Viola guaxarensis (Violaceae): a new Viola from Tenerife, Canary Islands, Spain

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Viola guaxarensis (*Violaceae*): a new *Viola* from Tenerife, Canary Islands, Spain

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Abstract: *Viola guaxarensis* M. Marrero, Docoito Díaz & Martín Esquivel, sp. nov., belonging to *V.* sect. *Melanium* Ging. (*Violaceae*), is described and illustrated. It is a small chamaephyte currently known in only two localities within the high-mountain zone of Tenerife, Canary Islands. Data on aspects of its morphology, ecology, rarity and conservation status are provided, as well as the differences between this new taxon and the other two species from the Canary Island high-mountain habitats, *V. cheiranthifolia* Humb. & Bonpl. and *V. palmensis* Webb & Berthel., which are presumed to be the closest relatives.

Resumen: Se describe e ilustra una nueva especie, *Viola guaxarensis* M. Marrero, Docoito Díaz & Martín Esquivel, sp. nov. (V. sect. *Melanium* Ging., *Violaceae*). Es un pequeño caméfito conocido actualmente para dos localidades de la alta montaña de la isla de Tenerife, Islas Canarias. Se aportan datos sobre su morfología, ecología, rareza y estado de conservación, así como sobre las diferencias entre este nuevo taxón y las otras dos especies de los hábitats de alta montaña de las Islas Canarias, *V. cheiranthifolia* Humb. & Bonpl. y *V. palmensis* Webb & Berthel., las cuales presumiblemente son sus parientes más cercanos.

Key words: Canary Islands, endemic, high mountain, new species, Teide National Park, Tenerife, *Viola cheiranthifolia*, *Viola guaxarensis*, *Viola palmensis*, *Viola* sect. *Melanium*, *Violaceae*

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Introduction

Viola L. is the largest genus in the family *Violaceae*, with 583–620 species throughout most of the regions of the world uncovered by ice, including tropical and subtropical mountains and islands (Yockteng & al. 2003). *Viola* sect. *Melanium* Ging. is a morphologically well-defined group, with c. 125 species distributed mainly in Europe and western Asia (Marcussen & al. 2015; Yockteng & al. 2003), which includes those taxa called pansies. Most of the species of *V.* sect. *Melanium* are herbaceous, caulescent, with stipules (divided or not), frontally flattened corollas with a yellow throat and a well-developed spur of variable length. The style has a characteristic globose or capitate shape, with a stigmatic orifice in a ventral rostellum (Yockteng & al. 2003).

In the Canary Islands, the genus *Viola* includes eight species, of which five belong to *V.* sect. *Melanium*: *V. arvensis* Murray, *V. cheiranthifolia* Humb. & Bonpl., *V. kitaibeliana* Schult., *V. palmensis* Webb & Berthel., and *V. tricolor* L. (Rodríguez-Rodríguez & al. 2015). *Viola cheiranthifolia* and *V. palmensis* are the only ones that inhabit high-mountain ecosystems on the islands. The first is endemic to the island of Tenerife and grows in the

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Teide National Park between 2200 and 3700 m, while the second is endemic to La Palma and also occupies the highest areas of that island, within the Caldera de Taburiente National Park and its surroundings (1800–2400 m a.s.l.) (Fig. 1).

Viola cheiranthifolia was described at the beginning of the 19th century (Humboldt & Bonpland 1805–1817), with an area of distribution limited to the high-altitude habitat of the Teide-Pico Viejo volcano. This chorology remained unchanged in the bibliographic and exsiccata records until the last third of the 20th century, with the added references only mentioning the species in some new localities on the slopes of that volcano (Webb & Berthelot 1836–1841; Schenck 1907; Moritz 1962). The first records beyond the Teide-Pico Viejo volcanic edifice are from the last third of the 20th century and refer to sectors near Izaña, Topo de la Grieta, and Montaña Guajara (Barquín Díez & Voggenreiter 1988). These localities, in the outer edge of the caldera that surrounds the Teide-Pico Viejo volcano, were never visited by Humboldt and Bonpland because their route of ascent to Teide was more that 6 km away. At present, the Izaña population seems to have disappeared: we have not found specimens from this locality stored in any public collection and cannot therefore confirm its identity, but in the herbarium of the University of La Laguna we did find samples from Topo de la Grieta (1975, TFC 4582) and Montaña Guajara (1998, TFC 41482).

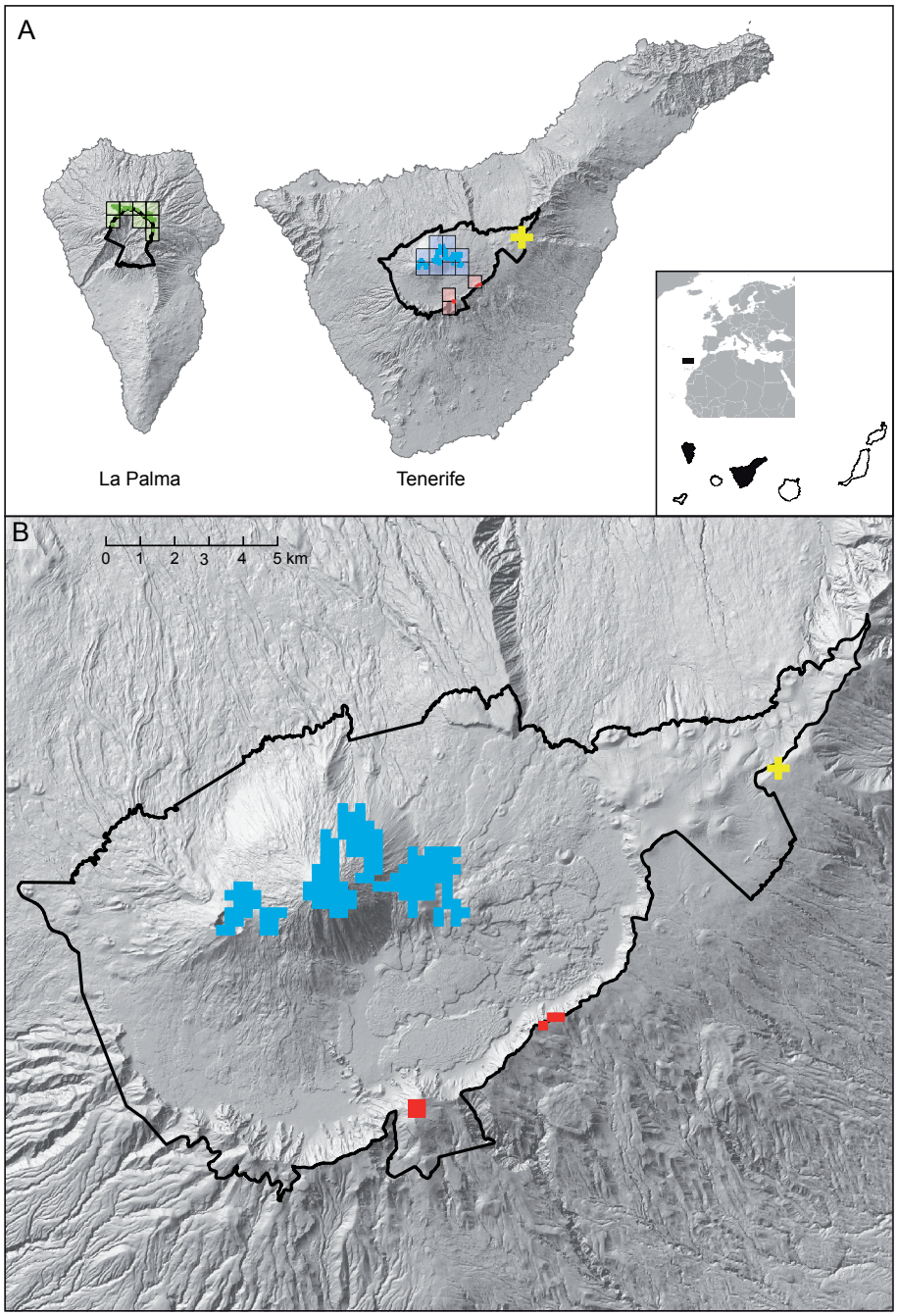

Fig. 1. A: distribution of *Viola cheiranthifolia* (blue squares), *V. guaxarensis* (red squares) and *V. palmensis* (green squares) in the high mountains of La Palma and Tenerife; inset showing position of Canary Islands. – B: detailed distribution of *V. cheiranthifolia* (blue squares) and *V. guaxarensis* (red squares) in Tenerife. – Large squares: 2 × 2 km cells; small squares: 500 × 500 m cells; yellow cross: disappeared population of Izaña (uncertain species); thick black line: limits of Teide and Caldera de Taburiente National Parks.

Viola cheiranthifolia has been traditionally associated with the interior slopes of the large caldera in the central part of the island of Tenerife (Las Cañadas caldera) and the flanks of the Teide-Pico Viejo volcano, in dry upper Supramediterranean and (arid to) semiarid to dry Oromediterranean belts (del Arco Aguilar & Rodríguez Delgado 2018), on poor soils, mainly haplic regosols, with a surface layer of pyroclastic material (normally pumice).

Only two populations are known currently outside Las Cañadas caldera, the larger one located at 2600 m a.s.l. on Montaña Guajara (2718 m a.s.l.). This population was discovered in the 1970s–1980s and, although it has been assessed by other authors (Wildpret & Martín

Fig. 2. *Viola guaxarensis*. – A: general aspect; B: upper leaf with stipules; C: ovary, style and stigma; D: anther; E: lower leaf; F: sepal; G: peduncle bracteoles; H: flower, lateral view; I: flower, frontal view; J: seed. – Drawn from TFC 53319 by M. V. Marrero Gómez.

Table 1. Diagnostic characters of *Viola cheiranthifolia, V. guaxarensis* and *V. palmensis*.

	V. cheiranthifolia	***V. guaxarensis***	***V. palmensis***
Upper leaves petiole	sessile or subpetiolate	petiole not reaching limb length	petiole reaching limb length
Upper leaves shape	non-falcate, lanceolate	non-falcate, lanceolate	falcate or subfalcate, linear-lanceolate
Upper leaves margin	entire	dentate-crenate	dentate-crenate
External stipules	short and linear or absent	2- or 3-sect with main lobe less than ¼ length of leaf	2- or 3-sect with main lobe more than ¼ length of leaf
Internal stipules	absent	linear	linear
Peduncle	less than 2× leaf length	more than 2× leaf length	more than 2× leaf length
Bracteoles	triangular without lobes at base	triangular with 1 triangular lobe pointing outward on each side of base (slightly hastate)	triangular with 1 or 2 triangular lobes pointing outward on each side of base
Sepal appendices	rounded at base	crenate-sinuate at base	crenate-sinuate at base
Spur	slightly hispid or glabrescent	glabrous	slightly hispid

2005), it was not then the subject of detailed taxonomic analysis.

Recent genetic studies point out important differences between the populations inside Las Cañadas caldera and those outside of it, at Montaña Guajara and Topo de la Grieta (Rodríguez-Rodríguez & al. 2019). Due to the peculiarity of these populations and the pressure of introduced herbivores, the Teide National Park administration fenced the Guajara population, and initiated intense permanent monitoring of the population. These activities allowed us to observe marked morphological differences between the specimens from Guajara and Topo de la Grieta and those from other localities on the Teide-Pico Viejo volcano. These differences indicate that the Guajara and Topo de la Grieta populations represent a new species, which we describe here as *Viola guaxarensis* M. Marrero, Docoito Díaz & Martín Esquivel.

Material and methods

Fresh material from the new species was compared with specimens from the main populations of *Viola cheiranthifolia* and *V. palmensis* and herbarium material deposited in ORT and TFC. Digital images of specimens from B, FI, FTG, K, MA, MPU, P and TUB were accessed online. Conservation status was assessed using the IUCN (2012) Red List categories and criteria.

Results

Viola guaxarensis M. Marrero, Docoito Díaz & Martín Esquivel, **sp. nov.** – Fig. 2–5.

Holotype: Spain, Canary Islands, Tenerife, Montaña Guajara, 28°12'54"N, 16°36'44"W, 2600 m a.s.l., 24 May 2019, *José Ramón Docoito Díaz* (TFC accession no. 53319-HOLO; isotypes: TFC accession no. 53319-ISO, ORT accession no. 47086).

Diagnosis — The new species differs from *Viola cheiranthifolia* Humb. & Bonpl. mainly by its larger size, longer and wider leaves, 2- or 3-sect outer stipules with main lobe up to ¼ the length of the leaves, longer peduncles, violet and slightly hastate peduncle bracteoles, sinuate-crenate sepal appendices with purple tones, and glabrous spur. It differs from *V. palmensis* Webb & Berthel. by its shorter, wider and non-falcate leaves with petiole never reaching the lamina length, shorter stipules, slightly hastate peduncle bracteoles, and shorter, wider, glabrous spur (Table 1, Fig. 3, 4).

Description — Perennial cushion-forming herb with a clear overwintering period, to 20 cm tall × 50 cm in diam. *Indumentum* present on almost all structures of plant, comprising smooth, hyaline trichomes 0.1–0.2 mm long. *Stems* 4–5 cm long, subterranean, with green, fistulous, subtetragonous branches. *Leaves* 3-grouped, greenish, petiolate or subpetiolate, stipulate. *Lower leaves* (25–)30–45 × (8–)10–15 mm, ovate to orbicular-ovate, petiolate, generally subdentate, stipulate; stipules linear, entire and 2–3 × c. 2 mm or bisected with median lobe 3–5 × c. 1 mm. *Upper leaves* frequently unevenly dentate-crenate with short incisions, lanceolate to linear-lanceolate, (30–)35–45 × 5–7 mm, base cuneate, apex subacute, usually purple; petiole <5 mm long, shorter than lamina; central leaf normally without stipules; lateral leaves stipulate; external stipules 2- or 3-sect (main lobe 10–15 × 1–1.5 mm); internal stipules linear, 12–17 × 1–1.5 mm. *Flowers* axillary, solitary. *Peduncle* more than 2× length of leaves, 7–10 cm long, hairy, arcuate, subtrigonous; bracteoles purple, 3–6 mm long, subopposite, inserted in upper ½ of peduncle, usually slightly hastate. *Sepals* subequal, 10–13 × 3–4 mm at base, linear-triangular, acuminate, purple at base and margin; basal appendix 1.5–2 mm long, crenate-sinuate at base, usually with 2 or 3 incipient lobes. *Corolla* 25–30 mm in diam., white-cream to violet, occasionally entirely white, petals slightly eroded. *Upper petals*

13–10 × 8–11 mm, glabrous, obovate, apex subacute. *Lateral petals* 12–10 × 7–9 mm, oval, glabrous, slightly clawed and densely hairy at base of claw, apex rounded. *Lower petals* 11–14 × 9–11 mm, lightly coloured, yellow near spur, retuse, slightly conduplicate, glabrous. *Spur* 8–9 × 2–2.5 mm, arcuate, glabrous, purple, obtuse, protruding 6–7 mm from sepal appendices. *Anthers* ovate, hairy, with an appendix orange and almost triangular. *Style* c. 1 mm long, geniculate. *Stigma* globose. *Capsules* subrounded, c. 8 × 7 mm, slightly sulcate, opening at ripening into 3 valves, with 25–30 seeds. *Seeds* c. 2 × 1 mm, chestnut-brown; elaiosome covering c. 1/5 of seed.

Phenology — Flowering from February to June (to July).

Distribution and ecology — Endemic to the high-mountain zone of Tenerife, Canary Islands, Spain, where it is known from only two localities (Fig. 1). Locally common near the summit of Montaña Guajara (28°12'54"N, 16°36'44"W, 2600 m a.s.l.) with nearly 3000 individuals, but scarce (with only a few dozen individuals) at the second locality, Topo de la Grieta 3 km to the northeast (28°14'20"N, 16°34'17"W, 2300 m a.s.l.). In general, the habitat is characterized by low or moderate slopes, with acid and rocky substrates sometimes mixed with pumice. These environments are subject to relatively strong winds (Wildpret & Martín 2005) and frequent winter frosts. Vegetation at the sites is dominated by a low mixed cushion-shrub community (Fig. 5) with *Adenocarpus viscosus* (Willd.) Webb & Berthel. subsp. *viscosus* (*Fabaceae*) one of the more common species. Other Canary Island endemics present are *Erysimum scoparium* (Brouss. ex Willd.) Wettst. (*Brassicaceae*), *Nepeta teydea* Webb & Berthel. (*Lamiaceae*), *Spartocytisus supranubius* (L. f.) Christ ex G. Kunkel (*Fabaceae*), and *Tolpis webbii* Sch. Bip. ex Webb & Berthel. (*Asteraceae*).

Etymology — The specific epithet refers to Montaña Guajara, the main location of the new species.

Additional specimens examined — *Viola cheiranthifolia* — Spain: Canary Islands: Tenerife: type locality, Pic de Tenerife, 1799, *A. J. A. Bonpland & F. W. H. A. von Humboldt* (P P00086031 [digital image], B B -W 04917 -01 0 [digital image]); in monte alto Nivariae Pico de Teyde, *P. B. Webb* (K K000231128 [digital image]); Pico de Teyde in excelsis, 1900, *J. Bornmüller* (MPU MPU752324 [digital image]); Mña. Blanca, 1905, *O. Burchard* (ORT 376); La Rambleta, 1948, *E. R. Sventenius* (ORT 17802); Oeste de Pico Viejo, 1957, *T. Bravo* (TFC 25710); Flanc NE du Teide, Cueva del Hielo, 1973, *H. M. Burdet* (MA 01-00848475 [digital image]); Cañada de Diego Hernández, Siete Cañadas, 1973, *M. C. Gil* (TFC 24090); Ladera sur del Teide, 2003, *W. Wildpret & V. E. Martín* (TFC 44843); Mña. Blanca, 1994, *W. Wildpret & V. E. Martín* (TFC 38800).

Viola guaxarensis — Spain: Canary Islands: Tenerife: type locality 1998, *A. Bañares & E. Carqué* (TFC 41482); ibidem, 2003, *Y. de Rioja* (TFC 42211); ibidem, 2019, *J. R. Docoito* (TFC 53317, TFC 53318); Topo de la Grieta, 1975, *P. L. Pérez & al.* (TFC 4582).

Viola palmensis — Spain: Canary Islands: La Palma: type locality, Insula Palma, Lomo del Biscayno, Cumbre de Garafía, *P. B. Webb* (FI FI000049 [digital image]); in monte excelso insulae Palmae, Cumbre de Garafia, *P. B. Webb* (TUB TUB-002821 [digital image]); Roque de los Muchachos, 1906, *O. Burchard* (ORT 000377); ibidem, 1949, *E. R. Sventenius* (ORT 003059); Cumbres de Puntallana, 1800 m, 1995, *A. Santos* (MA MA-01-00873107 [digital image]); north, along road LP-4, alpine with exposed rock, 2014, *A. Santos & J. Francisco-Ortega* (FTG NMNH3694331 [digital image]); Roque de los Muchachos, 2001, *E. Beltrán & al.* (TFC 43193); Barranquillo cerca del Pico de la Cruz, Carretera LP-4 km, 29 Jan 2012, *P. L. Pérez* (TFC 50564).

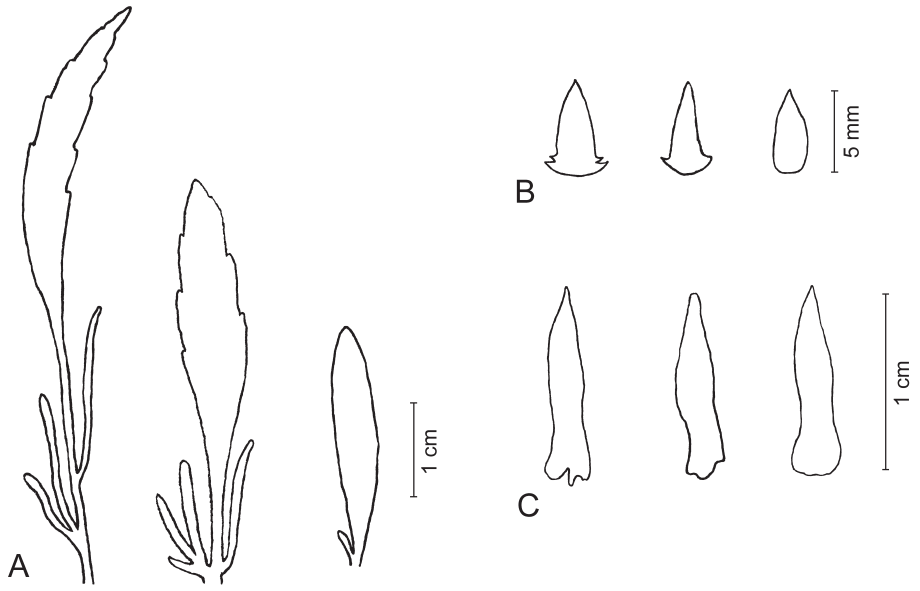

Fig. 3. Main differences between *Viola palmensis* (left), *V. guaxarensis* (middle and *V. cheiranthifolia* (right). – A: upper leaves; B: sepals; C: peduncle bracteoles.

Discussion

Systematic relationships — Although several features of the new species permit differentiating it from the presumed closest taxa, *Viola palmensis* and *V. cheiranthifolia*, its precise systematic relationships

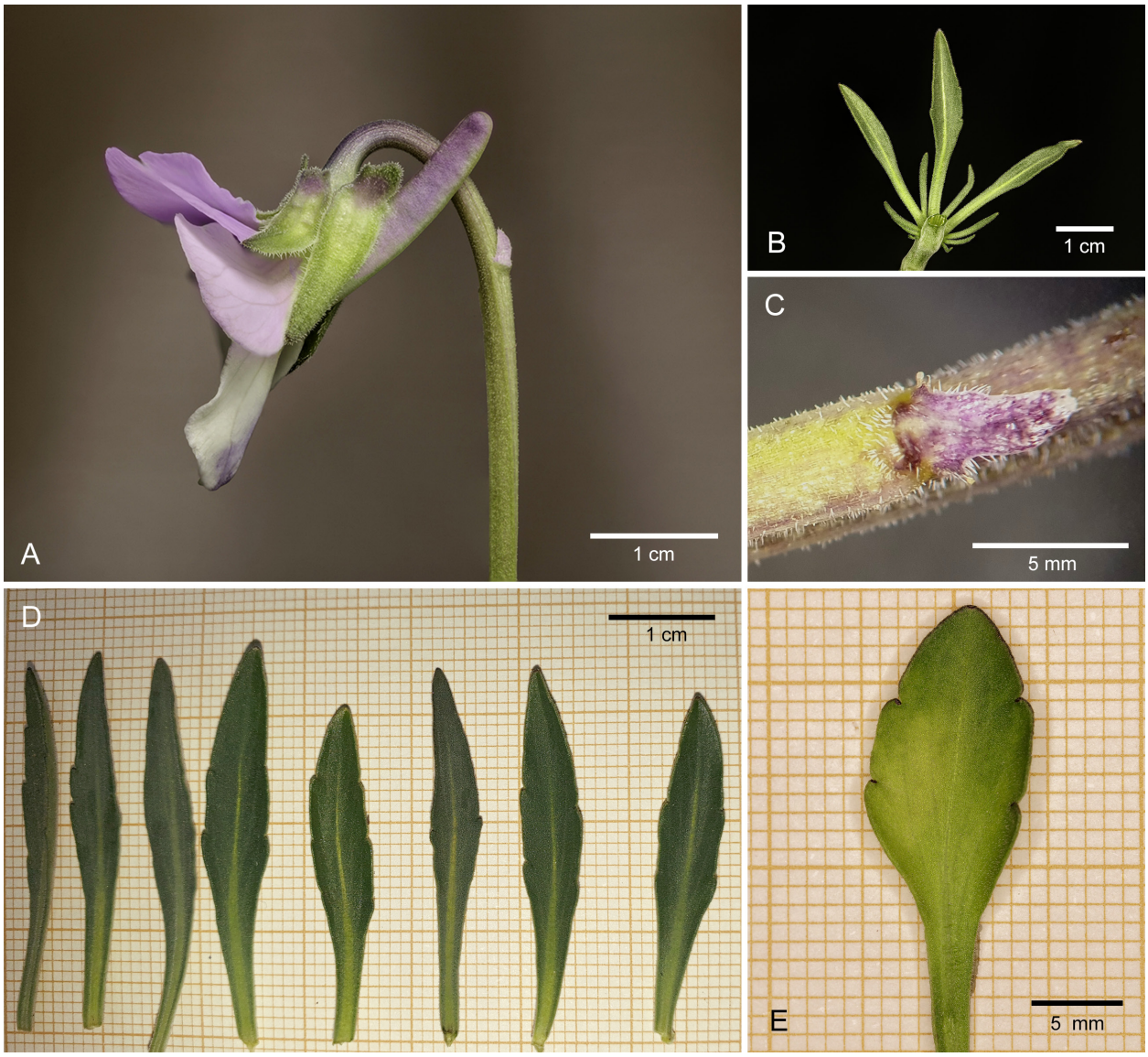

Fig. 4. Morphological characteristics of *Viola guaxarensis*. – A: flower; B: stipules; C: peduncle bracteole; D: upper leaves; E: lower leaf.

are not entirely clear. Some characters, such as the length of the peduncle, the laciniate stipules and the shape of the leaf, bring it close to *V. palmensis*, while details of floral structures resemble *V. cheiranthifolia*. In fact, the highest molecular similarity within *V.* sect. *Melanium* species was detected between *V. palmensis* and *V. cheiranthifolia* (Yockteng & al. 2003). Other studies suggest that *V. cheiranthifolia* and *V. guaxarensis* could have a common ancestor distributed outside the Cañadas caldera (Rodríguez-Rodríguez & al. 2019). However, it is not so far possible to infer the relationship among *V. palmensis* and the two taxa from Tenerife (*V. cheiranthifolia* and *V. guaxarensis*), because this relationship has not been studied genetically.

The presumed relationship between the new taxon and *Viola palmensis* could suggest a hybridization between *V. palmensis* and *V. cheiranthifolia* or perhaps a taxonomic separation only at the subspecific level. We have discarded these two possibilities due to *V. guaxarensis* having a geographical distribution farther away from *V. palmensis* (100 km) than from *V. cheiranthifolia* (6 km), so that distance is a major obstacle to hybridization with *V. palmensis* and genetic differentiation an important impediment to hybridization with *V. cheiranthifolia*. On the other hand, considering *V. guaxarensis* as a subspecies of *V. palmensis* would mean admitting that geographical barriers have been sufficient to separate *V. palmensis* from *V. cheiranthifolia* at a specific level, but not to segregate *V. guaxarensis* from *V. palmensis*. We think that considering *V. guaxarensis* as a new species is the most parsimonious option to interpret the evolutionary history of the violets of the high mountains of Tenerife and La Palma.

Habitat — The leaves and flowers of both *Viola cheiranthifolia* and *V. guaxarensis* are smaller than *V. palmensis*, possibly as an adaptation to a more xeric environment; the habitat of the two Tenerife taxa is much more arid (rain-

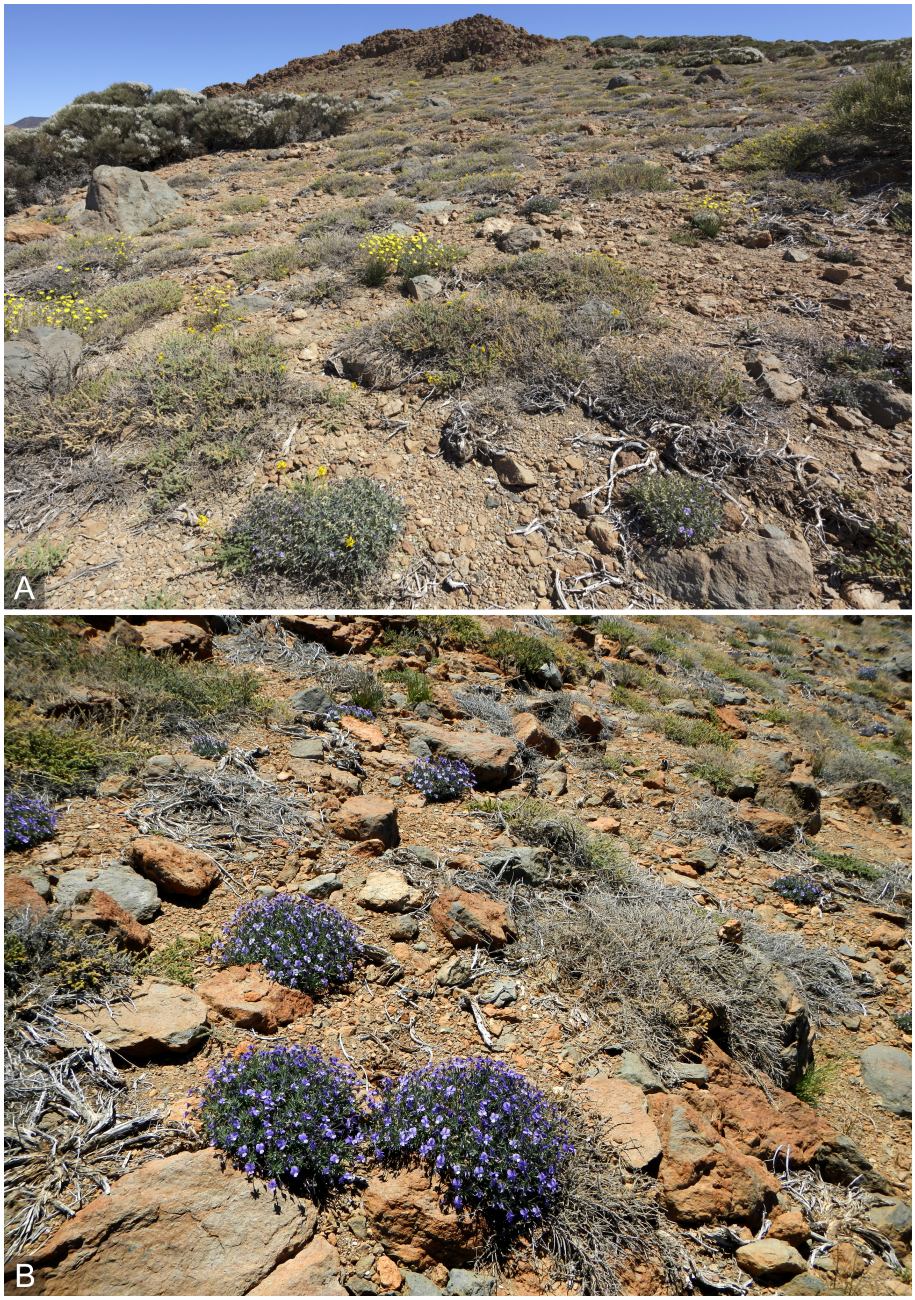

Fig. 5. Habitat of *Viola guaxarensis* (the blue-flowered plants). – A: Spain, Canary Islands, Tenerife, Montaña Guajara, Jun 2019, photograph by M. Suárez Izquierdo; B: same locality, May 2019, photograph by J. R. Docoito Díaz.

fall <500 mm/year) than that of the La Palma *V. palmensis* (rainfall c. 800 mm/year; Martín Osorio & al. 2007). The habitats of the Tenerife taxa also differ in temperature and precipitation, with *V. cheiranthifolia* occupying colder sites (annual average temperature 3.5–8.8°C) than *V. guaxarensis* (11.1°C). The pronounced reduction in some morphological structures in *V. cheiranthifolia* or even the disappearance of some of them (e.g. stipules) may indicate adaptations to a colder and harsher environment.

The distribution of *Viola guaxarensis* at the summit of a high mountain makes it extremely sensitive to climate change. Warming in the area has been very strong with 0.14 ± 0.07°C/decade in the last seventy years (Martín & al. 2012). Many species respond to warming by expanding their distribution to progressively higher altitudes, but those that inhabit mountain summits have nowhere to go, so are among those most vulnerable to climate change (Nogués-Bravo & al. 2007). Some environmental and distribution models constructed for *V. cheiranthifolia* by Rodríguez-Rodríguez & al. (2018) support this argument.

Conservation status — *Viola guaxarensis* is known from only two localities with little more than 3000 individuals in total. Its extent of occurrence and area of occupancy are 28 km^2 and 12 km^2 respectively, calculated at a 2 × 2 km grid-cell size (IUCN Standards and Petitions Subcommittee 2017). Since the exclusion of introduced domesticated livestock (originally goats) from the area in the 1950s, the main threat factor (perhaps the only one) in the two known localities is the more recent abundance of other alien herbivores: mouflon introduced for hunting purposes, and rabbits. These browse the plants and may cause their death.

Although the most important population is at present within a herbivore exclosure, the grazing activity of these animals on the outside prevents the expansion of the population. Most surviving specimens grow within *Adenocarpus* bushes that protect them from herbivores, due to their density and low palatability. Fewer *Viola* plants grow outside the exclosures where *Adenocarpus* is scarce or not present than in places where *Adenocarpus* is common. The absence of exclosures at Topo de la Grieta may be the reason for the very low number of individuals there and suggests a high probability of impending disappearance there.

We assume that the range of *Viola guaxarensis* would be greater than that known today if there were no herb-

ivores present; at least it should cover the area between the two current localities, and perhaps also to a larger extent toward the northeast, following the peaks that surround Las Cañadas toward the Izaña astronomical observatory. Therefore, it is possible to infer a reduction in the past of the potential habitat of the species as a result of centuries of herbivory. For this reason and because of the threat of further reductions due to climate change (Rodríguez-Rodríguez & al. 2019), *V. guaxarensis* should be categorized as Critically Endangered CR B1ab(iii,iv) following IUCN criteria (IUCN 2012).

Evolution and palaeogeography — Genetic studies (Rodríguez-Rodríguez & al. 2019) have shown a clear differentiation between the populations inside the Cañadas caldera and those outside it and discard the existence of continuity between both, but they do not pronounce about the taxonomic position of populations. However, the morphological differences between these populations and the observed genetic differentiation between them allow us to assume that they respond to two separated taxa: *Viola cheiranthifolia* for populations inside the Cañadas caldera and *V. guaxarensis* for those outside Cañadas caldera. Considering these data and the geological history of their habitats it is possible to elaborate a hypothesis about the natural history of the two taxa. About 200 000 years ago, the former Las Cañadas volcano underwent a lateral collapse, with subsequent episodes of massive landslides and eruptions that dramatically changed the morphology and topography of the Tenerife high-mountain zone. Later, the Teide-Pico Viejo complex arose inside the Las Cañadas caldera, culminating approximately 30 000 years ago in the current 3700 m altitude volcano (Carracedo & al. 2007). These circumstances could promote extinctions and intense speciation processes in isolated populations.

Rodríguez-Rodríguez & al. (2019) maintained that the Montaña Guajara population (*Viola guaxarensis*) was present after the lateral collapse of the northern flank of the island, and probably the Cañadas caldera was colonized from this population in more recent times. *Viola guaxarensis* showed higher levels of genetic variation than *V. cheiranthifolia*, supporting the idea of a founder effect in the Teide population. The expansion inside the Cañadas caldera could have occurred 30 000 years ago, when volcanic activity on Teide declined. However, new eruptions inside the caldera may have separated the Guajara populations from those on Teide itself, leading to their differentiation by genetic drift. Lava flows between the separate localities where the two taxa are found are very young (<2000 years old; Carracedo & al. 2007), which points to the appearance of an inhospitable territory ("malpaís") forming an effective barrier to genetic exchange, as also suggested by the molecular analysis (Rodríguez-Rodríguez & al. 2019). Previous collections of *V. cheiranthifolia* near the base of Guajara (e.g. "Siete Cañadas", TFC 24090) may indicate limited recolonization of the basin of the caldera in recent times. However, the extensive recent and historic lava field that separates Guajara from Teide is scarcely colonized by plant life and remains a powerful impediment to natural recolonization.

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