

Four new species of *Onosma* (Boraginaceae) from Iran as an important diversity center of the genus in the world

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Abstract

FOUR NEW SPECIES OF *ONOSMA* (BORAGINACEAE) FROM IRAN AS AN IMPORTANT DIVERSITY CENTER OF THE GENUS IN THE WORLD.— In this study, four new species of *Onosma* subsect. *Asterotricha* from Northwest, West and North of Iran are described and illustrated. An extensive review of literature and a comparative study with specimens from several herbaria lead to determine these new species. Our argument for mentioned innovations is the significant divergence in the most important morphological characters. A diagnostic key to the new species as well *Asterotrichous* members of the genus known from *Flora Iranica* region is provided. In addition, detailed description and distribution as well as comparison tables with closely related species, are included.

Keywords: Boraginaceae; ecology; geobotany; Irano-Turanian; *Lithospermeae*; SW Asia.

Resumen

CUATRO NUEVAS ESPECIES DE *ONOSMA* (BORAGINACEAE) DE IRÁN UN IMPORTANTE CENTRO DE DIVERSIDAD DEL GÉNERO EN EL MUNDO.— En este estudio, se describen e ilustran cuatro nuevas especies de *Onosma* subsect. *Asterotricha* del noroeste, oeste y norte de Irán. Estas especies se han descrito tras una revisión exhaustiva de la literatura y un estudio comparativo de especímenes de diversos herbarios. Esta propuesta se basa en la divergencia significativa de los caracteres morfológicos más importantes. Se incluye una clave diagnóstica para las nuevas especies y para los miembros de la sect *Asterotrichous* reconocidos en *Flora Iranica*. Se incluye también una descripción detallada y la distribución de las especies, así como una tabla comparativa con las especies más estrechamente relacionadas.

Palabras clave: *Boraginaceae*; ecología; geobotánica; *Lithospermeae*; región Irano-Turaniana; SW Asia.

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INTRODUCTION

Onosma L. (Boraginaceae tribe *Lithospermeae*) is a genus comprising about 240 species (He *et al.*, 2020) mainly distributed in xeric habitats. The main centers of diversity are the Irano-Turanian and Mediterranean regions, especially Iran and Turkey (Meusel *et al.*, 1978; Mehrabian *et al.*, 2013; Cecchi *et al.*, 2016). Systematics is complex because species show wide variability (Kolarčík *et al.*, 2010), creating challenges to their identification (Ball, 1972; Mehrabian *et al.*, 2014; Mehrabian, 2015). De Candolle (1846) provided the first classification of *Onosma* based on calyx characteristics which led to two sections: *Onosma*. sect. (*Eu*)*Onosma* DC. and *Onosma*. sect. *Aponosma* DC. Later, Schur (1866) as well as Borbás (1877) emphasized the importance of trichomes. Boissier (1875) also divided the genus into the three groups based on the trichome characteristics of leaves: *Haplotricha* Boiss. in Boissier (1875: 179), *Heterotricha* Boiss. in Boissier (1875: 180) [described as *Diplotrichae* in Borbás (1877: 418)], and *Asterotricha* Boiss. Stroth (1939) considered Boissier's groups as subsections. Recently, Peruzzi & Passalacqua (2008) referred to them as natural groups. Nevertheless, Cecchi *et al.* (2011), Cohen (2011), Chacón *et al.* (2016) and Weigend *et al.* (2016), believed that they are integrative sections and representatives of the *Echium*-clade (Cecchi *et al.*, 2016). Recent molecular studies have not confirmed their monophyly (Kolarčík *et al.*, 2010; Cecchi *et al.*, 2011). Several systematic studies have been done on *Onosma* L., including morphological and micro-morphological (Bigazzi & Selvi, 2000; Akçin & Engin, 2001, 2005; Akçin, 2007a, b; Peruzzi & Passalacqua, 2008; Teppner, 2008; Akçin, 2009; Binzet & Akçin, 2009; Akçin & Binzet, 2011; Akçin *et al.*, 2013; Martonfi *et al.*, 2014; Mehrabian *et al.*, 2014), karyological (Teppner, 1972, 1991, 1996, 2008, 2011, 2012; Vouillamoz, 2001; Martonfi & Kolarčík, 2008), palynological (Qureshi & Qaiser, 1987; Zemskova & Popov, 1991; Binzet & Orcan, 2003; Maggi *et al.*, 2008; Binzet *et al.*, 2010; Binzet, 2011; Kolarčík *et al.*, 2015), phytogeographical and ecological (Kolarčík & Martonfi, 2006), and molecular (Vouillamoz, 2001; Mengoni *et al.*, 2006; Cecchi & Selvi, 2009; Weigend *et al.*, 2009, 2013, 2016; Kolarčík *et al.*, 2010, 2014; Cohen, 2011; Chen &

Zhang, 2019; Nasrollahi *et al.*, 2019, 2020) studies. Riedl (1967) pioneered the research on *Onosma* L. from the Iranian Plateau and described 59 species from the three sections including *Onosma* L., *Podonosma* (Boiss.) Gürke. and *Protonosma* Popov. Afterward, Khatamsaz (2002) provided taxonomic notes on the *Flora of Iran* with a similar classification to that of Riedl. Several other studies on *Onosma* L., including systematic (Mehrabian *et al.*, 2011a, b; Sheidai *et al.*, 2015; Sayadi *et al.*, 2017), palynological (Mehrabian *et al.*, 2012), micro-morphological (Azizian *et al.*, 2000; Arab Ameri *et al.*, 2014; Mehrabian *et al.*, 2014), ecological and geobotanical research (Mehrabian, 2015; Moradi *et al.*, 2019; Khajoei Nasab *et al.*, 2020a; Naghizadeh *et al.*, 2020) as well as the identification of new species (Mehrabian *et al.*, 2013; Mehrabian & Amini Rad, 2018; Mehrabian & Mozaffarian, 2018), have been done by the *Onosma* studies team at Shahid Beheshti University as well Research Institute of Forests and Rangelands of Iran. During field excursions in the northwestern and northern geomorphologic zones of Iran and herbarium assessments, some unidentified species of *Onosma* were collected and evaluated through the examination of their valuable taxonomic traits and comparisons with similar species.

The current study aimed to evaluate the most important diagnostic characteristics of unidentified species compared to their related species, justify them as new species, and provide taxonomic as well as ecological descriptions of the new taxa.

MATERIALS AND METHODS

During field studies in various regions of the country, some unknown samples were collected. They were also collected by the authors during their scientific excursions in the Azerbaijan, Ilam and Alborz provinces. The new taxa were compared with fundamental diagnostic keys, including Boissier (1875), Flora of USSR (Popov, 1953), Johnston (1954), Post (1966), Riedl (1967), Polunin (1969), Ball (1972), Riedl (1979) Nasir & Ali (1979), and Khatamsaz (2002). Additionally, the results of several studies on the newly introduced species of *Onosma* (Mehrabian & Mozaffarian, 2018,

Mehrabian *et al.*, 2022) were assessed and compared with the new taxa. More than 2800 herbarium accessions of *Onosma*, were examined, including type specimens and image types, in several European herbaria (W!, WU!, LE, BG!, JE!, C!, B!, G!, and K) and Iranian herbaria (HSBU, TARI, IRAN) (acronyms follow Thiers, 2019) to reinforce the taxonomic reasons for introducing the mentioned new species (Appendix). Furthermore, morphological characters including trichome type (cauline and basal leaves and nectary ring), shape and size of the calyx, shape and size of the corolla, nutlet morphology, anther length and connection as well as their exertion and the type and size of pollen grains were studied and compared with closely related species.

Holotypes and isotypes were deposited and preserved in the Herbarium of Shahid Beheshti University (HSBU) as well Herbarium of Research Institute of Forests and Rangelands of Iran (TARI) with the collector and acronyms of herbariums in parentheses, according to *Index Herbariorum* (Thiers, 2019). In addition, the author's names are included in accordance with IPNI.

The upper and lower surfaces of basal and cauline dried leaves as well as pollen grains were mounted on stubs using double-sided adhesive tape and coated with gold by a DC magnetron sputtering desktop machine. Afterward, the samples were photographed by a scanning electron microscope (Cam Scan Hitachi SU3500). In addition, 15–30 pollen grains were assessed through analysis, and mature dried nutlets were photographed by a dinolite microscope. The morphological terminology follows that of Riedl (1967), Harris & Harris (2001), Simpson (2006), Punt *et al.* (2007), Halbritter *et al.* (2008), and Hesse *et al.* (2009). Lastly, morphological and micro-morphological evidence was provided to compare new introduced taxa with other asterotrichous and heterotrichous species of *Onosma* (Tables 1 and 2). A synoptic key to nearest taxa to new taxa was provided for decision making (Appendix).

RESULTS AND DISCUSSION

Iran and particularly a segment of the prominent natural plateau of Iran featuring several mountainous barriers (Zagros, Alborz, Kopet Dagh, and

Makran mountain ranges) and scattered internal mountains is considered one of the main centers of diversity and endemism for angiosperms in the world (Hedge & Wendelbo, 1978; Jalili & Jamzad, 1999) because of the area's variability in paleo-biogeographical events (Takhtajan, 1986) and climatic and geomorphologic heterogeneity (Khalili, 2005; Stöcklin, 1968).

The Zagros as well as the northwest geomorphologic unit of Iran are reported to be the main centers of diversity and endemism for *Onosma* in Iran (Mehrabian, 2015; Moradi, 2017; Naghizadeh, 2017; Khajoei Nasab *et al.*, 2020a). Accordingly, the mentioned zones were evaluated by our team through several field studies, which led to the discovery and identification of numerous new species of *Onosma* (Mehrabian *et al.*, 2013; Mehrabian & Amini Rad, 2018; Mehrabian & Mozaffarian, 2018, Mehrabian *et al.*, 2022). Moreover, this area is one of the main targets for scientific field work in the region, leading to the collection and determination of unknown species. Accordingly, a comprehensive literature review and the evaluation of numerous Iranian and European herbaria led to the identification of these novelties. Our argument for these novelties is based on the prominent divergence in the most important morphological characteristics (e.g. trichome type, shape and size of the calyx, shape and size of cauline and basal leaves, annulus hairs, shape and size of the corolla, anther length, and connection as well as their exertion, nutlet morphology, and pollen type and size) compared with their closest allied species that were highlighted by literature (Boissier, 1875; Popov, 1953; Jhonston, 1954; Riedl, 1967; Polunin, 1969; Ball, 1972; Nasir & Ali, 1979; Post, 1986; Khatamsaz, 2002; Mehrabian *et al.*, 2013; Sayadi *et al.*, 2017; Mehrabian & Amini Rad, 2018; Mehrabian & Mozaffarian, 2018). In addition, these new species have been confirmed by the noticeable geobotanical divergence emphasized in recent studies (Cecchi *et al.*, 2011; Mehrabian, 2015; Moradi, 2017; Nikjouyan, 2018; Nemati, 2019; Naghizadeh *et al.*, 2020). Thus, the new species represent a significant differentiation compared with the species last introduced from the area under study as well as neighboring regions and improve our arguments that these unknown specimens can be considered as new species.

Table 1. Main characters distinguishing *Onosma madjnoniani* and *Onosma riahii* from its morphologically similar species. MXc: Mediterranean xeric-continental, MPc: Mediterranean pluviseasonal continental, Ig: Igneous Rocks, Me: Metamorphic, Vo-Se: Volcano-Sedimentary, Se: Sedimentary, QD: Quaternary Deposits, LS: Lithosols from igneous rocks, brown soils, and Sierozome Soils CL: Calcareous Lithosols-Brown Soils and Chestnut Soils, BS: Brown Soils, Op: Ophiolitic.

Characters	<i>Onosma madjnoniani</i>	<i>Onosma riahii</i>	<i>Onosma rascheyana</i>	<i>Onosma armena</i>	<i>Onosma kurdica</i>	<i>Onosma moussavi</i>
Plant height (cm)	20–25	30–35(40)	12–25	15–30	30–35	22–30
Rosette leaves size (mm)	90–140(150) × 4–9	30–40 × 2–3	20–55 × 3–10	15–35 × 1–3.5	15–22 × 3–4	20–44(45)
Rosette leaves shape	lanceolate to lanceolate-linear	linear to linear-lanceolate	spathulate to linear-spathulate	linear-spathulate	linear, linear-lanceolate	spatulate-lanceolate
Basal leaf size (mm)	25–45 × 4–7	30–40 × 2–3	20–40 × 3–8	20–40 × 2–3.5	100–200 × 3–5	15–25
Basal leaf shape	lanceolate to lanceolate-linear	linear-lanceolate	spathulate to linear-spathulate	linear-spathulate	narrowly obovate, lanceolate	spatulate-lanceolate
Cauline leaf size(mm)	25–90 × 5–9(10)	50–90 × 4–4.5(5.5)	20–40 × 3–8	20–35 × 2–3.5	100–200 × 3–5	30–50 × 2–6
Cauline leaf shape	lanceolate to lanceolate-linear	linear-lanceolate	oblong	spathulate	linear-lanceolate	linear-lanceolate
Indumentum	sub-dense, sub-adpressed	dense, sub-adpressed	sub-dense, sub-adpressed	dense sub-adpressed	dense, adpressed	sub-dense, adpressed
Tubercle rays	short, semi-dense	long, semi-dense	long and dense	long, dense	long, dense	long, dense
Pilies	sub-dense	sub-dense	sparsely	sub-dense	sparsely	sparsely
Inflorescence	up to 8(9) flowers	up to 4 flowers	up to 7–9 flowers	up to 8–10 flowers	up to 7–9 (10) flowers	up to 9 flowers
Corolla color	yellow, violet at the apex	yellow	yellow turning to top	white, pale yellow	reddish yellow	yellow
Corolla shape	clavate	tubular to clavate	clavate	tubular, tubular-sub clavate	clavate	clavate to clavate-campanulate
Corolla length (mm)	up to 25	23–25	20–25	16–20	25–26	17–18
Pedicle length (mm)	ca. 1.5	2	ca. 2	ca. 1.5	ca. 10	ca. 7
Calyx length (mm)	16–18(19)	15–17	19–20	9–10	20–25	12–16
Bract shape	lanceolate	linear-lanceolate	lanceolate	linear	linear-lanceolate	linear-lanceolate
Bract length (mm)	15–20(22)	18–20(25) × 2–3	7–8	9–10	20–25	ca. 10
Anther length (mm)	ca. 8	ca. 8	7–8	5–6	5–6	ca. 4
Annulus	glabrous	glabrous	glabrous	glabrous	glabrous	glabrous
Nutlet (mm)	(2.8)3 × 3.8(4)	-	3–3.2 × 2–3	3.5–4 × 2–2.5	4.5–6.5 × 3–3.5	3.8–4 × 2.5–2.8
Elevation range (a.s.l., in m)	2100–2200	2100–2280	2100–3200	1700–2500	2200–2600	2800–3235
Phytochorion	Atropatene	Atropatene	Atropatene, Kurdistan-Zagros	Atropatene	Kurdistan-Zagros	Atropatene
Geomorphologic Unit	Alborz	Alborz	northwest	northwest	west	northwest
Geologic formation	Ig	Ig	Ig, Me, Se, Vo-Se, QD	Ig, Me, Se, Vo-Se, QD	Se	Op
Bioclimatic Unit	MXc	MXc	MXc, MPc	MXc, MPc	MPc	MXc
Soil	LS	LS	Cl-BS	Cl-BS	BS	Cl-BS

Table 2. Main characters distinguishing *Onosma pseudohebebulba* and *Onosma bozghushica* from its morphologically similar species. MXc: Mediterranean xeric-continental, MPc: Mediterranean pluviseasonal continental, Ig: Igneous Rocks, Me: Metamorphic, Vo-Se: Volcano-Sedimentary, Se: Sedimentary, QD: Quaternary Deposits, LS: Lithosols from igneous rocks, brown soils and Sierozome Soils CL: Calcareous Lithosols-Brown Soils and Chestnut Soils, BS: Brown Soils.

Characters	<i>Onosma pseudohebebulba</i>	<i>Onosma bozghushica</i>	<i>Onosma iranshahri</i>	<i>Onosma bilabiata</i>	<i>Onosma hebebulba</i>
Plant height (cm)	25–30	22–25(30)	30–35	15–25	20–35
Rosette leaves size (mm)	30–80(85) × 8–10(12)	40–75(85) × 7–10(12)	25–50 × 10–25	30–110 × 7–25	70–100 × 25–30
Rosette leaves shape	spathulae	spathulae	spathulae-oblong	oblanceolate, lanceolate, oblanceolate-spathulate, obovate-lanceolate	obovate-spathulate
Basal leaf size (mm)	12–25 × 4–5	15–32 × 2–4	20–35 × 10–20	10–15 × 3–5	15–5 × 10–20
Basal leaf shape	spathulate	spathulate	pathulae-oblong	spathulate	obovate-spathulate
Cauline leaf size (mm)	18–35(40) × 7–9(10)	30–35 × 4–7	25–50 × 10–20	30–80 × 10–18	20–50 × 5–12
Cauline leaf shape	spathulate	spathulate	spathulae-lanceolate	lanceolate-oblong	lanceolate to lanceolate-oblong
Indumentum	sub-dense, semi-adpressed	dense, adpressed	sub-dense, sub-adpressed	sub-dense, sub-adpressed	sub-dense, sub-adpressed
Tubercle rays	short, sparse	short, sub-dense	long, severely dense	short, sub-dense	short, sub-dense
Pilies	dense	sparse	sparse	dense	dense
Inflorescence	dense	dense	sub-dense	dense	sub-dense
Corolla color	yellow	yellow	yellow	white to yellow	yellow
Corolla shape	clavate, tubular to clavate	tubular to campanulate	clavate-campanulate	tubular-campanulate	tubular-tubular-campanulate
Corolla length(mm)	17–19 (20)	20–22	18–20	25–30	18–20
Pedicel length (mm)	ca. 7	ca. 7	ca. 5–9	ca. 3	ca. 4
Calyx length (mm)	18–20(22)	16–18(20)	18–20	18–27	15–17
Bract shape	lanceolate to lanceolate-linear	lanceolate	lanceolate	lanceolate	lanceolate-linear
Bract length (mm)	12–25	18–24 × 5–6(7)	9–10	10–18	10–12
Anther length (mm)	ca. 7	ca. 10	ca. 8.5	9–10	6–8
Annulus	glabrous	glabrous	sparsely pilose	glabrous	glabrous
Nutlet (mm)	3.5–4 × 2.5–3	-	-	5–6.5 × 3–3.5	-
Elevation range (a.s.l., in m)	1374	2560	1800–1900	2000–2600	1900–2200
Phytochorion	Kurdistan-Zagros	Atropatene	Kurdistan-Zagros	Atropatene	Atropatene-Kurdistn-Zagros
Geomorphologic Unit	west	Alborz	west	west	northwest, west
Geologic formation	Ig, Se	Ig	QD, Ig	Ig, Vo-Se, QD	Se, QD
Bioclimatic Unit	MPc	MPc	MPc	MXc	MXc, MPc
Soil	CL-BS	LS	CL-BS	BS-LS	CL, LB

Onosma madjnoniani Mehrabian & Naghizadeh, **sp. nov.** (Fig. 1)

Type: Iran. Eastern Azerbaijan province: Oscoo, Kord Abad to Gonbarf Village, 2200 m a.s.l., 37° 43' 13" N, 46° 12' 40" E, 28 May 2017, *Naghizadeh 2018658* (Holotype: HSBU).

Diagnosis: *Onosma madjnoniani* is closest to *O. armena* DC. Nevertheless, it is distinguished by its rosette leaf size, lanceolate to lanceolate-linear leaves, short and sparse dense rays, and shorter calyx and bracts. In addition, it is similar to *O. rascheyana* Boiss., but *O. madjnoniani* is differentiated by its

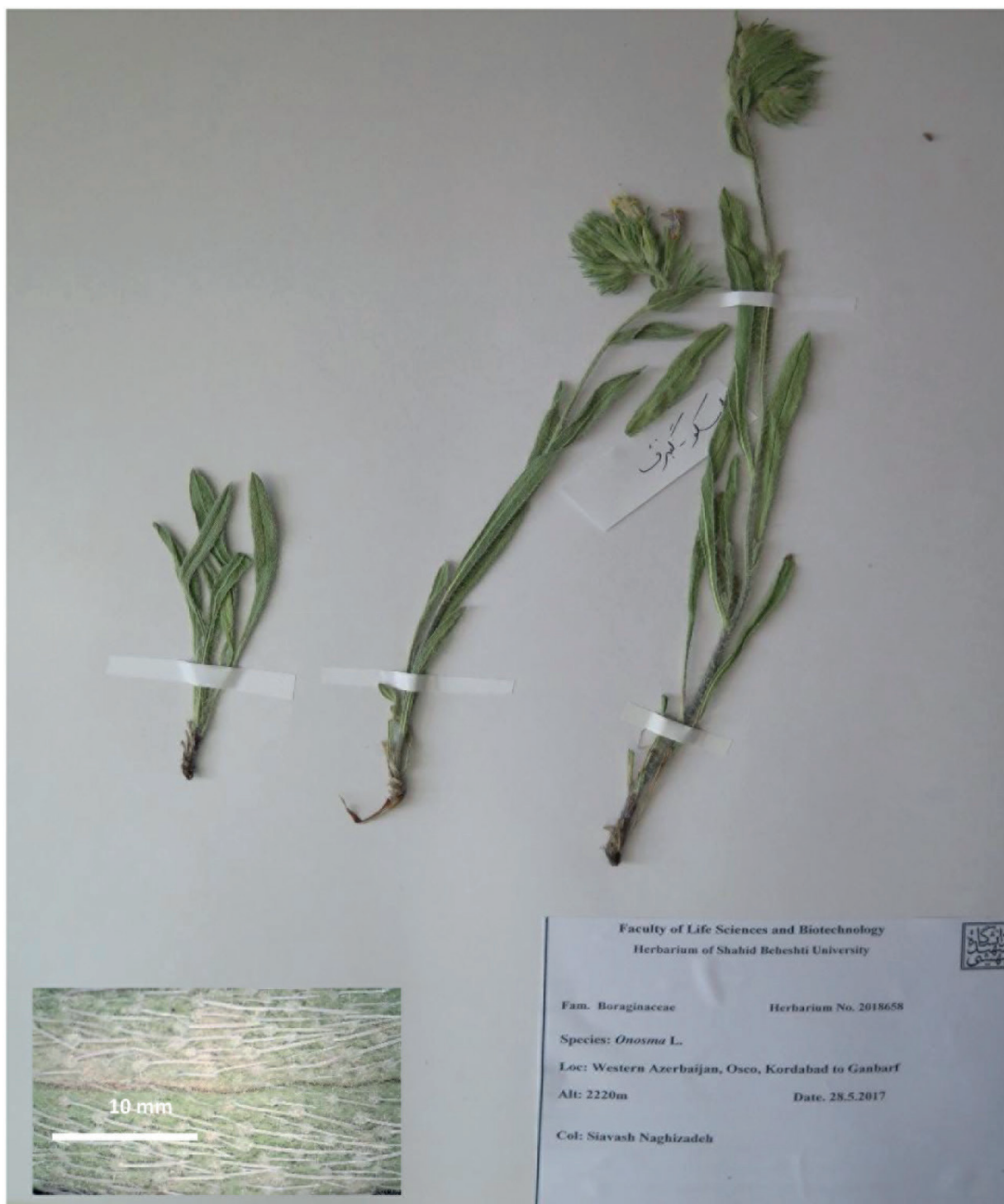


Figure 1. Holotype of *Onosma madjnoniani* Mehrabian & Naghizadeh sp. nov.

lanceolate to lanceolate-linear leaves, long rosettes, long bracts, short and sparse trichomes, and sparse hairs. Additionally, it is similar to *O. kurdica* Tepner, a restricted endemic species found in western Iran; however, it differs from *O. kurdica* in having lanceolate to lanceolate-linear cauline leaves, long basal leaves, short pedicels, nearly dense tuberculate rays, and sub-dense hairs. Moreover, it is apparently close to *O. moussavi* Mehrabian & Amini Rad, a restricted endemic species found in western Iran, but distinguished by long rosettes, lanceolate to lanceolate-linear rosette and cauline leaves, short and sub-dense tubercles of setae, nearly dense hairs and longer corolla, bracts, and calyx (Table 1).

Description: Perennial, with woody rootstock. Stems branched at the base, partly diffuse, flowering stems up to 20(25) cm tall. Indumentum asterotrichous (Fig. 2 A–L). Rosette leaves lanceolate to lanceolate-linear, 90–140(150) × 4–9 mm, attenuate at the base into a short petiole, obtuse to acute at apex, involute, covered by nearly dense monomorphic hairs, each consisting of an antrorsely appressed central seta, 1.2–1.8 mm long inserted on a multicellular tubercle with 8–10 asterosetulae, ca. 5–6 times shorter than the central seta. Basal leaves similar to rosette leaves, 25–45 × 4–7 mm. Cauline leaves sessile, lanceolate to lanceolate-linear, 25–90 × 5–9(10) mm, tapering into a short petiole, obtuse to acute at apex involute, setae similar to rosette leaves. Inflorescence simple to bifurcate, with 2–3 apical cymes, each cyme up to 8(9) flowers, pedicel ca. 1.5 mm long; bracts lanceolate, 15–20(22) mm. Flowering calyx 16–18(19) mm long, divided to base in linear to oblanceolate lobes, covered with short hairs mixed to yellowish setae, sparse near the margins and along the central vein, dense at the base and on the pedicel. Corolla clavate, up to 25 mm long and 1 mm wide, puberulent outside. Stamens included, inserted at the upper 3/4 of the corolla tube, anthers connate at the base, ca. 8 mm, apically bifid. Style protruding outside the corolla limb, up to 29 mm. Stigma bilobed. Nutlet not seen.

Pollen: Heteropolar, tricolporate, prolate, polar axis 13.8–16.8 µm, mean: 14.3 µm, equatorial axis 11.1–12.8 µm, mean: 11.8 µm, exine granulate 0.15–0.28 µm wide (Fig. 2 M–P).

Phenology: These plants flower from May to June and fruit from June to July.

Etymology: This plant was named in honor of Professor Henric Madjnonian, a pioneering,

outstanding as well famous environmental conservationist of Iran, who has made extensive efforts and several scientific references to protecting Iran's nature as well Protected areas.

Distribution and habitat: *Onosma madjnoniani* is a sub-alpine species confined to the NW geomorphologic unit of Iran in volcano-sedimentary rocks and brown soils (lithosols) as well as the Mediterranean xeric-continental (Mxc) global bioclimatic unit. Additionally, it is distributed in the steppes as cushion-shaped plant formations on the western slopes of the Sahand Mountains in the Irano-Armenian province of the Irano-Turanian region (Fig. 3).

Conservation status: The estimated area of occupancy is less than 5000 km². The number of mature individuals in the population is less than 20. The status of critically endangered (CR) is suggested based upon the IUCN criteria (Bland *et al.*, 2017) because of its restricted distribution range and existing threatening issues in its habitats (e.g. over-grazing, land-use change, etc.).

***Onosma riahii* Mehrabian, sp. nov. (Fig. 4)**

Type: Iran. Alborz, Taleghan, North of Taleghan Dam, 2140–2250 m a.s.l., 36° 11' 23" N, 50° 39' 12" E, 13 June 2018, *Mehrabian 2018981* (Holotype: HSBU).

Diagnosis: *Onosma riahii* is similar to *O. rascheyana* but, it is characterized by linear to linear-lanceolate, cauline leaf size, dense hairs, longer calyx, and denser inflorescences. It is similar to *O. armena*, but, it is distinguished by its shorter rosette leaves, linear to linear-lanceolate leaves, oblong cauline leaves, sparse hairs, and longer calyx. Also similar to *O. kurdica*, it is nonetheless differentiated from it by its lanceolate-linear basal leaves, shorter cauline leaves, sparse hairs and pedicels, and long calyx. It is apparently also similar to *O. moussavi*, a restricted endemic species in northwestern Iran, but distinct in its rosette leaf size, linear to linear-lanceolate leaves, nearly dense hairs, and long corolla and pedicels (Table 1).

Description: Perennial, with woody rootstock and long narrow rhizomes. Stems partly erect, the flowering ones up to 35(40) cm, covered at the base with scaly remains of the previous years shoots. Indumentum asteritericous (Fig. 5 A–L). Rosette leaves linear to linear-lanceolate, 30–40 × 2–3 mm, acute to acute-acuminate at apex, involute, tapering

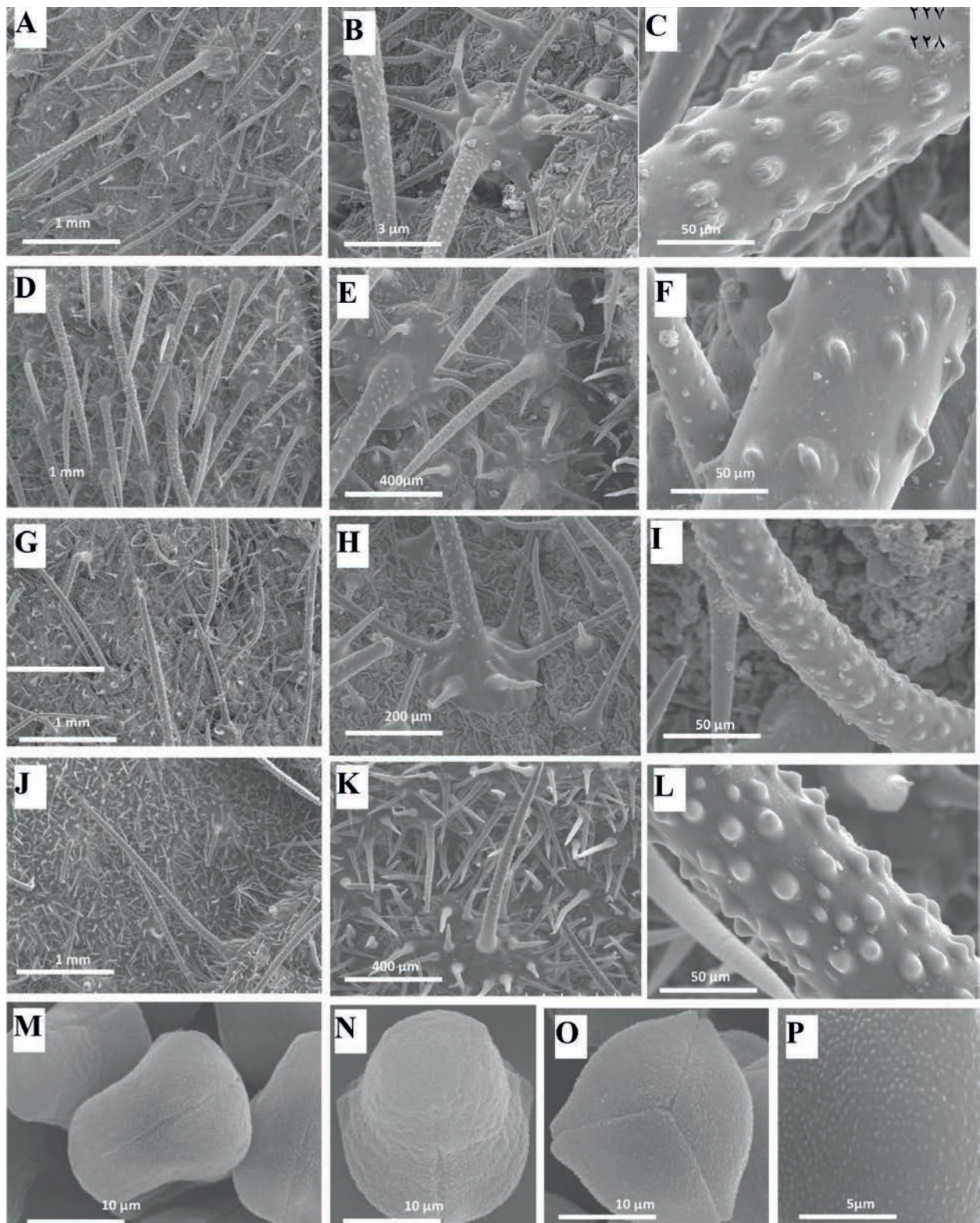


Figure 2. Scanning electron micrographs of *Onosma madjnoniani*: (A–C), indumentum of cauline leaves in the ventral surface; (D–F), indumentum of cauline leaves in the dorsal surface; (G–I), indumentum of basal leaves in the ventral surface; (J–L), indumentum of basal leaves in the dorsal surface; (M–P), pollen in polar and equatorial view



Figure 3. Geographic location of the type locality of *Onosma madjnoniani*, *O. riahii*, *O. pseudohebebulba* and *O. bozghushica* in Iran.

into a long petiole, hispid, white to yellowish white, upper surface covered by dense as well monomorphic setae, each consisting of an antrorsely appressed, central setae 1.2–1.5 mm long, inserted on a multicellular tubercle with 10–12 asteroetulae, *ca.* 4–5 times shorter than the central seta. Basal leaves, sessile, other characters similar to rosette leaves. Cauline leaves linear-lanceolate, sessile, 50–90 × 4–4.5(5.5) mm. Inflorescence, bifurcate, 2–3 apical cymes, each cymes with 3–4 flowers, Pedicel *ca.* 2 mm long in fruit. Bracts linear-lanceolate, pubescent, 18–20(25) × 2–3 mm. Flowering and fruiting calyx divided to base, 15–17 mm long, linear lobes, covered with short yellow hairs very dense at the base and on the pedicel. Corolla tubular to clavate, yellow, with very reflexed lobes short, up to 24 mm long yellow, glabrous to puberulent outside. Nectary ring glabrous. Stamens excluded, inserted, connate at base, inserted upper

4/5 corolla tube, anthers up to 8 mm, apically bifid, Style protruding outside the corolla limb, up to 26 mm long. Stigma bilobed. Nutlets unknown.

Pollen: Heteropolar, tricolporate, prolate, polar axis 12.9–15.2 µm, mean: 13.8 µm, equatorial axis 8.5–10.8 µm, mean: 9.8 µm, exine granulate 0.14–0.26 µm wide (Fig. 5 M–P).

Phenology: This species flowers from May to June and fruits from June to July.

Etymology: The specific epithet is based on in honor of the eminent Phycologist-Mycologist Prof. Dr. Hossein Riahi in Iran, who has played a prominent role in improving our knowledge in this field in Iran.

Distribution and habitat: *Onosma riahii* is known only from the restricted zone in igneous formations in the lithosol (from igneous rocks), brown soils, and seirozome zone of Taleghan (Alborz). It is distributed in the Mediterranean xeric-continental (Mxc) global bioclimatic units of Iran (Fig. 3).



Figure 4. Holotype of *Onosma riahii* Mehrabian sp. nov.

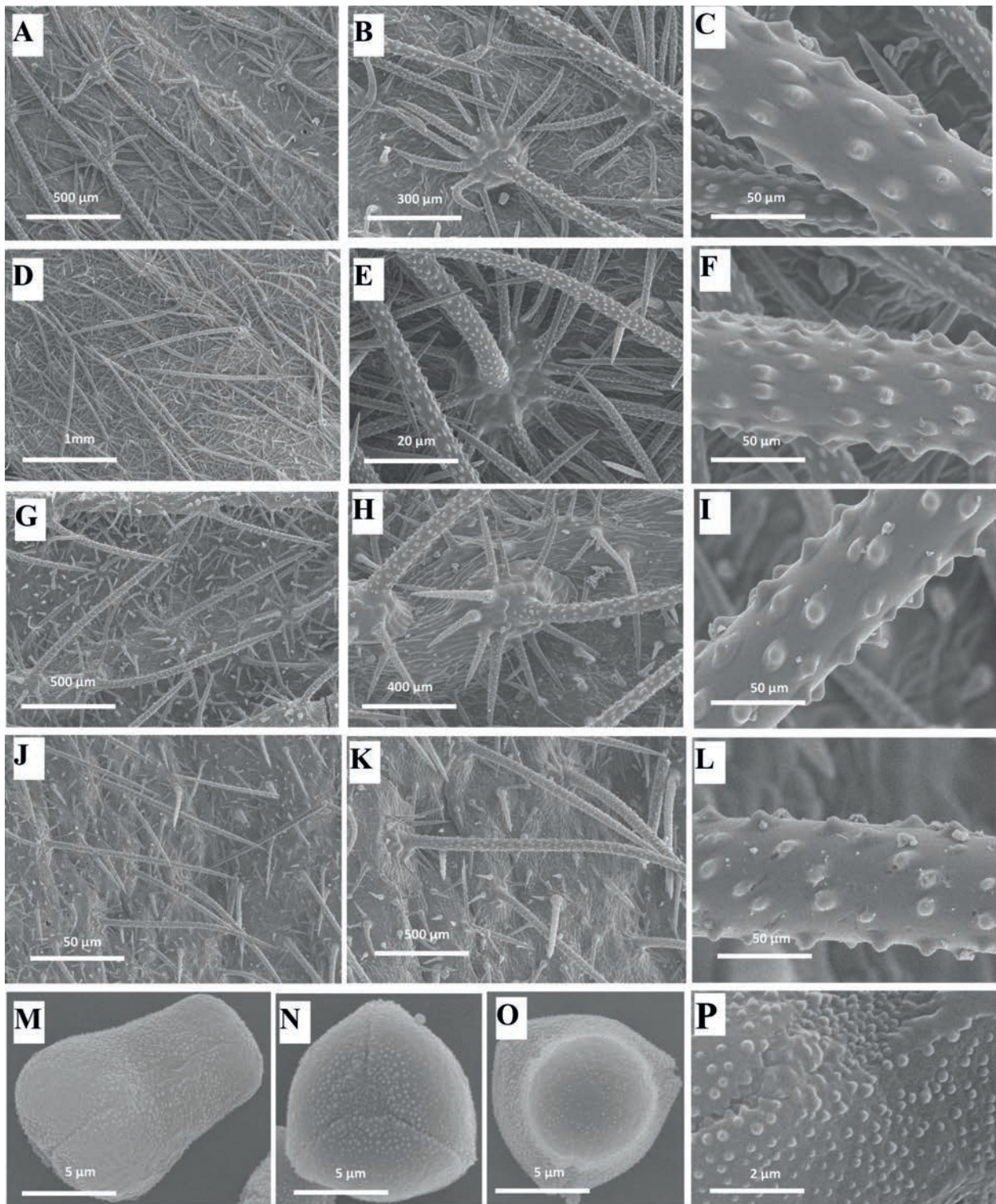


Figure 5. Scanning electron micrographs of *Onosma riahii*: (A–C), indumentum in the ventral surface of basal leaves; (D–F), indumentum in the dorsal surface of basal leaves; (G–I), indumentum in the ventral surface of cauline leaves; (J–L), indumentum in the dorsal surface of cauline leaves; (M–P), pollen in polar and equatorial view

Conservation status: *Onosma riahii* is known only from the restricted zone on the southern slopes of the Western Alborz Mountains with an estimated

area of occupancy less than 5000 km². Critically endangered status (CR) is proposed based on IUCN criteria (Bland *et al.*, 2017).

Onosma pseudohebebulba Mozaffarian & Mehrabian, **sp. nov.** (Fig. 6)

Type: Iran. Charvar to Ivan, Tange Dalab 1374 m a.s.l., 33° 42' 24" N, 46° 28' 28" E, 5 May 2005, *Mozaffarian 92841* (Holotype: TARI).

Diagnosis: *Onosma pseudohebebulba* is similar to *O. hebebulba* DC., found in western and northwestern Iran, though it is differentiated by its spatulate and shorter rosette leaves, shorter cauline leaves, and shorter pedicels and bracts. *Onosma pseudohebebulba* is similar to *O. iran-shahri* Ghahr. & Attar, a restricted species endemic to western Iran. Regardless of its similarities, it differs in having shorter cauline leaves, sub-dense and sub-adpressed setae, shorter pedicels, and dense hairs. In addition, it is apparently close to *O. bilabiata* Boiss., a species endemic to western and northwestern Iran, yet distinguished by shorter rosette and cauline leaves, spatulate rosette leaves, thinner cauline leaves, sparse tubercle rays, shorter corolla, longer pedicels, and shorter anthers (Table 2).

Description: Caespitose perennial, with woody rootstock, creeping rhizome. Stems partly diffuse, branched at the base, covered at base with scaly remains of the previous year's shoots and bearing sterile leaf rosettes, the flowering stems up to 25 cm tall. Indumentum asterotrichous (Fig. 7 A–L). Rosette leaves spatulate, involute, obtuse to acute at apex, hispid, white to yellowish, 30–80(85) × 8–10(12) mm, upper surface covered by very dense and monomorphic seta and hairs, nearly dense setose, each consisting of an antrorsely appressed, central seta, 1.5–2 mm long, inserted on a multicellular tubercle with 14–16 asterosetulae, ca. 4–5 times shorter than the central seta. Basal leaves spatulate, 12–25 × 4–5 mm, obtuse to acute at apex, seta similar to rosette leaves. Cauline leaves sessile, spatulate, 18–35(40) × 7–9(10) mm acute to obtuse at apex. Inflorescence capitate, with 5–6 apical cymes, each cyme with 8–12 flowers, fruiting pedicel ca. 7 mm long. Bracts lanceolate to lanceolate-linear, 14–25 × 1–1.2 mm. Flowering Calyx divided near to base in oblanceolate lobes, 14–16(18) mm long, ca. 1 mm wide, Fruiting calyx 18–20(22) mm long, ca. 2.5 mm wide, covered by very dense seta and hairs. Corolla tubular, clavate to tubular-clavate, yellow, 17–19(20) mm long, yellow, densely puberulent outside., lobes ca. 1.5 mm

long, ca. 1.5 mm wide; annulus glabrous. Stamens included, inserted at the upper two-thirds corolla tube anthers connate at base, 6–7 mm, apically bifid. Style little out of corolla, stigma bilobed. Nutlet ovoid, 3.5–4 × 2.5–3 mm long, beak to 1 mm long, navicular, green.

Phenology: This plant flowers from May to June and fruits from June to July.

Etymology: The name of this species relates to its similarity to *O. hebebulba*.

Distribution and habitat: *Onosma pseudohebebulba* is distributed in open oak forests with well fertilized soils (Fig. 3).

Conservation status: *Onosma pseudohebebulba* is known only from Chavar (the restricted zone of Ilam province) to Ilam city and Tang Dalab on the western slopes of the Southern Zagros Mountains. It has an estimated area of occupancy less than 5000 km². The status of critically endangered (CR) is proposed based on IUCN criteria (Bland *et al.*, 2017).

Onosma bozghushica Mozaffarian & Mehrabian, **sp. nov.** (Fig. 8)

Type: Iran. Eastern Azerbaijan, Bozghoosh Mountains, Neshagh top Mountains 2560 m a.s.l. 37° 45' 54" N, 47° 41' 43" E, 24 June 2010, *Mozaffarian 94598* (Holotype: TARI).

Diagnosis: *O. bozghushica* is similar to *O. iran-shahri*, but differing in its longer rosette leaves, shorter cauline leaves, dense and adpressed setae, dense hairs, and long corolla and bracts. It is also apparently similar to *O. bilabiata*. Nevertheless, it differs by having shorter and spatulate rosette leaves, sub-dense tubercle rays, longer pedicels, and shorter bracts and calyx. Moreover, it is similar to *O. hebebulba*, although differing by having longer rosette leaves and spatulate leaves (Table 2).

Description: Caespitose perennial, with woody rootstock as well long rhizome. Stems diffuse, the flowering stems 22–25 (30) cm tall. Indumentum asterotrichous (Fig. 9 A–L). Rosette leaves spatulate, 40–75 (85) × 7–10 (12) mm, acute at apex, involute, attenuate at the base to a long petiole, hispid, upper surface covered by very dense, monomorphic seta and hairs, each consisting of an antrosely appresse, central seta 1.5–2 mm long, inserted on a multicellular tubercle with 16–20 asterosetulae, 5–6 times shorter than the central



Figure 6. Holotype of *Onosma pseudohebebulba* Mozaffarian & Mehrabian sp. nov.

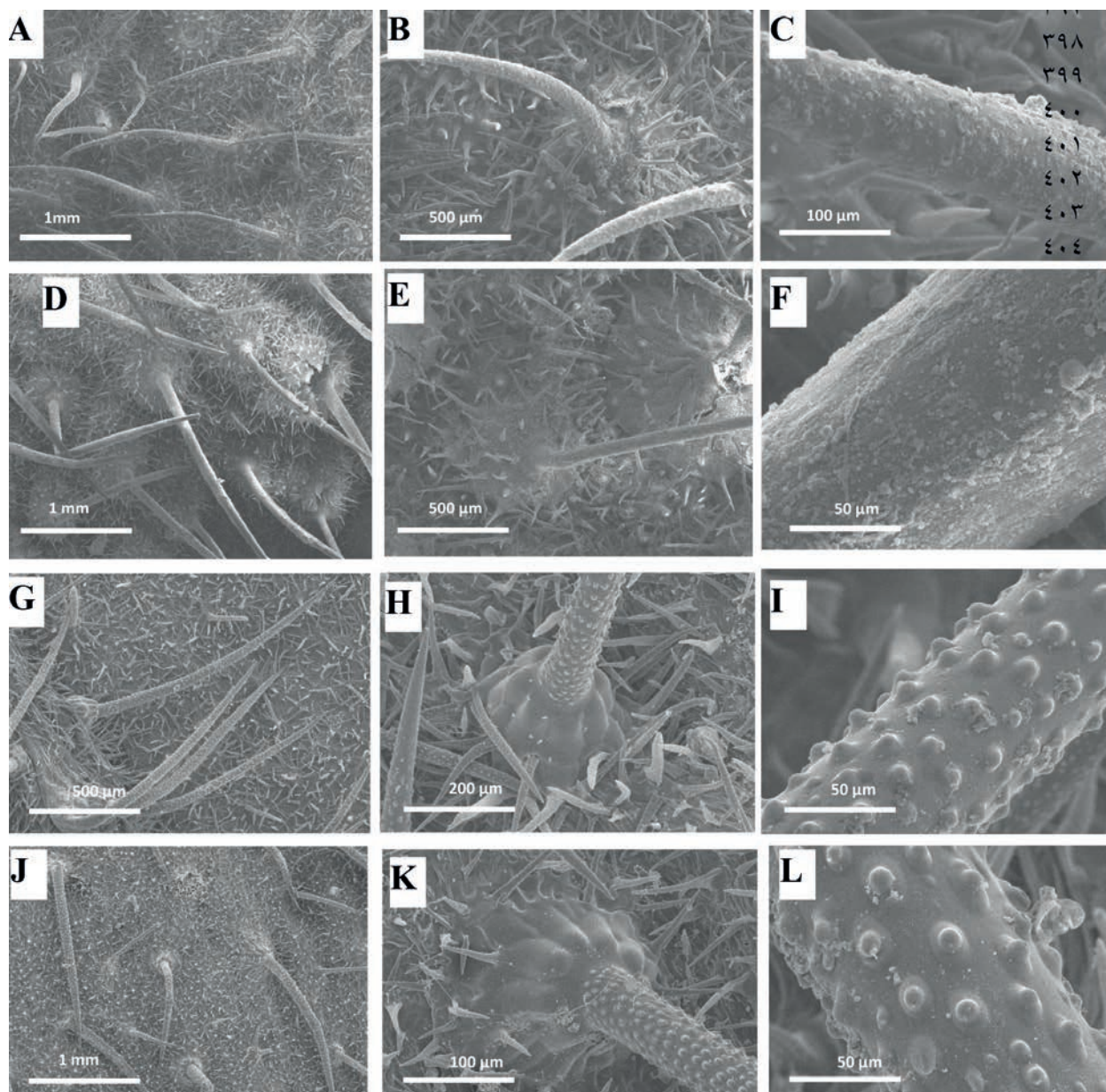


Figure 7. Scanning electron micrographs of *Onosma pseudohebebulba*: (A–C), indumentum in the ventral surface of basal leaves; (D–F), indumentum in the dorsal surface of basal leaves; (G–I), indumentum in the ventral surface of cauline leaves; (J–L), indumentum in the dorsal surface of cauline leaves.

seta. Basal leaves similar to rosette leaves, $15\text{--}32 \times 2\text{--}4$ mm. Cauline leaves sessile, $30\text{--}35 \times 4\text{--}7$ mm, spatulate, acute to obtuse at apex, involute. Inflorescence 2–3 apical cymes, each cymes with 12–15 (17) flowers, pubescent. Bracts widely lanceolate, leaf like, pubescent, $18\text{--}24 \times 5\text{--}6$ (7) mm. Pedicel *ca.* 7 mm long. Calyx divided to base in oblanceolate lobes, 16–18 (20) mm long, covered with short and dense hairs mainly at the base. Corolla tubular to campanulate, yellow, *ca.* 22 mm long, glabrous to puberulent outside, lobes *ca.* 1 mm long, *ca.* 1

mm wide; annulus glabrous. Stamens a little out of corolla, inserted at the upper 3/4 of corolla tube, connate at the base, *ca.* 10 mm, apically bifid. Style little out of corolla. Limb. Stigma bilobed. Nutlet not found.

Pollen: Heteropolar, tricolporate, prolate, polar axis $11.7\text{--}12.9$ μm , mean: 12.1 μm , equatorial axis $10.7\text{--}11.2$ μm , mean: 10.9 μm , exine granulate $0.09\text{--}0.29$ μm wide (Fig. 9 M–O).

Phenology: This plant flowers from May to June and fruits from June to July.



Figure 8. Holotype of *Onosma bozghushica* Mozaffarian & Mehrabian sp. nov.

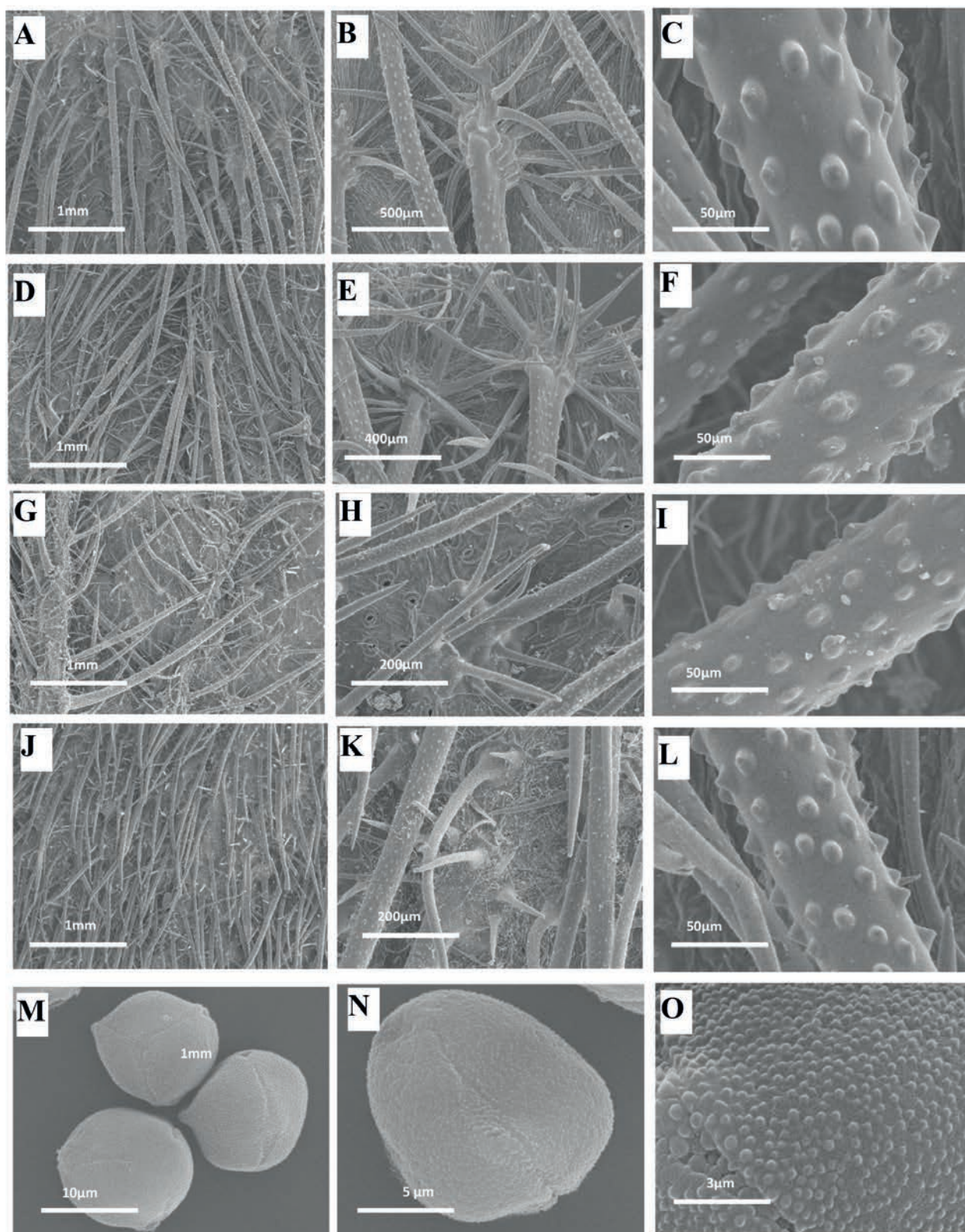


Figure 9. Scanning electron micrographs of *Onosam bozghushica*: (A–C), indumentum in the ventral surface of basal leaves; (D–F), indumentum in the dorsal surface of basal leaves; (G–I), indumentum in the ventral surface of cauline leaves; (J–L), indumentum in the dorsal surface of cauline leaves; (M–O), Pollen in polar and equatorial view.

Etymology: The specific epithet is based on the geographical origin of the species (Bozghoosh Mountain) a prominent mountain range in north-western Iran.

Distribution and habitat: *Onosma bozghushica* is known only from restricted zones in igneous formations in the lithosol (from igneous rocks), brown soils, and seirozome zone of Azerbaijan, on the southern slopes of the Bozghoosh Mountains. It is distributed in Mediterranean xeric-continent (Mxc) global bioclimatic units (Fig. 3).

Conservation status: *Onosma bozghushica* is known only from the restricted zone of Bozghoosh Mountains, Neshagh top mountains (Eastern Azerbaijan province) with an estimated area of occupancy less than 5000 km². Due to the narrow distribution range of the species, a status of critically endangered (CR) is proposed based on the IUCN criteria (Bland *et al.*, 2017).

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APPENDIX. Additional specimens examined, synoptic key to *Onosma* L. species in *Flora Iranica* region, and some additional notes.

Additional specimens examined

Onosma armena: Armenia, *Aucher* (Holotypus G 2358), Iran, West Azerbaijan, Makoo to Khoy, 2400–2650 m, *Assadi & Mozaffarian* (TARI 30353); Khoy to Ghotor, *Sharif* (IRAN 2693); Urmia, Ghooshchi, 1400–2100 m, *Mousavi & Tehrani* (IRAN 2692); Silvana, 1700 m, *Runemark & Forooghi* (TARI 19595); Zanzan, Mahneshan, Alam kandi, Ghalan Mts, 1900–2500 m, *Mousavi et al.* (IRAN 2689).

Onosma rascheyana: Iran, Between Rasch and Damascus, *Boissier* (G, Holotypus), West Azerbaijan, Bazargan, 2100–2250 m, *Rechinger* (W 06099); Azerbaijan, Kani Ziarat, Habasi bala, 2300–3000 m, *Rechinger & Renz* (W 05734); Chali Kuh be Rajan, 2600–3200 m, *Rechinger & Renz* (W 05728); Zanzan, Mahneshan to Takab, Belqeys Mts., 2700 m, *Mehrabian* (HSBU 281); Mahneshan, Angoran, 2700–2900 m (TARI 64841); 10 km E. Sanandaj, *Furse* (W 12625).

Onosma kurdica: Iran, Bijar, Kūh-e Ḥamzeh ‘Arab, 2200–2600 m, *Lamond & Termeh* (Holotype W 42261, isotype W 06112).

Onosma moussavi: Iran, West Azerbaijan, Salmas, Kozeh-Rash, Haravil Mountain, 2800–3235 m, 18 July 2016, *Amini Rad & Bahrami Shad* (Holotype IRAN 71503!, isotype HSBU 2016876).

Onosma hebebulba: Iran, Kurdistan, 45 km Kerend, Dalahoo Mts, 2000–2200 m, *Assadi* (TARI 60835); Kermanshah, Eslam Abad to Illam, *Sharif* (IRAN 5329); Illam, N.W. Ziam, Malegavan, 2200 m, *Mozaffarian* (TARI 95495).

Onosma iranshahri: Iran, Kurdistan, Marivan to Paveh, Gardan-e Tate, between Dezli and Hanigarmaleh, 1800–2600 m, *Mozaffarian* (isotype TARI 75701).

Onosma bilabiata: Iran, East Azerbaijan, Northern slopes of Sahand, 2300–2600 m, *Assadi & Mozaffarian* (TARI 30764); Mianeh, *Termeh* (W 579); Ardabil, Hashjin towards Barandigh, 1500m, *Moradi* (HSBU 2018229).

Synoptic key to *Onosma* L. species in *Flora Iranica* region

1. Haplotrichous

O. angustiloba Riedl, *O. asperrima* Bornm., *O. assadi* Mozaff. & Mehrabian, *O. azarbaidjanensis* Mehrabian, *O. bakhteganensis* Mozaff. & Mehrabian, *O. barszczewskyi* Lipsky, *O. bodeana* Boiss., *O. bulbotricha* DC., *O. chitralica* I.M. Jhonst., *O. chrysochaeta* Bornm., *O. cornuta* Riedl, *O. demawendica* Riedl, *O. dichroantha* Boiss., *O. gaubae* Bornm., *O. griffithi* Vatke, *O. haussknechtii* Bornm., *O. hispida* Steven, *O. khorassanica* Attar & Joharchi, *O. khyberiana* I. M. Johnst., *O. kilouyensis* Boiss. & Hausskn., *O. kotschy* Boiss., *O. limitanea* I. M. Johnst., *O. liwanovii* Popov, *O. longiloba* Bunge, *O. macrorrhiza* Popov, *O. marivanensis* Mozaff. & Mehrabian, *O. microcarpa* DC., *O. oreodoxa* Boiss. & Heldr., *O. pachypoda* Boiss., *O. platyphylla* Riedl, *O. rechingeri* Riedl, *O. rostellata* Lehm., *O. sabalanica* Ponert, *O. sanandajensis* Mehrabian & Mozaff., *O. sarvestanica* Mozaff. & Mehrabian, *O. sericea* Willd., *O. sheidaii* Mehrabian, *O. stenosphon* Boiss., *O. striata* Riedl, *O. subsericea* Freyn, *O. sulaimaniaca* Riedl, *O. trachytricha* Boiss., *O. yamagatae* Kitamura, *O. zerizamina* Lipsky

–. Asterotrichous or Heterotrichous.....2

2. Cauline leaves very long (up to 150 mm), with prominent veins.....
.....*O. macrophylla* Bornm., *O. nervosa* Riedl, *O. mozaffariani* Mehrabian

–. Cauline leaves short (up to 80 mm), lack of prominent veins.....3

3. Basal leaves obovate, widely spatulate
 *O. dasytricha* Boiss., *Onosma albo-rosea* Fisch. & C. A. Mey., *O. ovalifolia* Kotschy & Boiss., *O. qandilica* Rech. f. & Riedl, *O. bisotunensis* Attar & Hamzehee, *O. hawramanensis* Ahmad, *O. hebebulba* A. DC.
 -. Basal leaves linear to linear-lanceolate, lanceolate, Oblong, oblanceolate, spatulate4
4. Nectary ring pilos.....
 *O. straussi* (Riedl) Khatamsaz, *O. lanceolata* Boiss. & Hausskn., *O. iranshahrii* Ghahr. & Attar
 -. Nectary ring glabrous5
5. Basal leaves up to 200 mm *O. chlorotricha* Boiss. & Noë, *O. kurdica* Teppner
 -. Basal leaves up to 110 mm6
6. Bract up to 30 (32) mm. Rosette leaves oblong-spatulate, linear-spatulate. Cauline leaves ovate-lanceolate.....*O. cardiostegia* Bornm.
 -. Bract up to 25 mm7
7. Basal leaves up to 150 mm, linear-lanceolate. Corolla violet at the apex, up to 25 mm
 *O. madjnoniani*
 -. Basal leaves up to 110 mm8
8. Bract shorter than 19 (20) mm9
 -. Bract longer than to 25 mm10
9. Setae mixed or heterogeneous (haplotricha and asterotricha)..... *O. elwendica* Wettst, *O. olivieri* Boiss.
 -. Setae heterotricha11
10. Corolla up to 27 mm. Rosette leaves linear-spatulate. Bracts linear-lanceolate, up to 25 mm
 *O. targevarensis* Mozaffarian & Mehrabian
 -. Corolla up to 22mm. Bracts widely lanceolate, up to 24 mm. Rosette leaves spatulate
 *O. bozgushica*
11. Calyx up to 27 mm. Cauline leaves linear-oblanceolate, Oblanceolate-spatulate
 *O. bilabiata* Boiss. & Buhse
 -. Calyx up to 22 mm12
12. Bract up to 10 mm.....13
 -. Bract up to 20 mm14
13. Pedicel up to 2 mm. Corolla up to 25 mm *O. rascheyana* Boissier
 -. Pedicel up to 7 mm. Corolla up to 18 mm..... *O. moussavi* Mehrabian & Amini Rad

14. Rosette leaves linear-Lanceolate, Corolla up to 23 mm. *O. riahii*
 -. Rosette leaves linear- spathulate. Corolla campanulate-clavate. Bract up to 10 mm.....
 *O. armena* A. DC.
15. Cauline leaves up to 60 mm. Bract up to 17 mm
 *O. wendelboi* Mehrabian & Mozaffarian (2018: 380), *O. caerulescens* Boiss.
 -. Cauline leaves up to 35 mm. Bract up to 25 mm *O. pseudohebebulba*

Some additional notes

***Onosma microcarpa* DC.**

O. microcarpa is a widespread species distributed in southwest Asia with morphological diversity as well high polymorphism, which has caused some populations to be described as separate species.

Syn. *O. microcarpa* DC.var. *spathulata* (Wettst.) Bornm.

Syn. *O. microcarpa* DC.var. *stapfii* (Wettst.) Bornm. & Riedl.

Syn. *O. paboti* Riedl.

Syn. *O. lorestanica* Attar & Sotoodeh

***Onosma elwendica* Wettst.**

O. elwendica introduced from the Zagros region, which also spreads to Alborz with a very high variation. The density as well ratio of haplo and hetero setae showing high variation in different populations.

Syn. *O. demawendica* Riedl.

Syn. *O. trachytricha* Riedl.

***Onosma gaubae* Bornm.**

The observed morphological differences (e.g. height and size of the corolla, anther, pedicel, basal leaves, and style protruding) are severely affected by environmental variation, especially climate factors. Therefore, no significant differentiation was observed in Tar Lake populations (that named as *O. ghahremanii* Attar & Naqinezhad) compared with other populations of *O. gaubae* (Khajoei Nasab *et al.*, 2020b).

Syn. *O. borragoidinum* Ponert.

Syn. *O. ghahremanii* Attar & Naqinezhad

***Onosma straussii* (Riedl) Khatamsaz**

Syn. *O. sultanabadensis* Ranjbar & Almasi

***Onosma nervosa* Riedl**

Syn. *O. maculata* Ranjbar & Almasi

***Onosma armena* DC.**

Syn. *O. kerendica* Attar & Mirtadz

***Onosma bilabiata* Boiss & Buhse**

Syn. *O. khoramabadensis* Attar, Mirtadz. & Sotoodeh