

# Taxonomical study of seeds and fruit micromorphology of the *Geranium* (*Geraniaceae*) species in the Thrace region of Turkey (Europe)

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**Abstract.** The seed and mericarp micromorphology of 13 naturally growing *Geranium* species (*G. lucidum*, *G. purpureum*, *G. robertianum*, *G. rotundifolium*, *G. molle*, *G. pusillum*, *G. divaricatum*, *G. columbinum*, *G. dissectum*, *G. tuberosum*, *G. asphodeloides*, *G. sanguineum*, and *G. pyrenaicum*) in Thrace have been studied by scanning electron microscope. According to the analysis, seeds are generally ovate-elliptic, smooth-surfaced and faveolate, and only the seeds of *G. divaricatum* and *G. tuberosum* are reticulate. Mericarps are usually without the strand of fibres, callus and prong at the base, the rostrum is generally 10–20 mm long - minimum 5–8 mm long (*G. pusillum*), maximum 15–32 mm long (*G. sanguineum*). These results have shown that the species can be identified according to their mericarp and seed surface characteristics.

**Key words:** *Geranium*, mericarp, morphology, seed, taxonomy, Turkey

## Introduction

*Geranium*, the most important genus of *Geraniaceae*, is represented on earth by approximately 430 species in 24 sections belonging to three subgenera (Aedo & al. 1998a, 1998b, 2005; Aedo & Estralla 2006). In Turkey, it is featured by 44 species (46 taxa), 24 % of which are endemic (Davis 1967; Davis & al. 1988; Aitchison 1995; Conti 2006; Güner & al. 2000; İlçim & Behçet 2006; Özhatay & Kültür 2006; Öner & al. 2010).

Some morphological, palynological and karyological studies have been carried out into the *Geranium* genus. Biology and systematics of the section *Anemonifolia* Knuth (Yeo 1973), morphology and phylogeny of the section *Lucida* R. Knuth, *Unguiculate* (Boiss.) Reiche (Yeo 2004) have been examined, as well as the fruit unloading types of *Geranium* and the effects of

these types on the classification and evolutionary relationships (Yeo 1984). Also, *Geranium* in Southwest China (Yeo 1992) has been revised.

Van Loon (1984a, 1984b) examined the number of chromosomes in some *Geranium* species in Europe. Aedo (2001, 2002, and 2003) and Aedo & al. (1998b, 2005, 2006, and 2007) studied the revision of sections *Batrachioidea* W. D. J. Koch, *Divaricata* Rouy, *Brasilien-sia* Aedo, *Trigonium* Aedo, *Gracile* Aedo, *Dissecta* Aedo, *Andina* R. Knuth, *Chilensia* R. Knuth, *Azorelloida* Aedo, *Neoandina* Aedo, and *Paramensia* R. Knuth, and of subsections *Tuberosa* (Boiss.) Reiche with *Mediterranea* R. Knuth, and also prepared a checklist of *Geranium* in the world. Aedo (2000, 2001) also examined annual and perennial *Geranium* species in North America and identified a great number of new *Geranium* species. Mitchell & al. (2009) investigated the phylogeny of

some *Geranium* species in New Zealand. Semercioğlu (2000) made morphometric analysis of some *Geranium* species. İlçim and Dadandı (2008) also investigated the morphology and palynological characters of *G. tuberosum*. Deniz & al. (2013) analyzed the pollen morphology of *Geranium* species in Thrace. Moghadam & al. (2015) made a systematic study of fruit and seed micro-morphology of 22 *Geranium* species spreading in Iran. As it can be seen from these studies, the seeds and fruit morphology of genus *Geranium* have not been studied comprehensively in Turkey. Therefore, a micromorphological study has been carried out into the *Geranium* species in the Thrace region in Turkey.

## Material and methods

Specimens of the *Geranium* species were obtained from almost every region of Thrace during fieldwork from the beginning of March 2009 and to the end of July 2009 (Table 1).

Some of the collected specimens were dried according to standard procedures and saved as herbarium specimens for use in morphological investigations. The identified plants were kept in the Herbarium of Trakya University Faculty of Science (EDTU). Ripe fruit and seeds were stored in envelopes from fresh specimens and herbarium specimens of the species (Table 1).

The stored seeds and mericarps were analyzed by scanning electron microscope (SEM). LEO 440, computer-controlled digital brand electron microscope, was used to make SEM analyses of the seeds and mericarps and microphotographs in the Dokuz Eylül University Characterization Laboratory of Metallurgy and Material Engineering. Seeds and mericarps were secured on metal pollen-carrier stubs with the help of two-sided adhesive tape and binocular microscope POLARON SC 7620 brand coating device was used to coat non-conductive seeds and mericarps by means of sputtering. The coating procedure lasted averagely for 1.5 minutes and the seeds and mericarps were vacuumed and analyzed by SEM. These analyses have determined the mericarp, rostrum, awn, callus, stigmatic remains, basal prong, longitudinal rib, and strand of fibres, etc. Also, the seed type, ornamentation character and color status were assessed by biometric methods, by means of 30 separate measurements. The arithmetic mean and standard deviation were calculated separately. Seed and mericarp characters were identified according to Stearn

**Table 1.** Locality information on the examined *Geranium* materials from Turkey.

Species	Locality
<i>G. asphodeloides</i> Burm. fil.	Kırklareli: İğneada to Demirköy 10 km, under forest canopy, 340 m, 10.06.2009, <i>İ. Deniz s.n.</i> , (EDTU 11481) (seed and fruit).
<i>G. columbinum</i> L.	Kırklareli: Çağlayık to Dereköy 2 km, under forest canopy, 420 m, 28.05.2009, <i>İ. Deniz s.n.</i> , (EDTU 11301) (seed). Kırklareli: Çukurpınar-Armutveren 2 km, under forest canopy, near watercourse, 450 m, 10.06.2009, <i>İ. Deniz s.n.</i> , (EDTU 11305) (seed).
<i>G. dissectum</i> L.	Tekirdağ: Tekirdağ to M. Ereğlisi 10 km, near road, 10 m, 20.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11414) (seed and fruit).
<i>G. divaricatum</i> Ehrh.	Edirne: Küçükönü to Hacıdanişment 4 km, near watercourse, in bushes, 280 m, 24.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11449) (seed and fruit).
<i>G. lucidum</i> L.	Tekirdağ: Kırkalli to Yürük 2 km, near watercourse, in bushes, 80 m, 19.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11019) (seed and fruit).
<i>G. molle</i> L.	Tekirdağ: Hacıköy to Banarlı 2 km, in bushes, 160 m, 19.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11219) (seed and fruit).
<i>G. purpureum</i> Vill.	Çanakkale: Gelibolu to Keşan 48 km, under forest canopy, in bushes, 240 m, 17.05.2009, <i>İ. Deniz s.n.</i> EDTU 11070 (seed and fruit).
<i>G. pusillum</i> L.	Çanakkale: Kavaklı village, Demirci pond, under forest canopy, in bushes, 30 m, 18.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11247) (seed and fruit).
<i>G. pyrenaicum</i> Burm. fil.	Kırklareli: Kadıköy to Kuzulu 2 km, in bushes, near road, 360 m, 10.06.2009, <i>İ. Deniz 443</i> , (EDTU 11505) (seed and fruit).
<i>G. robertianum</i> L.	Kırklareli: Çukurpınar to Armutveren 2 km, under forest canopy, near watercourse, 450 m, 10.06.2009, <i>İ. Deniz s.n.</i> (EDTU 11096) (seed). Kırklareli: Pınarhisar-İğneada 35 km, Kadinkule region, under forest canopy, 650 m, 11.06.2009, <i>İ. Deniz 452</i> , (EDTU 11100) (Fruit).
<i>G. rotundifolium</i> L.	Tekirdağ: Sultanköy to İstanbul 1 km, near road, hard pan, 30 m, 20.05.2009, <i>İ. Deniz 415</i> , EDTU 11121 (seed and fruit).
<i>G. sanguineum</i> L.	Kırklareli: Malkoçlar to Beyci 1 km, near watercourse, in bushes, 370 m, 28.05.2009, <i>İ. Deniz s.n.</i> (EDTU 11487) (seed and fruit).
<i>G. tuberosum</i> L.	ANK 1359 (seed and fruit).

(1996), Aedo (2000), Aedo & al. (2005), Aedo and Estrella (2006) (Figs. 1 and 2).

## Results

*Geranium* is the most important genus of *Geraniaceae*. Thirteen species of the genus *Geranium* have been studied in terms of seed (Table 2) and mericarp characteristics. Figures of the seeds and mericarp characteristics obtained by SEM are shown in Figs 3–4. They are used to define the characters which help distinguish between the species.

### Seed characteristics of the investigated *Geranium* species

Values of six quantitative and qualitative seed traits have been observed or measured in 13 *Geranium* species given in Table 2. SEM photographs for each species, showing the seed character variations, are given in Fig. 3. Seeds are generally ovate-elliptic, with various degrees of deviation. However, ovate, elliptic and circular-ovate seeds were also occasionally observed among all the examined species. Seed size varies between 1.4–1.6 × 0.7–1 mm and 3.3–3.7 × (1.8–)2.1–2.5 mm, seed surface is generally faveolate and smooth, and seed colors are dark-brown and brown.

### Mericaip characteristics

#### *G. asphodeloides* (EDTU 11481)

Fruit 19–26 mm long; mericaip 2.4–3 × 1.8–2.2 mm, without a strand of fibres, smooth-faced, without longitudinal rib or callus at the base, with basal prong; vertical or horizontal, eglandular, hairy, occasionally sparsely cloth hairy, light-brown; rostrum 15–20 mm long, with a narrowed apex 4–6 mm long; stigmatic remains 1–1.9 mm long, 5-lobed, glabrous (Fig. 4a1, a2).

#### *G. columbinum* (EDTU 11305)

Fruit 18–25 mm long; mericaip 3.2–5 × 2–2.6 mm, without a strand of fibres, longitudinal rib, or basal

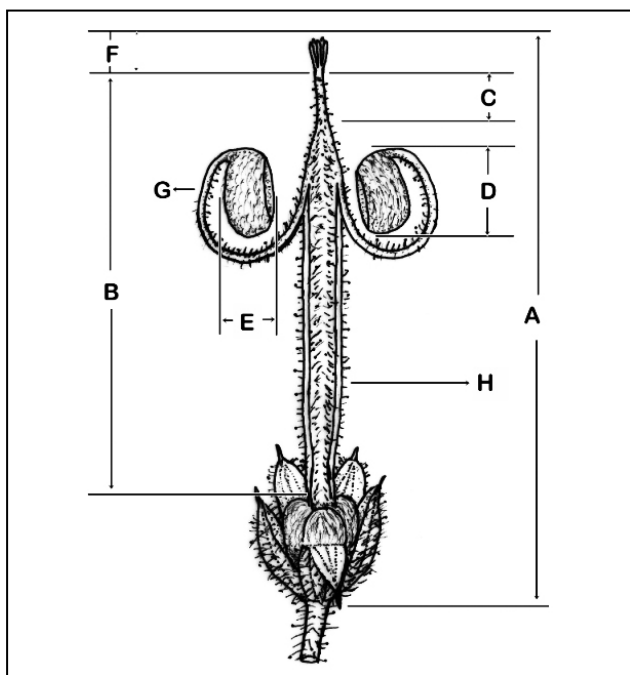
prong, smooth-faced, with a callus at the base, sparsely eglandular, hairy, gray-brown; rostrum 13–18 mm long, with a narrowed apex (neck) 3.4–6 mm long; stigmatic remains 1–1.6 mm, 5-lobed, outer surface eglandular, hairy, inner - glabrous (Fig. 4b1, b2).

#### *G. dissectum* (EDTU 11414)

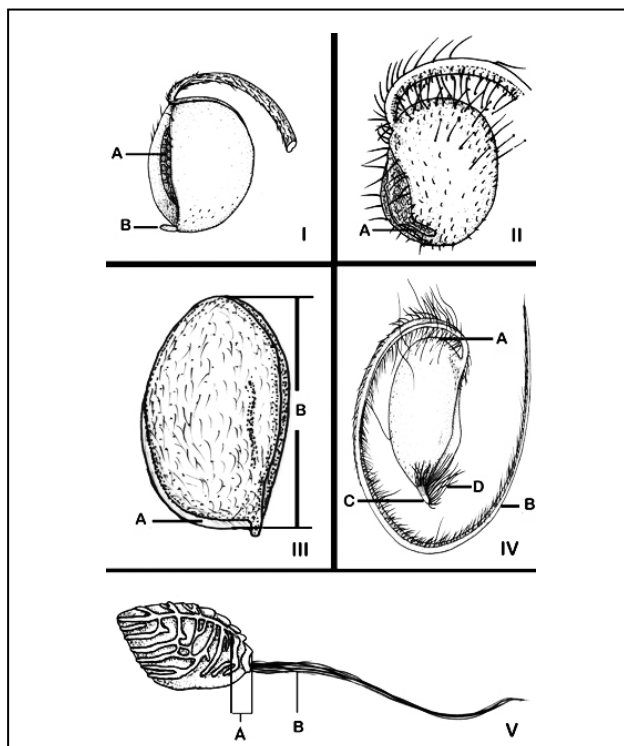
Fruit 13–19 mm long; mericaip 2.3–2.8 × 1.5–1.8 mm, without a strand of fibres, longitudinal rib, or callus at the base, smooth-faced, with a basal prong; vertical or horizontal, eglandular and sparsely cloth hairy, light-brown; rostrum 12–15 mm long, with a narrowed apex (neck) 1.8–2.5 mm long; stigmatic remains 0.8–1 mm long, 5-lobed, outer surface eglandular, hairy, inner surface glabrous (Fig. 4c1, c2).

#### *G. divaricatum* (EDTU 11449)

Fruit 9–12 mm long; mericaip 2.8–3.4 × 1.8–2.3 mm, without a strand of fibres, longitudinal rib, callus at the base, or basal prong; upper part with 3–4 transverse ribs, cheeks anastomose veined, vertical, eglandular and occasionally sessile cloth hairy, light-brown; rostrum 4–6 mm long; no rostrum with a narrowed apex (neck); stigmatic remains 0.7–0.9 mm long, 5-lobed, surface eglandular, hairy, prominent (Fig. 4d1, d2).



**Fig. 1.** Fruit of *Geranium*. A: Fruit size; B: Rostrum length; C: Rostrum with a narrowed apex (neck) length; D: Mericaip length; E: Mericaip width; F: Stigmatic remains; G: Awn; H: Columella.



**Fig. 2.** I. Parts of Mericaip. A: Seed, B: Rostrum; II: Basal prong. III: A: Longitudinal ribs, B: Mericaip length; IV: A: Ribs, B: Awn; C: Callus, D: Base, V: A: Collar-like overlapping ribs, B: Strand of fibres.

Table 2. Seed characteristics of *Geranium* (Fig. 3). (Min – minimum, Max – maximum, M – Mean, Std. – standard deviation).

SEED	Size	Length-width ratio	Seed type	Surface	Color
SPECIES	Min.-Max.(M±Std.)mm	Min.-Max. (M) mm			
<i>G. asphodeloides</i>	1.9–2.5 × 1.6–2 (2.07+0.15 × 1.83+0.13)	1–1.39 (1.14)	Circular-ovate	Faveolate	Dark-brown
<i>G. columbinum</i>	1.8–2.7 × 1.5–2.2 (2.12+0.08 × 1.77+0.28)	1.11–1.27 (1.20)	Ovate	Faveolate	Dark-brown
<i>G. dissectum</i>	1.6–2.2 × 1.3–1.7 (1.83+0.17 × 1.27+0.43)	1.19–1.54 (1.30)	Ovate	Faveolate	Dark-brown
<i>G. divaricatum</i>	2.2–2.6(–3.1) × 1.4–1.6(–1.8) (2.51+0.21 × 1.5+0.12)	1.38–1.86 (1.68)	Ovate	Reticulate	Dark-Brown
<i>G. lucidum</i>	1.7–2.1 × 0.9–1.2 (1.83+0.13 × 1.04+0.08)	1.58–1.91 (1.77)	Elliptical-ovate	Smooth	Brown
<i>G. molle</i>	1.4–1.6 × 1–1.3 (1.54+0.07 × 1.15+0.08)	1.17–1.45 (1.35)	Elliptical-ovate	Smooth	Brown
<i>G. purpureum</i>	1.7–2.2 × 1–1.3 (1.9+0.16 × 1.12+0.10)	1.5–1.9 (1.71)	Elliptical-ovate	Smooth	Brown
<i>G. pusillum</i>	1.4–1.8 × 0.7–1 (1.55+0.14 × 0.83+0.09)	1.67–2 (1.85)	Elliptical-ovate	Smooth	Brown
<i>G. pyrenaicum</i>	1.9–2.4 × 1–1.3 (2.15+0.17 × 1.14+0.11)	1.82–2.3 (1.90)	Elliptical-ovate	Smooth	Brown
<i>G. robertianum</i>	1.9–2.3 × 1–1.4 (2.2+0.15 × 1.14+0.11)	1.57–2.09 (1.94)	Elliptical-ovate	Smooth	Brown
<i>G. rotundifolium</i>	1.6–1.9 × 1.3–1.6 (1.69+0.11 × 1.34+0.10)	1.07–1.31 (1.11)	Circular-elliptical	Faveolate	Brown – dark-brown
<i>G. sanguineum</i>	3.3–3.7 × (1.8–)2.1–2.5 (3.56+0.16 × 2.2+0.19)	1.44–2 (1.63)	Elliptical	Smooth	Dark-brown
<i>G. tuberosum</i>	2–3 × 1.3–2 (2.63+0.48 × 1.6+0.29)	1.5–2 (1.65)	Elliptical	Reticulate	Brown

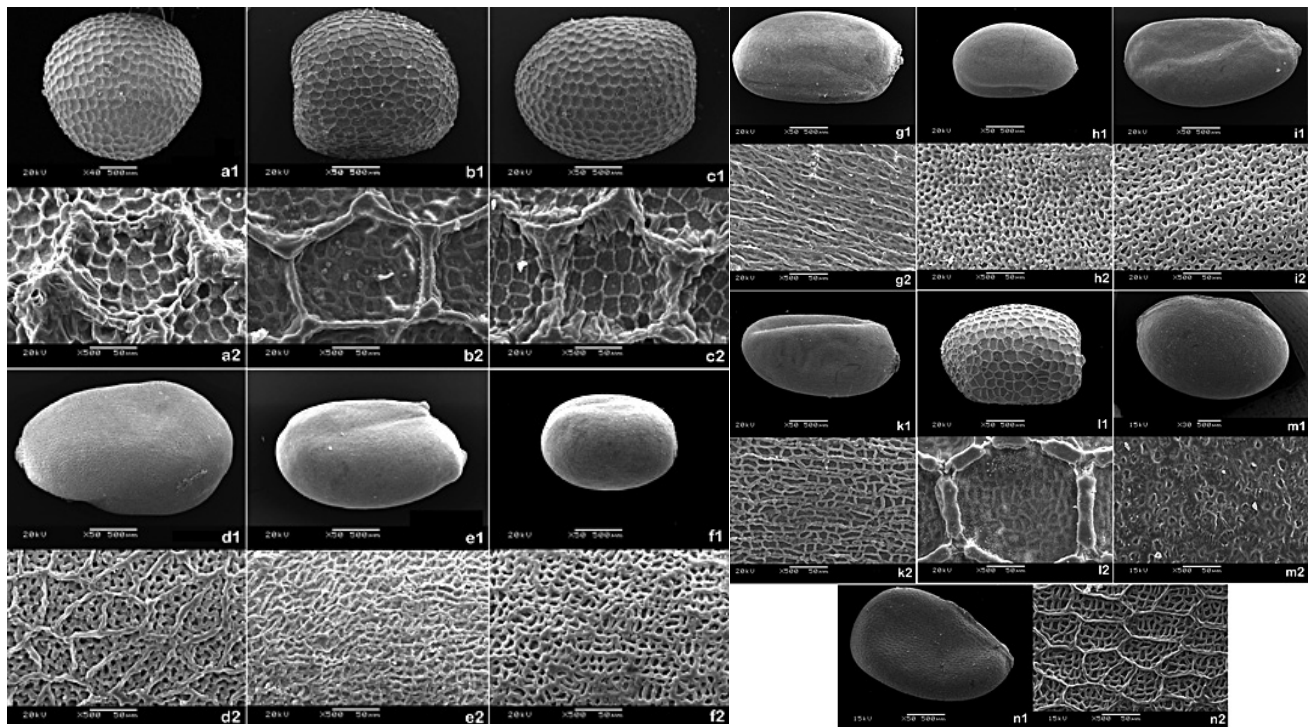


Fig. 3. Seed micromorphology of the *Geranium* species (SEM). *G. asphodeloides* (a1, a2); *G. columbinum* (b1, b2); *G. dissectum* (c1, c2); *G. divaricatum* (d1, d2); *G. lucidum* (e1, e2). *G. molle* (f1, f2); *G. purpureum* (g1, g2); *G. pusillum* (h1, h2); *G. pyrenaicum* (i1, i2); *G. robertianum* (k1, k2); *G. rotundifolium* (l1, l2); *G. sanguineum* (m1, m2); *G. tuberosum* (n1, n2).

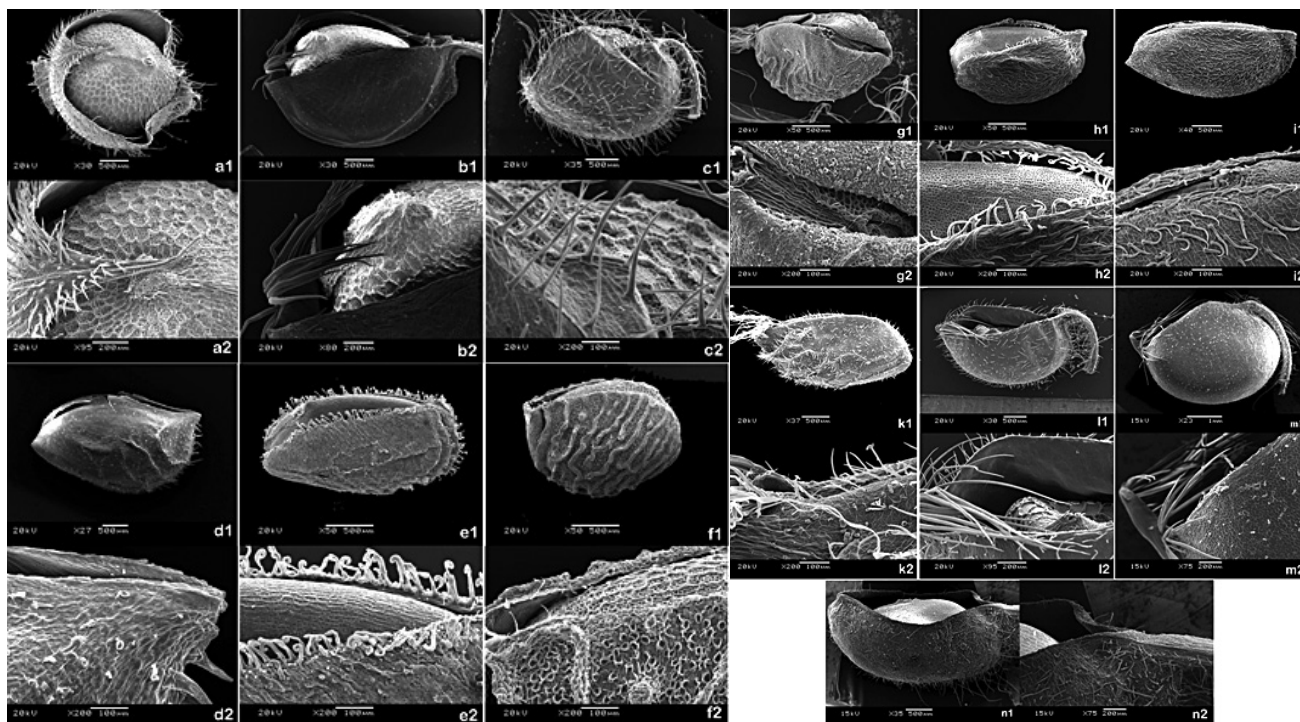


Fig. 4. Mericarp micromorphology of the *Geranium* species (SEM). *G. asphodeloides* (a1, a2); *G. columbinum* (b1, b2); *G. dissectum* (c1, c2); *G. divaricatum* (d1, d2); *G. lucidum* (e1, e2). *G. molle* (f1, f2); *G. purpureum* (g1, g2); *G. pusillum* (h1, h2); *G. pyrenaicum* (i1, i2); *G. robertianum* (k1, k2); *G. rotundifolium* (l1, l2); *G. sanguineum* (m1, m2); *G. tuberosum* (n1, n2).

#### ***G. lucidum*** (EDTU 11019)

Fruit 12–21 mm long; mericarp 1.8–2.3 × 1–1.4 mm, without a strand of fibres, longitudinal rib, callus at the base, or basal prong; upper part with parallel, reticulated ribs at the side, along rims and in parallel ribs cloth hairy, light-brown; rostrum 10–12 mm long, with a narrowed apex (neck) 4–6 mm long; stigmatic remains 0.4–1.1 mm long, 5-lobed, glabrous (Fig. 4e1, e2).

#### ***G. molle*** (EDTU 11219)

Fruit 9–17 mm long; mericarp 1.6–1.8 × 1.2–1.4 mm, without a strand of fibres, longitudinal rib, callus at the base, or basal prong; with cross-backed ribs, only a few hairy at the base, light-brown; rostrum 5–13 mm long, with a narrowed apex (neck) 1.2–2 mm long; stigmatic remains 0.8–1.3 (–2.1) mm long, 5-lobed, outer surface eglandular, hairy, inner - glabrous (Fig. 4f1, f2).

#### ***G. purpureum*** (EDTU 11070)

Fruit 12–24 mm long; mericarp 2.2–3 × 1.2–1.4 mm, with a white silky strand of fibres on the awn along the edge extending from stigmatic remains, upper part with 3–5 overlapping collar-shaped ribs, ribs reticulate at the side, without a longitudinal rib, callus at the base, or basal prong; eglandular, short-haired or glabrous, light-dark-brown; rostrum 10–20 mm long, with a nar-

rowed apex (neck) 5–6 mm long; stigmatic remains 1–1.1 mm long, 5-lobed, glabrous (Fig. 4g1, g2).

#### ***G. pusillum*** (EDTU 11247)

Fruit 7–10 mm long; mericarp 1.7–2 × 1–1.2 mm, without a strand of fibres, longitudinal rib, or basal prong, vertical, eglandular, hairy, brown; rostrum 5–8 mm long; almost no rostrum with a narrowed apex (neck); stigmatic remains 0.6–0.8 mm long, 5-lobed, outer surface eglandular, hairy, inner surface glabrous. (Fig. 4h1, h2).

#### ***G. pyrenaicum*** (EDTU 11505)

Fruit 13–20 mm long; mericarp 2.7–3.2 × 1.2–1.4 mm, without a strand of fibres, callus at the base, or basal prong; with a longitudinal rib, smooth, vertical, eglandular, hairy, brown; rostrum 11–16 mm long; almost no narrowed apex (neck) of the rostrum; stigmatic remains 1.5–1.8 mm long, 5-lobed, outer surface eglandular, hairy. (Fig. 4i1, i2).

#### ***G. robertianum*** (EDTU 11100)

Fruit 18–25 mm long, mericarps 2.7–3.1 × 1.3–1.7 mm, without a longitudinal rib, callus at the base, or basal prong, a white silky strand of fibres from the emerging top of the mericarp to stigmatic remains, 1–2 (3)

overlapping collar-shaped ribs on top, reticulated ribs at the side, eglandular, short-haired or glabrous, coffee-with-milk in color; rostrum 12–18 mm long, with a narrowed apex (neck) 5.5–7 mm long, stigmatic remains 1–1.2 mm, 5-lobed, glabrous (Fig. 4k1, k2).

***G. rotundifolium*** (EDTU 11121)

Fruit 15–23 mm long, mericarp  $2.3\text{--}3.2 \times 1.5\text{--}1.9$  mm, without a strand of fibres or longitudinal rib, smooth, with a callus at the base, eglandular, hairy, green-brown; rostrum 14–18 mm long, with a narrowed apex (neck) 3–5 mm long; stigmatic remains 0.7–1.2 mm long, 5-lobed, outer surface eglandular, hairy, inner - glabrous (Fig. 4l1, l2).

***G. sanguineum*** (EDTU 11487)

Fruit 20–40 mm long; mericarp  $3.8\text{--}5 \times 2.5\text{--}4$  mm, without a strand of fibres or longitudinal rib, smooth, with a callus at the base and a basal prong; from the upper part to half the rib eglandular, hairy, sessile cloth hairy on the top, brown; rostrum 15–32 mm long, with a narrowed apex (neck) 3–4 mm long; stigmatic remains 3–4.5 mm long, 5-lobed, eglandular, hairy (Fig. 4m1, m2).

***G. tuberosum*** (ANK 1359)

Fruit 13–25 mm long; mericarp  $2.5\text{--}4 \times 1.6\text{--}1.9$  mm, without a strand of fibres, longitudinal rib, callus at the base, or basal prong, smooth, vertical-erect, eglandular, upper part slightly short-erect-vertical cloth hairy, brown; rostrum 11–21 mm long, with a narrowed apex (neck) 0.8–1.5 mm long; stigmatic remains 0.9–1.6 mm long, 5-lobed, glabrous (Fig. 4n1, n2).

## Discussion

Thirteen species have been identified in the study area. *Geranium divaricatum*, one of these 13 species, is new to the Thrace region and was collected for the first time by us. Yeo (2003) and Aedo & al. (2005) differ in the fruit terminology. While Yeo (2003) includes carpel and stigma in the rostrum, Aedo & al. (2005) do not do it. The terminology of Aedo & al. (2005) was used.

In the morphological study, all seeds were recorded as non-hairy under the SEM and stereo microscope. Also, seed type is elliptical-ovate in *G. lucidum*, *G. molle*, *G. purpureum*, *G. pusillum*, *G. pyrenaicum*, and *G. robertianum*; circular-ovate in *G. asphodeloides*; ovate

in *G. columbinum*, *G. dissectum* and *G. divaricatum*; circular-elliptic in *G. rotundifolium* and, lastly, elliptic in *G. sanguineum* and *G. tuberosum*. The seed coat (or surface) is smooth, in *G. lucidum*, *G. molle*, *G. purpureum*, *G. pusillum*, *G. pyrenaicum*, *G. robertianum*, and *G. sanguineum*; faveolate in *G. asphodeloides*, *G. columbinum*, *G. dissectum*, and *G. rotundifolium* and, lastly, reticulate in *G. divaricatum* and *G. tuberosum* (Table 2, Fig. 3).

As a result of the observations, it has been determined that the seed color varies in young and mature seeds. Therefore, absolutely mature seeds should be selected, in order to avoid mistakes and this should be kept in mind. This may be the reason why the seed colors of some species in the studies of Moghadam & al. 2015 do not match the colors of some species in our study. For instance, while the seed colour of *G. purpureum* has been determined as red in the study of Moghadam & al. (2015), the seed colour of *G. purpureum* has been observed as brown in our studies (Table 2, Fig. 3g1, g2). Seed types usually seem to be alike, but it has been determined that the species have more distinguishing features in terms of seed surface.

Three types of seed surface have been observed in our investigation. Among them, *G. tuberosum* and *G. divaricatum* with their reticulate structure are clearly distinguished from the other species. The seed surface of *G. divaricatum* was defined as smooth in the Flora of Turkey (Davis 1967). Indeed, despite the fact that at magnification of 50 times it looked smooth, it was observed to be reticulate when magnified 500 times with the electron microscope (SEM) (Table 2, Fig. 3d1, d2).

Moghadam & al. (2015) also stated that the seed surface of *G. tuberosum* was reticulate. Although Aedo, Estrella (2006) and Davis (1967) stated that the surface of *G. tuberosum* was smooth, in the SEM studies by us it was determined as reticulate (Table 2, Fig. 3n1, n2). While Moghadam & al. (2015) defined the seed surface of *G. pyrenaicum* as reticulate-faveolate, Aedo & al. (1998b) defined it as slightly reticulate. However, in our study with SEM ( $\times 500$ ) it was not observed as reticulate. It was seen the same as the surfaces which have been defined as smooth (Table 2, Fig. 3i1, 3i2).

Although Moghadam & al. (2015) defined the seed surface of *G. rotundifolium* as reticulate-rugulate, the surface was clearly seen as faveolate in our studies. The same situation is valid for *G. columbinum* and *G. dissectum*. (Table 2, Fig. 3b1, b2, c1, c2, 3l1, 3l2). For mericarps, see the situation below.

Mericarps of *G. columbinum* in our study are  $3.2\text{--}5 \times 2\text{--}2.6$  mm and the mericarp surface is only eglandular and hairy, although the mericarps are given as  $2.5\text{--}3.5 \times 1.5\text{--}2$  mm, with surface eglandular and glandular hairy in Moghadam & al. (2015).

*G. dissectum* can be easily confused with *G. columbinum*. However, the easiest discrimination comes from the mericarp. While *G. columbinum* has a callus, *G. dissectum* has a prong (Fig. 4b1, b2, c1, c2).

*Geranium divaricatum* is characteristic with a rostrum without a thin, short and narrowing neck. It has been assumed that this reduces the fruit discharge efficiency of these species (Aedo & al. 1998b). In our study, the rostrum is 4–6 mm long and the mericarp size is  $2.8\text{--}3.4 \times 1.8\text{--}2.2$  mm, whereas in Moghadam & al. (2015), the rostrum is 5–9 mm and the mericarp size is  $4.7\text{--}5.2 \times 2\text{--}2.6$  mm (Fig. 4d1, d2). The mericarp surface of *G. lucidum* contains only glandular hairs in our study, but it contains eglandular hairs in Moghadam & al. (2015) (Fig. 4e1, e2). Although in Moghadam & al. (2015) the mericarp of *G. molle* is  $1.8\text{--}2.5 \times 1.1\text{--}1.5$  mm, it is  $1.6\text{--}1.8 \times 1.2\text{--}1.4$  mm in our study (Fig. 4f1, f2). Although in Moghadam & al. (2015) the mericarp surface of *G. purpureum* is only glabrous, it is short eglandular-hairy or glabrous in our study (Fig. 4g1, g2).

*Geranium pusillum* is usually confused with *G. molle* because of its external appearance, including the height of the plant, petal shape and size, life shape and size. It has wider living areas than it has been assumed. However, because of the above reasons, there are fewer records of *G. pusillum* in the herbaria. Also, it has been identified as *G. molle*. But *G. pusillum*, with its five stamens, five staminodes (10 fertile stamens in *G. molle*), and a smooth mericarp surface with a longitudinal rib and horizontal eglandular hair (against the mericarp surface with a rib, no longitudinal rib and glabrous, hairy surface only with a few ciliate at the base in *G. molle*) is easily distinguished from *G. molle*. Although in our study the observed mericarp surface is eglandular and hairy, in Moghadam & al. (2015) it is given as eglandular, or glandular and hairy (Fig. 4h1, h2).

*Geranium pyrenaicum* is divided into two subspecies (<http://www.theplantlist.org>): *G. pyrenaicum* subsp. *pyrenaicum* with hairy mericarps; and *G. pyrenaicum* subsp. *lusitanicum* (Samp.) S. Ortiz with glabrous mericarps. These subspecies are widespread in Spain and Portugal. In our study, the mericarp size of *G. columbinum* is  $2.7\text{--}3.2 \times 1.2\text{--}1.4$  mm, while in Moghadam & al. (2015) the mericarp size is  $1.9\text{--}2.8 \times 0.9\text{--}$

$1.3$  mm. *Geranium pyrenaicum* looks like *G. pusillum* with many similar characters, such as leaf shape, recessed petals, smooth seed surface, as well as the mericarp characters (longitudinal rib, smooth surface, appressed, eglandular and hairy). Yet, *G. pyrenaicum* is different from *G. pusillum* in both fruit size (*G. pyrenaicum* is 13–20 mm long; *G. pusillum* is 7–10 mm long) and rostrum size (*G. pyrenaicum* is 11–16 mm long; *G. pusillum* is 5–8 mm long (Fig. 4h1, h2, i1, i2).

It is considered that the characters of the mericarp ribs of *G. robertianum*, which are very important for determining the species, are related to the age of the plant (young or mature). Yeo (1973) seems to have maintained our above-mentioned idea, too. *Geranium robertianum* is usually confused with *G. purpureum*. All characters of the two species are very alike. The most important difference is that the petal of *G. robertianum* is longer than of *G. purpureum*. Other differences are the number and position of ribs on the mericarp, which are very difficult to distinguish. Mericarp surface is short, eglandular and hairy, or glabrous in our study, but mericarp surface of *G. robertianum* is glabrous in Moghadam & al. (2015) (Fig. 4g1, g2, k1, k2).

*Geranium rotundifolium* is usually confused with *G. molle* and *G. pusillum*. *Geranium molle* and *G. pusillum* toss its carpel, whereas *G. rotundifolium* throws its seeds. Although in their study Moghadam & al. (2015) give the rostrum of *G. rotundifolium* as 9–12 mm long and the mericarp surface as eglandular and cloth hairy, the rostrum is 14–18 mm long and mericarp surface is only eglandular and hairy in our study (Fig. 4l1, l2). Although in seed throwing, mature seeds per plant, mericarp, awn and columella are seldom observed in *G. sanguineum* (Fig. 4m1, m2). It has a single flower, which is its most important distinguishing feature. There is no structure to prevent (callus tail and rostrum) the early fall before throwing of the seeds (premature) in *G. tuberosum*. Instead, the mericarp is hinged to an awn which is thicker and stronger, thus ensuring pressure for an early departure of mericarp from the columella. It is specific for the immature fruits of *G. tuberosum*. Therefore, it is difficult to find more seeds of the specimens. The difference between Moghadam & al. (2015) and our study is in the size of mericarp of *G. tuberosum*. While Moghadam & al. (2015) give mericarp sizes as  $3.6\text{--}4.3 \times 2.3\text{--}3.1$  mm, they were  $2.5\text{--}4 \times 1.6\text{--}1.9$  mm in our study (Fig. 4n1, n2).

After further micromorphological investigation, a determination key of the investigated *Geranium* species has been prepared as follows:

1. Mericarps with strand of fibres ..... 2
  - Mericarps without strand of fibres ..... 3
2. Mature mericarp upper ribs, 3–5 of them overlapping collar-shape, prominent ..... *G. purpureum*
  - Mature mericarps upper ribs, 1–2 (3) of them overlapping collar-shape ???, less obvious .....  
..... *G. robertianum*
3. Mericarps with longitudinal rib ..... 4
  - Mericarps without longitudinal rib ..... 5
4. Fruit 7–10 mm long; mericarp 1.7–2 × 1–1.1 mm; seed 1.4–1.8 × 0.7–1 mm ..... *G. pusillum*
  - Fruit 13–20 mm long; mericarp 2.7–3.2 × 1.2–1.4 mm; seed 1.9–2.4 × 1–1.3 mm ..... *G. pyrenaicum*
5. Mericarps with a basal prong ..... 6
  - Mericarps without a basal prong ..... 7
6. Fruit 13–19 mm long; rostrum with a narrowed apex (neck) 1.8–2.5 mm long; stigmatic remains on outer surface eglandular and hairy ..... *G. dissectum*
  - Fruit 19–26 mm long; rostrum with a narrowed apex (neck) 4–6 mm long; stigmatic remains glabrous ..... *G. asphodeloides*
7. Mericarp with a callus ..... 8
  - Mericarp without callus ..... 10
8. Seed surface smooth ..... *G. sanguineum*
  - Seed surface faveolate ..... 9
9. Mericarps 2.3–3.2 × 1.5–1.9 mm; seed 1.5–1.9 × 1.3–1.6 mm ..... *G. rotundifolium*
  - Mericarps 3.2–5 × 2–2.6 mm; seed 1.9–2.7 × 1.6–2.2 .....  
..... *G. columbinum*
10. Mericarp surface smooth, rostrum 11–21 mm ...  
..... *G. tuberosum*
  - Mericarp surface not smooth; rostrum shorter ..... 11
11. Mericarps 2.8–3.4 mm long; no rostrum with a narrowed apex (neck); seed surface slightly reticulate .....  
..... *G. divaricatum*
  - Mericarp shorter; rostrum with a narrowed apex (neck); seed surface smooth ..... 12
12. Stigmatic remains glabrous; rostrum with a narrowed apex (neck) 4–6 mm long; along rims and in parallel ribs cloth hairy ..... *G. lucidum*

– Stigmatic remains eglandular and hairy; rostrum with a narrowed apex (neck) 1.2–2 mm long; only a few hairs at the base ..... *G. molle*

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