# A revision of the family Petrosaviaceae in Vietnam

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The family Petrosaviaceae is represented by two species in Vietnam, viz. *Petrosavia sakuraii* restricted to the northern part of the country and *P. stellaris* distributed in its southern part. The latter species is shown to possess a wide range of distribution in Vietnam, though it was previously believed to be an exclusively Malesian species. The inclusion of *P. sinii* in *P. sakuraii* is confirmed. Details on distribution, illustrations and an identification key for these species are provided.

Petrosaviaceae is currently considered as the only family of the order Petrosaviales which forms together with Acorales and Alismatales a basal grade of the monocots (APG IV 2016). The taxonomic position and proposed phylogenetic relations of the type genus of Petrosaviaceae, *Petrosavia* Becc., have been debated for a long time, largely because of the achlorophyllous (mycoheterotrophic) habit of its representatives. It was recently suggested on the basis of molecular data that Petrosaviaceae should accommodate two genera, the second being the monotypic *Japonolirion* Nakai (Cameron et al. 2003). This circumscription of Petrosaviaceae has become widely accepted (Stevens 2001, Heywood et al. 2007, Merckx et al. 2013, Trias-Blasi et al. 2015, Christenhusz and Byng 2016, Govaerts and Radcliffe-Smith 2016).

The genus *Petrosavia* itself also possesses a long taxonomic history, which has resulted in a large number of synonyms at the species and genus levels. The taxonomy and morphological diversity of Petrosavia was thoroughly reviewed by Ohashi (2000b), who concluded that this genus consists of two species, P. sakuraii (Makino) J.J.Sm. ex Steenis and P. stellaris Becc., and was the first to treat P. sinii (K. Krause) Gagnep. as a synonym of *P. sakuraii*. We here follow Ohashi (2000b) and Cameron et al. (2003) in species delimitation, though quite a lot of recently published floristic and taxonomic works, including the world checklist of Petrosaviaceae (Govaerts and Radcliffe-Smith 2016), still accept P. sinii, explicitly or by indicating the genus to contain three species. The oversight of the finding of Ohashi (2000b) is most probably a consequence of the compilative nature of such publications.

Here, we provide an account of the family Petrosaviaceae in Vietnam accompanied by a key to the species and original illustrations. We discuss the patterns of distribution of *P. stellaris* which was widely neglected in this country and believed to be an exclusively Malesian species.

This paper is a precursor of the forthcoming treatment of Petrosaviaceae for the flora of Cambodia, Laos and Vietnam. For the first two countries of this region no representatives of Petrosaviaceae are known (Newman et al. 2007), though they are likely to occur there as they are already reported from the surrounding areas.

# **Taxonomic treatment**

#### Petrosaviaceae Hutchinson (1934, p. 36), nom. cons.

Literature: Bullock (1959, p. 193), Hutchinson (1959, p. 546), Cronquist (1968, p. 330, 1981, p. 1074, 1988, p. 467), Li (1991, p. 694), Takhtajan (1997, p. 577, 2009, p. 598), Ohashi (2000a, p. 72, 2000b, p. 265), Hansen and Rasmussen (2005, p. 50), Cameron et al. (2003, p. 223), Heywood et al. (2007, p. 389).

#### Type genus: Petrosavia Becc.

Taxonomic synonyms: Miyoshiaceae Nakai (1941, p. 190), Type genus: *Miyoshia* Makino. – Japonoliriaceae Takhtajan (1996, p. 85), Takhtajan (1997, p. 479, 2009, p. 598), Type genus: *Japonolirion* Nakai.

### Description

Perennial achlorophyllous (*Petrosavia*) or photosynthetic (*Japonolirion*) herbs with sympodial subterrenean scaly rhizomes. Flowering stems erect, glabrous, simple and usually

single. Leaves on flowering stems reduced to scales, bifacial, alternate, simple, with entire margin. In Japonolirion leaves of vegetative shoots form a basal rosette, linear to linear-lanceolate, with scabrous margin. In Petrosavia all leaves scaly. Inflorescences racemose (racemes, corymbs or umbels), fewto many-flowered, terminal. Each flower subtended by a well developed lanceolate bract and bearing a bracteole attached at the pedicel base. Flowers bisexual, actinomorphic, trimerous. Perianth biseriate with outer tepals shorter and narrower than the inner ones, persistent. Tepals free, oblong to triangular, spreading or erect, smooth, dull-colored. Stamens 6 in two whorls, with flattened and relatively wide filaments, free (Japonolirion) or adnate to carpels and inner tepals (Petrosavia). Anthers basifixed, dithecal, tetrasporangiate, dehiscing by longitudinal slits, introrse. Pollen grains monosulcate. Gynoecium 3-carpellate, carpels stipitate (Japono*lirion*) or sessile (*Petrosavia*), mostly plicate with a very short sterile ascidiate zone. Ovary superior (Japonolirion) or semiinferior (Petrosavia), 3-locular. Carpels fused only postgenitally along the whole length of the ovary (Japonolirion) or united up to 1/2 of the ovary length (congenitally at the base and postgenitally upwards) and free from the level of insertion of inner tepals or from slightly below (Petrosavia). Styles free, usually recurved, short, hollow with capitate stigmas (Petrosavia) or solid with decurrent stigmas (Japonolirion). Septal nectaries present, infralocular (located on carpel stipes below the ovary locules, in Japonolirion) or interlocular (located between the ovary locules, in Petrosavia). Ovules 4-6 (Japonolirion) or numerous (Petrosavia) per carpel, attached on submarginal placentae in a plicate carpel zone, bitegmic, anatropous, crassinucellate. Embryo-sac of Polygonum-type. Endosperm development cellular, first division of the primary endosperm nucleus unequal (Petrosavia) or equal (Japonolirion). Fruits capsules, septicidal (Japonolirion) or follicular (Petrosavia). Seeds small, winged (Petrosavia) or without appendages (Japonolirion); endosperm copious; seed coat endotestal-endotegmic.

The family Petrosaviaceae includes two genera and three species, which are disributed in alpine meadows of Japan (*Japonolirion*) and in montane forests of Japan, China, Taiwan, mainland southeast Asia and western Malesia (*Petrosavia*). Within the territory of Vietnam, one genus and two species are reported.

#### Ecology

Green plants forming endotrophic mycorrhizae (*Japonolirion*) or achlorophyllous mycoheterotrophs (*Petrosavia*). Yamato et al. (2011, 2014, 2016) found that *Petrosavia* shows much narrower specialization and possesses significantly lower mycobiont diversity than *Japonolirion*.

# Morphology

The family is composed of two genera – mycoheterotrophic *Petrosavia* and photosynthetic *Japonolirion* – with striking differences in both vegetative and reproductive morphology. Traditionally, these two genera were never regarded as closely related, until their affinity was established using molecular data (Fuse and Tamura 2000, Cameron et al. 2003, Davis et al. 2004, Chase et al. 2006, Graham et al. 2006, Hertweck et al. 2015). Despite their strong dissimilarity, these two

genera share some special embryological features such as T-shaped megaspore tetrads (Tobe and Takahashi 2009).

### Phytochemistry

Calcium oxalate idioblasts are absent in *Japonolirion* but present mainly in the leaves in the form of raphides in *Petrosavia* (Groom 1895, but see Tomlinson 1982, Prychid and Rudall 1999).

# Uses

No economical value.

### Petrosavia Beccari (1871, p. 7)

Literature: Bentham and Hooker (1883, p. 828), Engler (1888, p. 20, 1897, p. 72), Ridley (1891, p. 170), Krause (1930, p. 256), Hutchinson (1933, p. 156, 1934, p. 36, 1959, p. 546), Gagnepain (1934, p. 802), van Steenis (1934, p. 52), Nakai (1941, p. 191), Melchior (1964, p. 516), Jessop (1979, p. 198), Chen (1980, p. 12), Ohba (1984, p. 110), Dahlgren and Clifford (1982, p. 172), Dahlgren et al. (1985, p. 209), Cronquist (1988, p. 467), Li (1991, p. 694), Tamura (1998, p. 389), Chen et al. (2000, p. 77), Pham Hoang Ho (2000, p. 473), Ohashi (2000a, p. 72, 2000b, p. 265), Cameron et al. (2003, p. 223), Kress et al. (2003, p. 63), Hansen and Rasmussen (2005, p. 50), Nguyen Thi Do (2005, p. 456), Takhtajan (2009, p. 598).

#### Type species: Petrosavia stellaris Becc.

**Taxonomic synonyms:** *Protolirion* Ridl., in Groom (1895, p. 56). Engler (1897, p. 72), Ridley (1907, p. 87, 1924, p. 322), Krause (1930, p. 257), Nakai (1941, p. 191), Ohwi (1953, p. 282, 1965, p. 280), Melchior (1964, p. 516), Dahlgren and Clifford (1982, p. 172), Satake (1982, p. 23), Dahlgren et al. (1985, p. 209), Ohwi and Kitagawa (1992, p. 386). **Type species**: *Protolirion paradoxum* Ridl. – *Miyoshia* Makino (1903, p. 144). Nakai (1941, p. 191). **Type species**: *Miyoshia sakuraii* Makino.

#### Description

Perennial mycoheterotrophic, whitish, pale yellowish or creamy (brownish when dried), glabrous herbs. Rhizome scaly, slender. Leaves scaly, membraneous, ovoid to deltoid, with more or less attenuate tip and a sheathing base, and entire margin. Lower leaves densely arranged, appressed to stem; upper leaves distant, loose. Inflorescence a raceme or corymb/umbel, terminal, bracteate and bracteolate. Flowersubtending bracts lanceolate, longer or equal to pedicels in the older buds and beginning of anthesis but much shorter in fruits due to pedicel elongation. Bracteoles well-detectable, located at the pedicel base, shorter than flower-subtending bracts. Flowers erect, bisexual. Perianth biseriate, persistent; tepals 3 in each whorl, erect in the beginning of anthesis, spreading in fruits, the outer tepals 1.5-2.0 times shorter and much narrower than the inner, do not touch each other in bud, the inner tepals erect, inserted higher up than the outer, deltoid-triangular, valvate. Stamens 6, shorter than the inner tepals; outer stamens slightly fused to carpels and inner ones fused to inner tepals by their filament bases; filaments subulate; anthers ovoid, basifixed, dithecal, tetrasporangiate.

Carpels 3, sessile, united up to 1/2 of the ovary length. Ovary semi-inferior, 3-locular in syncarpous region; ovary bowl as long as inner tepals at anthesis. Styles short, recurved or more or less erect, hollow, sealed by secretion in their upper part; stigmas capitate, facing outwards. Septal nectaries interlocular. Ovules numerous, with funicular obturator. Capsule hemisyncarpous, follicular; each carpel dehiscing along ventral slit and dorsal vein. Seeds brownish, elliptic to oblong, with a hyaline wing around the seed body, numerous, dusty, longitudinally striated, embryo minute and underdifferentiated.

The genus *Petrosavia* has two species distributed in Japan, China, Taiwan, Myanmar, Thailand, Vietnam, Malaysia, Indonesia. Within the territory of Vietnam, both of them are reported.

The species of this genus occur on forest floor at 0-2300 m a.s.l.

# Key to the Petrosavia species

 Inflorescence an umbel or corymb; fruits with laterally flattened and strongly recurved carpels ..... 1. *P. stellaris* 
 Inflorescence a raceme; fruits with rounded and moderately recurved carpels ...... 2. *P. sakuraii*

### 1. *Petrosavia stellaris* Beccari (1871, p. 8, t. 1) (Fig. 1–2)

Literature: Ridley (1891, p. 171, '*Petrosavia stellata*' – sphalm.), Groom (1892, p. 380), Hutchinson (1933, p. 156, 1934, p. 36, Fig. 5, 1959, p. 546, Fig. 347), van Steenis (1934, p. 52, Fig. 12 right), Nakai (1941, p. 191), Henderson (1954, p. 178, Fig. 103), Stant (1970, p. 147), Jessop (1979, p. 199, Fig. 5a), Ohba (1984, p. 110), Dahlgren et al. (1985, p. 210, Fig. 99f–i), Cameron et al. (2003, p. 223).



Figure 1. *Petrosavia stellaris*. (A) Flower bud with flower subtending bract and bracteole, (B) floral diagram, (C) an artificially opened late floral bud with unopened anthers and stigmas without papillae, top view, (D) flower at a stage of self-pollination, oblique view; note outer stamens touching stigmas, (E) immature fruit with persistent perianth and stamen filaments, (F) dehisced fruit. All figures drawn from various sources by M. Remizowa, except (C), (F) which are drawn from Averyanov et al. 1116 (LE) by L. Averyanov and re-drawn by M. Remizowa.



Figure 2. *Petrosavia stellaris*, photos of living plants from the specimen Nuraliev 486. (A), (B), flower at oblique and top view; note three stamens touching stigmas, (C) inflorescence with immature fruits, (D) immature fruit, top view, (E) completely dried fruits of the previous season. All photos by M. Nuraliev.

**Type**: Malaysia. Borneo, Sarawak: Mt Poe, about 3000 ft, Aug 1866, Beccari 2399 (holotype: FI!).

Taxonomic synonyms: *Protolirion paradoxum* Ridl., in Groom (1895, p. 57, pl. 3). Ridley (1907, p. 87, 1924, p. 322, Fig. 195), Nakai (1941, p. 191). Type: Malaysia. Malay Peninsula, Perak: Larut Hills, in dry hill woods at an altitude of between 1000–3000 ft, Ridley s.n., mounted by Groom on 25 Oct 1895 (holotype: K!). – *Petrosavia borneensis* P.J.M. Maas, in sched.

#### Description

Up to 10–12 cm tall, whitish, pale yellowish or creamy herb. Rhizome scaly, slender. Stem slender. Leaves scaly, up to 5 mm long, membraneous, alternate, ovoid to deltoid with more or less attenuate tip, and entire margin. Inflorescence a terminal few-flowered umbel or corymb. Flowers 1–12 (usually 3–5). Flower-subtending bracts lanceolate, 2–3 mm long. Flowers erect, bisexual, 3–5 mm in diameter. Perianth biseriate, persistent. Outer tepals 3, deltoid to ovate, sometimes lanceolate, about twice shorter and much narrower than the inner ones. Inner tepals 3, 1.5 mm long, deltoid-triangular. Stamens 6, 1 mm long. Carpels 3, united to 1/4–1/2 of the ovary length. Ovary semi-inferior, 3-locular in syncarpous region; ovary bowl as long as inner tepals at anthesis. Styles short, more or less recurved at full anthesis, hollow. Capsule hemisyncarpous, follicular, star-like; carpels strongly recurved to an almost horisontal position, laterally flattened, opening ventrally and later dorsally in the apocarpous region. Seeds elliptic to oblong, with a hyaline wing around the seed body, 0.3–0.5 mm long, brown. Flowering February–September, fruiting (April) August–October.

# Distribution and ecology

*Petrosavia stellaris* is distributed in the Vietnam provinces Kon Tum (Ngoc Linh Mt and Kon Plong district), Dak Lak (Krong Bong, Lak districts), Khanh Hoa (Cam Lam district), Ninh Thuan (Bac Ai [former Ninh Son] district), Lam Dong (Bi Doup Mt and Lac Duong district), as well as in Malaysia (Malay Peninsula, Borneo) and Indonesia (Sumatra, Sulawesi). It grows in montane primary mossy forests on sandy soils, and in secondary forests with bamboo, at 100–1900 m a.s.l. The species prefers 'more tropical' conditions. Our preliminary observation indicates that in flower the three outer stamens touch the stigmas by their dehisced anthers at a certain stage of blooming (Fig. 1d, 2a, b), most likely accomplishing autogamous self-pollination by the same mechanism as has been described for *P. sakuraii* (below).

# Vernacular name

Vietnamese: Vô diệp liên hình sao.

# Additional specimens examined

Vietnam. Kon Tum: primary dry forest with Lithocarpus and Quercus on northwestern slope of Ngoc Linh mountain system above Long Nam village, 1800-1900 m a.s.l., 4 Apr 1995, Averyanov, Hiep, Loc VH 1116 (LE, MO, P); Kon Tum: evergreen primary forest on western slope of Ngoc Linh mountain system on elevation to Ngoc Gua peak, dry forest with Lithocarpus and Quercus sp., 1800-1850 m a.s.l., 10 Apr 1995, Averyanov, Hiep, Loc VH 1301 (LE, P); Kon Tum: Kon Plong district, Thach Nham protected forest, 17 km north from Mang Den town, in open forest, 14°45'23"N, 108°17'30"E, 1580 m a.s.l., 18 Apr 2015, Kuznetsov, Kuznetsova, Nuraliev 1381 (MW); Kon Tum: Kon Plong district, Thach Nham protected forest, 18 km north from Mang Den town, 14°45'44"N, 108°17'33"E, 1540 m a.s.l., 7 Jun 2016, Nuraliev, Alexandrova 1668 (MW); Dak Lak: Krong Bong district, Cu Pui municipality, elevation from Dak Tour village (12°30'N, 108°30'E) to main peak of Chu Yang Sinh mt system (12°24'N, 108°26'E) along Dak Tour river (north slope), primary wet closed mountain broad-leaved and mixed forest on granite along very steep shady slopes of river canyon, on vertical mossy shady cliffs along river, 1700 m a.s.l., 11 May 2000, Averyanov, Hiep, Hieu, Hoang, Du, Vinh VH 6348 (MO, photo record in HN); Dak Lak: Lak district, Bong Krang municipality, Chu Yang Sin National Park, 14 km south from Krong Kmar village, in mixed forest, on the mountain ridge, 12°22'45"N, 108°21'25"E, 1800 m a.s.l., 6 Apr 2012, Nuraliev 486 (MW); Dak Lak: Lak district, Bong Krang municipality, Chu Yang Sin National Park, 14 km south from Krong Kmar village, in mixed forest, on the mountain ridge, 12°22'54"N, 108°21'34"E, 1700 m a.s.l., 20 Mar 2013, Kuznetsov, Kuznetsova, Nuraliev 681 (MW); Dak Lak: Lak district, Bong Krang municipality, Chu Yang Sin National Park, 12 km south-southeast from Krong Kmar village, in mixed forest, 12°24'30"N, 108°23'15"E, 1600 m a.s.l., 20 May 2014, Kuznetsov, Kuznetsova, Nuraliev 946 (MW); Khanh Hoa: Cam Lam district, Hon Ba Nature Reserve, evergreen primary montane mostly broadleaved forest, 12°06'47.9"N, 108°56'46.0"E, 1535 m a.s.l., 30 Jun 2011, Leong-Skornickova, Rybkova, Tran, Truong, Ponert HB-34 (SING); Ninh Thuan: Ninh Son district, Phuoc Binh municipality and Lam Dong province, Lac Duong district, Da Chay municipality boundary region in 34 km to northeast from Dalat city, closed primary broadleaved cloud very wet forest along Gia Rinh Mt ridge, mossy shadow place, 12°07'N, 108°41'E, 1800-1900 m a.s.l., 4 Apr 1997, Averyanov, Binh, Loc VH 3687 (LE); Lam Dong: Lac Duong district, Da Chay municipality, 40 km to northeast of Dalat city, closed primary wet broadleaved cloud forest on the southwestern macroslope of Hon Giao Mt ridge, shaded steep slope, 12°11'N, 108°43'E, 1800 m a.s.l., 21 Apr 1997, Averyanov, Binh, Hiep VH 4131 (LE, MO); Lam Dong: Hon Giao Forest Station, 23 May 2011, Luu Hong Truong s.n. (photo record); Lam Dong: Lac Duong district, Da Chais municipality, SIE Forest Dynamics Plot, near Giang Ly Forest Station, evergreen forest mixed with conifers, 12°10'21"N, 108°41'14"E, 1608 m a.s.l., 28 Jul 2013, Dang Minh Tri BD022 (VNM); Lam Dong: Bi Doup Mt, Aug 2014, Phung My Trung s.n. (LE).

# Notes

The specimen Averyanov, Hiep, Loc VH 1301 stored in LE consists of several individuals of *P. stellaris* with immature flower buds and a single fruiting plant of *P. sakuraii*. As the locality of this collection is far beyond the known distribution range of the latter species, we suppose that this plant was placed into the specimen by accident. Thus, we do not include this record of *P. sakuraii* into the account. This is consistent with material of the other part of this collection stored at P.

On the basis of the Vietnamese specimens, the structure of the plastid genome of *P. stellaris* was investigated. As the study has revealed, the plastome of this species possesses multiple rearrangements of the gene order and several other unusual traits (Logacheva et al. 2014).

# 2. *Petrosavia sakuraii* (Makino) J.J.Sm. ex van Steenis (1934, p. 52) (Fig. 3–4)

Literature: Masamune (1938, p. 46), Jessop (1979, p. 200, Fig. 5b–d), Chen (1980, p. 13, as erroneously '*Petrosavia sakurai* (Makino) Dandy', Ohba (1984, p. 110), Shimizu (1997, p. 1194), Chen et al. (2000, p. 77), Ohashi (2000a, p. 72, 2000b, p. 266, Fig. 1), Cameron et al. (2003, p. 223), Kress et al. (2003, p. 63).

# Basionym: *Miyoshia sakuraii* Makino (1903, p. 145, Pl. 5, as 'Sakuraii'). Nakai (1941, p. 191).

**Based on the same type**: *Protolirion sakuraii* (Makino) Dandy (1931, p. 53). Maekawa (1939, p. 147), Ohwi (1953, p. 282, 1965, p. 281), Maekawa et al. (1961, p. 827, *'Petrosavia sakuraii* Dandy' – sphalm.), Hatusima (1971, p. 780), Okuyama (1977, p. Fig. 3316), Satake (1982, p. 23, Pl. 13-2), Dahlgren et al. (1985, p. 210, Fig. 99j–o), Ohwi and Kitagawa (1992, p. 386). – *Protolirion miyoshiasakuraii* Makino (1903, p. 208, as *'Miyoshia-Sakuraii*', nom.



Figure 3. *Petrosavia sakuraii*. (A) anthetic flower, side view, (B) immature fruit with flower subtending bract and bracteole, side view. All drawn from various sources by M. Remizowa.



Figure 4. *Petrosavia sakuraii*, photos of the specimen Harder et al. 5409 (HNU) showing plants at a stage of young fruits. Photos by L. Averyanov.

nud., based on *Miyoshia sakuraii* Makino). Makino (1925, p. 678, Fig. 1305, as erroneously '*miyoshi sakuraii*', 1940, p. Fig. 2275), Krause (1930, p. 257). – *Petrosavia miyoshia-sakuraii* Makino (1903, p. 208, as '*Miyoshia-Sakuraii*', nom. nud., based on *Miyoshia sakuraii* Makino). Pilger (1908, p. 44, Fig. 8), Makino and Nemoto (1925, p. 1272, 1931, p. 1561).

**Type**: Japan. Mino: foot of Mt Ena, shady forests, 27 Jul 1903, H. Sakurai, s.n. (holotype and isotype: MAK!).

**Taxonomic synonym**: *Petrosavia sinii* (K. Krause) Gagnepain (1934, p. 802, Fig. 78 (10–13)). Anonymous (1976, p. 424), Chen (1980, p. 12, Fig. 1), Ohba (1984, p. 110), Wu (1984, p. 1888); Li (1991, p. 694, Pl. 213), Chen et al. (2000, p. 77, Fig. 64), Pham Hoang Ho (2000, p. 473, Fig. 9592), Hansen and Rasmussen (2005, p. 50), Nguyen Thi Do (2005, p. 456). **Basionym**: *Protolirion sinii* K. Krause (1929, p. 806). **Based on the same type**: *Miyoshia sinii* (K. Krause) Nakai (1941, p. 191), *Petrosavia sinii* (K.Krause) Chun (1940, p. 269), nom. illeg. **Type**: China. Guangxi: Yao shan, in a bamboo thicket, 3000 ft, 6 Jun 1928, S.S. Sin and K.K. Whang 421 (holotype: B!).

#### Description

Usually up to 10-20 cm tall, whitish, pale yellowish or creamy herb. Rhizome scaly, slender. Stem slender. Leaves scaly, up to 5 mm long, membraneous, alternate, ovoid to deltoid with more or less attenuate tip, and entire margin. Inflorescence a terminal several- to many-flowered raceme, sometimes thyrsoid in its basal part. Flowers (3)6-25(30), usually about 10, equally spaced, on equal pedicels. Flowersubtending bracts lanceolate, 2-3 mm long. Flowers erect, bisexual, 3-5 mm in diameter. Perianth biseriate, persistent. Outer tepals 3, deltoid to ovate, about twice shorter and much narrower than the inner ones. Inner tepals 3, 1.5-2.0 mm long, deltoid-triangular. Stamens 6, about 1 mm long. Carpels 3, united up to 1/2 of the ovary length. Ovary semiinferior, 3-locular in syncarpous region; ovary bowl as long as inner tepals at anthesis. Styles short, more or less erect at full anthesis, hollow. Capsule hemisyncarpous, follicular, star-like; free carpel parts recurved to about 45° of their initial position, rounded in cross-section, opening ventrally and dorsally in the apocarpous region. Seeds elliptic to oblong, with a hyaline wing around the seed body, about 0.5-0.8 mm long and 0.2–0.4 mm wide including the wing, small, dark brown. Flowering March-August (November), fruiting September-October.

#### Distribution and ecology

*Petrosavia sakuraii* is distributed in the Vietnam provinces Lao Cai (Sapa area), Ha Giang (Vi Xuyen district), Nghe An (Ky Son district), as well as in Japan, southern China, Taiwan, Myanmar, northern Thailand, and Indonesia (northern half of Sumatra). It grows in montane primary broad-leaved and mixed forests, as well as in secondary forests with bamboo, at 0–2300 m a.s.l. The species prefers more temperate conditions. Takahashi et al. (1993) found *P. sakuraii* to be self-pollinating. The flower is protogynous and stigmas are already receptive when the flower opens. During anthesis, the initially erect styles move gradually outwards and finally

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come in contact with the outer stamens. Insects can enhance selfing rate or provide cross-pollination.

#### Vernacular name

Vietnamese: Vô diệp liên sa-ku-ra.

#### Similar species

The distinction between Petrosavia sinii and P. sakuraii in 'Flora of China' (Chen et al. 2000) is based on the length of the flower-subtending bract vs length of pedicel and the internode length. The original description of Protolirion sinii K. Krause (the basionym of Petrosavia sinii) was made with reference to a single type specimen which contains plants with immature fruits (Krause 1929). We agree with Ohashi (2000b), that flower-subtending bract length itself is a variable feature and is hardly a diagnostic character. In addition, our investigation demonstrates that the pedicel length, as well as the internode length, increases during the ontogeny to reach its maximum at fruit maturity. In contrast, the flower-subtending bracts are fully developed already before anthesis. Consequently, the bracts are longer than pedicels in mature flower buds and shorter than pedicels at full anthesis due to pedicel elongation.

#### Additional specimens examined

Vietnam. Lao Cai: Sapa, 1500 m a.s.l., Sep 1929, Petelot 3598 (P); Ha Giang: Vi Xuyen district, Cao Bo municipality, Tam Ve village, closed mossy (cloud) primary broadleaved montane forest, 22°46'30"N, 104°49'01"E, from top (1900 m a.s.l.) down to ca 1800 m a.s.l., 10 Sep 2000, Harder, Du, Hieu, Loc 5409 (HNU, LE, MO); Ha Giang: Vi Xuyen district, Tay Con Linh mountain, Xan Xa Ho Village Lao Commune, 22°49'37"N, 104°49'49"E, 1175 m a.s.l., 11 Oct 2014, Bui Hong Quang s.n. (photo record in HN); Nghe An: Ky Son district, Na Ngoi municipality, village, eastern slopes of Phu Xai Lai Leng Mountain, primary very humid broad-leaved forest on steep mountain slopes composed of sandstone and gray shale, shady place along edge of ridge, 19°11'58.2"N, 104°11'38.6"E, 2000-2300 m a.s.l., 24 Oct 2013, Averyanov, Hiep, Khang, Tuan, Trang, Dan CPC 6184 (LE); Nghe An: Ky Son district, Na Ngoi municipality, village, eastern slopes of Phu Xai Lai Leng Mt, primary and secondary broad-leaved forest on steep mountain slopes composed of sandstone and gray shale, shady place, 19°12'54"N, 104°12'01"E, 1300-2000 m a.s.l., 26 Oct 2013, Averyanov, Hiep, Khang, Tuan, Trang, Dan CPC 6321 (LE).

# Discussion

# Distribution patterns of the genus *Petrosavia* in Vietnam and worldwide

Although *P. stellaris* occurs in several Vietnamese mountain areas frequently visited by botanists (e.g. Bi Doup, Chu Yang Sin, Hon Ba, Ngoc Linh) and seems to be not rare at least in some of them, to date this species is absent from all the main regional accounts (Pham Hoang Ho 2000, Nguyen Thi Do 2005). The only source which lists *P. stellaris* in Vietnam



Figure 5. Distribution map of the species of *Petrosavia* in Vietnam. Some of the locations on the map represent more than one specimen.

(as well as anywhere else outside Malesia) is a technical report by Tordoff et al. (2000), where the record of this species is based on the specimen Averyanov et al. VH 1116 (listed as VA 1116). The other specimen stated there as belonging to *P. stellaris*, Averyanov et al. VH 1323 (listed as VA 1323), is in fact a representative of the genus *Balanophora* J.R.Forst. and G.Forst. (Balanophoraceae).

One of the reasons for this inconsistency is obviously the scarcity of existing collections: we were unable to find any specimen of *P. stellaris* from Vietnam collected before 1990. The other reason is misidentification of the collections, as we had to re-identify a significant portion of them during preparation of this revision.

The Vietnamese specimens of *P. stellaris* extend the known distribution area of this species far to the north from the previously reported findings in Malaysia and Indonesia (Jessop 1979). The nearest Malaysian populations are located more than 1000 km from the Vietnamese ones. A very similar distribution pattern was recently reported for *Plocoglottis quadrifolia* J.J.Sm. (Orchidaceae), which was known only from the Malay Peninsula and Sumatra before it was found in southern Vietnam (Nuraliev et al. 2015).

Vietnam appears to be the second country where both species of *Petrosavia* are known. It is remarkable that within

this country *P. stellaris* is restricted to the southern part (to the south of the 16th parallel), while *P. sakuraii* is distributed exclusively in the northern part (along the border with China and in Nghe An province) (Fig. 5). The other country inhabited by both species of *Petrosavia* is Indonesia. In contrast to their distribution pattern in Vietnam, in northern Sumatra these species are not strictly delimited geographically and sometimes even occur together (e.g. the specimens Bünnemeijer 5762 of *P. sakuraii* and Bünnemeijer 5761 of *P. stellaris* both collected 16 Nov 1918).

Finally, it should be noted that we were unable to locate a number of specimens of *Petrosavia* listed in various databases. Among them, there are plants collected in Cao Bang and Ha Tinh provinces of Vietnam, which are outside the distribution area of *Petrosavia* outlined in this account.

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