Pollinator and Stem- and Corm-Boring Insects Associated with Mycoheterotrophic Orchid *Gastrodia elata*

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ABSTRACT The nonphotosynthetic orchid *Gastrodia elata* Blume (Orchidaceae) is a mycoheterotroph associated with the wood-decomposing fungus *Armillaria mellea*. Here, we report the symbiotic and parasitic associations of some insects with this orchid. The flowers are nectarless and were visited by females of a halictid bee, *Lasioglossum* sp. The bees entered the tubular flower and collected the tissue from the orchid's labellum. Pollinia were attached to the hind thorax of the bee and transported to the stigma of receptive flowers. The stems and corms of the orchid were infested by two rare dipterans, *Azpeytia shirakii* Hurkmans (Syrphidae) and a new genus and species of scatophagid, *Orchidophaga gastrodiacola* n. sp. M. Kato. Adult flies of the latter species laid eggs in the flower. The hatched larvae infested the immature ovary, bored downward into the flowering stem, and occasionally entered the underground corms. The high rate of infestation by these dipterans suggests that the robust flower stem of the orchid has evolved as counteradaptation against these particular stem-boring dipterans. A molecular phylogenetic analysis suggests that *O. gastrodiacola* belongs to Delininae, which is one of the basal groups of Scatophagidae.

KEY WORDS Scatophagidae, *Gastrodia*, orchid, pollination, mycoheterotrophy

The orchid *Gastrodia elata* Blume (Orchidaceae), lacking green leaves and chlorophyll, is a characteristic member of understory plants in Asian temperate deciduous forests. It depends on the fungus *Armillaria mellea* (Vahl.:Fr.) Kummer, a key wood decomposer in these forests, for nutrients (Kusano 1911). The fungus invades the nutritive or primary corm of the orchid, arresting and digesting the fungal hyphae in the cortical layer of the corm (Zhou et al. 1987). The primary corm produces a secondary terminal corm that is resistant to the fungal infection and will produce a flowering stem (Jintang and Shunxiang 2000). Small embryos of the orchid are also symbiotic with litter-decomposing fungi such as *Mycena osmundicola* Lange, because the fungal hyphae invade the embryonic cells and provide the nutrients necessary for sprouting (Xu et al. 1989). The symbiotic relationship of the orchid with these fungi may have led to the evolution of antifungal proteins, which are important in medicine and agriculture (Zhou et al. 1987, Hu and Huan 1994, Wang et al. 2001).

Compared with fungal relationships, mutualistic and parasitic relationships of *G. elata* with insects have been little studied. Our preliminary survey of the biology of the orchid showed that the stems and corms were often infested by taxonomically unknown dipteran larvae. We reared larvae collected from the stems and corms and identified them as rare, undescribed syrphid and scatophagid dipterans. Five genera of Syrphidae are phytophagous, namely, *Taxomerus*, *Cheilosia*, *Portevinia*, *Eumerus*, and *Merodon* (Ferrar 1987). However, the syrphid species collected from *Gastrodia* corms did not belong to of any of these genera. Scatophagidae includes a variety of phytophagous genera, e.g., *Gymnomera*, *Hydromyza*, *Norellisoma*, *Cordilura*, *Nanna*, *Norellia*, *Hexamitochera*, *Neochirosia*, *Delina*, and *Parallelomma*, the last seven of which are associated with monocots (Ferrar 1987), and the last two with orchids (Meijere 1940, de Jong 2000). The scatophagid fly collected from *Gastrodia* stems and corms did not belong to any of these genera.

In general, orchids have evolved characteristic pollination systems associated with specific insects. According to one brief report, the pollinator of *G. elata* in China is a "reed bee" (species name not given; Zhou et al. 1987). The frequent infestation of fruiting stems by the dipterans described above suggests that adult females of the phytophagous dipterans may pollinate the flowers to improve fitness of their progeny as in fig wasps (Wiebes 1979), yucca moths (Riley 1892), and *Glochidion*-associated gracillariid moths (Kato et al. 2003). To identify the pollinator of this orchid, we observed the insects that visited its flowers in a natural forest in Japan.

We found that the orchid is pollinated by small halictid bees. We also found that two insect species infest the stems and corms of the orchids, and we describe one of these as a new species and genus of

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