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Invasive Pest Species of Gall-Inducing Cecidomyiidae (Diptera) in Japan

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ABSTRACT

Certain pest species of gall midge (Diptera: Cecidomyiidae) have invaded Japan in recent decades. *Contarinia maculipennis* Felt probably came to Japan from Southeast Asia, and it is now an exceedingly problematic pest for *Dendrobium* orchids (Orchidaceae) in Okinawa. Molecular phylogenetic analyses have revealed that *C. maculipennis* is a polyphagous species infesting more than eight plant families, including *Momordica charantia* (Cucurbitaceae), a chief vegetable crop in Okinawa. A similar *Contarinia* species was found to induce leaf-fold galls on roses (Rosaceae) cultivated in greenhouses in various prefectures of Japan. A molecular phylogenetic analysis detected geographical variations in the gene sequences of this gall midge, suggesting that this *Contarinia* species is a native to Japan, in contrast to *C. maculipennis*. However, wild host(s) of this gall midge have never been found. *Procontarinia mangicola* (Shi) that attacks the leaves of *Mangifera indica* (Anacardiaceae) was found in Okinawa Prefecture in 2000, on Amami Island, Kagoshima Prefecture in 2008 and the Bonin Islands, Tokyo in 2016. In July 2015, *Dasineura oxycoccana* (Johnson), native to North America, was found to have infested new leaves of cultivated blueberry *Vaccinium* spp. in Honshu, Japan. In addition, three alien species *Stenodiplosis sorghicola* (Coquillett), *Obolodiplosis robiniae* (Halderman), and *Oligotrophus betheli* Felt are known to occur in Japan.

Key words: invasive pest, gall midge, *Contarinia*, *Dasineura*, *Procontarinia*

Introduction

Biological invasions are one of the most serious global concerns critically affecting ecosystems and biodiversity (e.g. Sax and Gaines, 2008; Bellard *et al*., 2016; Paini *et al*., 2016). International trade expansion and globalization trends have increased potential invasion risks, as well as actual invasions by alien species (Kiritani, 1998; Hurley *et al*., 2016).

The influence of invasive gall-inducing insects on natural and agricultural ecosystems is

also of global concern (e.g. Branco *et al*., 2016; Csóka *et al*., 2017). For example, *Quadrastichus erythrinae* Kim (Hymenoptera: Europhidae) probably originated from eastern Africa and has been reported to feed on coral and ornamental trees of the genus *Erythrina* (Fabaceae) in Taiwan, China, Japan, India, Thailand, the Philippines, Singapore, American Samoa, Guam, Hawaii, and Florida (Li *et al*., 2006; Uechi *et al*., 2007a; Howard *et al*., 2008; Rubinoff *et al*., 2010; Yang *et al*., 2014; Csóka *et al*., 2017). The species has rapidly broadened its range and heavily infested *Erythrina* trees in these areas. Another eulophid wasp, *Leptocybe invasa* Fisher & La Salle (Hymenoptera), which feeds on *Eucalyptus* (Myrtaceae) and is native to Australia, has expanded its range globally to most localities where *Eucalyptus* trees are planted (Mendel *et al*., 2004; Tung and La Salle, 2010; Csóka *et al*., 2017).

The chestnut gall wasp *Dryocosmus kuriphilus* Yasumatsu (Hymenoptera: Cynipidae) is indigenous to China and spread to East Asia in the 1940s (Moriya *et al*., 2003) then to eastern North America in the 1970s (Rieske, 2007). The recent invasion of European countries by *D. kuriphilus* has seriously harmed chestnut production (EFSA Panel on Plant Health, 2010; Matošević *et al*., 2014, 2015; Csóka *et al*., 2017).

This review summarizes invasive gall-inducing cecidomyiids (Diptera) in Japan and their current status.

Contarinia maculipennis Felt

The blossom midge *Contarinia maculipennis* Felt is a typical polyphagous gall midge infesting the flower buds of *Dendrobium* orchids as well as various plant species from other families (Tokuda, 2012; Gagné and Jaschhof, 2017). In Japan, *C. maculipennis* was first discovered in 1989 in several orchid greenhouses in Nago City, Okinawa Prefecture and subsequently in Kita-Nakagusuku Village and Ozato Village in Okinawa by 1993 (Yasuda and Uehara, 1994; Tokuda *et al*., 2002). Orchid flower buds infested by this gall midge usually remain closed and fall from the plant (Fig. 1) (Tokuda *et al*., 2002; Yukawa *et al*., 2004), and some growers in Okinawa have stopped cultivating orchids due to heavy infestation by *C. maculipennis* in addition to various economic factors (Uechi *et al*., 2007b). The description of *C. maculipennis* was originally based on Hawaiian specimens obtained from hibiscus (Felt, 1933), and this species was believed to have invaded from Southeast Asia (Gagné, 1995). Morphological examination revealed it to be a polyphagous pest feeding on at least seven plant families (Jensen, 1946; Nakahara, 1981; Gagné, 1995). It was confirmed by Uechi *et al*. (2003) through molecular analysis.

Fig. 1. *Dendrobium* flower buds infested by *Contarinia maculipennis*.

In 2005, *C. maculipennis* was found to have infested the flower buds of bitter gourd *Momordica charantia* (Cucurbitaceae), which is a major cash crop in Okinawa (Uechi *et al*., 2007b). During the same year, this species was discovered on *Dendrobium* spp. (Orchidaceae) in Fukuoka and Miyazaki Prefectures, Kyushu (Uechi *et al*., 2007b); and in 2008, in Mie Prefecture, Honshu (Uechi *et al*., 2011). *Contarinia maculipennis* was the most frequently intercepted species among Cecidomyiidae in Japanese plant quarantine inspections from 2000 to 2006 (Iwaizumi *et al*., 2007). Uechi *et al*. (2007b) warned orchid growers, international traders, and inspection officials against the potential risks of transporting infested plant materials and emphasized the urgency of investigating the host range of this gall midge in Japan.

Uechi *et al*. (2011) reported *Pseuderanthemum laxiflorum* (Acanthaceae) as a new host plant for

C. maculipennis. At present, at least 16 species belonging to eight plant families are regarded as host plants of *C. maculipennis* (Uechi *et al*., 2011).

Two natural enemies of *C. maculipennis*, endoparasitoids of the genus *Synopeas* (Hymenoptera: Platygastridae), are known to occur in Okinawa (Uechi *et al*., 2007c). Because *C. maculipennis* has developed resistance to various insecticides, including organophosphorus, synthetic pyrethroid, carbamate, and other major insect growth regulator chemicals (Tokuda *et al*., 2002), alternative management techniques to chemical applications are required. However, at present, the parasitism rates of *Synopeas* species are low in orchid greenhouses as well as on bitter gourd in fields (Uechi *et al*., 2007c).

Contarinia species on cultivated roses

In 1998, a *Contarinia* species that induces leaf-fold galls on cultivated roses in greenhouses was found in Yamaguchi and Fukuoka Prefectures (Tokuda and Yukawa, 2004). This gall midge has subsequently been detected in various prefectures from northern Honshu to Kyushu, Japan (Tokuda and Yukawa, 2004).

In Europe and North America, *Dasineura rosae* (Bremi) and *Dasineura* sp. are known to infest cultivated roses, and they induce similar leaf-fold galls to those induced by the Japanese *Contarinia* species (Barnes, 1948; Gagné, 1989; Tokuda *et al*., 2009; Gagné and Jaschhof, 2017). In Japan, such leaf-fold galls are found on the native roses *Rosa multiflora* and *Rosa rugosa*, and their inducers have been identified as a species of *Dasineura* (Tokuda *et al*., 2009). To date, *Contarinia* species have been observed inducing leaf-fold galls on *Rosa* only on greenhouse-cultivated roses in Japan (Tokuda and Yukawa, 2004; Tokuda *et al*., 2009).

According to Iwaizumi *et al*. (2007), gall midges associated with *Rosa* species were not intercepted by Japanese plant quarantine inspections between 2000 and 2005. By contrast, *C. maculipennis* was frequently captured (476 times during this period). In addition, preliminary molecular analyses of the mitochondrial cytochrome oxidase I (COI) region have detected sequence variations in the *Contarinia* species collected from Japanese cultivated roses that reflect the geographical differences among populations (M. Tokuda *et al*., unpublished). These analyses imply that the *Contarinia* species is not alien but native species to Japan. However, wild hosts of this gall midge have not yet been found, nor has the invasion pathway to rose-cultivation greenhouses in Japan been ascertained. Otherwise, the species might have invaded Japan multiple times. Further studies are required to reveal the origin of the *Contarinia* species.

Procontarinia mangicola (Shi)

At present, 15 species of *Procontarinia* are known to infest mango plants, *Mangifera indica* (Anacardiaceae). Among them, *Procontarinia mangicola* (Shi) was discovered in 2000 on Okinawa Island and subsequently on seven other islands in Okinawa Prefecture by 2001 (Fig. 2) (Uechi *et al*., 2002; Yukawa *et al*., 2004). The species was previously known to occur in China and in Guam (Uechi *et al*., 2002). This gall midge induces circular blister galls on young leaves. In mango orchards, leaves heavily galled by *P. mangicola* fall prematurely, and most of the remaining galled leaves suffered from anthracnose inoculum (Uechi *et al*., 2002). Notably, heavily infested shoots do not produce inflorescences, resulting in low mango yields (Uechi *et al*., 2002). This gall midge invaded Amami Island, Kagoshima Prefecture in 2008 (Kagoshima Plant Protection Office, 2009) and, most recently, the Bonin Islands (Chichijima and Hahajima Islands), Tokyo, in 2016 (Tokyo Metropolitan Plant Protection Office, 2017).

Dasineura oxycoccana (Johnson)

The blueberry gall midge *Dasineura oxycoccana* (Johnson) is native to North America and infests new leaves of the blueberry plant, *Vaccinium* spp. (Ericaceae). In Europe, *D. oxycoccana* was first detected in Italy in 1996 and was subsequently found in other countries such as the United Kingdom and Latvia (Collins *et al*., 2010; Gagné and Jaschhof, 2017). In Asia, the gall midge was first found in Korea in 2008

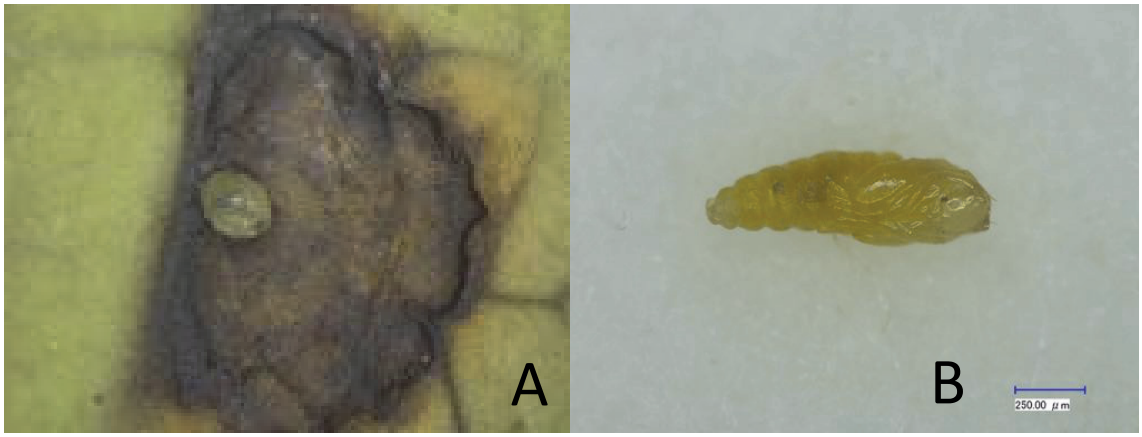

Fig. 2. (A) *Procontarinia mangicola* larva and (B) *Procontarinia mangicola* pupa..

and has caused a severe pest problem in blueberry cultivation there (Kim *et al*., 2015). In Japan, *D. oxycoccana* was first found in July 2015 in Gunma Prefecture, Honshu (Yoshida *et al*., 2017) and subsequently in Shizuoka, Toyama, and Aichi Prefectures during 2016 (Shizuoka Plant Protection Office, 2016; Toyama Plant Protection Office, 2016; Aichi Plant Protection Office, 2016). Females lay their eggs in the growing point of shoots, and the larvae develop in leaf galls at the shoot tips, causing leaf distortion and blackening of buds (Fig. 3) (Sampson *et al*., 2002; Roubos and Liburd, 2013; Rhodes *et al*., 2016). In North America, two genetically distinct strains, one feeding on highbush blueberry, *V. corymbosum*, and the other on cranberry, *V. macrocarpon*, are known to occur (Mathur *et al*., 2012). These strains produce different sex pheromones (Fitzpatrick *et al*., 2013). Phylogenetic analysis based on mitochondrial COI sequences revealed that the Japanese population belongs to the blueberry clade (Yoshida *et al*., 2017).

Fig. 3. *Dasineura oxycoccana* larva.

Other invasive species

The sorghum midge *Stenodiplosis sorghicola* (Coquillett) is an important pest of *Sorghum bicolor* (Poaceae) and its congeners worldwide (Harris, 1970). Although the time of invasion is unclear, *S. sorghicola* is known to occur in Honshu and Kyushu, Japan, where it was sometimes regarded as a pest from the 1950s until the 1970s (Yukawa and Tanaka, 1976). Studies of this gall midge have not been conducted during the past three decades in Japan.

Obolodiplosis robiniae (Halderman) induces leaf-margin galls on *Robinia pseudoacacia* (Fabaceae), which is one of the nectar-source trees for honeybees in Japan (Fig. 4). Heavy infestation by this gall midge can cause leaf drying and premature abscission (Csóka *et al*., 2017). This species was found in 2002 in Korea and in 2003 in Japan (Kodoi *et al*., 2003; Woo *et al*., 2003). In Japan, this species is distributed from Hokkaido to Kyushu (Uechi *et al*., 2005; Hara, 2010). A parasitoid *Platygaster robiniae* (Hymenoptera: Platygastridae) that was possibly introduced, together with *O. robiniae*, to Europe and Asia from North America has been known to occur in Japan, but detailed parasitism rates have not been surveyed (Buhl and Duso, 2008).

Oligotrophus betheli Felt causes discoloration in the young twig tips of *Juniperus*

Fig. 4. Leaf-margin galls and a mating pair of *Obolodiplosis robiniae*.

Fig. 5. Galls induced on young twig tips of *Juniperus horizontalis* by *Oligotrophus betheli*.

horizontalis (Cupressaceae), an ornamental plant used for hedge and garden trees in Japan (Fig. 5). This gall midge was first found in 2013 in Japan (Yukawa *et al*., 2017). A parasitoid *Aprostocetus* sp. (Hymenoptera: Eulophidae) and several predators (spiders and a big-eyed bug) were reported by Yukawa *et al*. (2017).

Conclusion

Iwaizumi *et al*. (2007) reported that gall midges were intercepted at Japanese seaports and airports more than 2,000 times from 2000 to 2005, approximately one discovery per day. To reduce the risk of biological invasion and promote the management of invasive species, international information sharing and cooperation are crucial. For example, Iwaizumi *et al*. (2007) found through plant quarantine inspection a *Contarinia* species associated with *Alstroemeria* (Alstroemeriaceae) that was imported from Australia and New Zealand. Although these countries had no records of gall midges associated with *Alstroemeria*, this species was later found in Australia and in several other countries. Then it was described as new to science by Kolesik *et al*. (2017). Information about gall midges intercepted through plant quarantine inspections is useful for discovering species in the original distribution areas. Taxonomic and ecological studies in the native ranges can promote the development of control measures for the pest species.

We hope this review promotes international collaboration and contributes to reducing the risk of future biological invasions by gall-inducing insects.

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摘　　要

近數十年間，數種癭蚋害蟲入侵日本。蘭花癭蚋 *Contarinia maculipennis* Felt 推測由東南亞入侵，為目前琉球地區嚴重危害的石斛蘭屬園藝作物的害蟲物種。分子分析顯示蘭花癭蚋為一多食性物種，危害超過八科的植物，包含沖繩地區一重要瓜科栽植作物 *Momordica charantia*。*Contarinia* 屬一近似物種於日本多個縣的玫瑰栽植溫室造成葉片捲曲蟲癭，相對於 *C. maculipennis* 而言，分子分析反映該物種的分子序列有地區變異性，顯示危害玫瑰的 *Contarinia* 屬癭蚋是一原生物種，然而其野外寄主仍待釐清。危害檬果葉片的 *Procontarinia mangicola* (Shi) 於 2000 年發生於沖繩縣，後於 2008 年記錄於鹿兒島縣的奄美群島及 2016 年記錄於東京小笠原群島。於 2015 年 7 月，原生於北美的 *Dasineura oxycoccana* (Johnson) 於日本本州記錄其危害栽植藍莓—越橘屬植物新葉。此外，另三種外來物種 *Stenodiplosis sorghicola* (Coquillett)、*Obolodiplosis robiniae* (Halderman) 及 *Oligotrophus betheli* Felt 亦發生於日本。

關鍵詞：入侵害蟲、癭蚋、*Contarinia*、*Dasineura*、*Procontarinia*