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Pollen morphology in the genus *Bolanthus* (Ser.) Reichb. (Caryophyllaceae) in Turkey

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Abstract

Bolanthus including 11 species and all endemic in Turkey. Pollen morphology that belong to the genus *Bolanthus* were investigated using light microscopy (LM) and scanning electron microscopy (SEM). In this study, all of 11 species in *Bolanthus* were studied. Pollen of seven species were determined from Turkey and reported for the first time. Pollen shape has two different ornamentation at genus *Bolanthus* as prolate-spheroidal and oblate-spheroidal. Pollen grains are polipantoporate and isopolar symmetrical. The pollen ornamentation is scabrate-perforate. Pollen diameter, pore diameter, pore numbers, exine thickness, operculum diameter, distance between two pores, spinule numbers, punctum numbers are varying characters between *Bolanthus* species. The taxonomic separations of the species have been demonstrated with SPSS analysis as dendrogram.

Keywords: *Bolanthus*, Caryophyllaceae, LM, pollen, SEM

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1. INTRODUCTION

Caryophyllaceae is a large family in terms of the number of species and genus for Turkey [1-2-3]. The Caryophyllaceae family contains about 86 genera and about 2200 species. This family is generally common in temperate regions [4]. The tribe Caryophylleae includes 17 genera, namely *Acanthophyllum* C. A. Mey., *Dianthus* L., *Gypsophila* L., *Petrorhagia* (Ser. ex DC.) Link, *Saponaria* L., *Vaccaria* Medic., *Allochrusa* Bunge ex Boiss., *Ankyropetalum* Fenzl, *Bolanthus* (Ser.) Reichb., *Cyathophylla* Bocquet et Strid, *Diaphanoptera* Rech. f., *Kohlrauschia* Kunth, *Ochotonophila* Gilli, *Phrynella* Pax et K. Hoffm., *Pleioneura* Rech. f., Scleranthopsis Rech. f. and *Velezia* L. and about 600 species [4].

The family Caryophyllaceae of genus *Bolanthus* is located in the Caryophylleae tribes in the subfamily Caryophylloideae. It is perennial plants in the form of slants or pillows. The leaves are small, stripy and flowers dicazium. The genus *Bolanthus* comprising 29 species, mostly occurring in the Mediterranean region in the world. The genus is represented by six taxa found in Syria, Palestine, Israel and Lebanon [5-7]. The eight taxa growing in Europe are known from Greece or the East Aegean Islands [8]. The flora of Turkey includes five *Bolanthus* taxa. As a result of recent studies, six additional taxa were added to *Bolanthus*, of which one is an overlooked species (*B. huber-morathii* C. Simon) and five are new species (*B. stenopetalus* Hartvig & Strid, *B. mevlaneae* Aytaç, *B. turcicus* Koç & Hamzaoğlu, *B. sandrasicus* Hamzaoğlu & Koç, *B. aziz-sancarii* Koç & Hamzaoğlu) [9-10-11-12]. Together with these additions, the number of taxa belonging to the genus *Bolanthus* that occur in Turkey increased to 11, all of which are endemic.

There are many studies on pollen morphology of Caryophylleae [15-16-17-18-19-20-21]. Palynological characteristics of Caryophyllaceae such as pore shape, number of pores and ornamentation are proved to have taxonomical importance [22-23-24-25-26-27-28]. Using palynological features, scientists identified new species and also distinguished new species from other similar species [29-30-31-32-33].

The aim of this study is determined the pollen morphology of the genus *Bolanthus* and contributing to taxonomy. For this purpose, the pollen morphology of 11 endemic species of *Bolanthus* have studied by using scanning electron microscopy (SEM) and light microscopy (LM). In addition, taxonomic relationships between species have been revealed.

2. MATERIALS AND METHODS

The pollen of 11 taxa of genus *Bolanthus* were examined with light microscopy (LM) and scanning electron microscopy (SEM) (Figure 1 and 2).

The localities of the specimens are given below Table 1. After the plants were diagnosed and pollen materials the plants were left in the Gazi University Herbarium (GAZI) for storage. Saffron with glycerine-gelatin was used for staining pollen. Pollen grains were prepared for light microscopy (LM) using [34].

The pollens were photographed with a spot in-sight colour digital camera on a LEICA DM1000 microscope with digital imaging system which is Leica Application Suit program equipped with an apochromatic 100x oil immersion objective [34]. Morphological observations were carried out in microscope in the LM of Ankara University.

For scanning electron microscopy, each of the pollen was attached on stubs applying double-sided adhesive tape. Every sample was coated with a 100-Å-thick layer of gold in a Polaron SC7620 rotating and tilting vacuum coating apparatus for 60 s and scanned using a JEOL 5600 LV SEM (Scanning Electron Microscopy) with 20-kV accelerating voltage [35-36]. Morphological observations were carried out in a Jeol 5600 electron microscope in the Electron Microscopy Laboratory of Gazi University.

Pollen ornamentation, operculum ornamentation, pollen diameter, pore diameter, pollen shape, distance between two pore, operculum diameter, pore numbers, spinule numbers, number of spinules on operculum, punctum numbers, punctum diameter, exine and intine thickness measurements were made with 20 to 30 pollen grains. Measurements were made with AlaMet 0.06 program. The average of the measured samples was calculated with Microsoft Office Excel Programme. Pollen morphologies were determined by using glossary of pollen and spore terminology [37]. The taxonomic separation of the species has been demonstrated with SPSS software analysis as dendrogram (Figure 3).

3. RESULTS AND DISCUSSION

Bolanthus including 11 species and all endemic in Turkey. Pollen morphology of four species from this genus was reported from Turkey [38]. Pollen morphology of the other seven species was determined for the first time in this study. Pollen in the Caryophyllaceae family are generally radially symmetrical, apolar or isopolar, spheroidal, polygonal or polygonal spheroidal, oblate-spheroidal, prolate spheroidal, periporate or pantopoliporate [13-18-38-39-23-40-41]. The findings of the study shows, *Bolanthus* taxa pollens are isopolar symmetry, shape of pollen is oblate-spheroidal (9 species) and prolate-spheroidal (2 species). The pollen ornamentation have been observed scabrate-perforate.

Our results are consistent with those reported by Pınar [38] who worked on *B. minuartioides, B. spergulifolius, B. thymoides, B. frankenioides* var. *fasciculatus* and *B. turcicus.* Likewise, in the species, pollen shape is polipantoporate. Pollen and pore diameters are similar average. Pınar's of the study [38], pollen is spheroidal. In our study, pollen is prolate-spheroidal and oblate-spheroidal. However, in this study, exine thickness was measured about 1.3 µm while Pınar's of the study as 2 µm in this species [38]. When our study was compared to Pınar's study, the exine thickness was measured as thinner. In addition, in this study, it was determined that *B. minuartioides* taxa have a fewer number of pores. Pore numbers of the others taxa are similar average.

The pollen characteristics of *Bolanthus* taxa in 11 species were listed in detail in Table 2. All characters were evaluated under the separate titles. In addition, the pollen morphologies of *Bolanthus* taxa were compared with related genera. Moreover, the taxonomic separations of the species were demonstrated as dendrogram (Figure 3).

Cluster analysis divided the taxa into 2 groups: clusters as number of pores which is A and B. Cluster A was divided into 2 subgroups according to the distance between the pores: A1 (*B. turcicus, B. stenopetalus, B. cherlierioides, B. aziz-sancarii and A2 (B. minuartioides*). Cluster B was divided into 2 subgroups according to the spinule number: B2 (*B. frankenioides*) and B1, which B1 was further divided C1 and C2 according to punctum number. C1 are *B. frankenioides* var. *fasciculatus, B. thymoides, B. huber-morathii* and *B. mevlanae* C2 is *B. spergulifolius* (Figure 3). The data obtained and the cluster analysis results are consistent with each other.

3.1. Evaluation of the findings of *Bolanthus* taxa

3.1.1. Pollen shape

The findings of the study shows, pollen shape have 2 different at genus *Bolanthus*. prolate-spheroidal (*B. spergulifolius, B. huber-morathii*) and oblate-spheroidal (*B. thymoides, B. aziz-sancarii, B. frankenioides, B. frankenioides* var. *fasciculatus, B. cherlerioides, B. stenopetalus, B. minuartioides, B. turcicus, B. mevlanae*). All the species are isopolar symmetrical. Another study, pollen grains of *Bolanthus* taxa in 4 species (*B. minuartioides, B. spergulifolius, B. thymoides and B. frankenioides* var. *fasciculatus*) were determined as spheroidal [38]. In additon to the pollen grains of *Acanthophyllum, Dianthus, Gysophila, Bolanthus* have spheroidal [44]. In the literature, *B. filicaulis* species pollen is radially symmetrical and spheroidal [16]. *Bolanthus* is isopolar symmetrical.

3.1.2. Pollen ornamentation

The findings demonstrated that, pollen grains ornamentation have scabrate-perforate (Figure 2, Table 2). However, another study, pollen grains of four Turkish endemic *Bolanthus* taxa belong to *B. minuartioides, B. spergulifolius, B. thymoides* and *B. frankenioides* var. *fasciculatus* were detected tectate-perforate [38].

The pollen ornamentation was observed scabrate, scabrate-perforate ve scabrate-perforate-foveolate for *Dianthus* taxa [45]. Silenoideae, a subgroup of the Caryophyllaceae family, is usually characterized by polypantoporate [15]. Likewise *Bolanthus* taxa pollen aperture type are polypantoporate.

3.1.3. Pollen diameter

The largest pollen diameter has been observed in *Bolanthus turcicus* as 30.33±1.14 μm (mean±standard deviation), the smallest in *Bolanthus frankenioides.* var. *fasciculatus* as 22.30±0.30 μm (mean±standard deviation) (Table 2). The pollen grains of *Acanthophyllum, Dianthus, Gysophila, Bolanthus* are spheroidal. The pollen grains of *Acanthophyllum* with a diameter of 28.65–30.87 μm, *Dianthus* 30.05–40.22 μm and *Gypsophila* 16.95–27.77 μm [44]. The pollen grains of *Bolanthus* has been measured as 22.23-30.33 μm. In terms of pollen diameter, *Bolanthus* is generally smaller than *Acanthophyllum* and *Dianthus*, larger than *Gypsophila.*

3.1.4. Pore diameter

The largest pore diameter has been observed in *B. thymoides* as 4.25±0.63 μm (mean ± standard deviation), the smallest in *B. mevlanae* as 2.31±0.40 μm (mean ± standard deviation) (Table 2). The pore diameter was measured as 2.2-9.3 μm for *Dianthus* taxa [45]. The biggest species *Silene bupleuroides* subsp. *bupleuroides* with 6.96±1.65 μm whereas the smallest species *Silene cartilaginea* with 3.54±0.66 μm of the pore diameter [42]. Pore diameter of *Bolanthus* taxa is smaller than *Silene and Dianthus.*

3.1.5. Distance between two pores (μm^2)

The findings shows that the largest species *B. minuartioides* with 6.75±2.01 μm (mean±standard deviation) while the smallest species *B. turcicus* with 3.90±1.07 μm (mean±standard deviation) of the distance between two pores. In the literature, *Gypsopila* and *Dianthus* have been measured as 4.69-9.86, 9.42-13.07 μm respectively [44]. Comparing the distance between pores, *Bolanthus* is different from *Dianthus*, similar to *Gypsophila.* Therefore, the distance between pores of *Dianthus* are more than *Bolanthus*.

3.1.6. Pore numbers

The results demonstrated that the highest species *B. spergulifolius* with 22±3 while the lowest species *B. minuartioides* with 10±3 (Table 2) of the pore numbers. In another study, pore numbers have been detected as 21-22 in *B. minuartioides* and *B. spergulifolius* 19-22 [38]. Therefore, in this study, it was determined that *B. minuartioides* taxa have a fewer number of pores. In the literature, pore numbers are determined as 10-16 in *Acanthophyllum, Dianthus, Gysophila* [44]. Likewise, *Bolanthus* pollen is 10-22 pores.

3.1.7. Operculum diameter

The largest operculum diameter has been observed in *Bolanthus thymoides* as 3.33±0.53 μm, the smallest in *Bolanthus turcicus* as 1.19±0.22 μm (Table 2). The operculum diameter was measured as 1.2-5.2 μm for *Dianthus* taxa [45]. *Saponaria karapinarensis* (Caryophyllaceae) have operculum diameter 2 μm [43] Similarly, *Bolanthus* taxa have been measured as approximately 2 μm.

3.1.8. Exine thickness

The findings indicated that, the largest species *B. stenopetalus* with 1.47±0.14 μm (mean±standard deviation) while the smallest species *B. turcicus* with 0.94±0.11 μm (mean±standard deviation) (Table 2) of the exine thickness. In the literature, *Bolanthus filicaulis* was measured 2 μm [16]. In our study, exine thickness have determined as more thinner compered to other studies. *Petrorhagia,* which is close to the *Bolanthus*

genus, have been measured from 1.73 µm to 3.78 µm [25]. In another study, exine thickness was determined as above 2 for all studied taxa [38]. In our study, exine thickness have been detected as about 1.3.

3.1.9. Intine thickness

The largest intine thickness has been observed in *B. thymoides* as 0.66±0.10 µm (mean±standard deviation), the smallest in *B. frankenioides* as 0.47±0.07 µm (mean±standard deviation) (Table 2). In another study, the intine thickness was measured as 0.4-1.1 µm for *Dianthus* taxa [45].

3.1.10. Spinule and punctum numbers

The most spinule numbers have been observed in *B. frankenioides* as 24-26, the least species *B. minuartioides as* 8-10.

The most punctum numbers have been determinated in *B. spergulifolius* as 15-17, the least in *B. frankenioides* as 3-5 (Table 2). All species have differed when compared within themselves. In the literature, the spinule and punctum numbers have been measured as 9-28 and 1-23 µm for *Dianthus* taxa [45].

3.2. Description:

3.2.1. *B. spergulifolius* pollen features: Pollen shape is prolate-spheroidal (P/E=1.06). In general aspect pollen is isopolar. Polar axis is 26.44±0.77 µm, equatorial axis is 24.93±1.98 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate-perforate. Pore numbers are 19-25. Pore diameter is 2.59±0.27 µm. The distance between two pores are 3.94±1.81 µm. Operculum diameter is 1.31±0.15 µm. Number of spinules on operculum are 5-7. Number of spinule is 13-16. Number of punctum is 15-17. Exine thickness is 1.39±0.09 µm. Intine thickness is 0.60±0.08 µm (Table 2, Figure 1, 1 a-b-c, Figure 2, 1 a-b).

3.2.2. *B. huber-morathii* pollen features: Pollen shape is prolate-spheroidal (P/E=1.04). In general aspect pollen is isopolar. Polar axis is 25.32±0.51 µm, equatorial axis is 24.25±0.71 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate-perforate. Pore numbers are 13-19. Pore diameter is 3.22±2.65 µm. The distance between two pores are 4.83±1.42 µm.

Operculum diameter is 1.72±0.31 µm. Number of spinules on operculum are 6-8. Number of spinule is 13-16. Number of punctum is 11-13. Exine thickness is
1.33±0.07 µm. Intine thickness is 0.56±0.10 µm (Table 2, Figure 1, 2 a-b-c, Figure 2, 2 a-b).

3.2.3. *B. frankenioid*es pollen features: Pollen shape is oblate-spheroidal (P/E=0.95). In general aspect pollen is isopolar. Polar axis is 22.91±0.28 µm, equatorial axis is 23.99±0.23 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate-perforate. Pore numbers are 17-23. Pore diameter is 2.81±0.25 µm. The distance between two pores are 4.02±1.43 µm. Operculum diameter is 1.67±0.20 µm. Number of spinules on operculum are 4-6. Number of spinule is 24-26. Number of punctum is 3-5. Exine thickness is 1.30± 0.10 µm. Intine thickness is 0.47±0.07 µm (Table 2, Figure 1, 3 a-b-c, Figure 2, 3 a-b).

3.2.4. *B. frankenioides* var. *fasciculatus* pollen features: Pollen shape is oblate-spheroidal (P/E=0.97).). In general aspect pollen is isopolar. Polar axis is 23.71±0.56 µm, equatorial axis is 24.23±0.80 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate- perforate. Pore numbers are 15-21. Pore diameter is 3.51±0.40 µm. The distance between two pores are 4.17±1.78 µm. Operculum diameter is 2.65±0.32 µm. Number of spinules on operculum are 4-6. Number of spinule is 16-18. Number of punctum is 7-9. Exine thickness is 1.35±0.09 µm. Intine thickness is 0.66±0.08 µm (Table 2, Figure 1, 4 a-b-c, Figure 2, 4 a-b).

3.2.5. *B. minuartioides* pollen features: Pollen shape is oblate-spheroidal (P/E=0.97). In general aspect pollen is isopolar. Polar axis is 25.86±0.64 µm, equatorial axis is 26.43±0.68 µm. Pollen type is polipantoporate. Pollen

ornamentation is scabrate- perforate. Pore numbers are 7-13. Pore diameter is 3.75±0.87 µm. The distance between two pores are 6.75±2.01 µm. Operculum diameter is 1.89±0.35 µm. Number of spinules on operculum are 5-7. Number of spinule is 8-10. Number of punctum is 10-12. Exine thickness is 1.31±0.07 µm. Intine thickness is 0.55±0.07 µm (Table 2, Figure 1, 5 a-b-c, Figure 2, 5 a-b).

3.2.6. *B. cherlierioides* pollen features: Pollen shape is oblate-spheroidal (P/E=0.91). In general aspect pollen is isopolar. Polar axis is 21.74±0.29 µm, equatorial axis is 23.86±0.29 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate-perforate. Pore numbers are 11-17. Pore diameter is 3.02±1.64 µm. The distance between two pores are 4.21±1.41 µm. Operculum diameter is 1.39±0.30 µm. Number of spinules on operculum are 4-6. Number of spinule is 15-18. Number of punctum is 4-6. Exine thickness is 0.96±0.12 µm. Intine thickness is 0.57±0.07 µm (Table 2, Figure 1, 6 a-b-c, Figure 2, 6 a-b).

3.2.7. *B. turcicus* pollen features: Pollen shape is oblate-spheroidal (P/E=0.95). In general aspect pollen is isopolar. Polar axis is 27.11±0.62 µm, equatorial axis is 28.47±0.34 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate- perforate. Pore diameter is 4.25±0.63 µm. The distance between two pores are 4.83±1.12 µm.Operculum diameter is 3.33±0.53 µm. Number of spinules on operculum are 7-9. Number of spinule is 16-18. Number of punctum is 9-11. Exine thickness is 0.94±0.06 µm. Intine thickness is 0.66±0.10 µm (Table 2, Figure 1, 9 a-b-c, Figure 2, 9 a-b).

3.2.10. *B. aziz-sancarii* pollen features: Pollen shape is oblate-spheroidal (P/E=0.92). In general aspect pollen is isopolar. Polar axis is 23.36±0.45 µm, equatorial axis is 25.14±0.35 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate- perforate. Pore numbers are 13-19. Pore diameter is 3.91±0.35 µm. The distance between two pores are 5.19±1.56 µm. Operculum diameter is 2.48±0.52 µm. Number of spinules on operculum are 7-9. Number of spinule is 10-12. numbers are 11-17. Pore diameter is 2.78±0.31 µm. The distance between two pores are 3.90±1.07 µm. Operculum diameter is 1.19±0.22 µm. Number of spinules on operculum are 5-7. Number of spinule is 12-15. Number of punctum is 4-6. Exine thickness is 0.94±0.11 µm. Intine thickness is 0.50±0.11 µm (Table 2, Figure 1, 7 a-b-c, Figure 2, 7 a-b).

3.2.8. *B. mevlanae* pollen features: Pollen shape is oblate-spheroidal (P/E=0.97). In general aspect pollen is isopolar. Polar axis is 23.26±0.24 µm, equatorial axis is 23.79±0.72 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate- perforate. Pore numbers are 15-21. Pore diameter is 2.31±0.40 µm. The distance between two pores are 3.98±1.42 µm. Operculum diameter is 1.60±0.39 µm. Number of spinules on operculum are 4-6. Number of spinule is 13-15. Number of punctum is 9-11. Exine thickness is 1.25±0.09 µm. Intine thickness is 0.59±0.10 µm (Table 2, Figure 1, 8 a-b-c, Figure 2, 8 a-b).

3.2.9. *B. thymoides* pollen features: Pollen shape is oblate-spheroidal (P/E=0.99). In general aspect pollen is isopolar. Polar axis is 23.32±0.49 µm, equatorial axis is 23.53±0.43 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate- perforate. Pore numbers are 13-19. Pore

Number of punctum is 4-6. Exine thickness is 1.13±0.12 µm. Intine thickness is 0.65±0.06 µm (Table 2, Figure 1, 10 a-b-c, Figure 2, 10 a-b).

3.2.11. *B. stenopetalus* pollen features: Pollen shape is oblate-spheroidal (P/E=0.92). In general aspect pollen is isopolar. Polar axis is 20.84±0.38 µm, equatorial axis is 22.56±0.65 µm. Pollen type is polipantoporate. Pollen ornamentation is scabrate-perforate. Pore numbers are 11-17. Pore diameter is 3.06±0.31 µm. The distance between two pores are 6.03±1.79 µm. Operculum diameter is 2.39±0.32 µm. Number of spinules on operculum are 5-7. Number of spinule is 13-15. Number of punctum is 4-6. Exine thickness is 1.47±0.14 µm. Intine thickness is 0.54±0.28 µm (Table 2, Figure 1, 11 a-b-c, Figure 2, 11 a-b).

Specimens examined

Table 1
List of the studied *Bolanthus* taxa and localities

Taxa	Collector Name and Number	Localities
B. spergulifolius	Koç 2043	B2 Kütahya: Gediz, Murat Mountain, Kaplıcalar road, serpentine soils, grassy levels, 1495 m, 25.06.2016
B. huber-morathii	Koç 2352	A2 Bursa: Between Soğukpınar and Keles, on the way out Soğukpınar, 40˚30'80" K – 29˚70'20", 930 m, 19.07.2016
B.frankenioides	Koç 2167	C3 Burdur: Altınyayla southwestern, Akpınar yaylası around limestone slopes, 1865 m, 04.08.2016
B.frankenioides var. fasciculatus	Koç 2188	C2 Muğla: Köyceğiz, Yayla village, Gökçeova lake around, Sandras Mountain, serpentine rocky, 2030 m, 05.08.2017
B. minuartioides	Koç 2006	B2 Kütahya: Aslantepe, between Çavdar and Hisar, calcareous rocks, 1090 m, 24.06.2015
B. cherlerioides	Koç 3054	B4 Between Akşehir and Şarkikaraağaç, Yellibel gateway around, slopes around, 38˚14'06" K- 031˚19'36" D, 1550 m, 14.07.2017
B. turcicus	Koç 2226	B4 Aksaray: Karkın Beldesi, Karbeyaz Hotel around, Hasan Mountain to the south, 2760 m, 07.08.2016
B. mevlanaea	Koç 3365	C3 Antalya: Between Akseki and Bozkır, 60. km, Gölcük kuruçay tableland, 1200 m, 23.07.2017
B. thymoides	Koç 1848	C3 Burdur: Between Yeşilova and Salda Village, Eşeler Mountain, watchtower around, serpantine, stony places, 37˚27'50" K – 29˚39'30" D, 2000 m, 18.08.2016
B. aziz-sancarii	Koç 1209	B3 Afyonkarahisar: between Bayat and Iscehisar, 1500 m, 02.07.2010
B. stenopetalus	Koç 2196	C2 Muğla: Köyceğiz, Yayla village, Gökçeova lake around, Sandras Mountain, 2030 m, 05.08.2017

Table 2
Pollen morphological characters of the *Bolanthus* taxa analyzed

	B.spergulifolius	*B.huber-morathii*	*B.frankenioides*	*B. frankenioides var. fasciculatus*	*B.minuartioides*
Pollen diameter (M±SD)	26.50±0.31	23.56±0.32	23.68±0.48	22.23±0.30	26.42±0,23
Polar axes (M±SD)	26.44±0.77	25.32±0.51	22.91±0.28	23.71±0.56	25.86±0.64
Equatorial axes (M±SD)	24.93±0.70	24.25±0.71	23.99±0.23	24.23±0.80	26.43±0.68
Pollen shape	Prolate-spheroidal	Prolate-spheroidal	Oblate-spheroidal	Oblate-spheroidal	Oblate-spheroidal
Pollen ornamentation	Scabrate-Perforate	Scabrate-Perforate	Scabrate-Perforate	Scabrate-Perforate	Scabrate-Perforate
Exine thickness (M±SD)	1.39±0.09	1.33±0.07	1.30± 0.10	1.35±0.09	1.31±0.07
Intine thickness (M±SD)	0.60±0.08	0.56±0.10	0.47± 0.07	0.66±0.08	0.55±0.07
Pore diameter (M±SD)	2.59±0.27	3.22±2.65	2.81±0.25	3.51±0.40	3.75±0.87
Number of pore	22±3	16±3	20±3	18±3	10±3
Distance between two pores (M±SD)	3.94±1.81	4.83±1.42	4.02±1.43	4.17±1.78	6.75±2.01
Operculum diameter (M±SD)	1.31±0.15	1.72±0.31	1.67±0.20	2.65±0.32	1.89±0.35
Number of spinule ($10\mu m^2$)	13-16	13-16	24-26	16-18	8-10
Number of spinules on operculum	5-7	6-8	4-6	4-6	5-7
Number of punctum ($10\mu m^2$)	15-17	11-13	3-5	7-9	10-12

	B.cherlierioides	*B.turcicus*	*B.mevlanae*	*B.thymoides*	*B.aziz-sancarii*	*B.stenopetalus*
Pollen diameter (M±SD)	23.06±0.43	30.33±1.14	25.71±0.93	24.76±0.38	24.25±0.39	23.86±0.36
Polar axes (M±SD)	21.74±0.29	27.11±0.62	23.26±0.24	23.32±0.49	23.36±0.45	20.84±0.38
Equatorial axes (M±SD)	23.86±0.29	28.47±0.34	23.79±0.72	23.53±0.43	25.14±0.35	22.56±0.65
Pollen shape	Oblate-spheroidal	Oblate-spheroidal	Oblate-spheroidal	Oblate-spheroidal	Oblate-spheroidal	Oblate-spheroidal
Pollen ornamentation	Scabrate – Perforate	Scabrate – Perforate	Scabrate – Perforate	Scabrate – Perforate	Scabrate – Perforate	Scabrate – Perforate
Exine thickness (M±SD)	0.96±0.12	0.94±0.11	1.25±0.09	0.94±0.06	1.13±0.12	1.47±0.14
Intine thickness (M±SD)	0.57±0.07	0.50±0.11	0.59±0.10	0.66±0.10	0.65±0.06	0.54±0.28
Pore diameter (M±SD)	3.02±1.64	2.78±0.31	2.31±0.40	4.25±0.63	3.91±0.35	3.06±0.31
Number of pore	14±3	14±3	18±3	16±3	16±3	14±3
Distance between two pores (M±SD)	4.21±1.41	3.90±1.07	3.98±1.42	4.83±1.12	5.19±1.56	6.03±1.79
Operculum diameter (M±SD)	1.39±0.30	1.19±0.22	1.60±0.39	3.33±0.53	2.48±0.52	2.39±0.32
Number of spinule ($10\mu m^2$)	15-18	12-15	13-15	16-18	10-12	13-15
Number of spinules on operculum	4-6	5-7	4-6	7-9	7-9	5-7
Number of punctum ($10\mu m^2$)	4-6	4-6	9-11	9-11	4-6	4-6

Abbreviations: M – mean value; SD – standard deviation

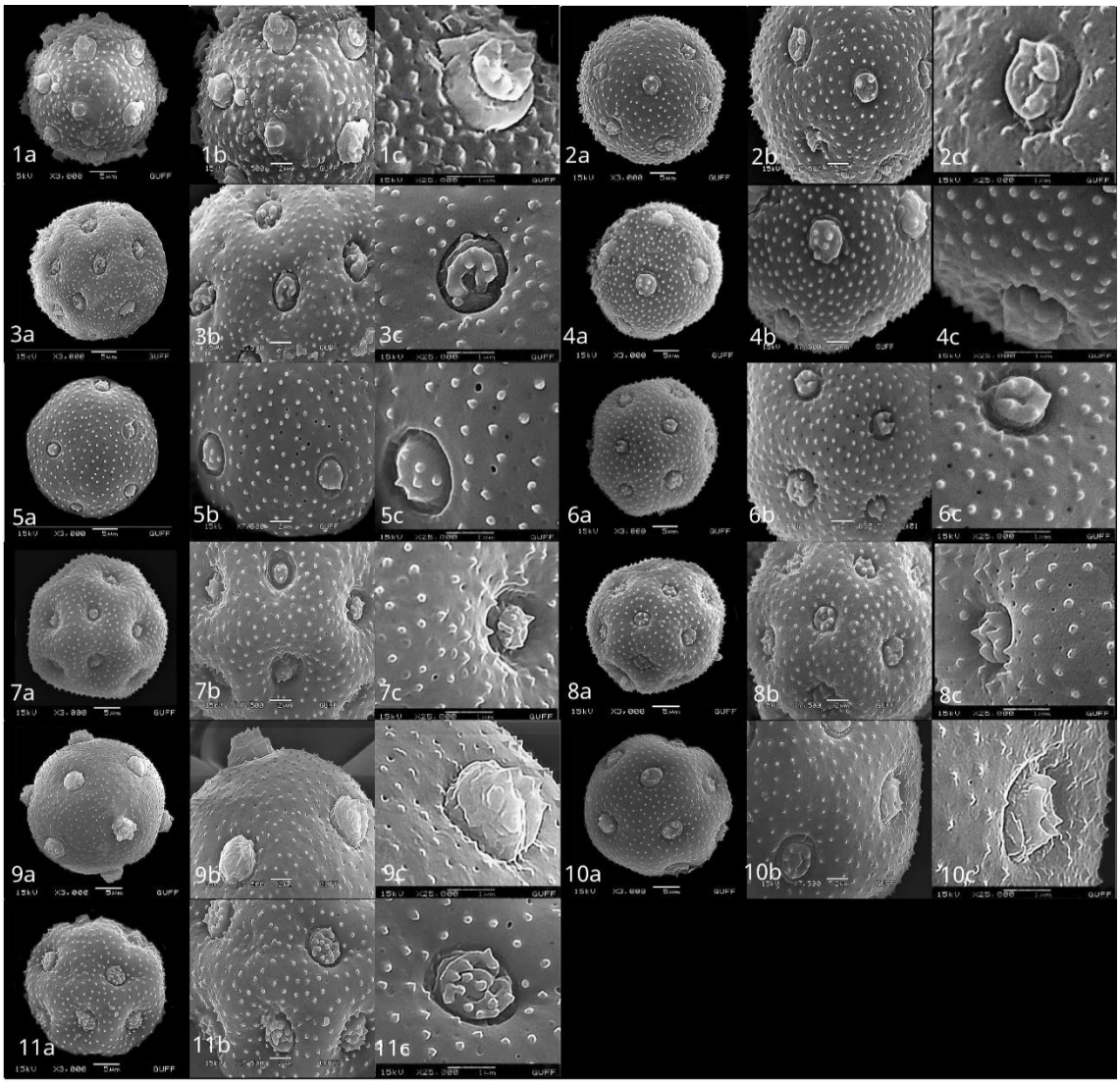

Figure 1 SEM photos of pollen grains of studied *Bolanthus* taxa: 1a-1b-1c: *B. spergulifolius,* 2a-2b-2c: *B. huber-morathii*, 3a-3b-3c: *B. frankenioides*, 4a-4b-4c: *B. frankenioides* var. *fasciculatus*, 5a-5b-5c: *B. minuartioides*, 6a-6b-6c: *B. cherlerioides*, 7a-7b-7c: *B. turcicus,* 8a-8b-8c: *B. mevlanae,* 9a-9b-9c: *B. thymoides,* 10a-10b-10c: *B. aziz-sancarii,* 11a-11b-11c: *B. stenopetalus*

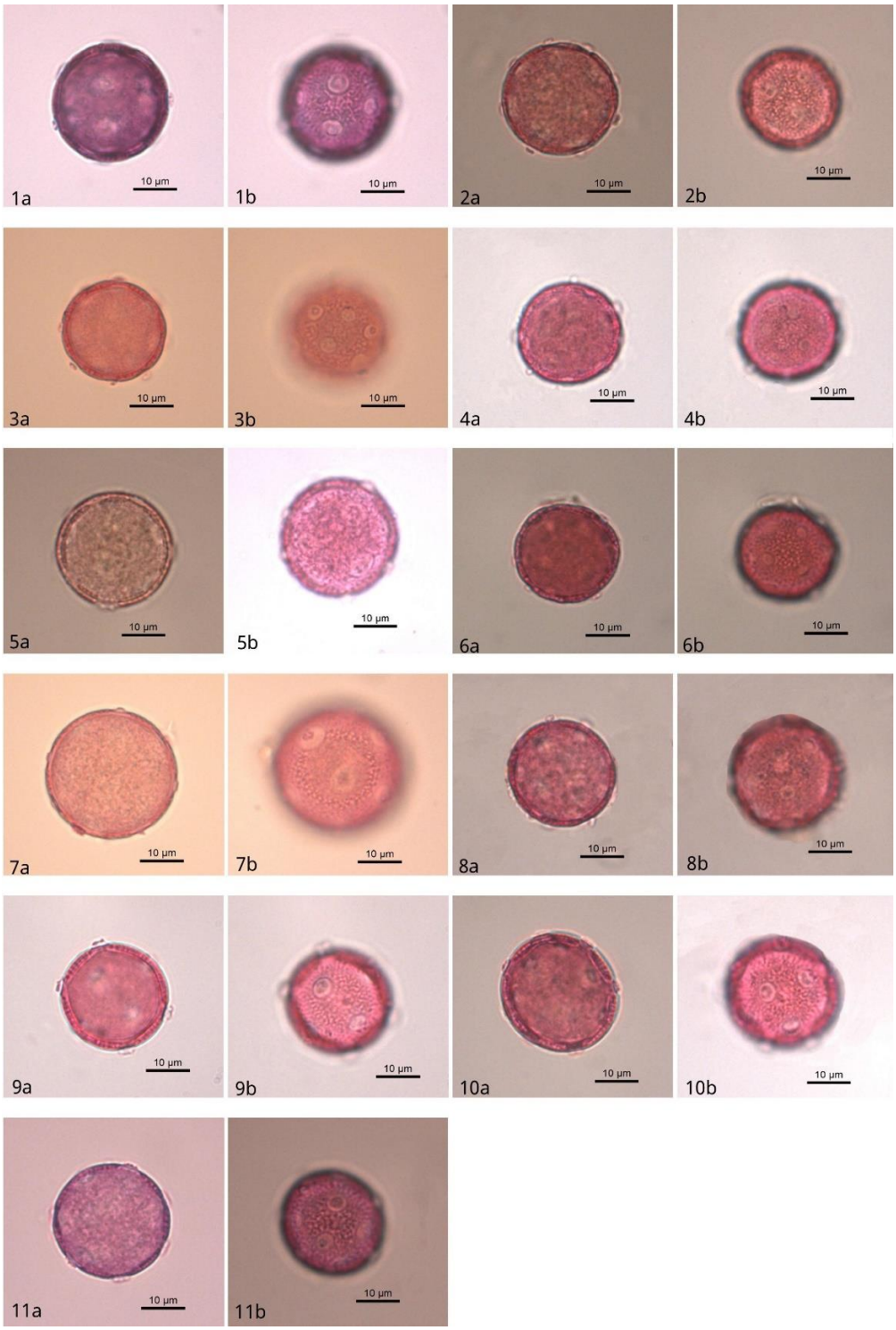

Figure 2 LM photos of pollen grains of studied *Bolanthus* taxa: 1a-1b: *B. spergulifolius*, 2a-2b: *B. hubermorathii*, 3a-3b: *B. frankenioides*, 4a-4b: *B. frankenioides* var. *fasciculatus*, 5a-5b: *B. minuartioides*, 6a-6b: *B. cherlerioides*, 7a-7b: *B. turcicus*, 8a-8b: *B. mevlanae*, 9a-9b: *B. thymoides*, 10a-10b: *B. azizsancarii*, 11a-11b: *B. stenopetalus*

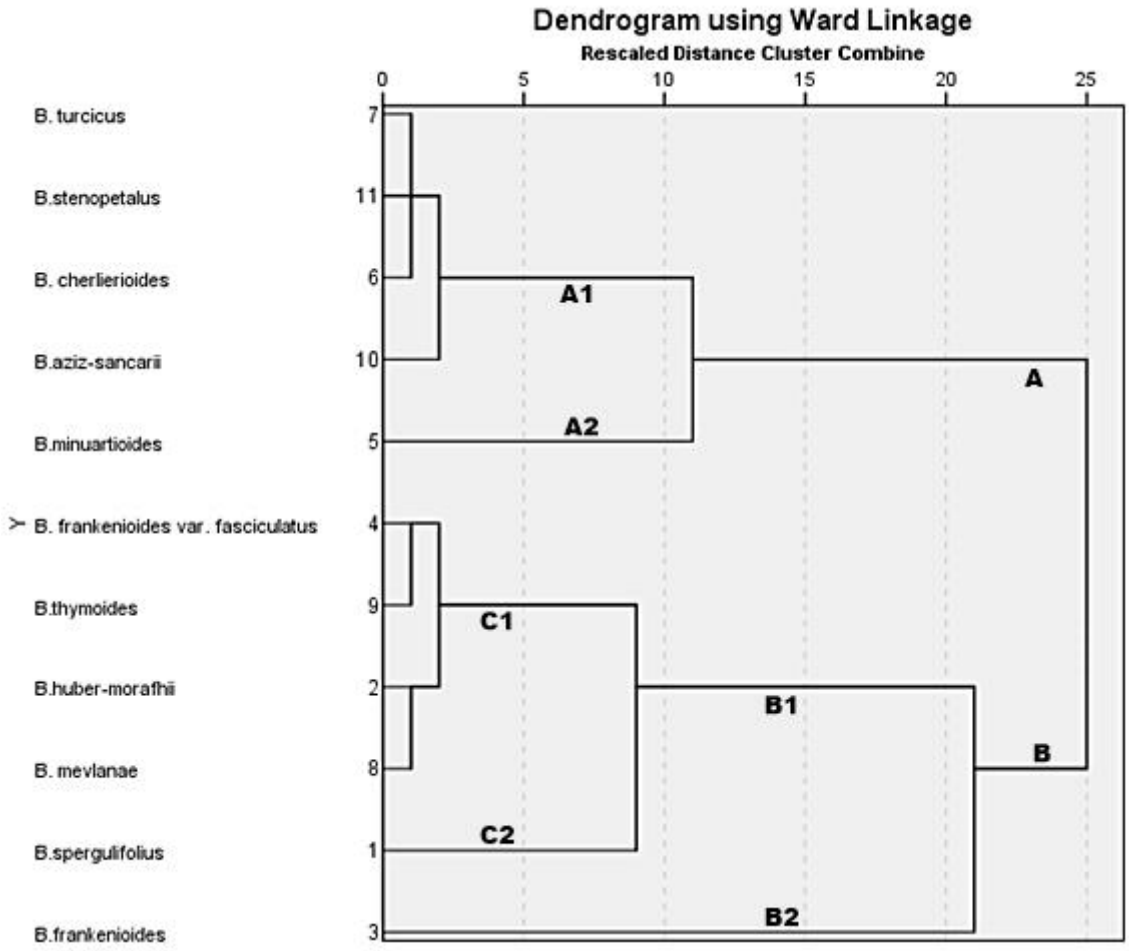

Figure 3 Cluster dendrogram showing species similarities based on pollen micro-morphological data

4. CONCLUSION

The findings of the study shows, pollen ornamentations and pollen shape to be important morphological characteristics for the systematics of the taxa. Pollen grains are isopolar symmetrical. The pollen grains of the *Bolanthus* taxa are oblate spheroidal and prolate spheroidal. The pollen grains are polipantoporate. The pollen ornamentation of all taxa is scabrate-perforate. Morphological structures of pollen seem to be useful for distinguish taxa. The outcomes of the study could be benefited in taxonomical studies.

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Authors' Contribution

Y.C: Literature research, data collection, organize the execution of the study, contribution

to article writing and study, data entry and measurement, create an idea.

M.N.T: Contribution to article writing and study, data entry and measurement.

M.K: Provision of the plant material, provide a working environment and tools, create an idea.

The Declaration of Ethics Committee Approval

The authors declare that this document does not require an ethics committee approval or any special permission.

The Declaration of Research and Publication Ethics

The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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