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Impatiens wuyiensis (Balsaminaceae), a new species from Fujian of Southeast China, based on morphological and molecular evidences

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Abstract

Background: Southeast Asia, together with tropical Africa, Madagascar, South India and Sri Lanka, and the eastern Himalayas, are the five primary hotspots of species diversity of *Impatiens* (Balsaminaceae). China is also rich in *Impatiens* species, especially in the limestone karsts or 'Danxia' landforms. With zygomorphic flowers and diverse corolla morphology and color, the species in *Impatiens* are well-known for their ornamental use, but they are also notorious in taxonomy. During the preparation of revision of *Impatiens* in Zhejiang and adjacent regions, an unknown species was collected from Mt. Wuyi in Fujian Province, Southeast China.

Results: Phylogenetic analyses based on nuclear ITS, chloroplast *atpB-rbcL* and *trnL-F* sequences, together with micromorphology of pollen grains and seed coats, strongly supported the close relationship of the new species with *Impatiens platysepala* Y.L.Chen and *I. chloroxantha* Y.L.Chen. In turn, both molecular data and morphological characters also were sufficient to distinguish the new species from the other two counterparts.

Conclusions: Our detailed morphological observations and molecular phylogenetic analyses support the recognition of *Impatiens wuyiensis* as a species new to science.

Keywords: Danxia landform, Flora of Southeast China, *Impatiens wuyiensis*, Sect. *impatiens*, Taxonomy

Background

Impatiens L., containing more than 1000 species, is one of the largest genera of seed plants and is a notorious genus for taxonomic difficulty (Hooker 1908; Chen 1978; Yu et al. 2016). The genus *Impatiens* has zygomorphic flowers with great diversity both in corolla color and morphology, thus it was regarded as 'the dicot counterpart of the orchid' (Yuan et al. 2004; Yu et al. 2016). Some species, e.g. *Impatiens balsamina* L. ('balsam') and *I. walleriana* Hook.f. ('busy lizzie'), are well-known for horticultural value and widely cultivated in East to South

China. The genus *Impatiens* differs from its sister group *Hydrocera* Blume ex Wight & Arn., a monotypic genus, in having lateral petals (sometimes also called wings) united in pairs and valvate and explosive capsules (Chen 2001; Chen et al. 2007). With membranous dried flowers and easily dehiscent fruits on specimens, descriptions of floral and fruit characters on herbarium specimens may therefore be incomplete or ambiguous. Consequently, field investigations are essential for accurately describing the reproductive characters (Chen 1978; Yu 2012).

The genus *Impatiens* has five recognized diversity hotspots: viz. tropical Africa, Madagascar, South India and Sri Lanka, the eastern Himalayas, and Southeast Asia (Song et al. 2003; Yuan et al. 2004). China is also rich in *Impatiens* species, including over 250 species which are mainly distributed in south-western regions, especially in Yunnan, Sichuan, Guangxi, Tibet and Guizhou (Chen 1978; Chen et al. 2007; Shui et al. 2011). Recently,

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molecular phylogenetics has contributed greatly to the understanding of relationships within *Impatiens* (Yuan et al., 2004; Janssens et al. 2006, 2007, 2012; Yu et al. 2016). Moreover, micromorphology of pollen grains and seed coats of *Impatiens* have great taxonomic values (Lu 1991; Lu and Chen 1991; Song et al. 2005; Janssens et al. 2012; Cai et al. 2013), and systematic implications (Jin et al. 2008; Guo et al. 2016; Zeng et al. 2016).

Chen (1988, 1989, 1999) carried out the taxonomic studies and described eight new species from Zhejiang, Anhui and Jiangxi provinces. However, the previous collection of this area was not satisfactory till now. Our field surveys of *Impatiens* from Zhejiang and adjacent regions in East China have resulted in the discovery of several new species and some infraspecific taxa (*Impatiens taishunensis*, Chen and Xu 1993; *I. jiulongshanica*, *I. neglacta*, *I. suichangensis* and *I. tienmushanica* var. *longicalculata*, Xu and Chen 1999; *I. huangyanensis*, Jin and Ding 2002; *I. platysepala* var. *kuocangshanica*, Jin and Zhang 2003; *I. yilingiana* and *I. huangyanensis* subsp. *attenuata*, Jin et al. 2008; *I. chekiangensis* var. *multiflora* and var. *cangnanensis*, Xu et al. 2018). In this study we report an additional distinctive new species, *I. wuyiensis*, from one of the typical Danxia landforms in northern Fujian Province, China.

Danxia, literally meaning 'rosy cloud', is a type of sandstone landform found in southeastern, southwestern and northwestern China that consist of a red bedrock characterized by steep cliffs, isolated peaks, steep pillars, ravines, mountains and hills that have formed after a long period of erosion by wind and running water (Liu et al. 1999; Peng et al. 2018). The Danxia landform in Fujian and Guangdong Provinces of China shows the block mountains and looks like isolated islands (Peng et al. 2018).

Based on its flower structure, and micromorphology of pollen grains and seeds, *Impatiens wuyiensis* is similar to *I. platysepala* and *I. chloroxantha*, but evidences of molecular data (ITS, *trnL-F* and *atpB-rbcL*) and other morphological characters well support the status of this taxon as new.

Methods

SEM observations on pollens and seeds

Dried mature pollen grains and seeds of the new species, together with its allied *Impatiens platysepala* and *I. chloroxantha*, were directly collected from the field (see

further methodological details in Appendix 1). Pollen grains and seeds were mounted on stubs using double-sided adhesive tape, and directly coated with a layer of gold. The coated pollen grains and seeds were observed and photographed under a Hitachi SU8010 SEM. The sizes of pollen grains and seeds were respectively measured on twenty grains per species using light microscopy. Pollen terminology follows Wang and Wang (1983) and Lu (1991), and that of seed follows Liu et al. (2004) and Lu and Chen (1991).

Taxon sampling and DNA sequencing

Seventeen samples representing eight species and one variety of *Impatiens* were collected, and total genomic DNA of these samples were isolated from dried leaf tissue using the TIANGEN Plant Genomic DNA Kit (China). Three DNA regions, ITS (White et al. 1990), *atpB-rbcL* (Janssens et al. 2006), and *trnL-F* (Taberlet et al. 1991) were amplified. PCR (the polymerase chain reaction) mixture (25 µL) contained 12.5 µL 2 × Reaction Mix, 1.0 µL each primer (10 pmol/µL), 1.0 µL genomic DNA (<0.5 µg), 0.5 µL Golden DNA Polymerase (2.5 U/µL) and 9.2 µL ddH₂O. The PCR conditions were: 1 cycle of 3 min at 94 °C for denaturation, 35 cycles of 30 s at 94 °C for denaturation (for ITS, 38 cycles), 30 s at 55 °C for annealing and 1 min at 72 °C for extension (for ITS, 45 s), with a final 5 min extension at 72 °C. The successful PCR products were checked using a 1% agarose gel electrophoresis. Sequencing was carried out on an ABI 3730 automated sequencer (Applied Biosystems, USA).

A total of 116 sequences representing 34 taxa (*Impatiens* species and varieties, plus *Hydrocera triflora* as out-group) were used to test the phylogenetic placement of the new species. The sampling representatively covered all the sections (with the exception of sect. *Tuberosae*) known in the phylogeny of *Impatiens* (Yu et al. 2016). Fifty-one sequences representing nine taxa being collected in the field were newly generated in this study. The rest of the sequences were obtained from GenBank (Appendix 1).

Phylogenetic analysis

Sequences were assembled and edited using DNASTar Lasergene 7.1 software. Assembled sequences of the same locus were aligned using MAFFT online version (<https://mafft.cbrc.jp/alignment/server/>) and trimmed manually in Mega 7.0 (Kumar et al. 2016). The best-fit nucleotide

substitution models were determined by the Akaike Information Criterion (AIC) using JmodelTest 2 (Darriba et al. 2012), which resulted in ITS for GTR+I+G, *atpB-rbcL* for GTR+G and *trnL-F* for GTR+G. Bayesian Inference (BI) was conducted in MrBayes 3.2.6 (Ronquist and Huelsenbeck 2003), running for 10 million generations and sampling one tree every 1000 generations with four chains of Markov chain Monte Carlo (MCMC). A 50% majority-rule consensus tree was calculated after discarding the first 25% trees as burn-in. A Maximum parsimony (MP) analysis was conducted using PAUP v.4.0b10 (Swofford 2003), using a heuristic search algorithm with 1000 random addition replicates and tree bisection-reconnection (TBR) branch-swapping. Node support was assessed using 1000 MP bootstrap (BS) replicates.

Results and discussion

Micromorphology of the pollen grains of the new species, *Impatiens platysepala* and *I. chloroxantha* were shown in Fig. 1. All were oblong-ellipsoid, regularly reticulate, densely granulate in lumen, and with a few perforations. The size of the pollen grains of the new species ($E1 \times E2$) was $35.20 (\pm 1.01) \times 16.27 (\pm 1.00) \mu\text{m}$, and those of *I. platysepala* and *I. chloroxantha* were respectively $35.27 (\pm 1.30) \times 16.98 (\pm 1.21) \mu\text{m}$ and $34.08 (\pm 1.82) \times 16.40 (\pm 1.26) \mu\text{m}$. This confirmed that the size and micromorphology of pollen grains is similar among three species (Fig. 1).

Seeds of the new species, *Impatiens platysepala* and *I. chloroxantha* were all ovoid, slightly compressed, and surface cells regularly elevated, with granules on cell surfaces. The micromorphology of seed coat was revealed to be closely similar in the three studied species (Fig. 2). The seed size of the new species (length \times width) was $2.39 (\pm 0.12) \times 1.29 (\pm 0.12) \text{mm}$, and those of *I. platysepala* and *I. chloroxantha* were respectively $2.51 (\pm 0.10) \times 1.54 (\pm 0.11) \text{mm}$ and $2.96 (\pm 0.20) \times 1.63 (\pm 0.16)$. Observed seed size of *I. chloroxantha* was larger than in *I. platysepala* and the new species (Fig. 2).

The combined dataset of ITS, *atpB-rbcL* and *trnL-F* included 2505 aligned characters (ITS: 697 bps, *atpB-rbcL*: 869 bps and *trnL-F*: 939 bps). The phylogram with posterior probability values (PP) of Bayesian analysis and bootstrap supports (BS) of Maximum parsimony analysis is respectively depicted in Fig. 3. Five individuals of the

new species were shown forming a well-supported clade (PP = 1.00, and BS = 99), which was sister to the clade of two similar species, *I. platysepala* and *I. chloroxantha*. Together with the other ten species (*I. chekiangensis*, *I. noli-tangere*, *I. tienmushanica*, *I. davidi* etc.), these species are easily distinguished as members in *I. sect. Impatiens*, which is characterized by inflorescence shortly racemose or umbel-like, ovary 5-capellate, and capsules clavate (Yu et al. 2016).

Conclusion

According to our results, we proceed to formally describe the new species.

Impatiens wuyiensis J.S.Wang, Y.F.Lu & X.F.Jin, **sp. nov.**: TYPE: CHINA, Fujian, Wuyishan City, Mt. Wuyi, Dawangfeng, moist places by roadside, $27^{\circ}38'57.13''\text{N}$, $117^{\circ}57'47.42''\text{E}$, alt. 420 m, 23 May 2018, X.F. Jin, Y.F. Lu & J.S. Wang 4158 (holotype: ZM barcode ZMNH0068001, isotypes: HTC barcode HTC0021906, KUN, PE, ZJFC). 武夷凤仙花 (Figs. 4 and 5).

Diagnosis: *Haec species in characteribus floralibus est affinis Impatienti platysepala Y.L. Chen et I. chloroxanthae Y.L. Chen, a qua floribus luteis, sepalis lateralibus dense purpureo-rubro-maculatis, costas vexilli dorso in medio breviter clavatis vel cornutis, bracteis herbaceis linearis vel anguste ovato-lanceolatis, 3–4 mm longis, ca. 0.5 mm latis differt.*

Description: Herbs annual, 20–75 cm tall, glabrous. Stems succulent, erect, usually simplex; lower nodes swollen or slightly swollen. Leaves alternate; blades membranous, ovate-elliptic or elliptic-oblong, rarely ovate or oblong, 2.5–13 cm long, 1.5–5.5 cm wide, apex acuminate, base cuneate and gradually attenuate into a 1–8 cm long petiole (upper aggregated leaves subsessile), margin crenate and mucronulate, dark green adaxially, pale green and pale red abaxially, lateral veins 6–8 pairs, obliquely curved. Inflorescence in leaf axils, shortly racemose or umbel-like, shorter than leaves; peduncles shorter than petioles, 10–13 mm long, 2–4-flowered, rarely 5- or 6-flowered; pedicels 14–20 mm long, base bracteate; bracts herbaceous, persistent, linear or narrowly ovate-lanceolate, 3–4 mm long, ca. 0.5 mm wide, apex acuminate. Flowers golden yellow, 4–5 cm long, 2–2.2 cm wide. Lateral sepals 2, broadly ovate or ovate-rounded, 6–7 mm long, 5.5–6.5 mm wide, densely purple-red spotted, base nearly aequilateral, apex obtuse

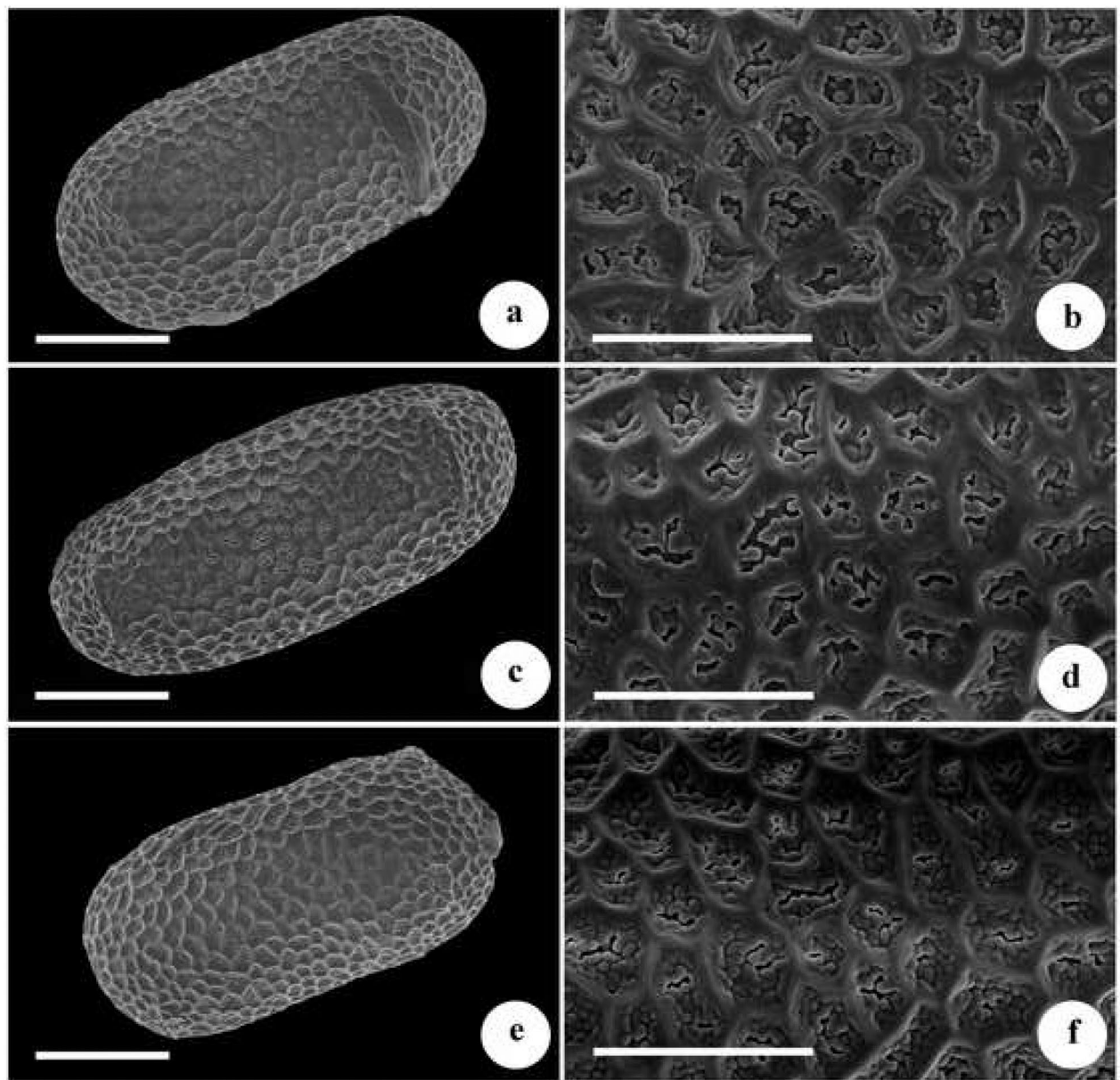


Fig. 1 Micromorphology of pollen grains of *Impatiens wuyiensis*, *I. platysepala* and *I. chloroxantha*. **a, b** *I. wuyiensis*; **c, d** *I. platysepala*; **e, f** *I. chloroxantha*. **a, c, e** overview of pollen grain (scale bar: 10 μ m); **b, d, f** sexine sculpture (scale bar: 5 μ m)

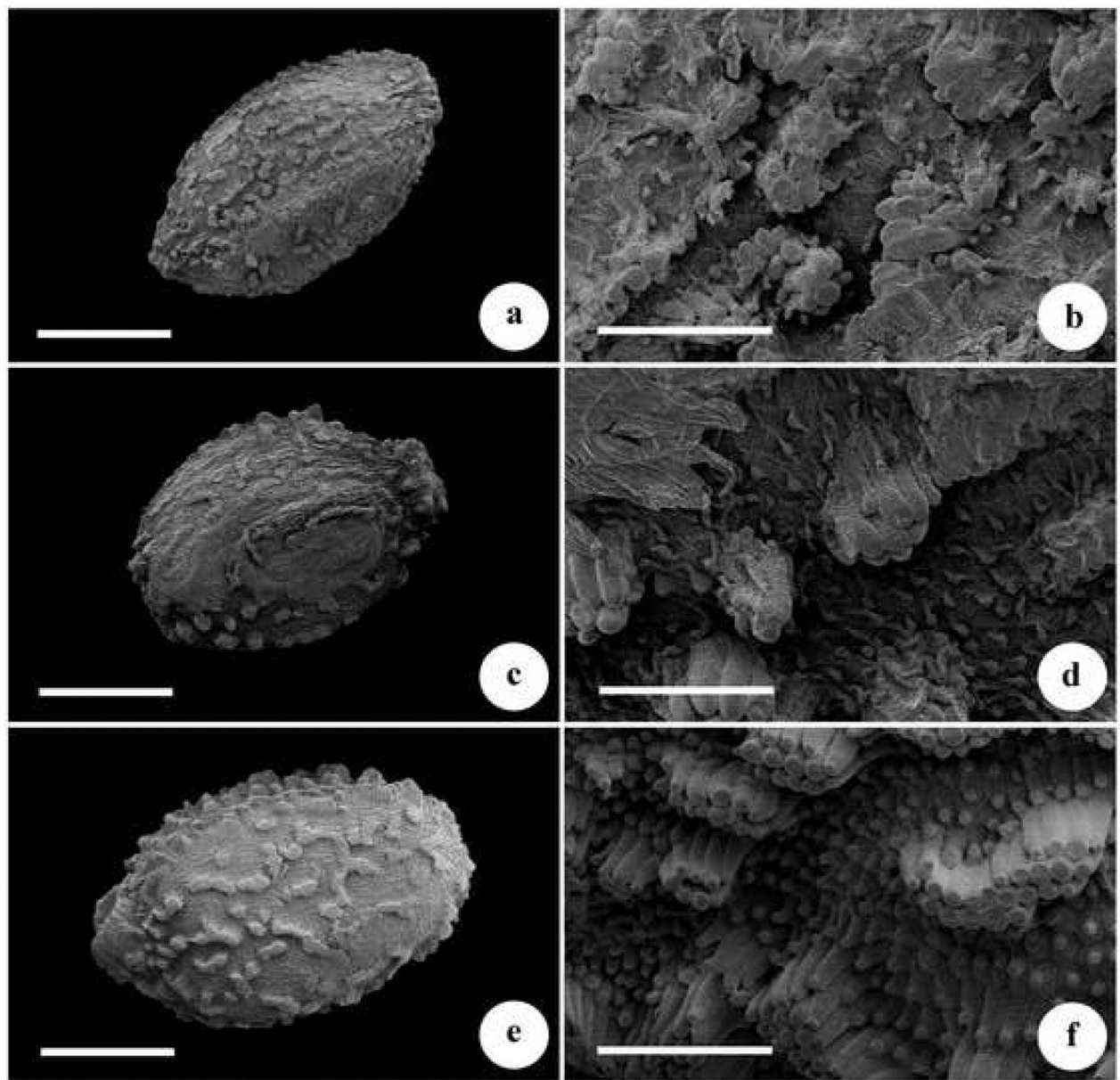
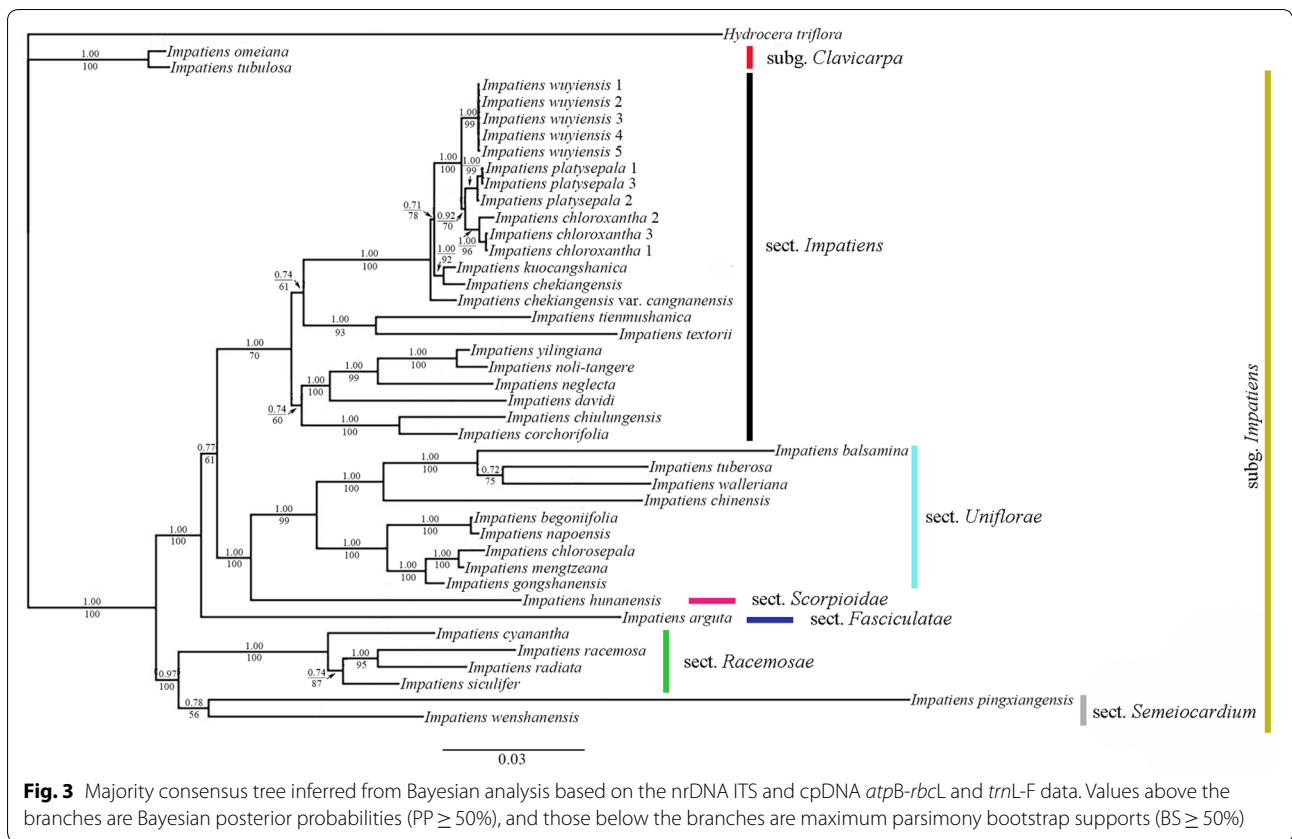


Fig. 2 Micromorphology of seeds of *Impatiens wuyiensis*, *I. platysepala* and *I. chloroxantha*. **a, b** *I. wuyiensis*; **c, d** *I. platysepala*; **e, f** *I. chloroxantha*. **a, c, e** shape of seeds (scale bar: 1 mm); **b, d, f** surface ornamentation of seedcoat (scale bar: 200 μ m)



and mucronulate, abaxial midvein keeled. Lower sepal funnellform, 4–4.5 cm long, purple-red striate, base abruptly narrowed into a 2.5–3 cm long and slightly incurved spur; mouth vertical, 16–18 mm wide, tip acute. Upper petal orbicular, 11–13 mm long, 19–21 mm wide, purple-red spotted, apex emarginate and mucronate, abaxial midvein keeled and clavate or corned at middle.

Lateral united petals 22–25 mm long, 12–14 mm wide, purple-red striate, 2-lobed; basal lobes oblong, 8–9 mm long, 3–3.5 mm wide, apex obtuse, with a 4–4.5 mm long stipe; distal lobes dolabriform, apex obtuse, with reflexed and golden yellow auricle. Stamens 5; filaments 4–6 mm long; anthers ovoid, apex obtuse. Ovary fusiform, ca.

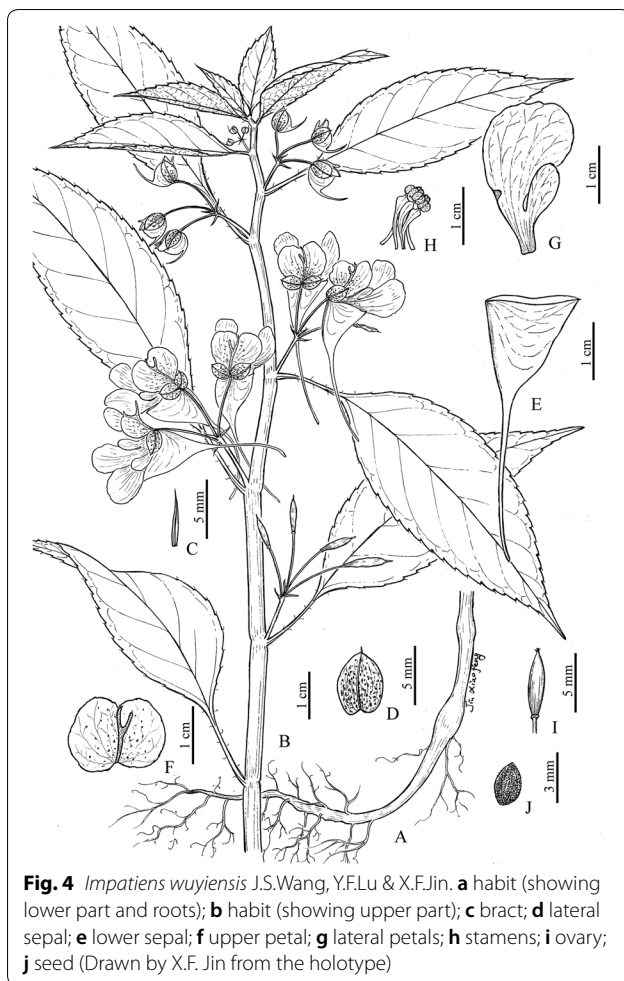


Fig. 4 *Impatiens wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin. **a** habit (showing lower part and roots); **b** habit (showing upper part); **c** bract; **d** lateral sepal; **e** lower sepal; **f** upper petal; **g** lateral petals; **h** stamens; **i** ovary; **j** seed (Drawn by X.F. Jin from the holotype)

3 mm long, apex acute. Capsule clavate, 10–20 mm long, apex with a 2–3.5 mm long beak. Seeds ovoid, brown, ca. 2.5 mm long, ca. 2 mm wide, densely verrucous.

Distribution, habitat and ecology: *Impatiens wuyiensis* seems to be restricted to Mt. Wuyi. It is widely distributed along several scenic spots, such as Dawangfeng, Tianyoufeng, Shuiliandong and Lianhuafeng views. It grows in moist places by roadside or in grasslands, on rock face, under forest or at forest margins, at an elevation between 220 and 430 m (Fig. 5: a, b).

Phenology: Flowering and fruiting of this new species is from early April to late September.

Etymology: The specific epithet ‘*wuyiensis*’ is derived from the type locality, Mt. Wuyi, northern Fujian Province.

Notes: This new species is morphologically similar to *Impatiens platysepala* and *I. chloroxantha* in habit and floral structure (Chen 1988, 2001; Zhang et al. 2017), but is easily distinguished from these two species in having flowers golden yellow, lateral sepals densely purple-red spotted, upper petals with abaxial midvein clavate or corned at middle, bracts herbaceous, linear or narrowly ovate-lanceolate, 3–4 mm long, ca. 0.5 mm wide. Morphological characters distinguishing the new species from *Impatiens platysepala* and *I. chloroxantha* are detailed in Table 1, Figs. 5 and 6.

Micromorphology of pollen grains and seeds of the new species, *Impatiens platysepala* and *I. chloroxantha* revealed that these three species are closely related. Phylogenetic analysis detected that the new species is also related to *I. platysepala* and *I. chloroxantha*, but considerably different from each other with strong supports.

Additional specimens examined (paratypes): Fujian, Wuyishan City, Mt. Wuyi, Dawangfeng, moist places by roadside, 27°38′57.15″N, 117°57′47.36″E, alt. 430 m, 23 May 2018, X.F. Jin, Y.F. Lu & J.S. Wang 4156 (ZJFC, ZM), *ibid.*, 23 May 2018, X.F. Jin, Y.F. Lu & J.S. Wang 4157 (PE, ZJFC, ZM); Mt. Wuyi, Shuiliandong, in grass under forest, 27°40′56.23″N, 117°58′32.04″E, alt. 220 m, X.F. Jin, Y.F. Lu & J.S. Wang 4165 (ZM), 4166 (KUN, PE, ZM), 4167 (KUN, PE, ZM), *ibid.*, by stream, alt. 270 m, 4 April

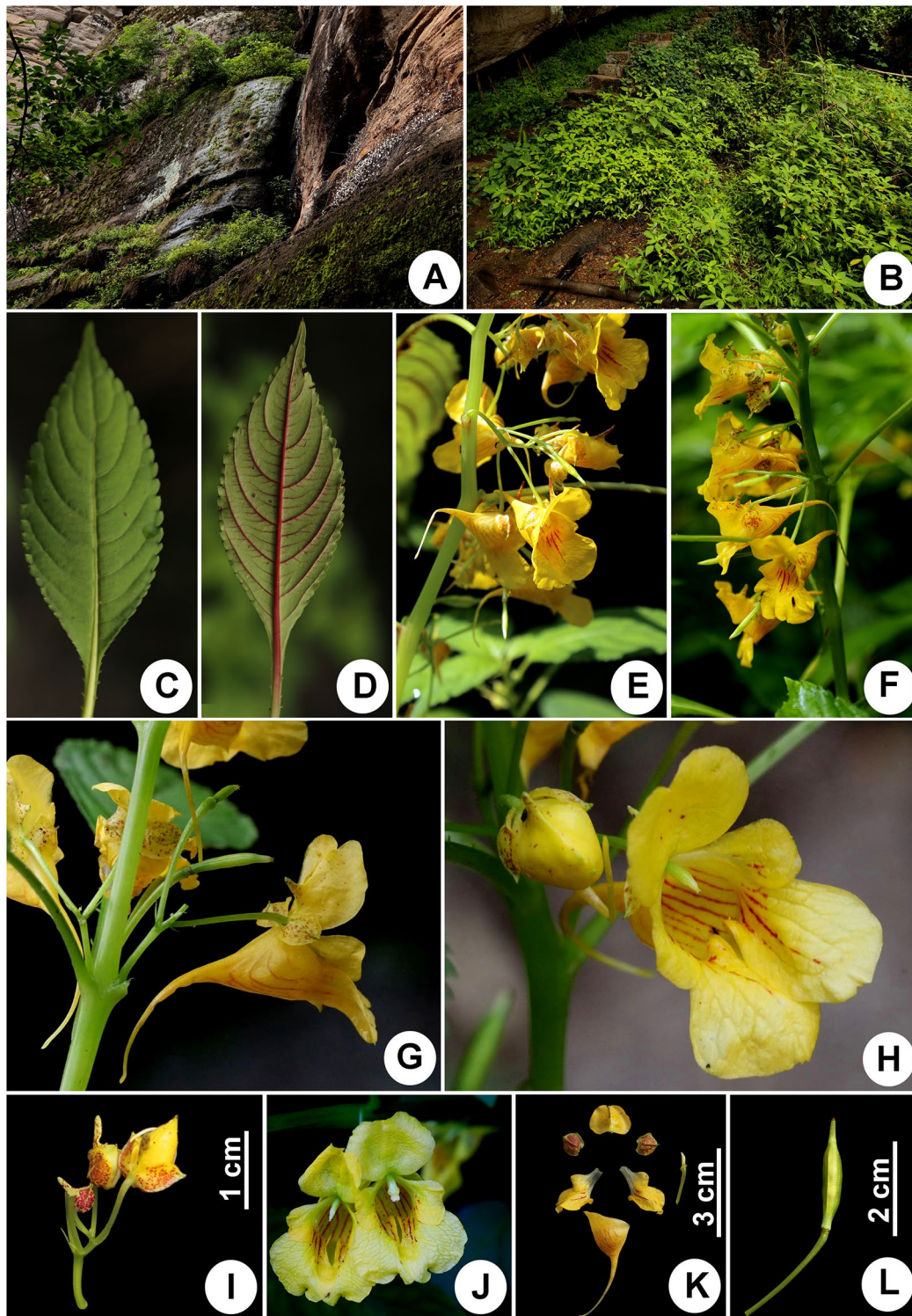


Fig. 5 *Impatiens wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin. **a, b** habitat; **c** adaxial surface of leaf; **d** abaxial surface of leaf; **e, f** inflorescence; **g** lateral view of flower; **h** frontal view of flower; **i** pedicel and bract; **j** upper petal and lateral united petals; **k** flower structure; **l** capsule

Table 1 Comparison of *Impatiens wuyiensis*, *I. platysepala* and *I. chloroxantha*

Characters	<i>Impatiens wuyiensis</i>	<i>Impatiens platysepala</i>	<i>Impatiens chloroxantha</i>
Leaves			
Abaxial color	Pale green and pale red	Pale green, rarely pale red	Pale green
Lateral veins	6–8 pairs	8–11 pairs	7–9 pairs
Bracts			
Texture	Herbaceous	Thinly membranous	Thinly membranous
Shape	Linear or narrowly ovate-lanceolate	Ovate-lanceolate	Ovate or narrowly ovate
Size	3–4 × ca. 0.5 mm	10–12 × 4–6 mm	8–11 × 4–5 mm
Flower			
Color	Golden yellow	Pink	Yellow-green
Lateral sepals	Densely purple-red spotted	Not spotted	Not spotted
Upper petals	Middle with abaxial midvein clavate or corned	Middle with abaxial midvein cristate	Middle with abaxial midvein cristate

2019, X.F. Jin, Y.F. Lu & J.S. Wang 4375 (ZJFC, ZM), *ibid.*, 21 September 2019, X.F. Jin & Y.F. Lu s. n. (ZM); Mt. Wuyi, Tianyoufeng, in grass by roadside, alt. 227 m, 7 May 2019, Y.F. Lu 186 (ZM).

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Authors' contributions

JSW, YFL and XFJ discovered the new species, SHJ and XFJ designed the project, JSW, YFL, YLX and XFJ collected the materials, YFL and XFJ collected the molecular data and performed the analysis, JSW, YFL and XFJ wrote the first draft of the manuscript. All authors read and approved the final manuscript.

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Availability of data and materials

All DNA sequences generated in this study have been registered to GenBank.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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Appendix 1

Taxon: NCBI accession numbers (ITS/*atpB-rbcL/trnL-F*), voucher information. Samples marked with ‘*’ were newly added, and ‘#’ were those pollen grains and seeds collected.

Hydrocera triflora (L.) Wright & Arn.: AY348853/ DQ147895/ -, Sri Lanka, *Robyns* 7260, 0,249,369 (BR).

Impatiens arguta Hook.f. & Thomson: AY348746/ DQ147812/ KP776116, China, Yunnan and Xizang, Y. M. Yuan CN2k1-74 (NEU) and S.X. Yu 5406 (PE).

I. balsamina L.: AY348749/ DQ147816/ -, Kruidtuin Leuven (Cult.), *Janssens* SJ 001 (LV).

I. begoniifolia S. Akiyama & H. Obha: AY348752/ DQ147819/ -, China, Yunnan, Y. M. Yuan CN2k1-51 (NEU).

I. chekiangensis Y.L.Chen: KP776064/ KP776014/ KP776121, China, Zhejiang, H.N. Qin et al. 20,141 (PE).

I. chekiangensis Y.L.Chen var. *cangnanensis* Y.L.Xu & X.F.Jin*: MN974564/ MN974547/ MN974581, China, Zhejiang, Cangnan, Dangyuanlin, Y.L. Xu 318 (ZM).

I. chinensis L.: AY348761/ DQ147825/ KP776122, China, Yunnan and Guangxi, Y.M. Yuan CN2k1-49 (NEU) and *I. chiulungensis* Y.L.Chen: KP776066/ KP776016/ KP776124, China, Sichuan, S.X. Yu et al. 3989 (PE).

I. chlorosepala Hand.-Mazz.: KP776067/ KP776017/ -, China, Guangxi, S.X. Yu et al. 4209 (PE).

I. chloroxantha Y.L.Chen (individual 1)*: MN974563/ MN974546/ MN974580, China, Zhejiang, Suichang, Mt. Jiulong, Luohanyuan, X.F. Jin s. n. (HTC). *I. chloroxantha* Y.L.Chen (individual 2)*#: MN974573/ MN974556/ MN974590, China, Zhejiang, Suichang, Mt. Jiulong, Luohanyuan, J.L. Liu s. n. (HTC). *I. chloroxantha* Y.L.Chen (individual 3)*: MN974574/ MN974557/ MN974591,

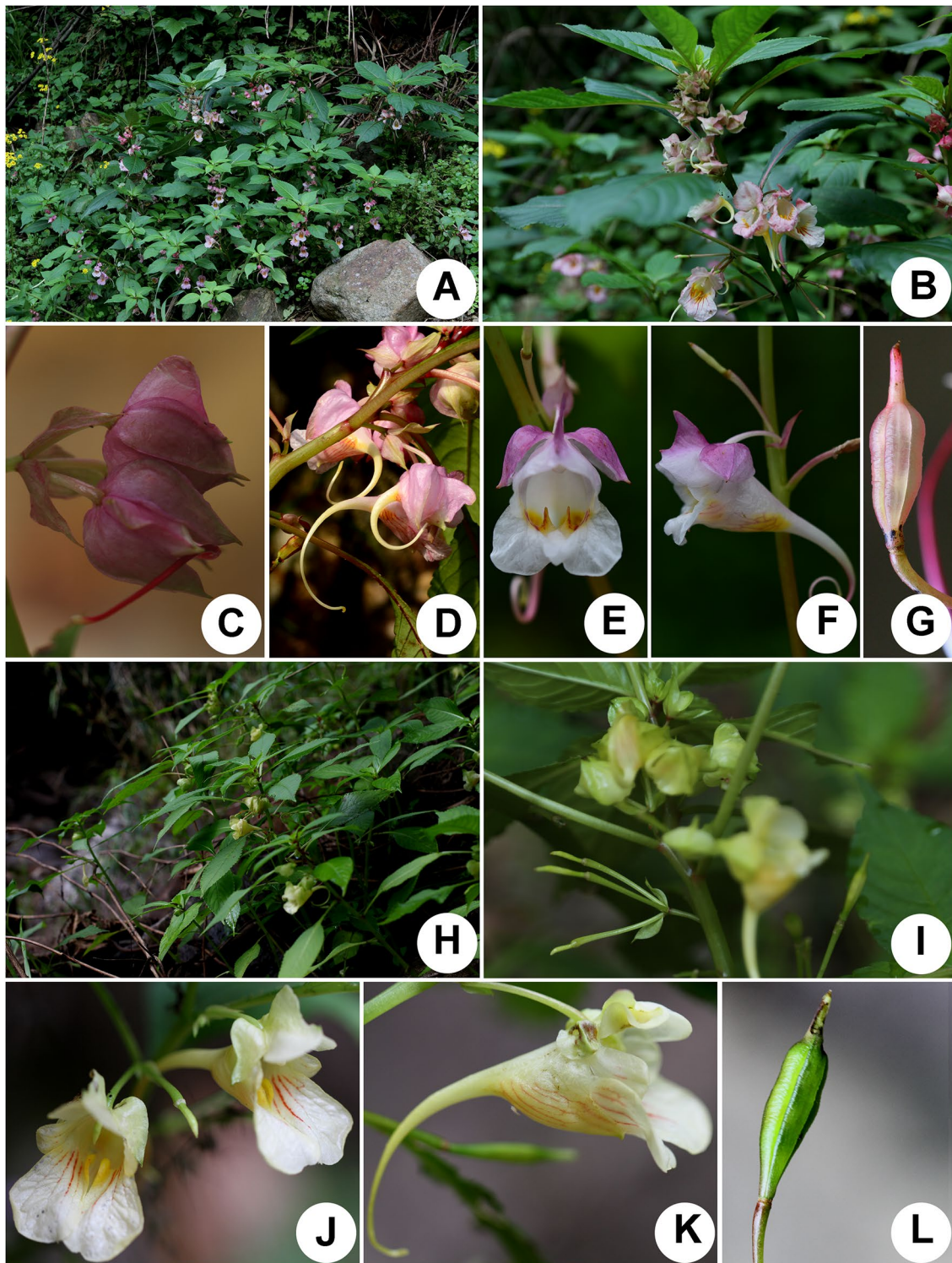


Fig. 6 *Impatiens platysepala* Y.L.Chen (a–g) and *I. chloroxantha* Y.L.Chen (h–l). **a** habitat; **b** upper part of plant; **c** bracts and flowers; **d** inflorescence; **e** frontal view of flower; **f** lateral view of flower; **g** capsule; **h** habitat; **i** inflorescence and bracts; **j** frontal view of flower; **k** lateral view of flower; **l** capsule

China, Zhejiang, Suichang, Mt. Jiulong, Luohanyuan, J.L. Liu s. n. (HTC).

I. corchorifolia Franch.: AY348767/ DQ147831/ KP776127, China, Yunnan and Sichuan, Chassot & Y.M. Yuan 99–173 (NEU) and S.X. Yu et al. 4596 (PE).

I. cyanatha Hook.f.: AY348770/ DQ147833/ -, China, Yunnan, Y.M. Yuan CN2k1-84 (NEU).

I. davidi Franch.*: MN974568/ MN974551/ MN974585, China, Zhejiang, Yinzhou, Wulongtan, X.F. Jin & Y.F. Lu 4357 (HTC).

I. gongshanensis Y.L.Chen: KP776074/ KP776024/ KP776135, Myanmar, Putao, PT-ET 975 (PE).

I. hunanensis Y.L.Chen: KP776077/ KP776028/ KP776137, China, Guangxi, S.X. Yu 3759 (PE).

I. kuocangshanica (X.F.Jin & F.G.Zhang) X.F.Jin & Y.L.Xu*: MN974567/ MN974550/ MN974584, China, Zhejiang, Linhai, Mt. Kuocang, Zhangjiadu, B.Y. Ding & X.F. Jin 6924 (PE).

I. mengtzeana Hook.f.: AY348806/ DQ147858/ -, China, Yunnan, Y.M. Yuan CN2k1-60 (NEU).

I. neglecta Y.L.Xu & Y.L.Chen*: MN974569/ MN974552/ MN974586, China, Zhejiang, Longquan, Mt. Fengyang, Y.F. Lu 203 (HTC).

I. napoensis Y.L.Chen: AY348811/ DQ147861/ KP776146, China, Yunnan and Guangxi, Y.M. Yuan CN2k1-61 (NEU) and S.X. Yu 3049 (PE).

I. noli-tangere L.: KP776088/ KP776039/ KP776148, China, Guangxi, S.X. Yu 4017 (PE).

I. omeiana Hook.f.: KP776092/ DQ147864/ KP776152, China, Sichuan and Univ. California Bot. Gard. (Cult.), S.X. Yu 4093 (PE) and 2002.0214 (UC).

I. pingxiangensis H.Y.Bi & S.X.Yu: KP776093/ KP776043/ -, China, Guangxi, S.X. Yu et al. 3088 (PE).

I. platysepala Y.L.Chen (individual 1)*#: MN974572/ MN974555/ MN974589, China, Zhejiang, Jiangshan, Zhoucun, Z.H. Chen et al. JS19061201 (HTC). *I. platysepala* Y.L.Chen (individual 2)*#: MN974570/ MN974553/ MN974587, China, Zhejiang, Jiangshan, Zhoucun, Z.H. Chen et al. JS19061203 (HTC). *I. platysepala* Y.L.Chen (individual 3)*#: MN974571/ MN974554/ MN974588, China, Zhejiang, Jiangshan, Nianbadou, Z.H. Chen et al. JS19061205 (HTC).

I. racemosa DC.: KP776098/ DQ147873/ KP776159, China, Yunnan and Xizang, S.X. Yu 4221 (PE) and *De Haas* 2620 (U).

I. radiata Hook.f.: AY348824/ KP776047/ KP776160, China, Xizang and Sichuan, *De Haas* 2620 (U) and S.X. Yu et al. 4760 (PE).

I. siculifer Hook.f.: KP776101/ KP776049/ -, China, Guangxi, S.X. Yu 3211 (PE).

I. textori Miq.: AY348841/ -/ KP776168, Japan and Korea, Kanno et al. 1114 (TUS) and H.N. Qin et al. 18,048 (PE).

I. tienmushanica Y.L.Chen*: MN974565/ MN974548/ MN974582, China, Zhejiang, Pan'an, Mt. Dapan, Huaxi, Y.F. Lu s. n. (HTC).

I. tuberosa H. Perrier: AY348844/ DQ147886/ -, Madagascar origin: Bot. Gard. Univ. Copenhagen (Cult.), Janssens SJ 005 (LV).

I. tubulosa Hemsl.: KP776108/ KP776056/ KP776172, China, Guangxi, S.X. Yu 3762 (PE).

I. walleriana Hook.f.: AY348849/ DQ147892/ AB043641, Kenya, Nat. Bot. Gard. Meise (Cult.) and Tokyo (Cult.), O. Phaebler & M. Schnell 108 (NEU), S3926 (BR) and H. Fujihashi 3 (TI).

I. wenshanensis S.H.Huang: KP776110/ KP776057/ KP776175, China, Guangxi, S.X. Yu 4044 (PE).

I. wuyiensis J.S.Wang, Y.F.Lu & X.F.Jin (individual 1)*: MN974558/ MN974541/ MN974575, China, Fujian, Mt. Wuyi, Shuiliandong, X.F. Jin et al. 4167 (ZM). *I. wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin (individual 2)*: MN974559/ MN974542/ MN974576, China, Fujian, Mt. Wuyi, Dawangfeng, X.F. Jin et al. 4156 (ZM). *I. wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin (individual 3)*#: MN974560/ MN974543/ MN974577, China, Fujian, Mt. Wuyi, Dawangfeng, X.F. Jin et al. 4158 (ZM). *I. wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin (individual 4)*: MN974561/ MN974544/ MN974578, China, Fujian, Mt. Wuyi, Shuiliandong, X.F. Jin et al. 4165 (ZM). *I. wuyiensis* J.S.Wang, Y.F.Lu & X.F.Jin (individual 5)*: MN974562/ MN974545/ MN974579, China, Fujian, Mt. Wuyi, Tianyoufeng, Y.F. Lu 186 (ZM).

I. yilingiana X.F.Jin, S.Z.Yang & L.Qian*: MN974566/ MN974549/ MN974583, China, Zhejiang, Lin'an, Mt. Tianmu, Dashuwang, X.F. Jin 1901 (HTC).

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References

- Cai X-Z, Yi R-Y, Zhuang Y-H, Cong Y-Y, Kuang R-P, Liu K-M (2013) Seed coat micromorphology characteristics of *Impatiens* L. and its systematic significance. *Acta Hort Sin* 40:1337–1348. <https://doi.org/10.16420/j.issn.0513-353x.2013.07.014>
- Chen Y-L (1978) Notulae de genere *Impatiens* L. florum Sinicae. *Acta Phytotax Sin* 16(2):36–55
- Chen Y-L (1988) A revision of *Impatiens* L. from Chekiang—studies on the genus *Impatiens* L. in China (II). *Bull Bot Res* 8(2):1–15
- Chen Y-L (1989) Four new species of *Impatiens* (Balsaminaceae) from China. *Acta Phytotax Sin* 27:395–404
- Chen Y-L (1999) Six new species of *Impatiens* L. from China. *Acta Phytotax Sin* 37:88–99
- Chen Y-L (2001) *Flora Reipublicae Popularis Sinicae*, Tomus 47(2): Balsaminaceae. Science Press, Beijing
- Chen Y-L, Akiyama S, Ohba H (2007) Balsaminaceae. In: Wu Z-Y, Raven PH (eds) *Flora of China*, vol 12. Science Press and Missouri Botanical Garden Press, Beijing and St-Louis, pp 43–114
- Chen Y-L, Xu Y-L (1993) A new species of *Impatiens* (Balsaminaceae) from Zhejiang. *Bull Bot Res* 13(1):11–13

- Darriba D, Taboada GL, Doallo R, Posada D (2012) jModelTest 2: More models, new heuristics and parallel computing. *Nature, Meth* 9:772
- Guo H, Yan R-Y, Zhang M, Luo Q, Zhang L-J, Yu S-X (2016) Taxonomic significance of the pollen morphology of sect. *Racemosae* (*Impatiens*). *Guihaia* 36:83–95. <https://doi.org/10.11931/guihaia.gxzw201601175>
- Hooker JD (1908) Les espèces du genre "*Impatiens*" dans l'herbier du Museum de Paris. *Nouv Arch Mus Nat Hist Paris. Ser. 4*, 10: 233–272.
- Janssens SB, Geuten K, Yuan Y-M, Song Y, Küpfer P, Smets E (2006) Phylogenetics of *Impatiens* and *Hydrocera* (Balsaminaceae) using chloroplast *atpB-rbcL* spacer sequences. *Syst Bot* 31:171–180. <https://doi.org/10.1600/036364406775971796>
- Janssens SB, Geuten K, Viaene T, Yuan Y-M, Song Y, Smets E (2007) Phylogenetic utility of the AP3/DEF K-domain and its molecular evolution in *Impatiens* (Balsaminaceae). *Mol Phylogenet Evol* 43:255–239. <https://doi.org/10.1016/j.ympev.2006.11.016>
- Janssens SB, Wilson SY, Yuan Y-M, Nagels A, Smets EF, Huysmans S (2012) A total evidence approach using palynological characters to infer the complex evolutionary history of the Asian *Impatiens* (Balsaminaceae). *Taxon* 61:355–367. <https://doi.org/10.1002/tax.612007>
- Jin X-F, Ding B-Y (2002) A new species of *Impatiens* from eastern Zhejiang, China. *Acta Phytotax Sin* 40:167–169
- Jin X-F, Yang S-Z, Chen Z-H, Qian L (2008) *Impatiens yilingiana* sp. nov. and *I. huangyanensis* subsp. *attenuata* subsp. nov. (Balsaminaceae) from Zhejiang, eastern China. *Nordic J Bot* 26:207–213. <https://doi.org/10.1111/j.1756-1051.2008.00325.x>
- Jin X-F, Zhang F-G (2003) A new variety of *Impatiens* L. from Zhejiang Province. *Bull Bot Res* 23:141–142
- Kumar S, Stecher G, Tamura K (2016) MEGA7: Molecular Evolutionary Genetics Analysis version 7.0 for bigger datasets. *Molec Biol Evol* 33:1870–1874. <https://doi.org/10.1093/molbev/msw054>
- Liu C-J, Lin Q, He J-X (2004) Methods and terminology of study on seed morphology from China. *Acta Bot Bor-Occid Sin* 24:178–188
- Liu W-Q, Li Z-H, Liu LF (1999) A preliminary study on the flora of the tourist landform of Danxiashan, Guangdong, China. *Guihaia* 19:15–21
- Lu Y-Q (1991) Pollen morphology of *Impatiens* L. (Balsaminaceae) and its taxonomic implications. *Acta Phytotax Sin* 29:352–357
- Lu Y-Q, Chen Y-L (1991) Seed morphology of *Impatiens* L. (Balsaminaceae) and its taxonomic implications. *Acta Phytotax Sin* 29:252–257
- Peng H, Liu P, Zhang GH (2018) Small scale vegetation differentiation structure in Danxia landforms. Southeast China. *Scientia Geographica Sinica*. 38:944–953. <https://doi.org/10.13249/j.cnki.sgs.2018.06.014>
- Ronquist F, Huelsenbeck JP (2003) MrBayes 3: Bayesian phylogenetic inference under mixed models. *Bioinformatics* 19:1572–1574
- Shui Y-M, Janssens S, Huang S-H, Chen W-H, Yang Z-G (2011) Three new species of *Impatiens* L. from China and Vietnam: preparation of flowers and morphology of pollen and seeds. *Syst Bot* 36:428–439. <https://doi.org/10.1600/036364411X569615>
- Song Y, Yuan Y-M, Küpfer P (2003) Chromosomal evolution in Balsaminaceae, with cytological observations on 45 species from southeast Asia. *Caryologia* 56:463–481. <https://doi.org/10.1080/00087114.2003.10589359>
- Song Y, Yuan Y-M, Küpfer P (2005) Seedcoat micromorphology of *Impatiens* (Balsaminaceae) from China. *Bot J Linn Soc* 149:195–208. <https://doi.org/10.1111/j.1095-8339.2005.00436.x>
- Swofford DL (2003) PAUP*: Phylogenetic Analysis Using Parsimony (*and Other Methods), v4.0b10. Sinauer Associates, Sunderland.
- Taberlet P, Gielly L, Pautou G, Bouvet J (1991) Universal primers for amplification of three non-coding regions of chloroplast DNA. *Plant Mol Biol* 17:1105–1109
- Thompson JD, Gibson TJ, Plewniak F, Jeanmougin F, Higgins DG (1997) The ClustalX windows interface: Flexible strategies for multiple sequence alignment aided by quality analysis tools. *Nucl Acid Res* 25:4876–4882
- Wang K-F, Wang X-Z (1983) Outline of Palynology. Peking University Press, Beijing
- White TJ, Bruns T, Lee S, Taylor J (1990) Amplification and direct sequencing of fungal ribosomal RNA genes for phylogenetics. In: Innis MA, Gelfand DH, Sninsky JJ, White TJ (eds) *PCR Protocols: A Guide to Methods and Applications*. Academic Press, New York, pp 315–322
- Xu Y-L, Chen Y-L (1999) New taxa of *Impatiens* L. (Balsaminaceae) from Zhejiang. *China Acta Phytotax Sin* 37:194–200
- Xu Y-L, Zhang H-W, Zhang Y, Zhou X (2018) New materials of seed plants from Zhejiang and Anhui, China. *J Hangzhou Univ (Nat Sci Ed)* 17:8–10. <https://doi.org/10.3969/j.issn.1674-232X.2018.01.003>
- Yu S-X (2012) Balsaminaceae of China. Peking University Press, Beijing
- Yu S-X, Janssens SB, Zhu X-Y, Lidén M, Gao T-G, Wang W (2016) Phylogeny of *Impatiens* (Balsaminaceae): integrating molecular and morphological evidence into a new classification. *Cladistics* 32:179–197. <https://doi.org/10.1111/cla.12119>
- Yuan Y-M, Song Y, Geuten K, Rahelivolona E, Wohlhauser S, Fischer E, Smets E, Küpfer P (2004) Phylogeny and biogeography of Balsaminaceae inferred from ITS sequence data. *Taxon* 53:391–403. <https://doi.org/10.2307/4135617>
- Zhang H-W, Lu Y-F, Xu Y-L, Jin X-F (2017) New materials of the seed plants in Zhejiang (V). *J Hangzhou Univ (Nat Sci Ed)* 16:32–35. <https://doi.org/10.3969/j.issn.1674-232X.2017.01.010>
- Zeng L, Yan R-Y, Zhang M, Xu W-B, Zhang L-J, Yu S-X (2016) Taxonomic significance of the pollen morphology of subg. *Clavicarpa* (*Impatiens*, Balsaminaceae). *Guihaia* 36:1245–1252. <https://doi.org/10.11931/guihaia.gxzw201507037>

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