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Contribution to Knowledge on The Anatomy of The Genus *Noccaea* Moench (Brassicaceae) From Türkiye

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ABSTRACT

The anatomical properties of *Noccaea camlikensis* and *N. cariensis* were determined in this study. The roots have a secondary root type. The stem cross-sections have a single-layered epidermis, parenchymatous cortex, one layered distinct endodermis, vascular bundles with sclerenchymatic caps, and parenchymatic pith cells. Equifacial and bifacial mesophyll types are observed in the leaves, with multiple-layered palisade tissue, and the spongy parenchyma is well-developed. Vascular bundles are small in the leaves except in the leaf midrib. Anisocytic stomata type are observed in the surface sections. The assessment of anatomical characteristics of the studied *Noccaea* species, such as the number of cortex in the stem and the shape of midvein of leaf, are of taxonomical value.

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ÖZET

Bu çalışmada, *Noccaea camlikensis* ve *N. cariensis*'in anatomik özellikleri belirlenmiştir. Kökler, sekonder kök tipine sahiptir. Gövde enine kesitlerinde, tek tabakalı epidermis, parankimatik korteks, tek tabakalı belirgin endodermis, sklerenkimatik başlıklı iletim demetleri ve parankimatik öz hücreleri vardırYapraklarda çok tabakalı palizat parankiması ve 3-4 sıralı sünger parankiması bulunan ekvifasiyal mezofil tipi gözlemlenmiştir. İletim demetleri orta damar hariç küçüktür. Yüzeysel kesitlerde anizositik tip stoma gözlemlenmiştir. İncelenen *Noccaea* türlerinin gövde korteksinin sayısı ve yaprak orta damarının şekli gibi anatomik özelliklerinin değerlendirilmesi taksonomik değere sahiptir.

Biyoloji

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INTRODUCTION

The family Brassicaceae, or mustard family, is a monophyletic group of about 338 genera and 3709 species with global distribution (Hall et al. 2002; Bailey et al. 2006). An evaluation of its morphology and generic circumscriptions, and a new tribal alignment was proposed by Al-Shehbaz (Al-Shehbaz, 2012).

In the past, the generic and subgeneric concepts of the genus *Thlaspi* L. (Brassicaceae) have changed several times and have been the subject of partly polemically debated classifications. Meyer (1973, 1979; summary in 1991), who introduced a classification largely based on the seed-coat anatomical characters, which were considered to be conservative and thus apt for obtaining a more natural system, while the siliquae characters proved to have evolved convergent evolution, to split *Thlaspi* into 12 genera. These proposals were rejected by the Med-Checklist (Greuter et al., 1986) and the most recent standard Floras, such as Flora Europaea (Clapham and Akeroyd, 1993), Flora Iberica (Pujadas Salvá, 1993), Flora of Turkey Supplement 1 (Davis et al., 1988) Flora Hellenica (Artelari, 2002), and, by inference, also Flora of Turkey Supplement 2 (Yildirimli, 2000). In contrast, they were convincingly supported by the molecular-based studies of Mummenhoff and Zunk (1991), Koch et al. (1993), Mummenhoff and Koch (1994), Mummenhoff et al. (1997a, b) and Koch and Mummenhoff (2001).

When Aytac et al. (2000) described *Noccaea camlikensis* Aytaç, Nordt and Parolly as a new species for the genus *Noccaea*, they largely adopted Meyer's classification and generic concepts. Indeed, recent floristic studies (e.g., Al-Shehbaz, 2010, 2012; Al-Shehbaz and Watson, 2011) have recognized *Noccaea* as distinct from *Thlaspi*. Later, Al-Shehbaz (2014) announced a synopsis of the genus *Noccaea*, and *Thlaspi cariensis* Carlström was accepted as *Noccaea cariensis* (Carlström) Parolly, Nordt and Aytaç. In his *Noccaea* synopsis, Al-Shehbaz (2014) used a broad concept for delimitation of that genus and transferred all Meyer's segregates to *Noccaea*, with the exception of *Thlaspi* s.str. and *Noccidium*. The aim of the present study is not to discuss those controversial issues and in this study the generic concept of *Noccaea* adopted by Al-Shehbaz (2014) is accepted. Threated categories of *N. camlikensis* and *N. cariensis* are evaluated as critically endangered (CR) (IUCN, 2001).

For years, anatomical characters have been of crucial importance in detecting the taxonomic and phylogenetic relationships of particular plant groups and have been successfully used in the Brassicaceae (Atçeken et al., 2016; Karaismailoğlu, 2019; Şirin and Karaismailoğlu, 2020; Çıtak and Dural, 2020).Metcalfe and Chalk (1957) indicated that the important discriminative anatomical traits of Brassicaceae include stomata and epidermal cell type and structures of the vascular bundles, which may supply insight into many taxonomical characters displayed to be significant in the species classification (Stace, 1984). Some notes on *Thlaspi* genus were declared include the pattern of epidermal cell and mesophyll layers, the number and size of vascular bundles, and the thickness of the cortex and endodermis (Karaismailoğlu and Erol, 2020). However, there has been no taxonomic research conducted on the anatomy of the genus *Noccaea* in Turkey. Thus, the main aims of this study were to 1) identify and examine the anatomical characteristics of Turkish *Noccaea camlikensis and N. cariensis* and 2) elucidate the systematic value of the these traits.

MATERIAL and METHODS

Species collection

The specimens of *N. camlikensis* and *N. cariensis* were collected from the below-mentioned localities. The plant specimens of the studied species were stored at the herbarium of the Department of Biology, University of Selçuk (KNYA).

N. camlikensis: C4 Konya: Derebucak, Çamlık Village, Kızıldağ, stony places, 1400–1500 m., 21.05.2015, *H.Dural*-3569-*B.Çıtak*
N. cariensis: C2 Muğla: Marmaris, stony places, 1000 m., 03.06.2015, *H.Dural*-3590-*B. Çıtak*.

Anatomical analysis

The paraffin method was applied to the vegetative organs of both studied *Noccaea* species for taking the cross-sections (Johansen, 1940). The handmade cross-sections of the stems and superficial sections of the stomata were stained with phloroglusinol-HCl. On average, 20 preparations were made for each type of section for the 20 pieces of plant material, and 30 cell groups were measured. The measurements of the cells were made using Kameram 21 software (Argenit, Istanbul, Turkey). For vessel grouping in the xylem, the Metcalfe and Chalk (1957) classification was used.

RESULTS and DISCUSSION

Noccaea camlikensis

Root anatomy

The secondary root structure was observed in the root cross-sections of *N. camlikensis* with the peridermis, cortex, phloem and xylem (Fig. 1-A). The peridermis was a protective tissue composed of disintegrating or squashed cells. The width of the peridermis cells was 57.24±11.03 µm (Table 1). The cortex was 4–5 layered, and followed the periderm towards the center. The phloem was well-developed, and the cambium was not distinguished clearly (Fig. 1-B). Vessels in the xylem were irregular, according to Metcalfe and Chalk (1957) classification of vessel grouping. The center of the roots in the cross sections was covered with xylem (Fig 1A-C).

Stem anatomy

The cross-sections of the stem had an epidermis layer in the outermost surface. The cortex was 6–7 layered and characterized by parenchymatic cells (Fig. 2-A,B). Their dimension was 26.99 ± 5.77 µm (Table 1). The endodermis was rowed and fusiform-shaped (Fig. 2-A,B). The phloem and xylem were well-developed. Above the phloem, sclerenchymatic cells were present (Fig. 2-C). The diameter of the tracheas was 17.29 ± 2.86 µm (Table 1). The pith region of the stem consisted of large parenchymatic cells (Fig. 2-A).

Leaf anatomy

The cross sections of the leaf showed that the upper and lower epidermis were made up of rectangular cells with adaxial and abaxial cuticles (Fig. 3A-B). Cells of the lower epidermis (52.61 ± 31.9 µm wide × 37.96 ± 16.9 µm long) were wider than those of the upper epidermis (39.13 ± 12.6 µm wide × 41.11 ± 14.9 µm long) (Table 1)(Fig. 3B-C). The leaf was amphistomatic and bifacial. Vascular bundles were composed of phloem and xylem (collateral type). The stomata type was anisocytic (Fig. 3A-B).

Table 1. The anatomical measurements of *N. camlikensis* and *N. cariensis* (values in µm).
Çizelge 1. N. camlikensis ve N. cariensis'in anatomik ölçümleri (değerler mikrometre)

Species/Anatomic characters		*Noccaea camlikensis* Length Min-Max	Mean±SD	Width Min-Max	Mean±SD	*Noccaea cariensis* Length Min-Max	Mean±SD	Width Min-Max	Mean±SD
Root	Peridermis	-	-	43.41-72.46	57.24±11.03	-	-	32.38-55.62	43.34±7.73
	Cortex	21.71-39.24	30.64±6.88	51.68-118.64	85.97±25.15	10.44-21.71	15.6±3.54	28.98-59.05	39.58±10.53
	Vessel	-	-	87.33-110.04	101.2±6.99	-	-	23.48-68	42.9±12.86
Stem	Cuticle			2.81-4.65	3.77±0.66			5.08-8.81	7.64±1.54
	Epidermis	11.92-18.67	15.52±2.22	16.96-27.42	21.98±3.40	15.47-23.53	19.83±2.94	20.26-31.18	24.17±3.49
	Cortex	35.02-58.76	45.93±7.38	44.76-76.29	55.13±9.72	14.15-23.21	18.64±3.27	22.34-35.83	28.35±4.25
	Vessel			13.87-25.62	21.22±5.41			16.45-29.35	22.57±3.86
	Pith cell			70.28-118.91	92.42±13.93			31.96-61.4	41.88±8.78
Leaf	Cuticle on upper epidermis			3.99-6.96	5.17±1.20			3.90-5.24	4.61±0.52
	Cuticle on lower epidermis			2.56-5.19	3.54±1.00			3.90-6.3	5.08±0.93
	Upper epidermis	23.86-66.81	41.11±14.9	26.85-61.44	39.13±12.6	18.19-52.85	29.75±10.88	16.15-44.87	29.67±9.35
	Lower epidermis	17.76-58.09	37.96±16.9	29.04-105.65	52.61±31.9	27.16-41.27	31.98±5.63	23.93-48.31	37.68±9.17
	Palisade parenchyma	39.54-73.05	55.94±9.6	14.08-30.93	21.57±5.48	26.52-57.83	38.76±8.79	11.77-21.63	16.63±2.62
	Spongy parenchyma			22.36-52.27	33.51±9.4			19.89-37.74	30.8±6.57

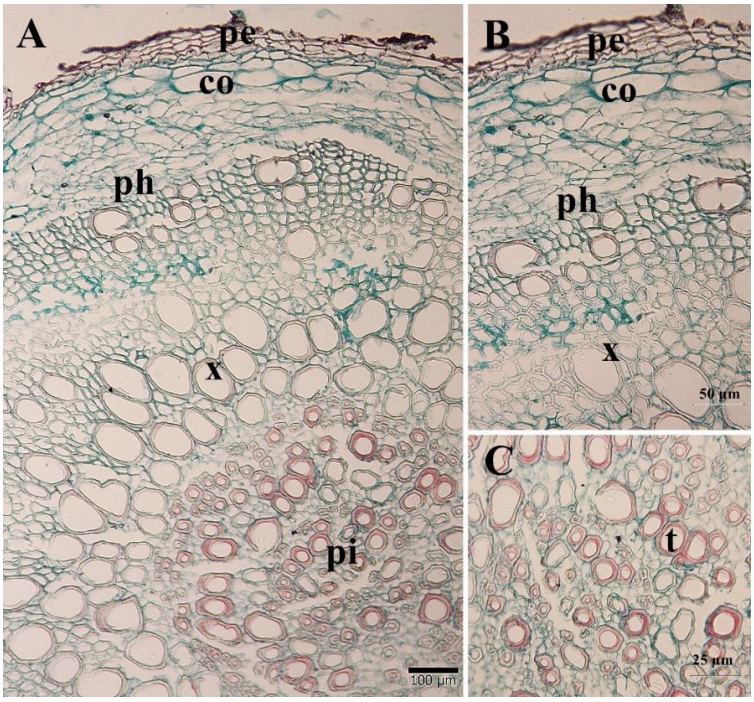

Figure 1. The root cross sections of *Noccaea camlikensis*. A. General view of root pe: peridermis, co: cortex, ph: phloem, x: xylem, pi: pith region, B. Close view of peridermis, cortex and, phloem, C. Tracheal elements t: trachea

Şekil 1. Noccaea camlikensis'in kök enine kesitleri. A. Kök genel görünüşü pe: peridermis, co: korteks, ph: floem, x: ksilem, pi: öz bölgesi, B. Peridermis, korteks ve floemin yakın görünüşü, C. Trakeal elemanlar t: trake

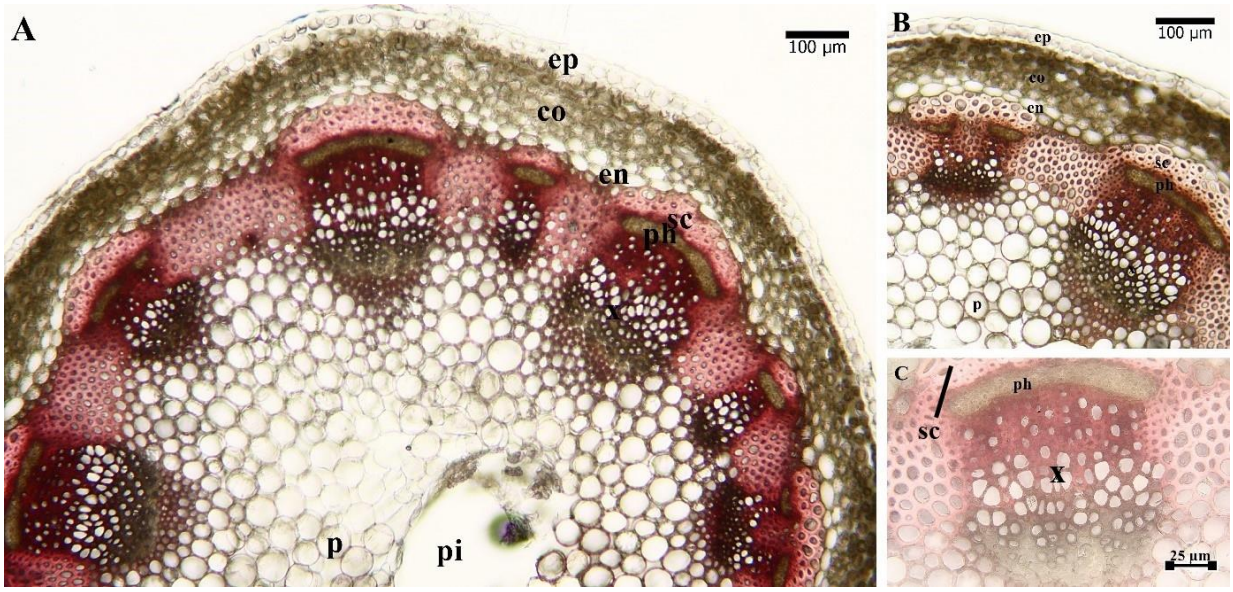

Figure 2. The stem cross sections of *Noccaea camlikensis*. A. General view of stem ep: epidermis, co: cortex, en: endodermis, sc: sclerenchyma, ph: phloem, x: xylem, p: parenchyma, pi: pith region, B. Close view of epidermis, cortex and vascular bundles, C. Close view of vascular bundle.

Şekil 2. Noccaea camlikensis'in gövde enine kesitleri. A. Gövde genel görünüşü ep:epidermis, co:korteks, en:endodermis, sc:sklerenkima, ph:floem, x:ksilem, p:parenkima, pi:öz bölgesi, B. Epidermis, korteks ve iletim demetleri yakın görünüşü, C. İletim demeti yakın görünüşü

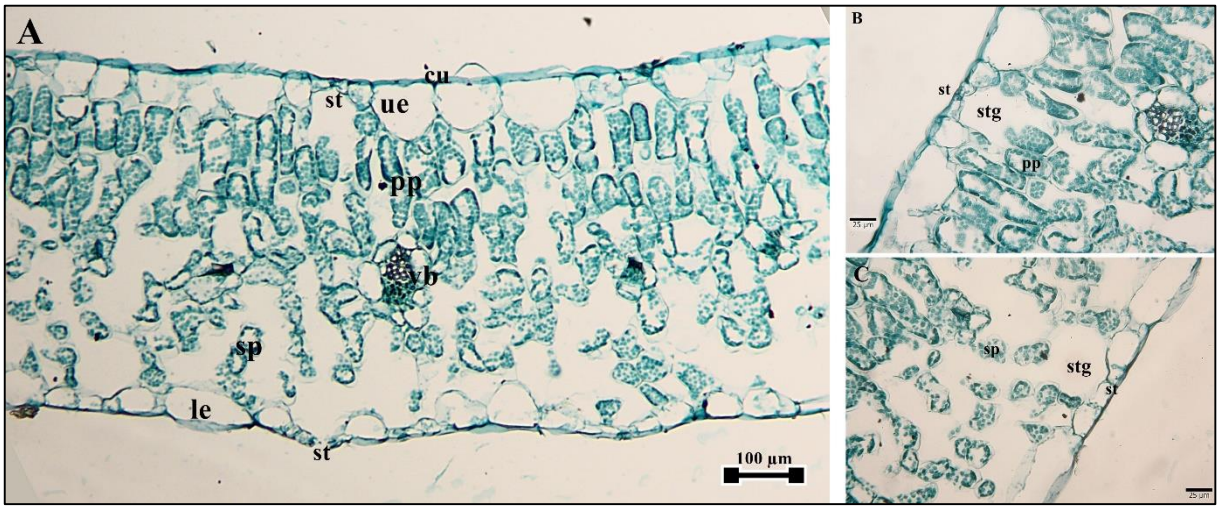

Figure 3. The leaf cross sections of *N. camlikensis*. A. General view of leaf cu: cuticle, ue: upper epidermis, le: lower epidermis, pp: palisade parenchyma, sp: spongy parenchyma, vb: vascular bundle, st: stomata, B. Close view of upper epidermis stg: stomatal gap C. Close view of lower epidermis

Şekil 3. N. camlikensis'in yaprak enine kesitleri. A. Yaprağın genel görünüşü cu:kütikul, ue: üst epidermis, le:alt epidermis, pp: palizat parankiması, sp: sünger parankiması, vb: iletim demeti, st: stoma, B. Üst epidermisin yakın görünüşü stg: stomata boşluğu C. Alt epidermisin yakın görünüşü

Noccaea cariensis

Root anatomy

The secondary root structure was observed in the root cross-sections of *N. cariensis* with the peridermis, cortex, phloem, and xylem (Fig 5-A). The peridermis was a protective tissue composed of disintegrating or squashed cells. The width of the peridermis cells was 43.34 ± 7.73 µm (Table 1). The cortex was 5–6 layered, and followed periderm towards the center. The phloem was well developed, and the cambium was not distinguished clearly (Fig. 5-B). Vessels in xylem were irregular, according to the Metcalfe and Chalk (1957) classification of vessel grouping. The center of the roots in the cross sections was covered with xylem (Fig. 5-C).

Stem anatomy

The cross-sections of the stem had an epidermis layer in the outermost surface (Fig. 6-A). The cortex was 8–9 layered and characterized by parenchymatic cells.

Their dimension was 45.93±7.38×55.13±9.72 µm. The endodermis was rowed and fusiform-shaped. The phloem and xylem were well developed. Above the phloem, sclerenchymatic cells were present (Fig. 6-B). The diameter of the tracheas was 21.22 ± 5.41 µm (Table 1). The pith region of the stem consisted of large parenchymatic cells (Fig. 6-C).

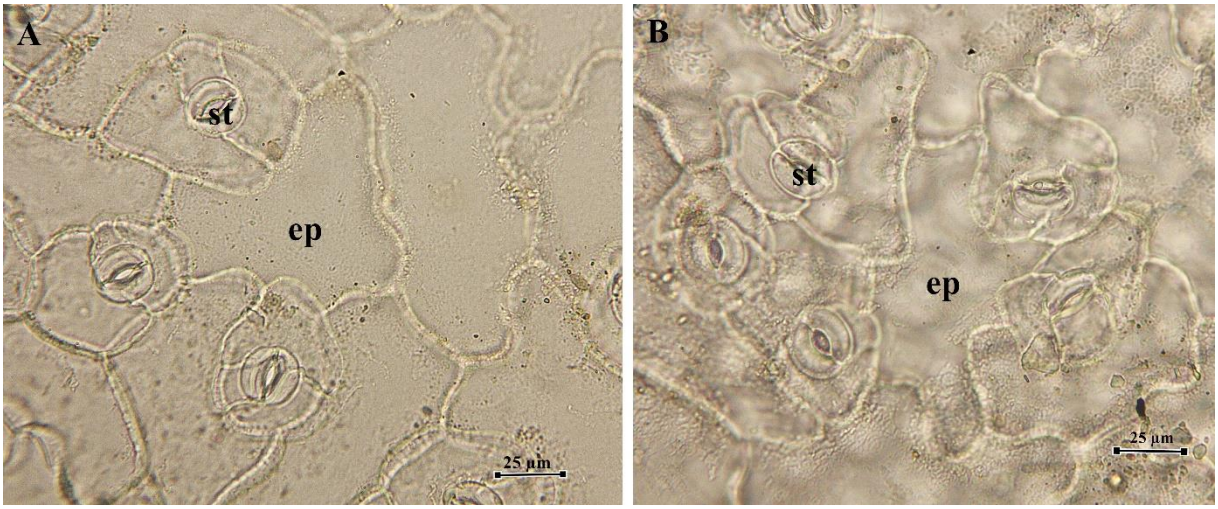

Figure 4. The cross sections of leaves of *N. camlikensis*. A. Upper surface B. Lower surface st: stomata ep: epidermis

Şekil 4. N. camlikensis'in yapraklarının yüzeysel kesitleri. A. Üst yüzey B. Alt yüzey st: stoma, ep: epidermis

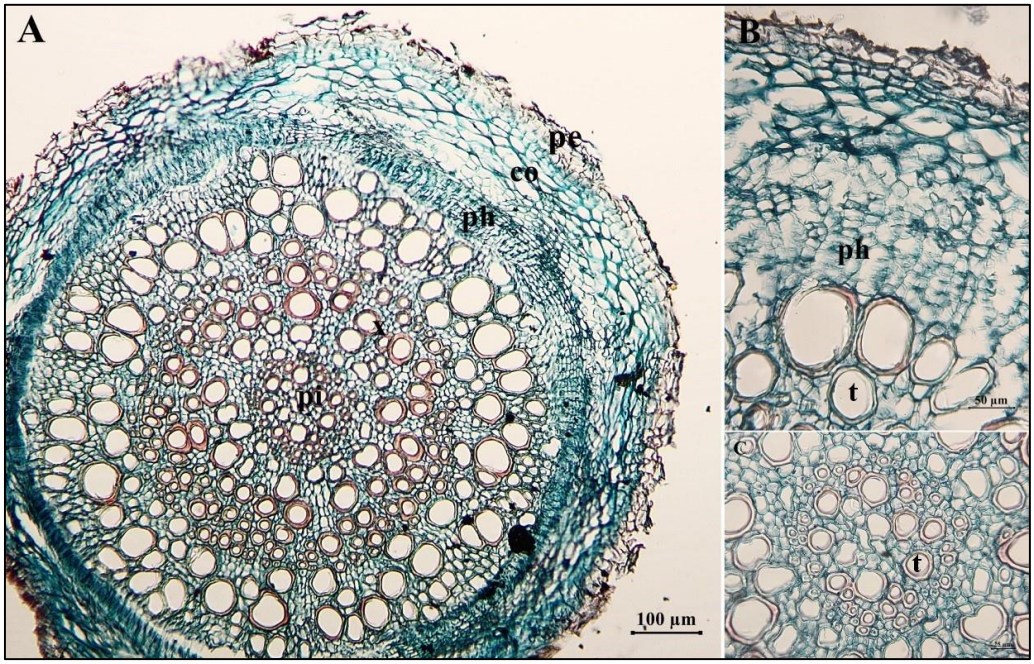

Figure 5. The root cross sections of *Noccaea cariensis*. A. General view of root pe: peridermis, co: cortex, ph: phloem, x: xylem, pi: pith region, B. Close view of peridermis, cortex and, phloem, C. Tracheal elements t: trachea.

Şekil 5. Noccaea cariensis'in kök enine kesitleri. A. Kök genel görünüşü pe: peridermis, co: korteks, ph: floem, x: ksilem, pi: öz bölgesi, B. Peridermis, korteks ve floemin yakın görünüşü, C. Trakeal elemanlar t: trake

Leaf anatomy

The cross sections of the leaves showed that the upper epidermis was made up of rectangular cells with adaxial and abaxial cuticles, and the lower epidermis was oval-rectangular shaped (Fig. 7-A). Cells of the lower epidermis (27.16–41.27 µm long × 23.93 ± 48.31 µm wide) were wider than those of the upper epidermis (18.19–52.85 µm long × 16.15–44.87 µm wide) (Table 1). The mesophyll was equifacial. The palisade parenchyma was on both sides of the leaves.

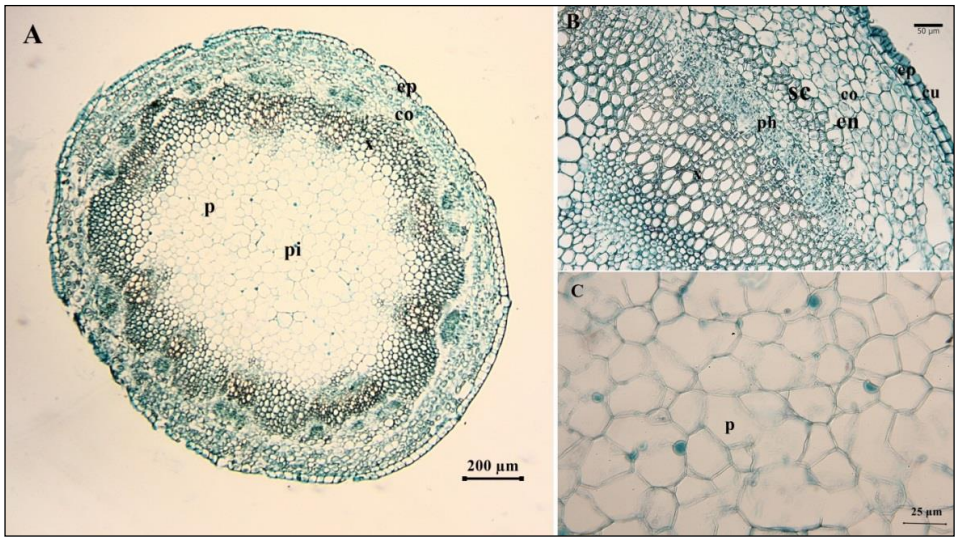

Figure 6. The stem cross sections of *Noccaea cariensis*. A. General view of stem cu: cuticle, ep: epidermis, co: cortex, sc: sclerenchyma, en: endodermis, ph: phloem, x: xylem, p: parenchyma, pi: pith region, B. Close view of epidermis, cortex and vascular bundles, C. Close view of vascular bundle.

Şekil 6. Noccaea cariensis'in gövde enine kesitleri. A. Gövde genel görünüşü ep:epidermis, co:korteks, en:endodermis, sc:sklerenkima, ph:floem, x:ksilem, p:parenkima, pi:öz bölgesi, B. Epidermis, korteks ve iletim demetleri yakın görünüşü, C. İletim demeti yakın görünüşü.

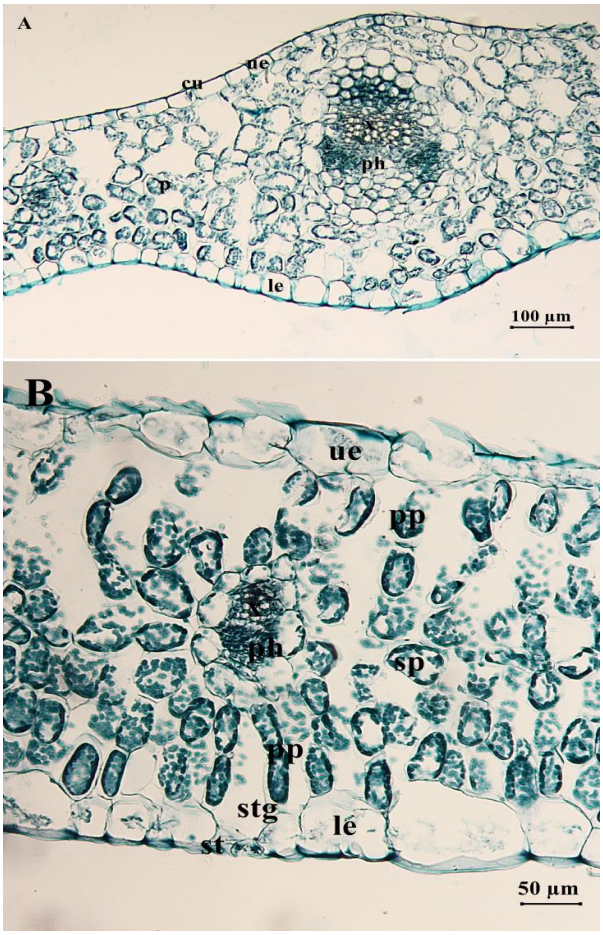

Figure 7. The leaf cross sections of *N. cariensis*. A. General view of midrib cu: cuticle, ue: upper epidermis, le: lower epidermis, p: parenchyma, x: xylem, ph: phloem, B. Close view of lamina st: stomata, pp: palisade parenchyma, sp: spongy parenchyma, stg: stomata gap.

Şekil 7. N. cariensis'in yaprak enine kesitleri. A. Orta damarın genel görünüşü cu:kütikul, ue: üst epidermis, le:alt epidermis, p: parankima, x:ksilem, ph: floem, B. Laminanın yakın görünüşü pp:palizat parankiması, sp: sünger parankiması, st:stoma, stg: stoma boşluğu.

N. camlikensis and *N. cariensis* were selected to determine their anatomical characteristics for the first time and it was aimed to confirm their systematic position.

The root anatomy of the studied species showed that there was a secondary root structure with a peridermis, cortex, phloem, and xylem. The cortex parenchymatic cells were more or less oval-shaped. The phloem and xylem were well-developed and the centre of the roots were covered with xylem elements.

In the root cross-sections, the studied taxa had a similar secondary structure with regards to their peridermis, cortex parenchyma, xylem, phloem, and sclerenchymatic pith region, as reported in the root anatomy of the family Brassicaceae (Tekin et al., 2013; Atçeken et al., 2016; Çıtak and Dural, 2020). Most species have a single cambium, wherein the growth rings are inconspicuous, with narrow vessels ranging from 16–71 µm in the wood anatomy of Brassicaceae (Carlquist, 1971), as in studied species.

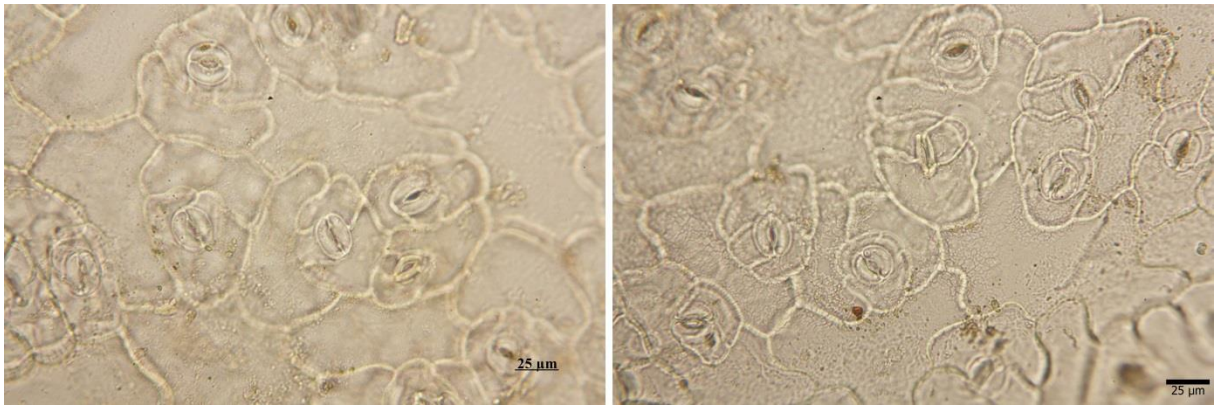

Figure 8. The cross sections of leaves of *N. cariensis*. A. Upper surface B. Lower surface st: stomata ep: epidermis
Şekil 8. *N. cariensis'in yapraklarının yüzeysel kesitleri. A. Üst yüzey B. Alt yüzey st: stoma, ep:epidermis*

The studied species shared similar stem anatomical characteristics, which were characterized by a single-layered epidermis, containing chlorophyll pigments in the cortex parenchyma, well-developed phloem, and xylem and pith cells in the center, as in the other members of Brassicaceae (Tekin et al., 2013; Atçeken et al., 2016; Çıtak and Dural, 2020). The contour of the stem cross-sections was rounded with collenchymatic ridges, ovoid, or polygonal in the family Brassicaceae and also rounded in the studied *Noccaea* species. The rounded-shape cross-sections of the stem in *N. camlikensis* and *N. cariensis* were observed to have the general characteristics of the primary stem.

The family Brassicaceae includes unifacial, bifacial, and equifacial mesophyll in its leaf anatomy (Tekin et al., 2013; Atceken et al., 2016; Çıtak and Dural, 2020). The cross-sections of shapes of leaves of *N. camlikensis* were linear-shaped, while they were v-shaped in *N. cariensis*, and the median vascular bundle was larger than the others, with a bifacial mesophyll in the examined species.

CONCLUSION

With this study, the anatomical characteristics of *Noccaea camlikensis* and *N. cariensis* were determined and these characteristics were found to be not specific for the species taxonomic position. Nevertheless, the anatomical traits can be more valuable if other species of *Noccaea* are also investigated.

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Statement of Conflict of Interest

Authors have declared no conflict of interest.

Author's Contributions

The contribution of the authors is equal.

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