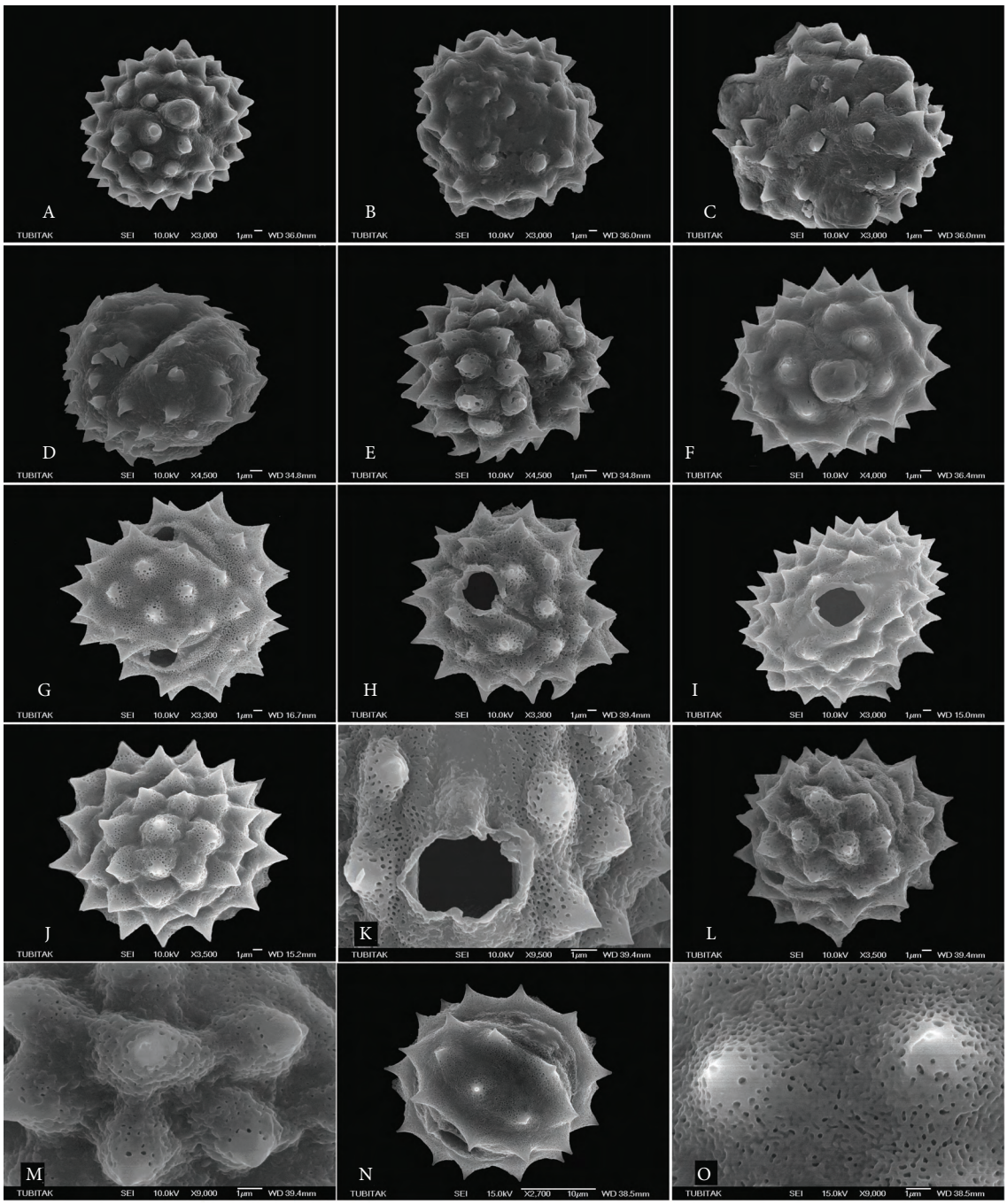

Figure 10. Scanning electron micrographs of pollen grains. *Achillea biebersteinii*: A-C (Arabacı 1402), D-E (Arabacı 1399), F- (Arabacı 1410), G (Arabacı 2245), H (Arabacı 2226); *A. cappadocica*: I-J (Arabacı 1562b), K (Arabacı 1913a), L-M (Arabacı 1567a), N-O (Arabacı 1568a).

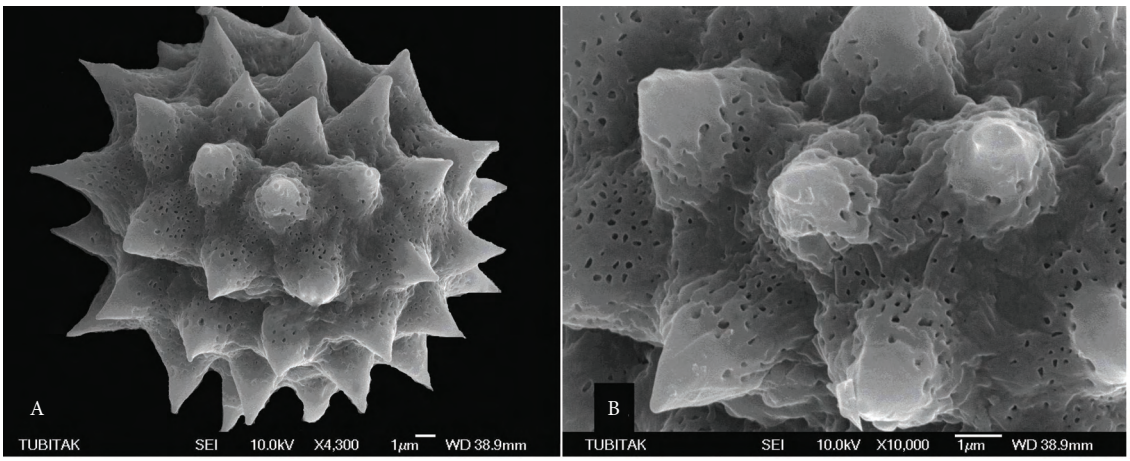

Figure 11. Scanning electron micrographs of pollen grains. *Achillea cappadocica*: A-B (Arabacı 2186).

Spine

The mean of spine length varies from 1.5 to 8 μm; spines are acute and psilate towards the apex. Perforations are homogeneous or not, circular, elliptical or amorphous between the spines and they continue around the spine base. The perforations are widened in the lower half of the spine and decrease in number around the spine.

Discussion

The genus *Achillea* has a widespread distribution from desert habitats to wet places and from sea coastal areas to the nival zone of high mountains (Ehrendorfer & Guo, 2006). *Achillea* sect. *Achillea* differs morphologically from other sections by its pinnatisect, linear, lanceolate, or oblong to ovate leaves, which are broader than 0.4 cm. The leaf segments are not imbricate and are longer than they are broad and the number of ligules is (2-)4-6. The species examined in this study have ivory-white to golden-yellow ligules. Other Turkish species of this section have white ligules, though they are at times ivory-white in *A. crithmifolia* Waldst. and Kit. (Huber-Morath, 1975).

The results of the present study show that the pollen morphologies of *A. nobilis* subsp. *neilreichii, A. nobilis* subsp. *densissima*, *A. nobilis* subsp. *sipylea*, *A. nobilis* subsp. *kurdica*, *A. filipendulina*, *A. clypeolata*, *A. coarctata*, *A. biebersteinii,* and *A. cappadocica* are heterogeneous (Figures 1-11, Tables 1-2).

The sizes of the pollen grains show wide variations. A specimen of *A. coarctata* has the smallest pollen grains, with the polar axis ranging from 15 to 20 μm (mean 17.6 μm) and the equatorial diameter ranging from 17 to 21 μm (mean 19.7 μm) (Figure 3). In contrast, a specimen from *A. biebersteinii* has the largest pollen grains, with the polar axis ranging from 47 to 70 μm (mean 57.5 μm) and the equatorial diameter ranging from 45 to 69 μm (mean 55.2 μm) (Figure 4, Table 1). In several studies, the polar and equatorial axes of the pollen grains of the genus *Achillea* have been reported as being less than 35 μm (Wodehouse, 1935; Erdtman, 1943; Skvarla & Turner, 1966; Nilsson et al., 1977; Skvarla et al., 1977; Moore & Webb, 1983; Moore et al., 1991; Faegri & Iverson, 1992; Yang & Ai, 2002; Meo & Khan, 2003; Jafari & Ghanbarian, 2007). Furthermore, variations were observed in exine thickness, spine length, and amb (Table 1). Similarly, Türkmen et al. (2010) reported variations in pollen size, exine thickness, and spine lengths in the genus *Scorzonera* L. (Asteraceae).

The basic diploid chromosome numbers of *Achillea* species are 2x, 2n = 18, though polyploidy taxa, often 4x, sometimes 6x, and even 8x have been reported (Ehrendorfer & Guo, 2006; Sahin et al., 2006; Kıran et al., 2008). The section *Achillea* is also taxonomically complex, with numerous diploid and polyploid

Table 1. Morphological parameters of *Achillea* species pollen grains.

Taxa	Specimens No	Pollen shape	P/E ratio	Polar axes (P)			Equatorial diameter (E)			Mean of measurements								
				Mean	SD	V	Mean	SD	V	Meso	t	Clg	Amb	Exine thickness	Ectexine thickness	Endexine thickness	An	Splg
A. nobilis subsp. *neilreichii*	2129	Oblate-spheroidal	0.93	30.6	±0.4	23-40	32.7	±0.4	26-40	18.6	9.7	20.3	33.13	5	4	1	3	4-5
	1573	Prolate-spheroidal	1.10	36	±0.4	30-40	32.6	±0.3	28-36	19.2	10.7	28.4	35.9	4.3	3.3	1	3	4-5
	1912	Prolate-spheroidal / Subprolate	1.12	30.7	±0.2	27-34	27.4	±0.2	25-30	15.1	8.2	23	30.8	5	4	1	3	4-5
	1899	Oblate-spheroidal	0.92	20.5	±0.2	19-23	22.2	±0.1	20-24	12	4.7	13.2	22.77	4	3	1	3	2,5-3
	2110	Prolate-spheroidal	1.11	30.9	±0.3	27-36	27.7	±0.2	24-31	15.5	7.4	24.7	31.2	4	3	1	3	4-5
	1430a	Prolate-spheroidal	1.12	48.4	±0.5	33-60	43.1	±0.4	31-50	-	-	-	48.2	-	-	-	3	5-7
A. nobilis subsp. *densissima*	2062	Prolate-spheroidal	1.07	33.1	±0.4	27-40	30.9	±0.3	26-36	17.5	7.7	23.8	33	5	4	1	3(4)	4-5
	1893	Oblate-spheroidal	0.98	26.2	±0.4	20-36	24.6	±0.5	16-42	15.3	5.7	18.9	27.5	5	3	2	3	4-5
A. nobilis subsp. *sipylea*	15751	Prolate-spheroidal / Subprolate	1.14	33.5	±0.2	30-38	29.3	±0.2	25-33	14.7	9	24.2	32	3.2	2.1	1	3(4)	3-4
A. nobilis subsp. *kurdica*	1428	Prolate-spheroidal	1.12	34.7	±0.7	21-50	30.8	±0.7	20-45	17.5	7	25.5	34.4	5.4	-	-	3	4-5
	1417a	Prolate-spheroidal	1.08	31.7	±0.3	27-39	29.2	±0.3	26-36	16.3	8	22.6	31.6	4	3	1	3	3-5
	1409	Prolate-spheroidal / Subprolate	1.14	27.2	±0.3	21-30	23.7	±0.2	22-26	14.4	6..2	21.4	27.5	3.3	2.3	1	3	3-4
A. filipendulina	1625	Prolate-spheroidal	1.07	29.9	±0.3	25-35	27.8	±0.3	25-34	16.8	6.8	21.3	30.9	5.2	4.2	1	3	4-5
	1397b	Prolate-spheroidal	1.13	45.06	±0.4	38-50	39.6	±0.3	35-45	22.4	10	35.3	41.3	5.04	4.6	1	3(4)	5-6
	2656	Subprolate / Prolate	1.2	25.06	±0.2	23-29	20.7	±0.2	18-24	12.8	5.4	16.2	24.3	4.7	3.2	1.6	3(4)	2,5-3
A. clypeolata	1546	Prolate-spheroidal	1.07	29.3	±0.2	25-34	27.3	±0.2	24-32	15.3	5.3	21.8	29.9	5.7	4.7	1	3	3-5
A. coarctata	1563	Prolate-spheroidal	1.13	32.2	±0.1	30-36	28.5	±0.1	25-30	15.8	7.1	23.2	31.5	5.4	4.1	1.2	3	4-5
	1907	Prolate-spheroidal	1.13	30.3	±0.4	22-36	26.6	±0.3	22-32	15.6	6.7	22	28.8	5	4	1	3	3-5
	1733	Prolate-spheroidal / Subprolate	1.14	30.5	±0.2	26-35	26.6	±0.2	24-30	14.6	5.4	22.3	29.7	5.3	3.8	1.2	3	3,5-5
	1898	Prolate-spheroidal	1.11	34.2	±0.3	30-40	30.7	±0.2	27-35	16.6	6.6	26	35.4	5	4	1	3	4-4,5
	1622	Oblate-spheroidal	0.99	27	±0.2	24-33	27.2	±0.2	25-32	15.4	7.8	18.1	27.6	4.9	3.7	1.2	3	3-5
	1589	Prolate-spheroidal	1.08	33.8	±0.2	28-38	31.06	±0.2	27-36	18	8.5	22.2	34.2	6.3	5.08	1.19	3	4,5-5
	2671	Oblate-spheroidal	0.89	17.6	±0.1	15-20	19.7	±0.1	17-21	10.7	4.7	11.2	18.8	3	2	1	3	1,5-2
	2568	Oblate-spheroidal	0.98	24.4	±0.1	22-27	24.8	±0.1	23-29	14	8.2	15.8	24.3	3.9	2.9	1.2	3	3-4
	2647	Oblate-spheroidal	0.90	23.5	±0.1	22-26	26.2	±0.1	25-29	14.9	6.2	15.5	25.3	4.4	3.4	1	3	3-4
	2622	Prolate-spheroidal	1.08	26.3	±0.3	23-33	24.3	±0.2	21-30	13.8	6.4	18.6	24.9	4.2	3.2	1	3	2,5-3

Table 1. (Continued).

Taxa	Specimens No	Pollen shape	P/E ratio	Polar axes (P)			Equatorial diameter (E)			Mean of measurements								
				Mean	SD	V	Mean	SD	V	Meso	t	Clg	Amb	Exine thickness	Ectexine thickness	Endexine thickness	An	Splg
A. biebersteinii	1496	Prolate-spheroidal	1.02	24.7	±0.2	20-29	24	±0.1	20-27	14.0	5.1	17.3	24.84	4.5	3.2	1.2	3	2-4
	1440	Prolate-spheroidal	1.13	29.5	±0.2	25-33	26	±0.2	22-32	14.7	6.5	22.6	28.8	3.7	2.7	1	3	4
	1521	Prolate-spheroidal	1.11	37.9	±0.3	33-48	33.9	±0.3	30-45	17.2	12.3	24.8	36.46	4.3	3.3	1	3	4-5
	1454	Prolate-spheroidal	1.04	28.2	±0.2	25-32	27.1	±0.2	24-32	14.9	5.6	20.3	28.52	4.7	3.7	1	3	4
	1750	Prolate-spheroidal	1.10	47.6	±0.6	26-56	42.9	±0.6	20-54	22.8	10.7	33.6	49.3	6.8	5.1	1.8	3	5-7
	2182	Subprolate	1.15	40.6	±0.3	35-48	35.2	±0.2	31-42	19.1	13	29	50.3	5.1	4.07	1.07	3(4)	4-6
	1424	Prolate-spheroidal	1.12	31.2	±0.1	28-34	27.8	±0.2	25-32	15.2	9.3	21.6	31.4	3.2	2.2	1	3	3-5
	1588	Prolate-spheroidal	1.05	45.5	±0.7	30-50	43	±0.6	30-50	-	-	-	-	5	4	1	3	3-5
	1590	Oblate-spheroidal	0.98	24.4	±0.6	16-37	24.8	±0.4	19-33	14.8	5.8	18.7	27.26	3.9	2.9	1	3(4)	3-5
	2185	Prolate-spheroidal	1.13	39.3	±0.4	28-45	34.7	±0.3	23-40	19	10.3	28.9	39.8	4.6	3.5	1.1	3(4)	3-6
	1382	Subprolate	1.22	31.9	±0.9	25-52	26	±0.2	23-32	14.9	8.2	20.9	30.7	4	3	1	3	4-5
	1386	Prolate-spheroidal	1.06	31.8	±0.3	26-37	29.8	±0.2	25-35	16.3	7.8	23.6	31.8	4.3	3.3	1	3	3-6
	1402	Prolate-spheroidal	1.03	57.5	±1.1	47-70	55.2	±1.1	45-69	-	-	-	55.51	-	-	-	3(4)	2-5
	1399	Prolate-spheroidal	1.04	34.4	±0.4	29-42	32.9	±0.3	26-39	18.3	8.9	23.7	34.3	5.2	4.1	1.1	3(4-5)	3-6
	1410	Prolate-spheroidal	1.01	27.5	±0.2	25-31	27.2	±0.2	24-32	15.1	7.3	19.6	28.5	4	3	1	3	3-4
	2245	Prolate-spheroidal	1.11	33.04	±0.5	28-38	29.7	±0.5	25-36	16.3	7.4	23.8	32.2	5.4	-	-	3(4)	3-6
	2226	Oblate-spheroidal	0.96	22.6	±0.3	20-34	23.3	±0.3	20-30	13	5.2	15.4	23.8	3.7	-	-	3	2-5
A. cappadocica	1562b	Prolate-spheroidal / Subprolate	1.14	34.2	±0.3	30-43	29.8	±0.3	27-40	16.6	9.3	22.7	34.96	6.3	4.6	1.3	3(4)	4,5-5,5
	1913a	Prolate-spheroidal	1.11	23.9	±0.2	20-28	21.5	±0.1	20-25	11.5	5.1	16.9	24.1	4.2	3.2	0.6	3	2,5-3
	1567a	Subprolate / Prolate	1.17	37.4	±0.3	32-42	31.8	±0.3	28-38	16.1	8.9	26.1	26.1	4.8	3.9	0.9	3	4-5
	1568a	Subprolate	1.16	44.9	±0.8	35-53	38.6	±0.8	34-46	19.7	10.7	32.1	44.6	8.5	6.3	1.7	3(4)	6-8
	2186	Oblate-spheroidal	0.90	28.3	±0.2	23-32	31.3	±0.2	27-35	19.1	9.4	19.2	31.05	5.7	4.7	1	3	3-4

An: number of aperture, Clg: colpus length, Meso: mesocolpium, SD: Standard deviation, Splg: spine length, t: distances between colpus apices, V: Variation, -: unmeasured. All measurements in μm.

Table 2. Pollen morphological features of *Achillea* species in SEM analyses.

Taxa	Specimens No	Ornamentation	Perforation
A. nobilis subsp. *neilreichii*	2129	echinate-microperforate	elliptic-circular
	1573	echinate-microperforate	elliptic-circular
	1912	echinate-microperforate	elliptic-circular
	1899	echinate-microperforate	elliptic-circular
	2110	echinate-microperforate	amorph
	1430a	echinate-microperforate	elliptic-circular
A. nobilis subsp. *densissima*	2062	echinate-microperforate	elliptic-circular
	1893	echinate-microperforate	elliptic-circular
A. nobilis subsp. *sipylea*	15751	echinate-microperforate	elliptic-circular
A. nobilis subsp. *kurdica*	1428	echinate-microperforate	elliptic-circular
	1417a	echinate-microperforate	elliptic-circular
	1409	echinate-microperforate	-
A. filipendulina	1625	echinate-microperforate	elliptic-circular
	1397b	echinate-microperforate	elliptic-circular
	2656	echinate-microperforate	elliptic-circular
A. clypeolata	1546	echinate-rugulate-microperforate	amorph
A. coarctata	1563	echinate-microperforate	elliptic-circular
	1907	echinate-microperforate	-
	1733	echinate-microperforate	elliptic-circular
	1898	echinate-microperforate	elliptic-circular
	1622	echinate-microperforate	elliptic-circular
	1589	echinate-rugulate-microperforate	few, elliptic-circular
	2671	echinate-microperforate	elliptic-circular
	2568	-	-
	2647	echinate-microperforate	elliptic-circular
	2622	echinate-microperforate	amorph
A. biebersteinii	1496	echinate-microperforate	elliptic-circular
	1440	echinate-microperforate	elliptic-circular
	1521	echinate-microperforate	elliptic-circular
	1454	echinate-microperforate	elliptic-circular
	1750	echinate-microperforate	elliptic-circular
	2182	echinate-microperforate	elliptic-circular
	1424	echinate-microperforate	amorph
	1588	echinate-microperforate	elliptic-circular
	1590	echinate-microperforate	elliptic-circular
	2185	echinate-microperforate	amorph
	1382	echinate-rugulate-microperforate	few, elliptic-circular
	1386	echinate-microperforate	amorph
	1402	-	-
	1399	echinate-microperforate	-
	1410	echinate-microperforate	-
	2245	echinate-microperforate	-
	2226	echinate-microperforate	-
A. cappadocica	1562b	echinate-microperforate	-
	1913a	echinate-microperforate	-
	1567a	echinate-rugulate-microperforate	few, circular
	1568a	echinate-microperforate	elliptic-circular
	2186	echinate-rugulate-microperforate	few, elliptic-circular

species such as *A. coarctata* and *A. biebersteinii,* which have diploid or tetraploid specimens (Guo et al., 2004). According to Ehrendorfer (1949) and Brochman (1992), pollen grain size is frequently correlated with the ploidy level of the gamete. Sharbel et al. (2005) reported that some of the pollen-size variation resulted from differences in chromosome number. Ten *A. coarctata* and 17 *A. biebersteinii* specimens collected from different localities showed variations in mean P, E, and minimal and maximal measurements (Table 1). The polyploidy level or gamete divisions in microsporogenesis may be the cause of this variation. However, variations are also observed in specimens of *A. nobilis* subsp. *neilreichii*, *A. nobilis* subsp. *densissima,* and *A. filipendulina* collected from different localities, but these taxa are known as diploids within the section *Achillea* (Guo et al., 2004). It is possible that polyploidy specimens occurred in these species. In addition, 5 specimens of *A. cappadocica* collected from different localities were examined. Similarly, wide variations were seen in the mean P/E ratios and minimal and maximal measurements of pollen grains (Table 1). As far as we know, the chromosome number of this endemic species is unknown.

The general aperture form of the genus *Achillea* was reported as tricolporate in previous studies (Wodehouse, 1935; Erdtman, 1943; Skvarla & Turner, 1966; Nilsson et al., 1977; Skvarla et al., 1977; Moore & Webb, 1983; Moore et al., 1991; Faegri & Iverson, 1992; Yang & Ai, 2002; Meo & Khan, 2003; Jafari & Ghanbarian, 2007; Punt & Hoen, 2009). The aperture forms of the specimens examined in the present study were generally tricolporate. Some species, such as *A. nobilis* subsp. *densissima*, *A. nobilis* subsp. *sipylea*, *A. filipendulina*, *A. biebersteinii,* and *A. cappadocica* have both tricolporate and tetracolporate aperture forms (Figures 1-2, 4-5). A specimen from *A. biebersteinii* also shows pentacolporate aperture form (Figure 4, Table 1). Some studies indicated that the different ploidy levels of the sporophyte were usually considered as the main cause of pollen heteromorphism and variations in pollen size-aperture type (Erdtman, 1969; Aytuğ, 1967; İnceoğlu, 1973; Borsch & Wilde, 2000; Pınar et al., 2009).

The pollen wall structures of the examined specimens are in good agreement with the Anthemoid type described by Vezey et al. (1994); they generally consist of a double tectum with vertical unbranching infratectal columellae joined at proximal and distal rounded expansions to form an external and internal tectal layer (Figure 9). The pollen ornamentations were established as echinate in LM, and echinate-microperforate and echinate-rugulate-microperforate in SEM analyses (Figures 6-11, Table 2).

In conclusion, the pollen morphologies of the examined species of *Achillea* sect. *Achillea* are heterogeneous, both between species and subspecies, and between specimens of the same species/subspecies collected from different localities. These variations could be an indication of different ploidy levels. This study is an initial part of a larger study planned on the palynological features of all Turkish *Achillea* species. With subsequent studies, the palynological variations between species and their taxonomical significance will be determined.

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