



## A Survey of the Morphology, Anatomy, and Palynology of Endemic *Bornmuellera kiyakii* and *B. glabrescens* (Brassicaceae) From Turkey

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### Highlights

- The anatomy of *Bornmuellera* genus are determined for the first time.
- Two types of leaf shape are defined: (1) linear, (2) triangular.
- Fruit and seed shape and colors are the most discriminative characteristics.
- In the species analyzed the pollen grains is similar.

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### Abstract

In the present study, the morphological, anatomical, and palynological properties of 2 *Bornmuellera* Hausskn. taxa, which are endemic to Turkey, were examined. *B. kiyakii* Aytac & Aksoy is known from the province of Konya, growing in serpentine areas, and *B. glabrescens* (Boiss. & Balansa) Cullen & T. R. Dudley is known from the province of Niğde. Through morphological analyses, the characteristics of the taxa were designated and the descriptions were expanded. The morphology of the stem, leaf, trichomes, and capsule are essential to separate the examined taxa. The anatomical analyses showed that the taxa had similar anatomical root, stem, and leaf tissue layers; however, their rows, and mesophyll thickness were different between the taxa. Anatomical traits, such as the presence of an endodermis in *B. kiyakii*, the pith region in the cross-sections of the stems, linear-shaped leaf in *B. glabrescens*, and triangular-shaped leaf in *B. kiyakii* have taxonomic importance. The pollen grains of the studied taxa were tricolpate, isopolar, and radial symmetrical, prolate-spheroidal, and had reticulate ornamentation. The fruit of *B. kiyakii* were characterized by globose, asymmetrical, and yellow-purplish-pink valves with rugose ornamentation, which clearly differed from that of *B. glabrescens*, which had ovoid, symmetrical, and light green-yellow valves. The seed traits clearly appeared to have taxonomic significance. The seeds of *B. glabrescens* were orbicular-shaped, yellowish-brown in colour, with reticulate ornamentation; however, the seeds of *B. kiyakii* were oblong-elliptic-shaped, and the tile was red-brown in colour.

## 1. INTRODUCTION

The family Brassicaceae, or mustard family, is a monophyletic group of about 338 genera and 3709 species with global distribution [1,2]. An evaluation of its morphology and generic circumscriptions, and a new tribal alignment was proposed by Al-Shehbaz [3]. According to this paper, 49 tribes were recognized. The genus *Bornmuellera* belongs to the tribe Alysseae [3,4] and includes 7 species distributed from the south-western Balkan Peninsula to Anatolia [5].

Haussknecht (1965) described the genus as having non-saccate deciduous sepals, white flowers with obtuse petals, filaments with appendages at the base, sessile subglobose glabrous fruit, and 2 seeds in each locus [6]. Recent molecular phylogenetic analyses of the tribe Alysseae [7] revealed that the monotypic genera *Leptoplax* Schulz and *Physocardamum* Hedge phylogenetically nest within *Bornmuellera*, and thus should be included within it [8]. In a recent paper, the tribe Alysseae was revised according to its chromosome numbers and ploidy-level estimates, and the genus *Bornmuellera* was accepted as having 9 taxa [9], of

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which *Bornmuellera angustifolia* (Hausskn. ex Bornm.) Cullen & T. R. Dudley, *Bornmuellera baldaccii* (Degen) Heywood, *Bornmuellera davisii* (Hedge) Rešetnik, *Bornmuellera dieckii* Degen, *Bornmuellera emarginata* (Boiss.) Rešetnik, and *Bornmuellera tymphaea* (Hausskn.) Hausskn. are endemics to the Balkans; and *Bornmuellera cappadocica* (Willdenow) Cullen & T. R. Dudley, *Bornmuellera glabrescens*, and *Bornmuellera kiyakii* are endemics to Turkey.

In fact, a large data gap exists regarding anatomical and micromorphological studies for this species. Only morphological descriptions are presented in Flora of Turkey and East Aegean Islands [6,10]. Hence, the main goal of this study was to determine the detailed morphological, anatomical, palynological, and micromorphological properties of *Bornmuellera kiyakii* and *B. glabrescens*, which are morphologically very similar species, and provide useful data for the systematics of the genus.

## 2. MATERIAL AND METHODS

### 2.1. Plant Sampling

The field excursion for the studied taxa took place in the provinces of Konya (*Bornmuellera kiyakii*) and Niğde (*B. glabrescens*) in Turkey at different times (Table 1). Some of the collected materials were dried for morphological analysis, while others were stored in 70% ethanol for anatomical analysis. All of the specimens were deposited in the KNYA herbarium. Flora of Turkey and Aytaç & Aksoy were followed for the herbarium specimens, which were examined using several morphological characters [6,10]. For the pollen grain observations, dried mature anthers were used from the herbarium materials.

**Table 1.** The localities of information for the studied taxa

Taxa	Locality	Herbarium No.
<i>B. kiyakii</i>	C3 Konya: Derebucak, Çamlık Village, Kızıldağ, 1400–1500 m., 16.06.2014	<i>H. Dural</i> 3527– <i>H. Demirelma, B. Çıtak</i>
<i>B. glabrescens</i>	C5 Niğde: Mazmılı Mountain, 25.06.2014, 1800–1850 m.	<i>H. Dural</i> 3532– <i>A. Savran</i>

### 2.2. Morphological Measurements

For each taxa, 15 specimens were studied for the morphological analyses and a minimum of 20 fruit and seed were used for the micromorphological analyses. All of the morphological characters were measured at least 10 times using either a ruler or Verner calliper. In light of these studies, the description of these species was expanded. Fruit and seeds were measured using a Vernier caliper and then photographed using a light microscope (LM) and later with Zeiss Evo LS10 scanning electron microscope (SEM). The Łangowski classification was used for the fruit and seed terminology [11]. Moreover, the trichomes of the examined taxa were directly investigated under a SEM. The classification systems of Ančev [12] and Goranova and Mutlu [13] were used for the trichome micromorphology terminology.

### 2.3. Anatomical Techniques

The paraffin method was used for the LM observations [14]. Sections of the roots, stems, and leaves were dehydrated in a graduated series of ethanol (70%–100%) and then embedded in paraffin blocks, which were later cut into cross-sections of between 10–12 µm thick using a Thermo Scientific Shandon Finesse 325 rotary microtome. The cross-sections were stained using safranin-fast green and observed under a Leica DM 1000 LM. If the paraffin method was unsuccessful, the cross-sections were then cut by hand using a razor blade. The handmade cross-sections and superficial sections were stained with phloroglucinol-HCl. On average, 20 preparations were made for each type of section for the 20 pieces of plant material, and the cell groups were measured at least 30 times (Table 2).

## 2.4. Palynological Method

The pollen grains were taken from the anthers and placed on glass slides, which were treated with 96% ethyl alcohol. Later, the glass slides were heated, and glycerin-gelatin with safranin was added, followed by mounting with Entellan [15]. Measurements and observations were made using a Leica DM 1000 LM attached to a Canon EOS 450D camera. A minimum of 30 pollen grains were measured using several palynological characters (Table 3). For the SEM observations, unacetolyzed pollen grains were first mounted on a double-sided carbon tape affixed to aluminium stubs, then covered with gold using a Cressington Auto 108 sputter coater, and photographed using a Zeiss Evo LS10 SEM. The pollen terminology of Punt et al. was followed [16].

## 3. RESULTS

### 3.1. Morphological Characterization

#### *Bornmuellera kiyakii*

Perennial herb, 7.5–15.3 cm, very branched from the base. Stems erect, 5.3–9.1 cm, sparsely hairy, hairs malpighiaceae (bifurcate). Leaves basal forming rosettes, filiform, 4–19 × 0.4–0.5 mm, glabrescent to indumentum few malpighiaceae (bifurcate) or 3–4 branched hairs, stem leaves absent or few, similar to basal leaves but smaller. Inflorescences unbranched, corymbose, 12–20 flowered, elongating in fruit. Pedicel 2–7 mm in flowers, 4–11 mm in fruit, patent with sparse malpighiaceae (bifurcate) hairs. Sepals yellowish to greenish, elliptic, 2–3 × 2–3 mm, with hyaline margins, with a few malpighiaceae (bifurcate) hairs. Petals white, orbicular, 3.5–4.5 × 2.5–3.5 mm attenuate into 1–2 mm claw, rounded at apex. Filaments linear, 1–2.5 mm, with a small tooth at base, anthers 0.3 × 0.6 mm, white-cream; nectaries one on each side of the short stamens. Ovary globose, 1–2 × 1–2 mm, glabrous; 4-ovulate (2 mature, 2 immature); style 0.5–0.7 mm in fruit; stigma capitate. Mature siliculae globose, inflated, 5.13 × 3.45 mm. Seeds ovoid, 2.49 × 1.61 mm. Flowering time May–June, 1400–1500 m., at the openings of *Pinus nigra* forest (Figure 1-a).

#### *Bornmuellera glabrescens*

Perennial herb, 23–36 cm. Stems erect, 13–27 cm, sparsely hairy, malpighiaceae (bifurcate) hairs. Leaves basal forming rosettes, oblanceolate, 7–21 × 0.5–1.5 mm, malpighiaceae (bifurcate) hairs. Inflorescence unbranched, corymbose, 5–12 flowered, elongating in fruit. Pedicel 3–8 mm in flower, 5–9 mm in fruit, patent with sparse malpighiaceae (bifurcate) hairs. Sepals greenish, elliptic, 1–2 × 1.5–2 mm, with hyaline margins, with a few malpighiaceae (bifurcate) hairs. Petals white-cream, orbicular, 3–4 × 3.2–4 mm attenuate into 1–2 mm claw, rounded at apex. Filaments linear, 1–2 mm, with a small tooth at the base, anthers 0.24 × 0.29 mm, white-cream; nectaries one on each side of the short stamens. Ovary globose, 0.6–1.5 × 0.5–1.5 mm, glabrous; 4-ovulate (2 mature, 2 immature); style 0.2–0.7 mm in fruit; stigma capitate. Mature siliculae ovoid, inflated, 6.59 × 4.67 mm. Seeds ovoid, 3.45 × 3.12 mm. Flowering time May–June, 1800–1850 m (Figure 1-b).



**Figure 1.** The general appearance of the studied *Bornmuellera* genus; (a) *Bornmuellera kiyakii* (b) *B. glabrescens*

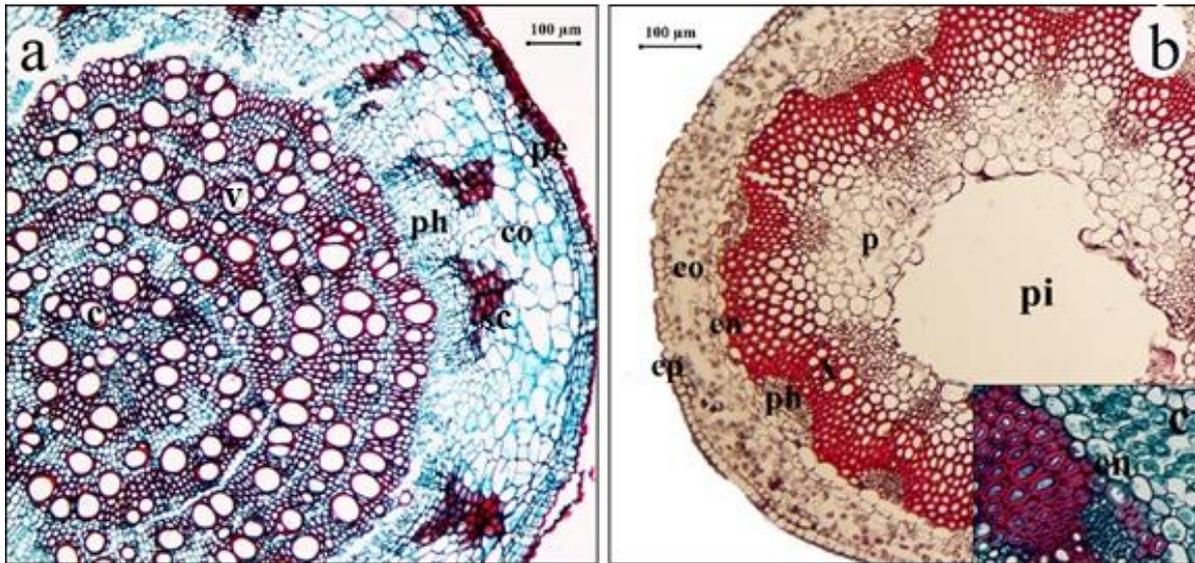
### 3.2. Anatomical Characterizations

#### *Bornmuellera kiyakii*

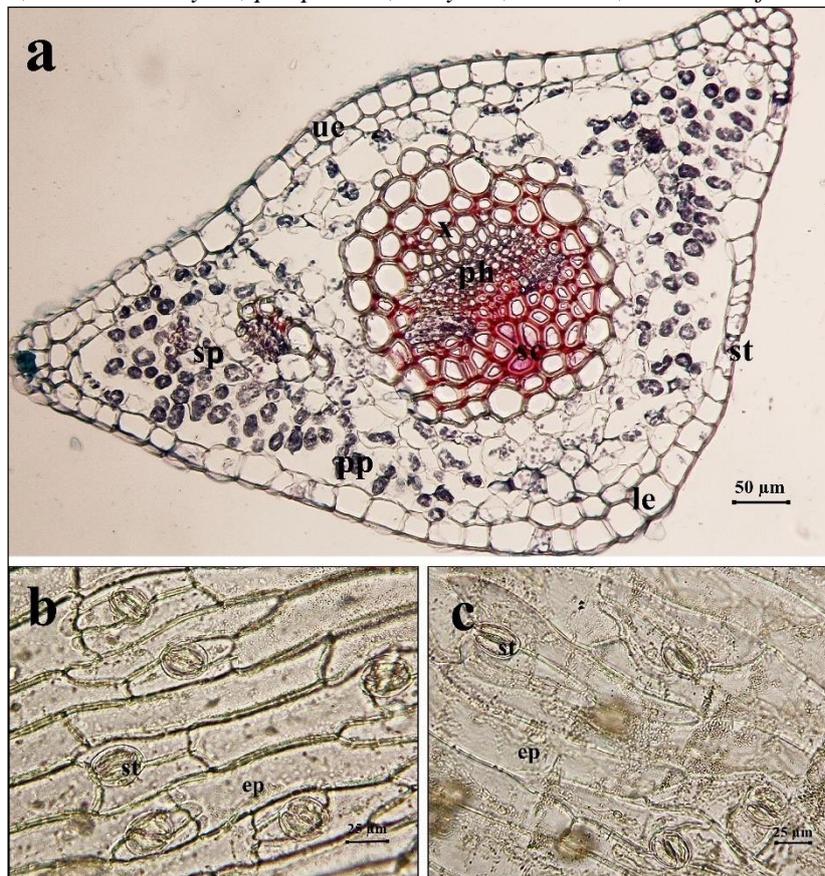
**Root:** The outermost surface of the root had a peridermis as a protective tissue that was  $50.46 \pm 4.29 \mu\text{m}$  thick (Table 2). Phellem cells were arranged in 4 or 5 layers and rectangular in shape. However, the phellogen and phelloderm cells were not explicitly distinguished in the root cross-sections. The cortex parenchyma comprised 9–11 rows and was rectangular-oval in shape. The fibre caps were located between the cortex parenchyma cells and were agglomerate. They were pentagon-shaped and between 4–10 layers. The conducting tissue (xylem and phloem) was well developed and the cambium could not be distinguished clearly. The xylem tissue contained many more vessels and they were oval in shape. The centre of root was full of xylem (Figure 2-a).

**Stem:** The epidermis limited the cross-sections of the stems in their outermost surfaces. It was composed of a single layer that was oval–rectangular-shaped. Over the epidermis cells, there was a cuticle layer that was approximately  $4 \mu\text{m}$  thick (Table 2). Oval-shaped cortex parenchyma cells with abundant chloroplasts followed the epidermis, which was composed of 4–5 layers. A single row of endodermis cells (starch sheath) could be distinguished easily. Vascular bundles lined the inside of the phloem and outside of the xylem. The pith had a large cavity and the pith cells were characterized as parenchymatic (Figure 2-b).

**Leaf:** The cross-sections of the leaves were triangular in shape. Both surfaces had an epidermis, which was single-rowed, and covered by a cuticle (thickness;  $5 \mu\text{m}$ ). The mesomorphic stomata were on both sides of the leaves. The mesophyll tissue was composed of 2 types of cells, palisade and sponge parenchyma (equifacial type), and it was about  $275 \mu\text{m}$  thick (Table 2). Vascular bundles were collateral and the middle part was larger than the others (Figure 3-a). In the superficial sections, which were taken from the upper and lower surfaces of the leaves, the stomata were anisocytic (Figure 3-b,c).



**Figure 2.** *Bornmuellera kiyakii*; a) Cross section of the root b) Cross section of the stem c) Endodermis. ep: epidermis, en: endodermis (starch sheath), p: parenchyma cell, pi: pith region pe: peridermis, co: cortex parenchyma, sc: sclerenchyma, ph: phloem, x: xylem, v: vessel, c: centre of the root



**Figure 3.** *Bornmuellera kiyakii*; a) Cross section of the leaf b) Superficial section of the upper surface of the leaf c) Superficial section of the lower surface of the leaf. ue: upper epidermis, le: lower epidermis, pp: palisade parenchyma, sp: spongy parenchyma, x: xylem, ph: phloem, sc: sclerenchyma, st: stomata, ep: epidermis

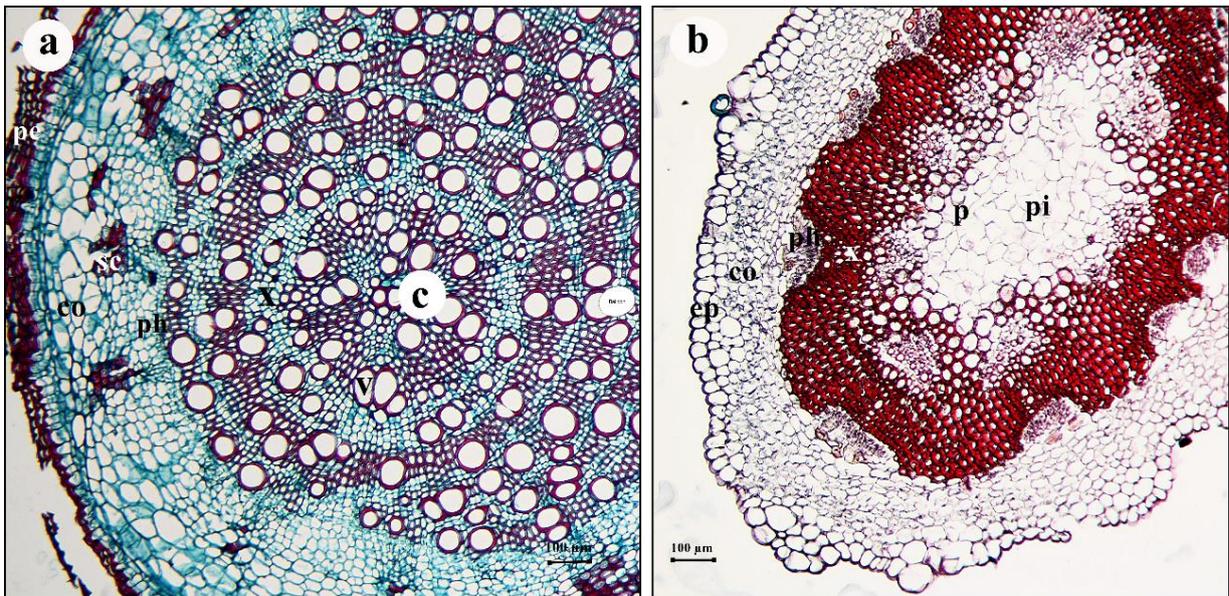
### *Bornmuellera glabrescens*

**Root:** The cross-sections of the root had a secondary root structure. The peridermis was about 60 µm and was surrounded by the roots (Table 2). The phellem was composed of 4 or 5 layers of rectangular-shaped

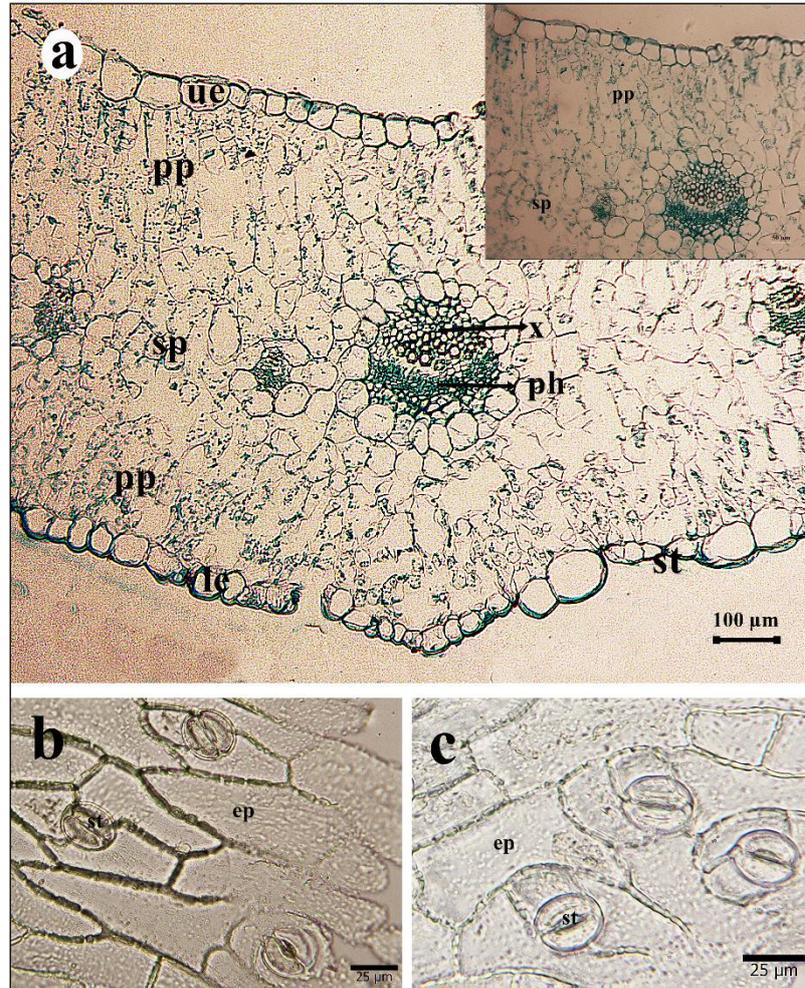
cells. The phellogen and phelloderm cells were not clearly distinguished in the root cross-sections. The cortex parenchyma comprised 9–11 rows, and it was pentagonal–oval-shaped, and followed the peridermis towards the centre. Between the cortex cells, there were 3–11 layers of sclerenchymatic cells. The cambium could not be distinguished clearly and the phloem was fewer in number and size than the xylem. The xylem covered a large area around the centre of the root. The xylem contained many more vessels and they were oval in shape (Figure 4-a).

**Stem:** There were 4 anatomical parts; the epidermis, cortex, vascular bundles, and pith region. The epidermis was a single layer that was oval–rectangular in shape. The cortex was composed of 6–7 layers of parenchymatic cells. The phloem covered a small area and there were a few phloem fibres over it. The xylem covered a large area in the stem. The pith was composed of isodiametric parenchymatic cells (Figure 4-b).

**Leaf:** The cross-sections of the leaves were linear in shape. The epidermis was single-layered on both sides of the leaf. There were 2 types of cells that could be distinguished in the mesophyll tissue, palisade parenchyma, and spongy parenchyma cells, and it was about 555  $\mu\text{m}$  thick (Table 2). The vascular bundle (collateral type), which was in the middle part of the leaves, was bigger than the others (Figure 5-a). In the Superficial sections, which were taken from the upper and lower surfaces of the leaves, the stomata were anisocytic and the leaves were amphistomatic (Figure 5-b,c).



**Figure 4.** *Bornmuellera glabrescens*; a) Cross section of the root b) Cross section of the stem. pe: peridermis, co: cortex parenchyma, sc: sclerenchyma, ph: phloem, x: xylem, v: vessel, c: centre of the root, ep: epidermis, p: parenchyma cell



**Figure 5.** *Bornmuellera glabrescens*; a) Cross section of the leaf b) Superficial section of the upper surface of the leaf c) Superficial section of the of lower surface of the leaf. ue: upper epidermis, le: lower epidermis, pp: palisade parenchyma, sp: spongy parenchyma, x: xylem, ph: phloem, st: stomata, ep: epidermis

**Table 2.** Measurements of the anatomical characteristics of the studied taxa

			Length (µm)			Width (µm)		
			Min	Max	Mean ± SD	Min	Max	Mean ± SD
<i>Bornmuellera kiyakii</i>	Root	Peridermis				41.29	54.64	50.46 ± 4.29
		Cortex cells	11.33	23.41	18.38 ± 2.82	25.21	46.77	35.09 ± 6.13
		Sclerenchyma				13.67	28.8	20.06 ± 4.23
		Vessels				11.78	53.46	30.42 ± 13.6
	Stem	Cuticle				2.45	5.99	3.96 ± 0.81
		Epidermis	11.78	17.34	14.11 ± 1.89	9.32	15.67	12.96 ± 1.91
		Cortex cells				7.61	18.62	12.34 ± 2.32
		Sclerenchyma				6.61	28.06	13.33 ± 4.42
	Leaf	Upper cuticle				2.96	7.27	5.11 ± 1.09
		Upper epidermis	13.26	25.79	21.32 ± 3.78	12.11	30.79	22.88 ± 5.95
		Mesophyll				255.45	303.39	274.64 ± 19.5
		Palisade parenchyma	16.58	39.97	28.87 ± 6.03	7.18	15.11	11.79 ± 2

Min: minimum, Max: maximum, SD: Standard deviation

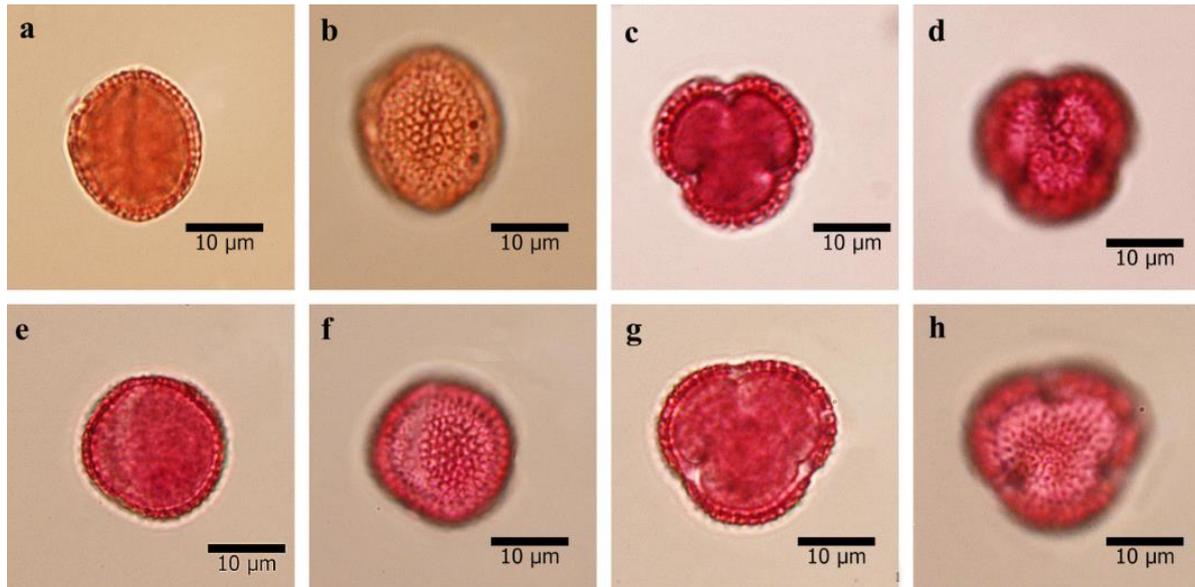
Borrmuellera glabrescens		Spongy parenchyma				12.27	37.38	23.19 ± 5.67
		Lower epidermis	13.71	32.07	20.71 ± 5.92	15.3	36.37	22.71 ± 6.46
		Lower cuticle				3.17	6.63	4.84 ± 1
	Root	Peridermis				45.84	64.18	56.59 ± 6.51
		Cortex cells	9.58	35.85	22.49 ± 7.5	16.22	67.12	41.26 ± 13.61
		Sclerenchyma				7.56	24.15	15.1 ± 4.31
		Vessels				24.83	51.82	38.27 ± 7.88
	Stem	Cuticle				4.25	7.68	5.78 ± 0.86
		Epidermis	20.8	40.38	26.53 ± 5.14	11.78	31.05	21.78 ± 5.9
		Cortex cells				12.04	22.27	17.35 ± 3.06
		Sclerenchyma				8.95	24.7	16.41 ± 4.82
	Leaf	Upper cuticle				4.29	14.64	7.47 ± 2.33
		Upper epidermis	24.37	42.38	33.8 ± 5.26	17.4	71.42	40.57 ± 13.59
		Mesophyll				515.7	600.16	554.64 ± 36.6
		Palisade parenchyma	32.59	91.43	56.91 ± 12.6	15.76	28.65	21.38 ± 3.56
		Spongy parenchyma				25.03	56.39	38.98 ± 8.93
		Lower epidermis	15.44	45.92	30.37 ± 7.13	15.27	62.53	33.21 ± 11.82
		Lower cuticle				3.17	5.79	4.54 ± 0.78

### 3.3. Palynological Characteristics

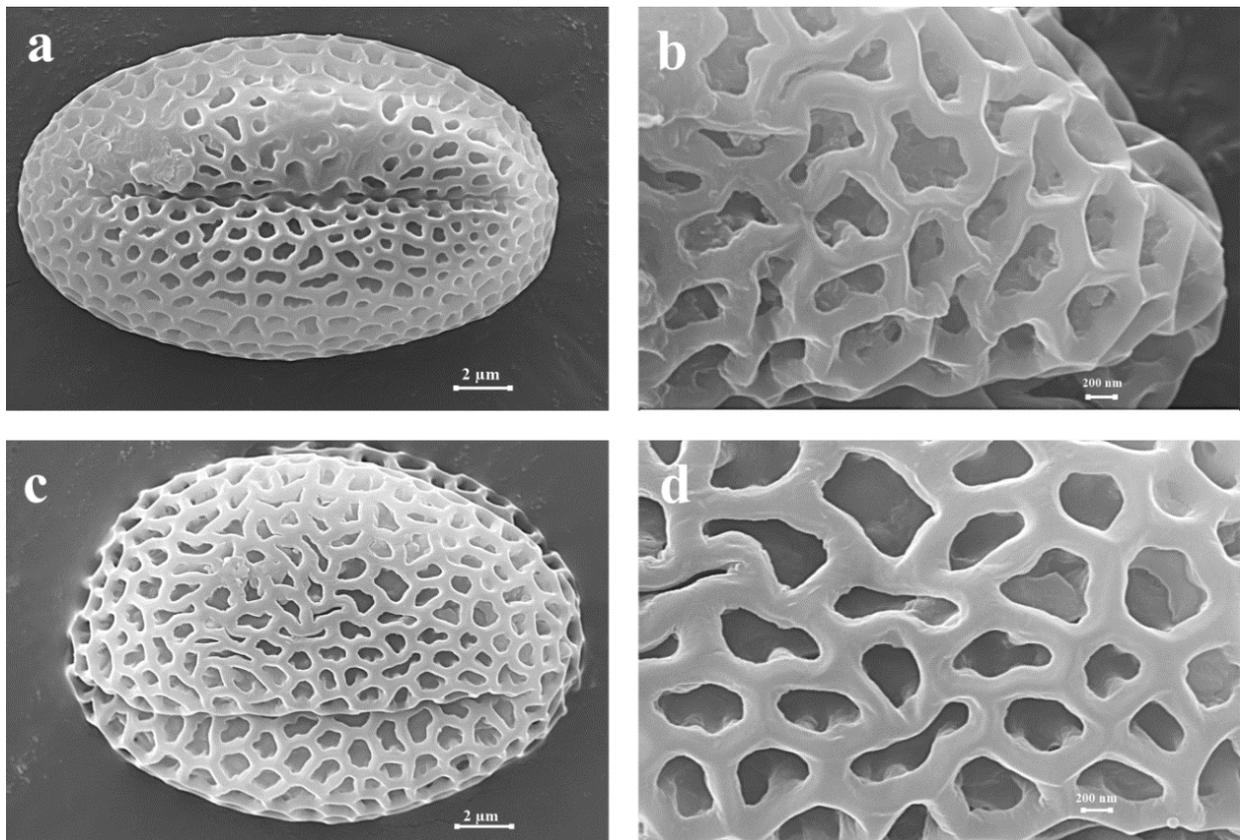
Pollen grains of *B. kiyakii* were monad, isopolar, and tricolpate (Figures 6, 7). The pollen grains were prolate-spheroidal in shape, the polar axis was 20.02 (±1.13) µm, and the equatorial axis was 19.7 (±0.77) µm, P/E 1.14. The pollen grains were triangular from a polar view and the Amb was 5 (±0.46) µm. The apocolpium was 10.41 (±1.71) µm. The colpi were long and narrow, Clg was 18.23 (±1.31) µm, Clt was 1.56 (±0.22) µm, and the distance between the 2 colpi was 7.63 (0.07) µm. The exine was very thin, 1.28 (±0.11) µm and intine was 0.62 (0.04) µm. The exine ornamentation was identified as reticulate under LM and SEM (Figures 6-a,d and 7-b).

Pollen grains of *B. glabrescens* were monad, isopolar, and tricolpate. The pollen grains were prolate-spheroidal in shape, the polar axis was 19.7 (±0.77) µm, and the equatorial axis was 18.48 (±1.17) µm, P/E 1.06. The pollen grains were circular in polar view, and the Amb was 7.51 (±0.6) µm. The apocolpium was 13.03 (±2.18) µm. The colpi were long and narrow, Clg was 18.36 (±1.59) µm, Clt was 2.08 (±0.33) µm, and the distance between the 2 colpi was 10.52 (0.67) µm. The exine was very thin, 1.64 (±0.33) µm and intine was 0.92 (0.13) µm. The exine ornamentation was identified as reticulate under LM and SEM (Figures 6-e,g,h and 7-d,c).

A summary of the pollen characters and measurements of the studied taxa is summarized in Table 3.



**Figure 6.** Pollen morphology of *Bornmuellera kiyakii* (a–d) and *B. glabrescens* (e–h) via LM



**Figure 7.** Pollen morphology of a,b) *Bornmuellera kiyakii* and c,d) *B. glabrescens* via SEM

**Table 3.** Pollen morphological data of *B. kiyakii* and *B. glabrescens*

Pollen characteristics	<i>B. kiyakii</i>	<i>B. glabrescens</i>
Equatorial axis (E)	$19.7 \pm 0.77 \mu\text{m}$	$18.48 \pm 1.17 \mu\text{m}$
Polar axis (P)	$20.02 \pm 1.13 \mu\text{m}$	$19.7 \pm 0.77 \mu\text{m}$
P/E	1.14	1.06
Pollen shape	Prolate-spheroidal	Prolate-spheroidal
Colpus length (Clg)	$18.23 \pm 1.31 \mu\text{m}$	$18.36 \pm 1.59 \mu\text{m}$
Colpus width (Clt)	$1.56 \pm 0.22 \mu\text{m}$	$2.08 \pm 0.33 \mu\text{m}$

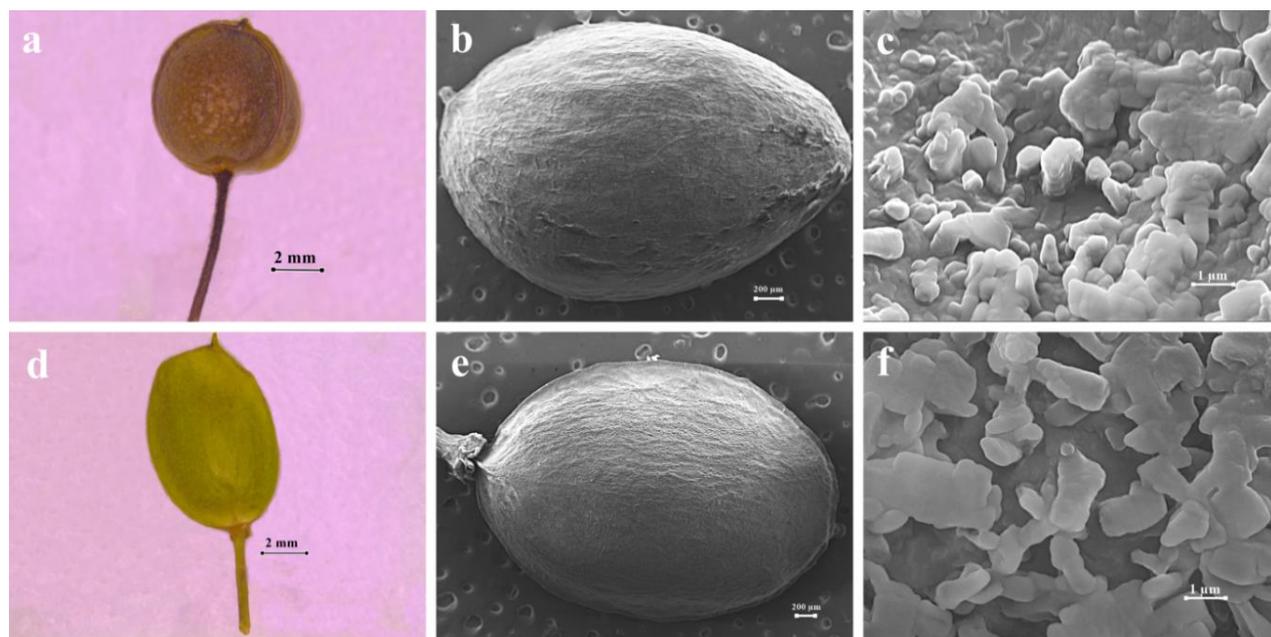
Intercolpus distance	$7.63 \pm 0.07 \mu\text{m}$	$10.52 \pm 0.67 \mu\text{m}$
Apocolpium	$10.41 \pm 1.71 \mu\text{m}$	$13.03 \pm 2.18 \mu\text{m}$
Amb	$5 \pm 0.46 \mu\text{m}$ , triangular	$7.51 \pm 0.6 \mu\text{m}$ , circular
Intine	$0.62 \pm 0.04 \mu\text{m}$	$0.92 \pm 0.13 \mu\text{m}$
Exine	$1.28 \pm 0.11 \mu\text{m}$	$1.64 \pm 0.33 \mu\text{m}$
Structure	Tectate	Tectate
Sculpture	Reticulate. Muri are asymmetric, $0.72 \pm 0.25 \mu\text{m}$ thick.	Reticulate. Muri are asymmetric, $0.96 \pm 0.18 \mu\text{m}$ thick.

### 3.4. Micromorphological Characteristics

#### Fruit features

The fruit of *B. kiyakii* were globose,  $3.43 \times 5.13$  mm, the fruit length/width ratio was 1.49, and the apex and base of the fruit was round. There was no trichome over the fruit, but the style and replum were present, at  $0.32 \pm 0.07$  mm. The septum was membranous. Valve was asymmetrical and transparent. The larger valve was yellow, while the smaller one was purplish-pink. The fruit had rugose ornamentation (Figure 8-a,b,c).

The fruit of *B. glabrescens* were ovoid,  $4.67 \times 6.59$  mm, the fruit length/width ratio was 1.41, and the apex and base of the fruit was round. There was no trichome over the fruit, but the style and replum were present, at  $0.46 \pm 0.06$  mm. The septum was membranous. Valve was symmetrical, leather-like, and coarse. The valve was light greenish-yellow. The fruit had rugose ornamentation (Figure 8-d,e,f).



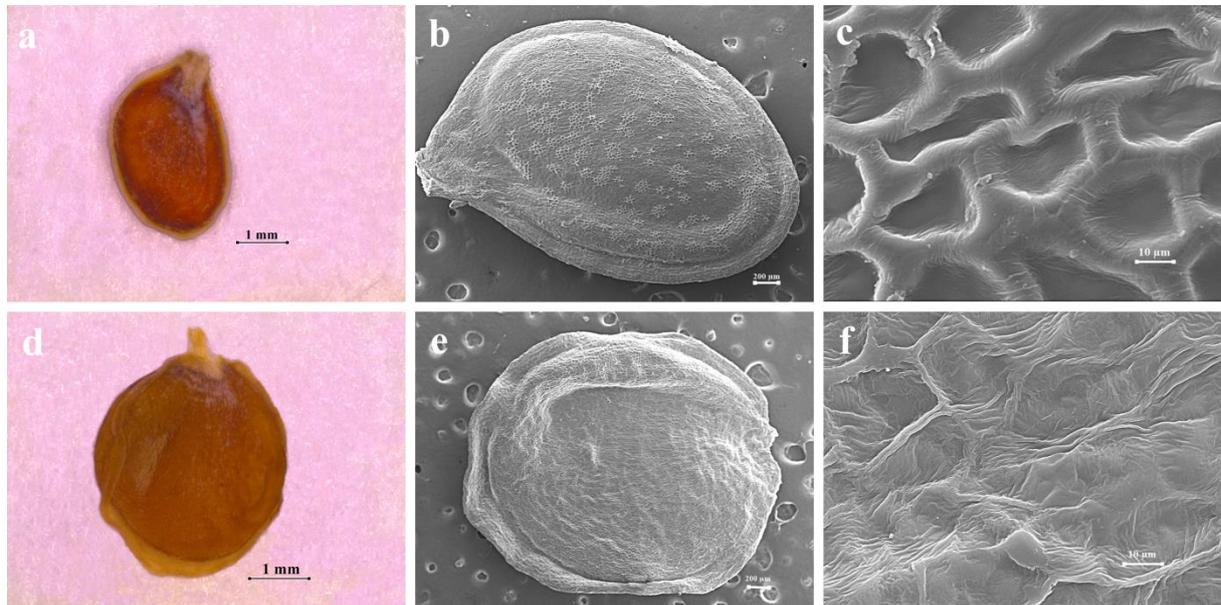
**Figure 8.** Fruit morphology of *Bornmuellera kiyakii*. (a–c) and *B. glabrescens* (d–f) via LM and SEM

#### Seed Features

The outline of the seeds of *B. kiyakii* was oblong-elliptic,  $2.49 \times 1.61$  mm, and the length/width ratio was 1.54. The dorsal face was concave in shape, hilum was distinct, chalazal and micropylar poles were rotundate, tile was reddish-brown, and it weighed 0.0005 g. The seed had reticulate-rugose ornamentation and the wing had rugose-striate ornamentation. The wing was  $0.13 \pm 0.03$  mm, muri were  $25.28 \pm 6.96 \mu\text{m}$ , and the walls of the muri were sinuous (Figure 9-a,b,c).

For *B. glabrescens*, it was orbicular,  $3.45 \times 3.12$  mm, and the length/width ratio was 1.1. The shape of dorsal face was concave, hilum was not distinct, chalazal and micropylar poles were rotundate, colour was

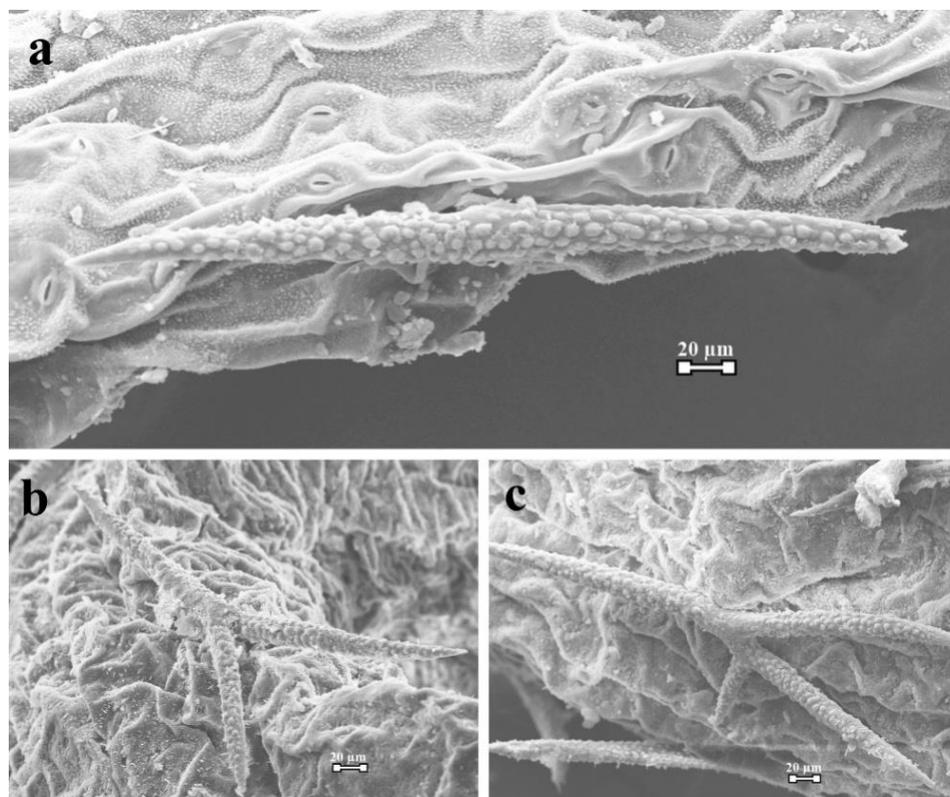
yellowish-brown, and it weighted 0.0036 g. The seed and wing both had reticulate ornamentation. The wing was  $0.26 \pm 0.13$  mm, muri were  $23.56 \pm 6.41$   $\mu\text{m}$ , and the walls of the muri were ruined (Figure 9-d,e,f).



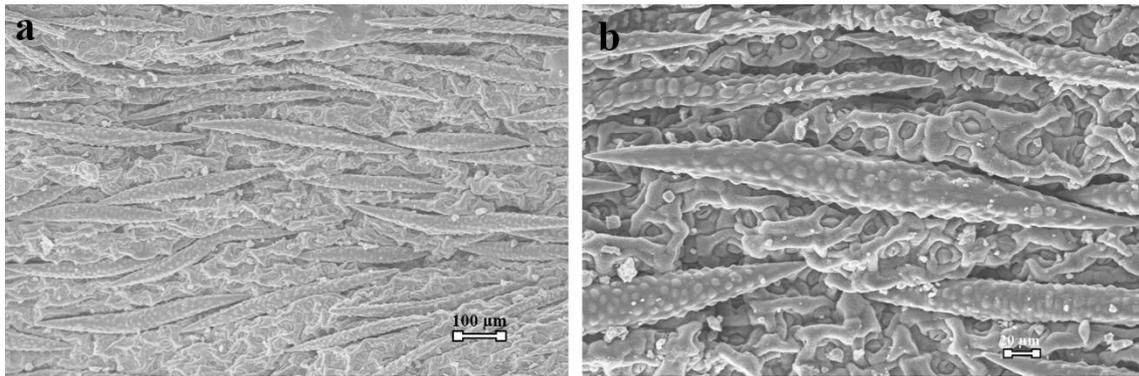
**Figure 9.** Seed morphology of *Bornmuellera kiyakii*. (a–c) and *B. glabrescens* (d–f) via LM and SEM

### 3.5. Trichome Features

Both *B. kiyakii* and *B. glabrescens* had malpighiaceous trichomes that were 2-rayed, which are characterized in the family Brassicaceae (Figures 10-a and 11-a,b). However, *B. kiyakii* also contained 3-rayed and 4-rayed trichomes (Figure 10-b,c).



**Figure 10.** *Bornmuellera kiyakii* trichome morphology (SEM); a) Malpighiaceous trichome b) 3-rayed c) 4-rayed



**Figure 11.** *Bornmuellera glabrescens* malpighiaceae trichomes (SEM)

#### Key for Distinguishing the Examined Taxa

1. Basal leaves filiform, petals whitish-cream, mature fruit globose, seeds  $2.49 \times 1.61$  mm, trichomes 2-, 3-, and 4-rayed..... ***B. kiyakii***
2. Basal leaves oblanceolate, petals white, mature fruit ovoid, seeds  $3.45 \times 3.12$  mm, trichomes only 2-rayed.....***B. glabrescens***

#### 4. DISCUSSION

Our morphological observations and measurements of *Bornmuellera kiyakii* and *B. glabrescens* were mostly congruent with previous studies [6, 10]. Specifically, the morphological description of *B. glabrescens* was expanded with the present study.

No literature exists regarding the anatomical structure of the genus *Bornmuellera* and our study is the first report for the anatomy of *Bornmuellera kiyakii* and *B. glabrescens*, which are very distinctive endemic plants for Anatolia. In the root cross-sections, *B. kiyakii* and *B. glabrescens* had a similar secondary structure with regards to their peridermis, cortex parenchyma, xylem, phloem, and pith region, as was reported in the root anatomy of the family Brassicaceae (Cruciferae) [17–19]. Most species have a single cambium; growth rings are inconspicuous, with narrow vessels ranging from 16–71  $\mu\text{m}$  in the wood anatomy of Brassicaceae (Carlquist 1971), as with *B. kiyakii* and *B. glabrescens* [20]. The studied taxa shared similar stem anatomical characteristics, which were characterized by a single-layered epidermis, containing chloroplasts in the cortex parenchyma, well-developed phloem, and xylem and pith cells in the centre. The leaves of *B. kiyakii* were triangular in shape and the median vascular bundle was larger than the others. However, *B. glabrescens* had linear-shaped leaves and the median vascular bundle was larger, as with *B. kiyakii*. The mesophyll was about 2 times greater in *B. glabrescens* than in *B. kiyakii* (Table 2). The other anatomical measurements are given in Table 2 and they are similar in the studied taxa. Small rhombic crystals were present in the libriform fibres of the *Parolinia ornata* Webb and *Descurainia briquetii* Webb in Brassicaceae [20–22].

When considering the genera in the tribe Alysseae, the fruit characteristics are important diagnostic macro-morphological aspects that can help in distinguishing genus or taxa [9]. [The genus *Bornmuellera* has fruit with no trichomes, terete, dehiscent, and thin leathery silicles [8] and there have been no investigations regarding the fruit micromorphology of the genus. In this study, the fruit micromorphology of *B. kiyakii* and *B. glabrescens* are presented for the first time. In *B. kiyakii*, the fruit were globose, valves were asymmetrical, transparent, and the larger valve was yellow, while the smaller one was purplish-pink. In spite of this, in *B. glabrescens* the fruit were ovoid, valves were symmetrical, leather-like, and the valve in the fruit was light greenish-yellow. Both of the studied taxa had similar fruit ornamentation (rugose). The investigation of the fruit of the genus *Bornmuellera* will be a guide for future discussions.

Pollen and seed morphology can contribute useful taxonomic characters for the identification and classification of Brassicaceae species [13, 23–29]. Palynological investigations about the family Brassicaceae were performed by Erdtman, who reported that Brassicaceae was a stenopalynous family with

pollen grains 3-zonocolpate, generally prolate to subprolate oblate to oblate-spheroidal, or prolate-spheroidal and reticulate or granulate exine ornamentation [23]. The same researcher reported reticulate and granulate pollen types, on the basis of the exine thickness of 2 pollen types that were identified by Erdtman in Brassicaceae [24]. Abdel Khalik et al. divided the family into 3 pollen types on the basis of the lumina size [30]. Perveen et al. recognized 4 distinct pollen types on the basis of the tectal surface (*Arabis bijuga*, *Erysimum melicentae*, *Farsetia ramosissima*, and *Draba lanceolata*) [26]. When we looked at our palynological results for *B. kiyakii* and *B. glabrescens*, their pollen was reticulate according to the study of Erdtman, type I (exine microreticulate) according to Abdel Khalik et al., and *Arabis bijuga* according to Perveen et al. [26, 30]. On the other hand, in a recent study of the genus *Bornmuellera*, Firat & Baser reported that *Bornmuellera cappadocica* had pollen grains that were prolate-spheroidal, 15.37–21.55  $\mu\text{m}$  in the polar axis, and 14.48–20.29  $\mu\text{m}$  in the equatorial axis [31]. The investigated species were only different with regards to the shape of the Amb, which was triangular in *B. kiyakii* and circular in *B. glabrescens*. The distance between the 2 colpi was also longer in *B. glabrescens* than in *B. kiyakii* (Table 3).

Regarding the seed morphology, our observations and measurements showed that *B. kiyakii* had a larger seed size than *B. glabrescens*, and the seed of *B. kiyakii* was oblong-elliptic in shape, while that of *B. glabrescens* was orbicular. In addition, Firat and Baser reported that *B. cappadocica* had seeds that were 1.82  $\times$  2.72 mm, yellow, ovate in shape, and rugulose-striate ornamentation [31]. The seed colour was different in the 2 studied taxa than those of *B. cappadocica*. We concluded that the seed colour, shape, and size are diagnostic characters for distinguishing the members of the genus *Bornmuellera*.

Trichome morphology was used by many authors as an important character in the classification of Brassicaceae [12, 32–39]. In a recent paper, malpighiaceus trichomes, which were determined as ‘2-rayed and medifixed’ were found in the genus *Bornmuellera* [9]. Both *B. kiyakii* and *B. glabrescens* had malpighiaceus trichomes over their leaves and stems (Figures 10-a, 11-a,b). Additionally, *B. kiyakii* also had 3–4-rayed trichomes, especially in its leaves (Figure 10-b,c).

As a conclusion, there have been no detailed studies on the Turkish local endemics *B. kiyakii* and *B. glabrescens* prior to this research. Our study is accordingly, the first comprehensive research of the morphology, pollen, anatomy, fruit, and seeds of both taxa. The results showed that the studied taxa were generally similar to each other in pollen morphology. However, the anatomical characters and morphological characters of the fruit, and the seed micromorphology of the samples, indicated some differences.

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## CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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