Phytotaxa 278 (3): 265–272
http://www.mapress.com/j/pt/

Article

ISSN 1179-3155 (print edition)
PHYTOTAXA
ISSN 1179-3163 (online edition)

http://dx.doi.org/10.11646/phytotaxa.278.3.6

Gastrodia kuroshimensis (Orchidaceae: Epidendroideae: Gastrodieae), a new mycoheterotrophic and complete cleistogamous plant from Japan

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Abstract

A new species, *Gastrodia kuroshimensis* (Orchidaceae: Epidendroideae: Gastrodieae), from Kuroshima Island, Kagoshima Prefecture, Japan, is described and illustrated. The outlined floral morphology indicates a close affinity to *G. fontinalis*, but it is easily distinguished by several characteristics, such as the cleistogamous floral condition, smaller perianth tube size and the anther cap joined with the column.

Key words: *Gastrodia*, Japan, mycoheterotrophy, Ryukyu Islands, taxonomy

Introduction

The genus *Gastrodia* Brown (1810: 330; Gastrodieae, Epidendroideae) is a group of mycoheterotrophic orchids that consists of ca. 90 acceptable species (Hsu *et al.* 2016). It is distributed throughout the temperate and tropical regions of Asia, Oceania, Madagascar and Africa (Chung & Hsu 2006, Cribb *et al.* 2010, Tan *et al.* 2012). The genus is characterized by fleshy tubers, the absence of leaves, as well as the union of its sepals and petals, and the production of two mealy pollinia that lack caudicles. Many species of *Gastrodia* section *Codonanthus* (Schlechter 1911, Tuyama 1967) produce inflorescences that are 3–15 cm in length at flowering (Chung & Hsu 2006). In addition, as is the case with most other mycoheterotrophic species, they occur in a small population and appear for a short reproductive period (Tuyama 1982, Suetsugu *et al.* 2012). Consequently, plants belonging to section *Codonanthus* are seldom found during the flowering season (Tuyama 1982, Suetsugu *et al*. 2012).

Despite these limitations, several studies have recently re-examined the diversity of species belonging to section *Codonanthus* in various countries in Asia (Chung & Hsu 2006, Meng *et al.* 2007, Hsu & Kuo 2010, 2011, Yeh *et al.* 2011, Hsu *et al.* 2012, Tan *et al.* 2012, Ong & Byrne 2012, Ong 2015, Suetsugu 2013a, 2014, Hu *et al.* 2014, 2016, Huang *et al.* 2015, Pelser *et al.* 2016, Tsukaya & Hidayat 2016). The flora of Japan is particularly rich in mycoheterotrophic plants, harboring ca. 50 species, and recent botanical surveys have resulted in the discovery of several new distributional records and new taxa in this region (Sawa *et al.* 2006, Fukunaga *et al.* 2008, 2016, Yagame *et al.* 2008, Yahara & Tsukaya 2008, Ohashi *et al.* 2008, Suetsugu *et al.* 2012, 2013, 2014, 2016 a, b, Suetsugu 2012, 2013a, 2014, 2015a, 2016a, b, Suetsugu & Ishida 2011, Suetsugu & Yagame 2014). Of particular interest are the lowland forests of the Ryukyu Islands, which are known to be a hotspot for endemic mycoheterotrophic taxa such as *Sciaphila yakushimensis* Suetsugu, Tsukaya & H. Ohashi (2016: 1), *Gastrodia takeshimensis* Suetsugu (2013: 375) and *Gastrodia flexistyloides* Suetsugu (2014: 270).

Considering the richness of the mycoheterotrophic species already discovered in the Ryukyu Islands, it is likely that comparative studies and re-examination of the species' diversity in this region could provide useful data regarding the contribution of this island chain to the overall diversity of the mycoheterotrophic flora in Japan. As expected, a new *Gastrodia* species, with significantly different floral morphology compared to other known species, was discovered during the recent botanical survey on Kuroshima Island located in the northern Ryukyu. Here I named the new species *Gastrodia kuroshimensis* after its type locality. In addition, during the additional field surveys and herbarium investigations, I also found other new populations (i.e. Yakushima Island and Akusekijima Island) of *G. kuroshimensis*. The most significant character of *G. kuroshimesis* is that it has only cleistogamous flowers, while cleistogamous plants usually adopt a mixed pollination strategy, also bearing chasmogamous flowers for insect-mediated pollination (reviewed by Culley & Klooster 2007).

Accepted by Zhong-Jian Liu: 24 Sept. 2016; published: 12 Oct. 2016

FIGURE 1. Flowering plants of *Gastrodia kuroshimensis* (from the type locality; Bar = 5 cm).

Gastrodia kuroshimensis Suetsugu, *sp. nov.* (Figs. 1–3)

Type:—JAPAN. Ryukyu. Kagoshima Pref., Kuroshima Island, Osato 16 April 2016, K. Suetsugu *s.n.* (holotype KYO).
Additional specimens examined:—JAPAN. Ryukyu. Kagoshima Pref., Kuroshima Island, 24 April 1985, H. Umata *s.n.* (KAG); JAPAN.

Ryukyu. Kagoshima Pref., Akusekijima Island, 25-30 March 1966, S. Sako 6311 (KAG); JAPAN. Ryukyu. Kagoshima Pref., Yakushima Island, Shiratani, 11 May, 2016, H. Yamashita *s.n.* (OSA).

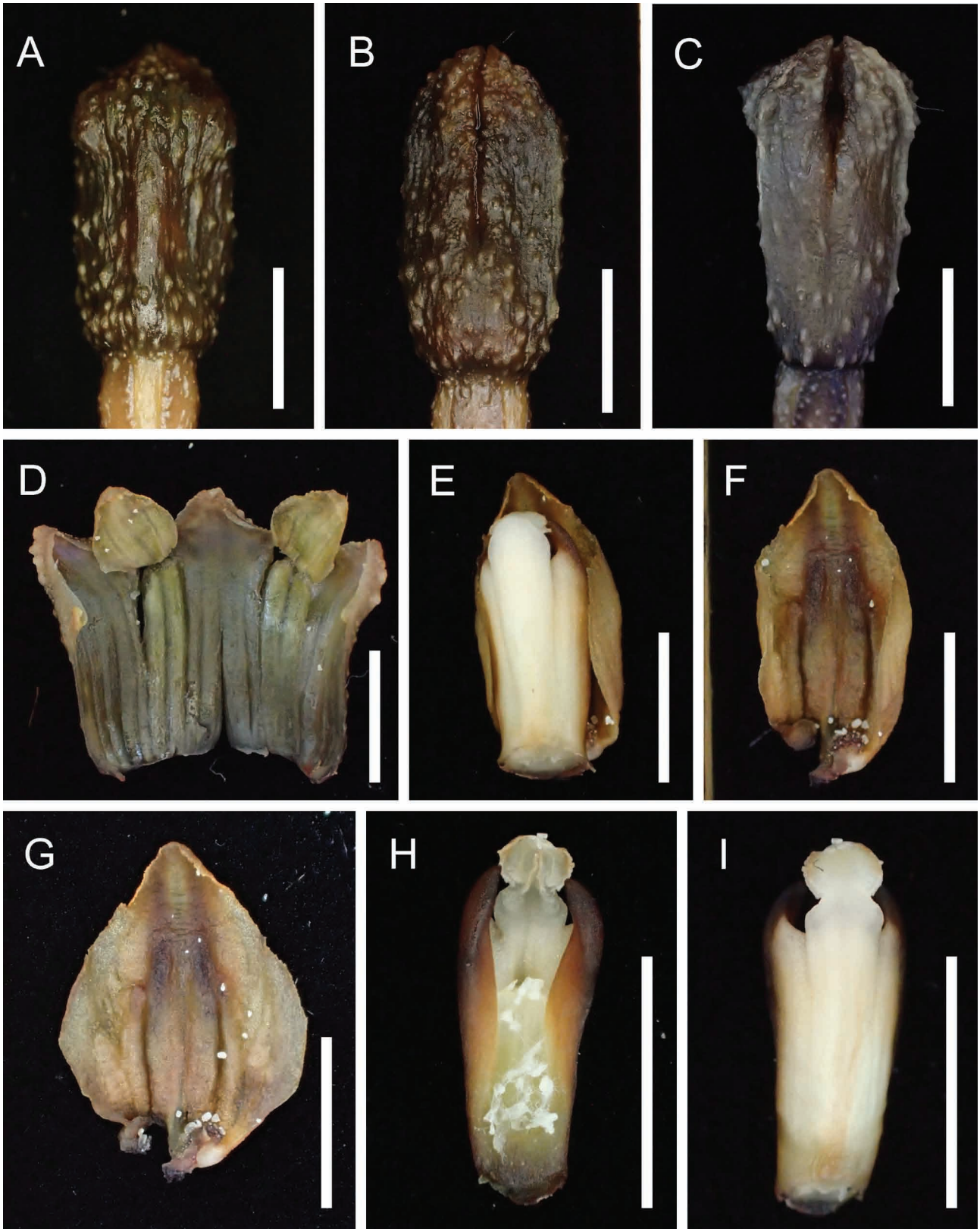

FIGURE 2. *Gastrodia kuroshimensis* (from the type locality). A–B. Flower (A, front view; B, back view). C. Flower with slit between the lateral sepals, back view). D. Flattened perianth tube. E. Lip and column. F. Lip. G. Flattened lip. H–I. Column (H, back view; I, front view). Bar = 5 mm.

Diagnosis:—*Gastrodia kuroshimensis* differs from its close relative *G. fontinalis* T.C. Hsu, S. W. Chung & C.M. Kuo (2012: 271) in that it has the cleistogamous flowers, the smaller perianth tube and the anther cap joined with the column.

Terrestrial, mycoheterotrophic herb. Roots few, slender, often germinating from the junction between rhizome and inflorescence after flowering season. Rhizome tuberous, fusiform or cylindrical, 3–11 cm long, 4–14 mm in diameter, yellowish brown, covered with numerous scales and root-hair-like unicellular hairs. Inflorescence erect, pale brown, 8–17 cm long, 2.5–5 mm in diameter, 3–4 nodes, with tubular, membranous sheaths. Bracts ovate, up to 6 mm long, 4 mm wide. Pedicel and ovary up to 15 mm long. Flowers 1–4, tubular, slightly upwards, resupinate, 11–13 mm long, ca. 7 mm in diameter. Sepals and petals united forming a five-lobed perianth tube. Perianth tube enclosed or hardly opening. Sepals subsimilar, 11–13 mm long, connate ca. 2/3 their length with petals, lateral ones connate ca. 3/5 their length with each other, outer surface dark greenish brown, densely verruculose, inner surfaces pale greenish brown, smooth; margins entire; free portion of dorsal sepal, ovate-triangular, retuse, ca. 5 mm long, 5 mm wide; free portions of lateral sepals spreading, obtuse at apex. Free portions of petals ovate or ellipse, ca. 4–5 mm long, 2 mm wide. Lip joined with perianth tube, ca. 10 mm long, hypochile reddish brown with two white degenerated smooth calli; epichile reddish brown, ovate-ellipse, base contracted, disc 2–4 ridged with a longitudinal keel extending toward apex, margin slightly undulate. Column straight, semi-cylindrical, ca. 7 mm long, 2–2.5 mm wide, white tinged with grayish brown at base; lateral wings (stelidia) brown, narrow, the edges parallel to column, base incurved, apex acute; rostellum degenerated; stigma located slightly above middle. Anther cap joined with column, hemispheric, ca. 1 mm in diameter, pollinia 2. Capsule cylindrical, ca. 3 cm long, pedicel elongating to ca. 30 cm long in fruit. Seeds fusiform, ca. 2 mm long.

Distribution:—To date, the distribution of *G. kuroshimensis* was discovered to cross three islands (Kuroshima Island, Akusekijima Island and Yakushima Island). Flowering was observed from mid April to mid May, and fruiting from mid May to late May.

Taxonomic notes:—*G. kuroshimensis* is similar to *G. fontinalis* T. P. Lin (1987: 129) due to the longer inflorescences and the keeled lip. However, *G. kuroshimensis* can be distinguished by the floral condition (cleistogamous vs. chasmogamous), small perianth tube size (11–13 mm long vs. 17–21 mm long), the lip morphology (epichile with 2–4 ridged vs. epichile with 6–8 ridged), the rostellum condition (degenerated vs. ca. 0.7 mm long), the stigma positon (slightly above middle vs. base) and the anther cap morphology (joined with column vs. independent).

Its outline floral morphology, such as the dark greenish-brown colored, densely verruculose, complete cleistogamous flower, is also similar to *G. clausa* T.C. Hsu, S. W. Chung & C.M. Kuo (2012: 271). However, *G. kuroshimensis* can be distinguished by the larger stature during flowering (8–17 cm vs. 2–4 cm), the lip morphology (well-developed, ca. 8–10 mm long vs. peloric, less than 5 mm long), the column morphology (semi-cylindrical, ca. 7 mm long without any ventral appendage vs. ca. clavate, less than 7 mm long with a prominent ventral appendage) and the anther cap morphology (joined with column vs. independent). For a detailed comparison of morphological characters between *G. kuroshimensis* and its related species, see Table 1.

TABLE 1. Morphological comparison of *Gastrodia kuroshimensis* and its related species.

Character	*G. kuroshimensis*	*G. fontinalis*	*G. clausa*	*G. uraiensis*
Plant height	8–17 cm	7–22 cm	2–4 cm	1–6 cm
Floral condition	cleistogamous	chasmogamous	cleistogamous	chasmogamous
Perianth tube size	11–13 mm long	15–21 mm long	9–13 mm long	11–13 mm long
Position of rostellum	absent	just below the anther cap	absent	just below the anther cap
Position of stigma	slightly above middle	base	near middle	base
Anther cap	joined with column	independent	independent	independent
Lip size	8–10 mm long	8–10 mm long	peloric, less than 5 mm long	6–7 mm long
Lip connection	joined with the perianth tube	adnate to the column foot	joined with perianth tube	adnate to the column foot
Number of ridges on the lip	2–4	6–8	none	4
Hypochile	with two white degenerated calli	with two red globose calli	without any appendages	with two orange globose calli

Data of related species from Lin (1987), Hsu *et al.* (2010, 2012), Suetsugu (2015a, 2016a, c), Suetsugu *et al.* (2013, 2014)

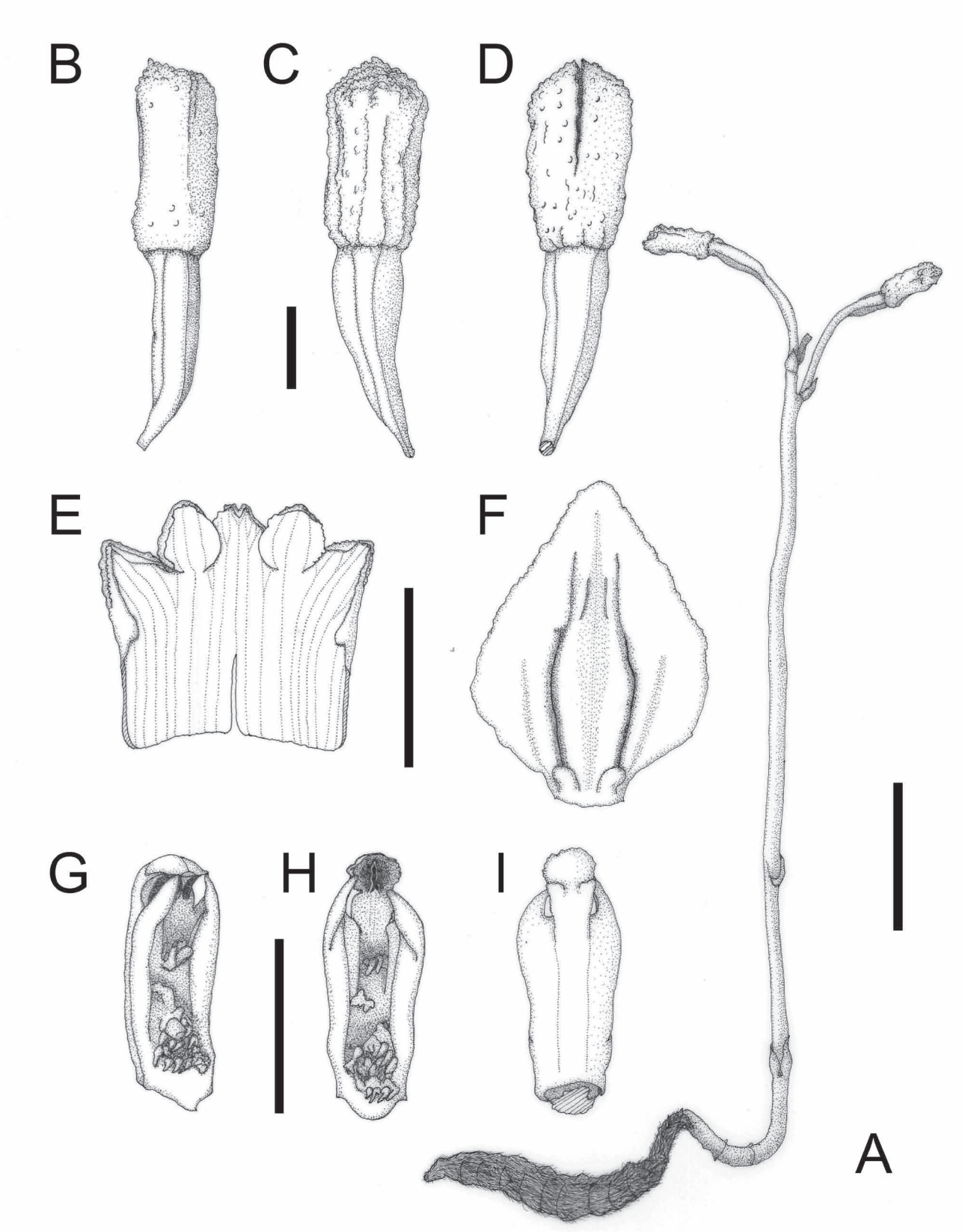

FIGURE 3. *Gastrodia kuroshimensis* (from the holotype). A. Habit. B–D. Flower. (B, side view; C, front view; D, back view). E. Flattened perianth tube. F. Flattened lip.G–I. Column (G, lateral view; H, back view; I, front view). A. Bar = 3 cm. B–I. Bar = 5 mm.

In addition, the dissected flower of *G. kuroshimensis* is similar to that of *G. uraiensis* T.C. Hsu & C.M. Kuo (2010: 244). However, *G. kuroshimensis* can be distinguished by the larger stature during flowering (8–17 cm vs. 1–4 cm), the floral condition (cleistogamous vs. chasmogamous), the lip morphology (hypochile with two white degenerated smooth

calli vs. hypochile with 2 orange globose calli), the rostellum condition (degenerated vs. ca. 0.7mm long), the stigma positon (slightly above middle vs. base) and the anther cap morphology (joined with column vs. independent).

Reproductive biology:—Although a slit was occasionally observed between the lateral sepals, most of the *G. kuroshimensis* flowers studied remained completely closed throughout the entire flowering period (Fig. 2). Although cleistogamous plants usually adopt a mixed pollination strategy, also bearing chasmogamous flowers for open pollination (reviewed by Culley & Klooster 2007), the completely cleistogamous nature of *G. kuroshimensis* indicates that it is an obligate self-pollinating species. Although complete cleistogamy is extremely rare, it is relatively common in the genus *Gastrodia*, having been observed in at least three species: *G. clausa*, *G. takeshimensis* Suetsugu (2013: 375) and *G. flexistyloides* Suetsugu (2014: 270). Careful dissection of the *G. kuroshimensis* flowers at different stages revealed that their pollinia fragment into massulae before the flowers matured. The flowers were also found to have degenerated rostellums, which allowed the massulae to drop directly onto the surface of the stigma, confirming the obligate self-pollinating nature of this species.

Although orchids have evolved many mechanisms to reduce or prevent incidents of self-pollination and enhance outcrossing, reports of autonomous self-pollination are still fairly common, and according to the review of Catling (1990), occurs in all orchid subfamilies. The most comprehensive estimate, based on the reports of peer-reviewed articles, indicates that self-pollination occurs in approximately 400 species of orchids, which corresponds to 31% of all species for which pollination systems are known (Peter 2009). The most common mechanism of self-pollination in orchids, occurring in approximately half of the self-pollinating species studied to date, results from a reduction in the size of the rostellum that allows contact between the pollinia and the stigma (Catling 1990). This is the same mechanism observed in the newly discovered species *G. kuroshimensis*.

It has been suggested that autonomous self-pollination represents an evolutionary response to ensure reproductive success when there is a lack of pollinators, and the frequency of pollination is regularly quite low (Baker 1955). Given that mycoheterotrophic plants commonly inhabit forest floors, where they are shaded by dense woodland or scrub, it is likely that they frequently experience such conditions. These environments have extremely low levels of light intensity in the dim to dark range, which have been linked to the development of mycoheterotrophy as an adaptation to survive these conditions (Bidartondo *et al.* 2004). However, such low-light environments are not suited to species of insects commonly associated with pollination, which could limit plant reproduction (Herrera 1995, 1997). Indeed, most of the mycoheterotrophic species investigated to date (especially nectarless species) seem to have abandoned insect pollinators in favor of self-pollination (e.g. Suetsugu 2013a, b, Suetsugu 2014, Suetsugu 2015b). The complete cleistogamy observed in the mycoheterotrophic genus *Gastrodia* can therefore be considered a mechanism that provides reproductive assurance to compensate for pollinator limitation due to their lack of nectar and pollinator-hostile habitat.

Acknowledgements

I am grateful to Tian-Chuan Hsu for useful discussions and Kumi Hamasaki for providing excellent line drawings. This study was partly supported by a grant-in-aid by the Japan Society for the Promotion of Science (15K18470) and Fujiwara Natural History Public Interest Incorporated Foundation.

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