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REVALIDATION OF *HEDLUNDIA CAUCASICA* (ZINSERL.) MEZHENSKYJ BASED ON MOLECULAR AND MORPHOLOGICAL EVIDENCE

HAYAL AKYILDIRIM BEĞEN[*] AND ÖZGÜR EMINAĞAOĞLU[1]

Health Services Vocational School, Artvin Çoruh University, 08000 Artvin, Türkiye

Keywords: Artvin, *Hedlundia caucasica*, *trnK-rps16*, Molecular, Türkiye

Abstract

Hedlundia caucasica (Zinserl.) Mezhenskyj previously placed as a synonym of *H. armeniaca* (Zinserl.) Mezhenskyj. Both species exhibit a distribution in closely related areas and are morphologically characterized by red and fleshy fruits, lobed leaves, and numerous flowers. However, these two *Hedlundia* species are sister group in phylogenetic analyses, and it has been determined that they do not share similar gene sequences in chloroplast *(trnK-rps16)* and nuclear *(ITS)* DNA gene regions analysis. Additionally, *H. caucasica* differs from *H. armeniaca* by its leaf sizes, leaf vein, leaf shape, number of leaf lobes, leaf apex, tomentose hairs below leaf and the structure and number of leaf teeth. Based on the result of the analyses, it has been determined that these two species differ morphologically and molecularly, and therefore, *Hedlundia caucasica* is considered a separate taxonomic species.

Introduction

The *Sorbus* L. (Rosaceae) genus is commonly known for its red-orange fruits found at the forest edges, belongs to the Amygdaloideae sub-family. It forms an important group with numerous taxa, hybrid forms, and are used as landscape plants. *Sorbus* s.l. consisted of 4 subsections (*Aria, Hedlundia, Sorbus, Torminalis*) before the study by Sennikov and Kurtto (2017). Recent morphological and molecular studies have led to the recognition of these subsections as distinct genera (Sennikov and Kurtto 2017, Banki *et al.* 2024). *Aria* (Pers.) Host is represented by 55 species, *Hedlundia* Sennikov and Kurtto by 55 species, *Sorbus* L. (1753) by approximately 108 species, 5 subspecies, and 17 varieties, and *Torminalis* Medik. is represented by 1 species (Aldasoro *et al.* 2004, Banki *et al.* 2024). The majority of these species are distributed in the Northern Hemisphere (Huntley 1993).

Hedlundia, a hybrid genus of these species, is naturally distributed in Europe and Western Asia, and is also cultivated as a cultivated form in Europe and America (Banki *et al.* 2024). Species of the genus *Hedlundia* were originally placed within the Lobatae section of the *Sorbus* genus by Gabrieljan (1978), later transferred to the Duales section by Zaik (1986), and subsequently classified under the Soraria genus by Májovský and Bernátová (2001) (Banki *et al.* 2022). As a result of morphological studies supported by molecular data, it has been concluded that all these species are synonyms of the genus *Hedlundia* (Sennikov and Kurtto 2017). Seven *Sorbus* taxa (*S. caucasica* var. *caucasica*, *S. caucasica* var. *yaltrikii*, *S. kusnetzovii*, *S. persicae*, *S. roopiana*, *S. takhtajanii*, *S. tamamschanae*) found in Türkiye are included within *Hedlundia* genus. Although *Hedlundia* species have a wide distribution in Europe and Asia, the species in Türkiye are generally distributed in the Caucasian region. Among these species, the *S. caucasica* var. *yaltrikii* taxon was identified as a new taxon for Türkiye and had been considered endemic. It had been classified as CR (Critically Endangered) in the IUCN Red List of Threatened Species (Gökşin 1982). Eminağaoğlu *et al.* (2010) recorded *S. caucasica* var. *caucasica* species as a new record in the Çevreli (Yusufeli, Artvin) region. Both of these taxa have been considered synonyms

*Author for correspondence: <h.akyildirim@artvin.edu.tr>. [1]Department of Forest Engineering, Faculty of Forestry, Artvin Coruh University, 08000 Artvin, Türkiye.

of *H. armeniaca* (Sennikov and Kurtto 2017). Accordingly the present taxonomic status of this species as per most authentic source Kew Science (Plants of the World Online 2025, *https://powo.science.kew.org › taxon) is as follows:*

Hedlundia armeniaca (Hedl.) Mezhenskyj in NULESU Coll. Fruit Ornament. Pl.: 31 (2018).

Basinym: *Sorbus armeniaca* Hedl. in Kongl. Svenska Vetensk. Acad. Handl., n.f., 35(1): 69 (1901).

Synonym: *Hedlundia caucasica* (Zinserl.) Mezhenskyj in NULESU Coll. Fruit Ornament. Pl.: 31 (2018), basionym: *Sorbus caucasica* Zinserl. in Bot. Mater. Gerb. Glavn. Bot. Sada R.S.F.S.R. 4: 142 (1923)

When examining the *H. armeniaca* species collected from the Yusufeli and Şavşat districts of Artvin, it was observed that they possessed different morphological structures. This study was conducted to determine whether *H. caucasica*, a synonym of *H. armeniaca*, is a separate species using morphological and molecular methods.

Materials and Methods

Hedlundia caucasica specimens were collected from 2 localities and *H. armeniaca* from single locality in Artvin between 2018-2021 (Fig. 1 and Table 1). Sampling was carefully conducted from the leaf, flower, and fruit parts of the plant to facilitate morphological identification and the preparation of herbarium materials. For identification of the specimens, the identification key in the *Flora of Turkey and the East Aegean Islands* (Davis 1965-85) *ve* Flora USSR (Kamarow 1934-78), illustrated plant atlases and studies were used (Eminağaoğlu and Anşin 2004, 2010, 2015, Eminağaoğlu *et al*. 2007, 2010, 2015, 2020, IPNI 2025, Komarow 1934-78). Herbarium specimens of the studied taxa were evaluated from various herbaria in Türkiye and around the world. Morphological features were analyzed based on our specimens and online images sourced from different herbaria and other platforms. These images were accessed from the Komarov Botanical Institute RAS (http://plants.jstor.org), Institute of Botany of the National Academy of Sciences of Armenia (https:// plants.jstor.org/) Depository of Life Systems (https://plant. depo.msu.ru/) and the Global Biodiversity Information Facility (GBIF; https:// www.gbif.org/). Measurements were obtained from both physical specimens and scaled images. Voucher specimens were dried and stored at Artvin Coruh University Herbarium (ARTH), giving a collection number to each specimen (Table 1).

Leaf tissues were processed for DNA extraction using the DNeasy Plant Mini Kit (Qiagen 2025). The chloroplast *trnk-rps16* and nuclear *ITS 4-5* gene region primers, along with PCR components and protocols for PCR amplifications are conducted (McBreen *et al*. 2003, Akyıldırım Beğen *et al*. 2024). Total DNA concentrations were assessed using a NanoDrop (Thermo Microvolume UV-Vis) and verified through 2% agarose gel electrophoresis. Sequencing reactions were performed with the dideoxy chain termination method running on an ABI 3100 Genetic Analyzer, Macrogene. The chloroplast DNA trnK-rps16 and nuclear ITS gene region of the taxon was aligned using MAFFT (Multiple sequence alignment) in Geneious prime 2025.0.3. In phylogenetic analyses, *Amelanchier ovalis* (MK920297.1) was selected as outgroup. Other sequence data of the studied taxa were obtained from GenBank database (Table 2). BI methods analyses were performed using MrBayes 3.2.6 (Geneious 2025).

Results and Discussion

In this revision it was found considerable taxonomic confusion in the herbarium samples, with misidentifcations of *Hedlundia caucasica*, predominantly determined as *H. armeniaca*. Corrected determinations were included in this revision.

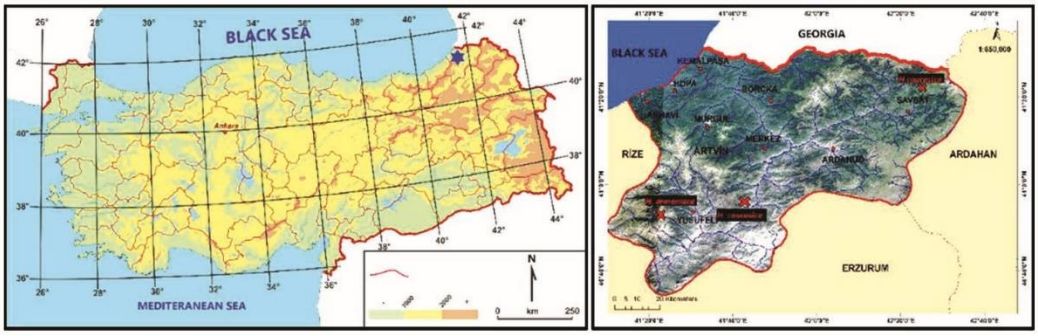

Fig. 1. Distribution areas of *Hedlundia* specimens in Artvin, Türkiye.

Table 1. Particulars of collected specimens data.

Species	Code	Collected number	Herbarium number	Location	High (m)
H. caucasica	SHAB52	*H.Akyil* 152	ARTH 16831	Demirkent, Yusufeli, Artvin	1504 m
H. caucasica	SHAB35	*H.Akyil* 136	ARTH 16814	Aşağıkoyunlu Köyü, Şavşat, Artvin	1544 m
H. armeniaca	SHAB36	*H.Akyil* 137	ARTH 16815	Barhal, Yusufeli, Artvin	1961 m

Table 2. Samples used for phylogenetic tree.

Species	Collector	Location	Accession number
H. arranensis	Liu,B.-B.	Beijing, China	NC085645
H. borbasii	Liu,B.-B.	Beijing, China	NC085590
H. hbrida	Liu,B.-B.	Beijing, China	NC085646
H. mougeotii	Liu,B.-B.	Beijing, China	NC085647
H. austriaca	Liu,B.-B.	Beijing, China	NC85584
H. armeniaca	Akyıldırım Beğen H.	Artvin, Türkiye	
H. caucasica	Akyıldırım Beğen H.	Artvin, Türkiye	
Amelanchier ovalis	Liu,B.-B., Hong,D.-Y., Zhou,S.-L., Xu,C., Dong,W.-P., Johnson,G. and Wen,J.	Beijing, China	MK920297

Resurrected species: Hedlundia caucasica (Zinserl.) Mezhenskyj in NULESU Coll. Fruit Ornament. Pl.: 31 (2018).

Holotype: Virtual herbarium of Komarov Botanical Institute, Leningrad RAS, LE [veb!] 01025623 (<“http://plants.jstor.org ” er. tar.: 01. X. 2021>).

Syn.: = Sorbus caucasica Zinserl. (1923). *In*: Not. Syst. Herb. Hort. Petrop. 4: 142.

(**Figs 2-3, Table 3**)

Description: Tree 6-7m, broad, scattered canopy structure. *Stem* bark dark grey, thick without cracks, circular lenticels represent. *Young branches* brown to reddish, bare, and glossy, shiny

surface with dense lenticels. *Buds* cone-shaped, 4-5 mm, with 3-4 scales, dark brown to black, densely covered with hairs when young. *Stipules* lanceolate, 1.5-2.5 cm, yellowish-green, and covered with deciduous, cotton-like hairs. *Leaves* lobed; leathery, ovate–rounded or broadly elliptic, broadly rounded base, obtuse, less often short acuminate, 8–12 (13) cm long, 6.5-9 (11) cm broad (length-to-width ratio 1.2-1.3), dark green upper part, gray-tomentose below, pubescent only along midrib above, 5 (7)-7 (9) lobed (lobes passing into teeth at the apex), with 7-9 pairs of lateral veins doubly serrate apically with tufted feathers at the points joined, forming an angle of ca. 45° with the midrib; leaf lobes oblong, subobtuse, apex and in lower part dentate, in upper part entire, less often some lobes with 1 or 2 small teeth in upper part; the lowest and the following lobes to half the half-width of blade; leaf teeth 30–50 on each margin, acute, those in upper part of leaf much larger than the others; *Petiol* 2.5-1.5 cm, yellowish green; *Inflorescence* a corymb with 20-50 flowers, 8-10 cm diam; *Flowers* 15-16 mm diam. *Pedicel* tomentose. *Sepal* 5, triangular, tomentose, inner part glabrous, acute at apex, persistent in fruit. *Petals* obovate, dirty white, 7-9 mm, eroded at apex. *Stamens* 14, 4-5mm; *Styles* 2-2.5 mm, tube dense tomentose, free. *Fruits* ovoid to globose without lenticels, brown red, glaucous, 30-40 per infructescence. *Seeds* 5-6 mm, dark brown at apex, 4 per fruit.

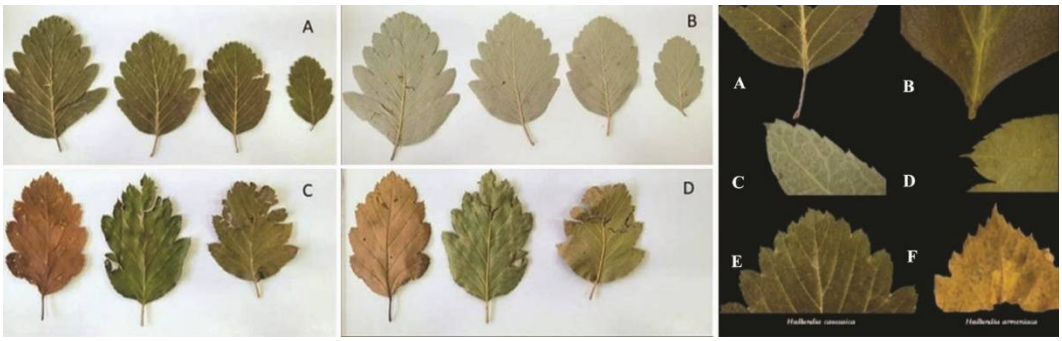

Fig. 2. a: Leaf morphology of *H. caucasica.* A: leathery upper part, B: tomentose hairs below leaves, *H. armeniaca*, C: paper like upper part, D: glabrous below leaves, b: *H. caucasica*; a: base, c: lobes, e: apex of *H. armeniaca*; b: base, d: lobes and g: apex.

DNA sequences: DNA sequences was created for the first time within the scope of this study. *Genbank numbers: xxx*

Distribution, habitat and ecology: Hedlundia caucasica generally grows in mountainous areas, upper part of forest zone, mainly on rocks at elevations between 1000 and 3000 meters, especially in humid forests and alpine regions in Caucasian region (Azerbaijan, Armenia, Georgia [Caucasus], North Caucasus, Türkiye, Crimea). It is resistant to cold and humid climatic conditions. It prefers well-drained, acidic, or slightly acidic soils. It avoids calcareous soils and thrives in moist, water-retentive soils. It develops well in high humidity and shaded conditions, and plays an important role in forest ecosystems (Əlizadə *et al*. 2013).

Phenology: Hedlundia caucasica blooms from April to May in Artvin.

Preliminary IUCN conservation assessment: Vulnerable: D1, *Hedlundia caucasica* is a rare species growing upper part of forest zone, mainly on rocks, at 900-1,600 m from Artvin, Türkiye and Georgia through Caucasia.

Additional material examined: TURKIYE- A8 Artvin • Şavşat, Aşağıkoyunlu, 41°16’42”N, 42°30’32”E; 1540 m; 15 Sep. 2024; ÖEmin 22792 (ARTH 17306) !; Yusufeli, Demirkent, semi-

deciduous forest; 40°51’28”N, 41°48’44”E; 1504 m; 21 Oct. 2017; *HAkyil.* 137 (ARTH 16831)!; Yusufeli, Demirkent, semi-deciduous forest; 40°51’20”N, 41°48’42”E; 1887 m; 14 August 2014; *Ö.Emin.* 8731 (ARTH!); Yusufeli, Çevreli, 2900m; 12.07.2010; *Ö.Emin. 8731* (ARTH!).

Vernacular name: English - Caucasian rowan; Türkçe -Kafkas üvezi.

Notes: Hedlundia caucasica is found in forest ecosystems in Türkiye and Caucasia and closely related to *H. armeniaca.* It is easily distinguished from the latter by its leaf shape, acute apex leaves, size, lob structure, number and shape of teeth, dense tomentose pubescence on the underside of the leaf, and differences in the bud structure.

Fig. 3. The type specimen of *H. caucasica, H. armeniaca,* and its synonym *S. caucasica* var. *yaltirikii* taxa.

Morphological affinities: In the field, the presence of tomentose hairs under the leaf and the large size of the leaf are notable, while laboratory studies revealed differences in the lobe structure and the number of teeth. It has been determined that *H. caucasica* is a valid name and that is not *H. armeniaca*’s synonym. While the leaf tip of *H. caucasica* is blunt-rounded, *H. armeniaca* has a pointed leaf tip (Figs 2 and 3, Table 3). The leaves of *H. caucasica* has thick, leathery leaves, with tomentose hairs below and on petiole, while *H. armeniaca* has thin, paper-like leaves, sparsely hairy or glabrous. The leaf base of *H. caucasica* is generally rounded, while in *H. armeniaca*, it is cuneate (Fig. 3). Leaves of *H. caucasica* is 6-9 lobed, leaf lobe teeth are broad, dentate, and blunt, while *H. armeniaca* is 5-7 lobed, they are concentrated towards the tip, serrate, and the tip is acute (Figs 2-3). The petiole length in *H. caucasica* is 1.5-2.5 cm, while in *H. armeniaca*, it is around 1.8-2 cm (Table 3).

Within the scope of this study, a key for the identification of seven species of *Hedlundia* in Türkiye including *H. caucasica* is prepared with its morphological characters that distinguish it from other species.

Identification key of *Hedlundia* species in Türkiye

1. Leaves 5-10 cm with l-3(-4) pairs of leaflets or deeply cut lobes towards the base, the upper part more shallowly lobed and dentate …….. *H. roopiana*

1. Leaves simple, lobed and or toothed

2. Leaves simple to shallowly lobed; serrate or dentate…….. *H. kusnetzovii*

2. Leaves lobed, not serrate or dentate

3. Leaves lamina ovate-elliptic; deeply lobed with narrow, overlapping lobes, the deepest lobes extending 1/2-3/4 of the way to the midrib, some of them with l-2(-3) lobes from one side reaching the mid-rib; leaf veins (7-)8-9 paired…… *H. tamamschjanae*

3. Leaves obovate-elliptic, rounded; tapering to cuneate base

4. Leaves glabrous; apex acute…… *H. armeniaca*

4. Leaves tomentose

5. Leaf lamina deep lobed, 8-12 x6.5-9 cm…….. *H. caucasica*

5. Leaf lamina lobed, 4-9.3 x 2.5-5.5 cm

6. Leaves broadly elliptic (4.5-10 x 3-9 cm); mucronate serrate lobed; entire only at base; lobes up to 10 mm deep; veins 7-paired; fruit oval-elliptic (0.6-1.4 cm) orange to goldish yellow without lenticels…….. *H. persica*

6. Leaves rhombic elliptic (4.5-7 x 3-5.5 cm), usually broadest at the middle; acute dentate lobed; fruit flattened globular (1.2-1.8 cm) yellowish-red, large lenticels…… *H. takhtajanii*

Table 3. Comparison of morphological characters of *H. caucasica* and *H. armeniaca.*

Characters	*H. caucasica*	*H. armeniaca*
Height	9-15 cm	8.5-12 cm
Width	5.5-11 cm	6-8 cm
Leaf	Thick, leathery	Thin, papery
Lower leaf surface	Dense tomentose	Glabrous
Leaf vein	Dense tomentose hairs with a distinct yellowish color	Not distinct, hairless
Petiole hair	Dense tomentose	Glabrous
Leaf apex	Rounded acuminate	Acute
Leaf base	Broad, rounded	Wedge-shaped
Number of lobes	6-9	5-7
Tooth shape	Blunt-tipped, flat	Divided, pointed, outwardly protruding
Petiole	1.5 -2.5 cm	1.8-2 cm

The type specimens of the *Hedlundia* species were examined from the herbariums where they are found, and the parts that would create morphological distinctions especially leaves apex, lobe number, size of leaves and hears under leaves were noted. The holotype specimen of *H. caucasica* Zinserl. has been examined from the Virtual Herbarium of Komarov Botanical Institute RAS, LE [web!] 01025623 (Fig. 3). Both in terms of size and structure, differences have been observed through the type specimens.

The chloroplast trnK-rps16 and nuclear ITS gene sequences have more clearly revealed the distinction between these two species of *Hedlundia.* In the phylogenetic analyses of *H. armeniaca* and its synonym *H. caucasica* using two different gene regions, the nuclear dataset represented 587 characters, the plastid dataset represented 914 characters, and the combined plastid + nuclear

dataset included 1501 analysed characters. When the ITS and trnK-rps16 gene region sequences of these samples were aligned, a significant amount of variation was found between the nucleotide sequences. Pairwise genetic distance matrix obtained from cpDNA (trnK-rps16) is 0.0051 between *H. caucasica* and *H. armeniaca* and genetic distance obtained from nDNA (ITS) is 0.0079.

The topologies produced by the BI and ML based on the plastid dataset. The GenBank database only contains samples of chloroplast trnk-rps16 gene sequences related to the species of *Hedlundia*, and no data has been found regarding the studied nuclear ITS 4-5 gene regions. Therefore, nucleotide differences for all gene regions have been numerically provided for both species, but a phylogenetic tree has only been constructed for the trnK-rps16 gene region (Fig. 4). It has been determined that there is a difference of 92 base pairs in the nucleotide sequences of the two species, with a similarity of 94.3%. Based on a dataset of 7 plastid sequences, phylogenetic relationships were analyzed using both Bayesian Inference (BI) and Maximum Likelihood (ML) methods (Fig. 4). *H. armeniaca* and *H. caucasica* are sister taxa with strong support (BS = 91%).

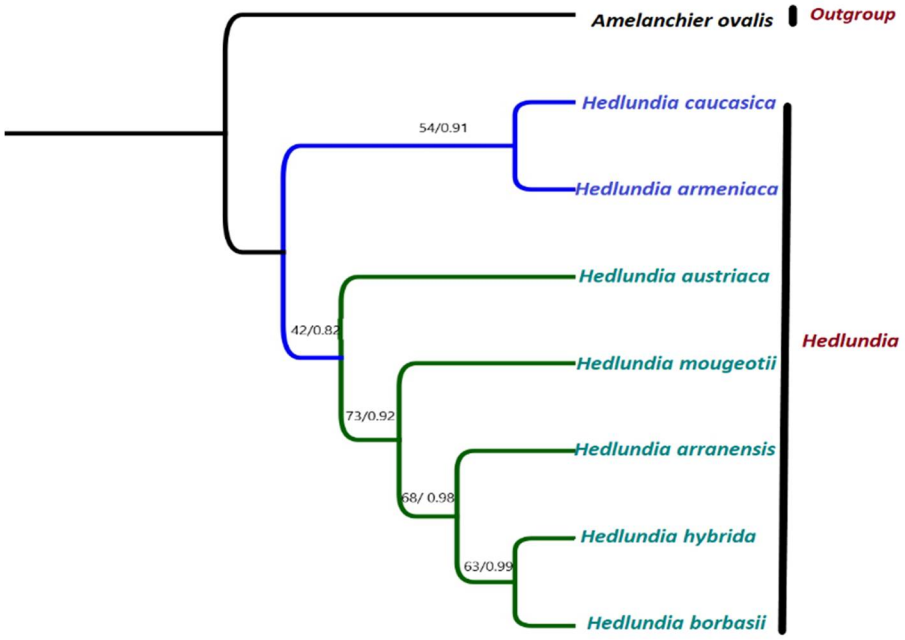

Fig. 4. Phylogenetic tree inferred from ML and MrBayes analysis. Bootstrap support values are shown near internal nodes inferred from chloroplast trnK-rps16 gene region.

No records of *H. armeniaca* in Türkiye are available in Flora of Turkey (Güner *et al.* 2012). Sennikov and Kurtto (2017) listed *Sorbus woronowi*, *Hedlundia caucasica* (Syn: *S. caucasica*), and *S. caucasica* var. *yaltrikii* as synonyms of *H. armeniaca* (IPNI 2025). As a result of the morphological and molecular data obtained in this study, it has been determined that *H. caucasica* should be considered a separate species. İbrahimov and Matsyura (2018) also published a study on new *Sorbus* species in Azerbaijan, but based on the visual photographs of *Sorbus caucasica* in the publication, it could be one of the synonyms of *H. armeniaca*, due to the acute leaf tip, the depth of the lobes, and the size and shape of the leaves. *S. caucasica* is known as a rare and endangered species in the Caucasus in Caucasian Red Book (Schatz *et al.* 2014). According to Zalibekov and Gabibova (2021), there are 6 *Sorbus* species in Dagestan, and 3 of them are listed in the Red Book

of Dagestan and among the Endemic Plants of the Caucasus. The distribution of these species is being threatened due to environmental and human factors. Therefore, it has been determined that, like in Dagestan, they should be included in the rare species group and classified under the VU (Vulnerable) category.

Seven species of the genus *Hedlundia* are distributed in Türkiye (Akyıldırım Beğen and Eminağaoğlu 2022). Although *Hedlundia caucasica* morphologically resembles *H. armeniaca*, *H. persica*, and *H. tamaschanae*, this study has shown that it is morphologically distinct. The distinction between these two species may arise from small-scale geographical separations between populations; however, further studies with more samples are needed to definitively determine the boundaries of the species.

Acknowledgements

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