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The Gall, Soldiers and Taxonomic Position of the Aphid *Tuberaphis taiwana* (Homoptera)

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Abstract Galls of "*Astegopteryx*" *taiwana* TAKAHASHI on *Styrax formosana* were collected to examine the occurrence of soldiers in this aphid. Morphological and behavioral observations on aphids obtained from these galls showed that "*A.*" *taiwana* produces many 2nd-instar soldiers in the gall. The coral-shaped gall of "*A.*" *taiwana* and its 1st-instar exules deposited by emigrants are described. On the basis of the morphology of the 1st-instar exules, it is concluded that this species belongs to the genus *Tuberaphis*.

Key words: Gall; soldier; aphid; Cerataphidini; *Styrax*; *Tuberaphis taiwana*.

TAKAHASHI (1934) described the aphid "*Astegopteryx*" *taiwana* (Hormaphidinae, Cerataphidini), which forms large coral-shaped galls on the snowbell *Styrax formosana* in Taiwan. TAKAHASHI (1936), TAO (1966) and HSU (1980) later referred to this species in their taxonomic works, but no information about its biology has been added since TAKAHASHI's 1934 paper. Between 1987 and 1992, a number of galls of "*A.*" *taiwana* were found around Sun Moon Lake, Nantou Hsien, central Taiwan. Having examined the morphology and behavior of their inhabitants, we found that this species produces 2nd-instar soldiers as other cerataphidines do (see, *e.g.*, AOKI *et al.*, 1977; AOKI & KUROSU, 1989 a, 1992; NOORDAM, 1991). We let some "*A.*" *taiwana* alates larviposit in a plastic container and obtained their 1st-instar offspring. Studying the morphology of these 1st-instar nymphs, we also found that this species belongs to the genus *Tuberaphis*. In this paper, we report the occurrence of soldiers and describe the gall and 1st-instar exule under the name of *Tuberaphis taiwana* (TAKAHASHI), n. comb.

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Materials and Methods

Five galls of *Tuberaphis taiwana* were collected from trees of *Styrax formosana* around Sun Moon Lake, and were submerged in 80% alcohol to collect all the inhabitants (for the collection date, see Table 1). They were dissected in the laboratory, and the number of aphids in each gall was counted under a dissecting microscope. For two immature galls (89064 and 90099), all soldiers were separated from the other aphids, and the percentage of soldiers was computed. Since the other three mature galls contained too many aphids, we subsampled 1,306, 1,698 and 955 aphids from galls 90082, 9010 and 87068, respectively, after stirring the entire aphids in a dish, and the percentage of soldiers was computed for these subsamples. Fifty soldiers from each of the five galls were heated in 10% KOH solution, stained, mounted in balsam, and examined under a differential interference microscope to see whether they have the next instar cuticle developing inside. Many other aphids were also examined in this way to determine whether soldiers are really of the 2nd instar and whether a dimorphism occurs in this instar.

For the experiments mentioned below, additional three mature galls were also collected from *S. formosana* around Sun Moon Lake: galls 92028 and 92029 on September 12, 1992, and gall 87069 on November 2, 1987.

To see whether soldiers of *T. taiwana* attack other insects, we placed a total of seven lepidopterous larvae (ca. 4–14 mm long, collected from tea and a grass) on galls 90082 and 92028, and observed them with a hand-lens. Prior to the experiment, the galls were cut off trees and were tapped with forceps, so that a number of soldiers appeared on the surface. The lepidopterous larvae were placed near these soldiers.

We placed 20 soldiers on the senior author's hand one by one, and recorded whether they bit the skin within one min. We also placed many aphids on his hand as a mass. These aphids were taken from galls 92028 and 87069.

A number of alates which had emerged from galls 87068 and 92029 were confined in containers. Some of them soon laid their 1st-instar offspring. They were deposited in alcohol, and later were mounted and examined as in other aphids.

First-instar nymphs of *Tuberaphis coreana* used for comparison were collected from colonies on the mistletoe *Viscum album* (Loranthaceae) at Chigasaki, Kana-

Table 1. Length and inhabitant composition of galls of *Tuberaphis taiwana*.

Gall * (Date of collection)	Gall length (cm)	No. of aphids	% Soldier	Alates
89064 (June 7)	4.5	985	34.6	Absent
90099 (July 9)	8.5	2,269	32.2	Absent
90082 (Sept. 22)	9	5,176	41.8	Present
9010 (Sept. 22)	14.8	18,344	30.8	Present
87068 (Oct. 29)	20	13,090	26.7	Present

* First two figures of the gall number indicate the year of collection.

gawa Pref., Japan, on April 4 and May 18, 1992.

Results and Discussion

1. *Gall*

The galls are coral-shaped (Figs. 1, 2 A). Each gall consists of a hollow tube

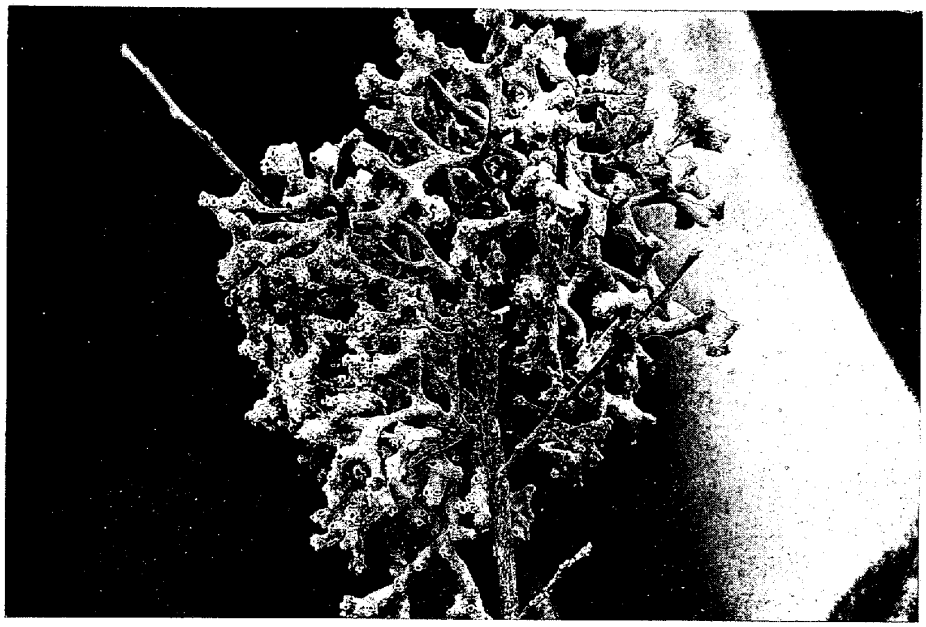

Fig. 1. A mature gall (no. 87068) of *Tuberaphis taiwana*.

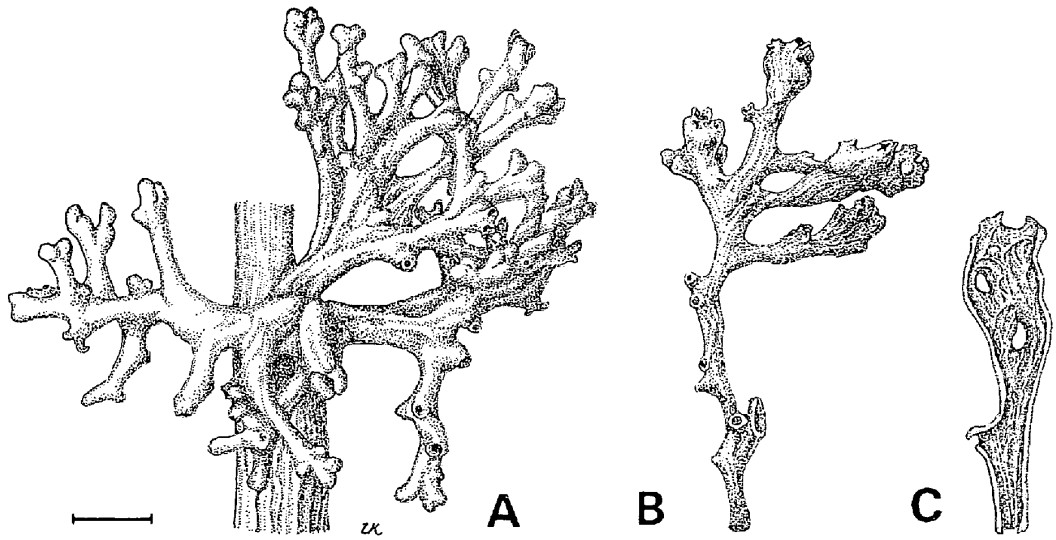

Fig. 2. Galls of *Tuberaphis taiwana*. —— A, An immature gall (no. 89064); B, a "twig" of a mature gall (no. 9010); C, ditto (a longitudinal section). Scale: 0.5 cm for A, C and 1 cm for B.

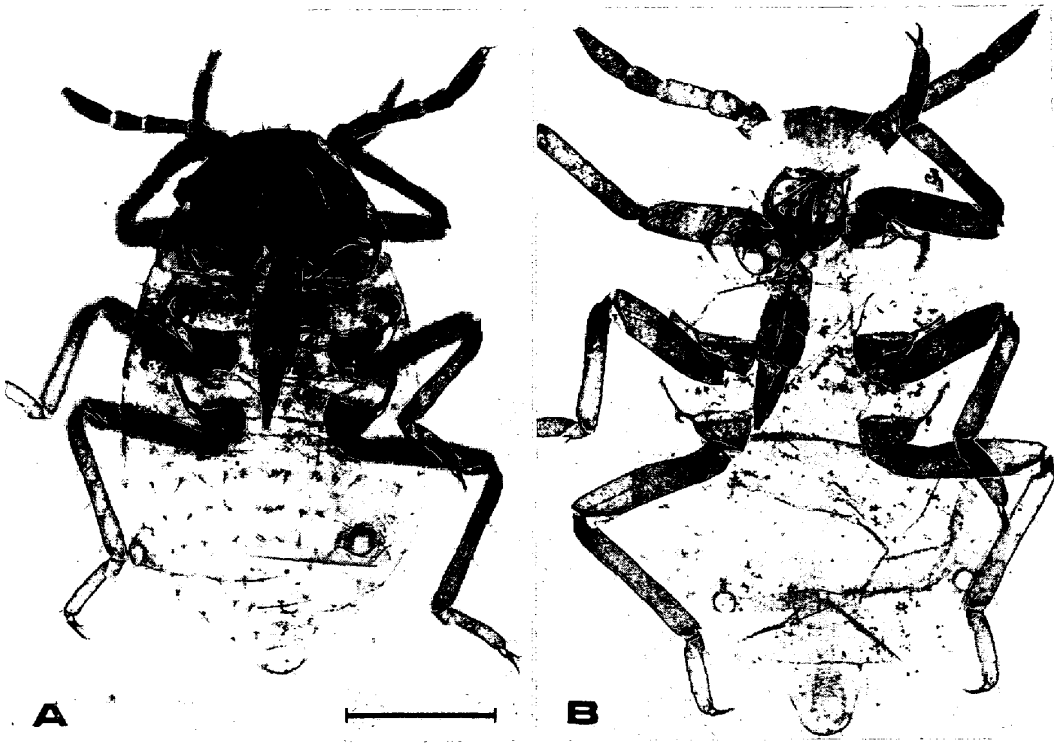

Fig. 3. Soldier (A) and normal 2nd-instar nymph (B) of *Tuberaphis taiwana*. Scale: 0.2 mm.

which is ramified like a tree (Fig. 2 A, B). The inner spaces of the "twigs" are united to form a single cell. The inner surface of the gall is smooth, without projections (Fig. 2 C). There are many ostioles, through which alates escape and soldiers appear on the outside of the gall. The two immature galls were fresh green in color, and the four mature galls collected in September were yellow or yellowish green. Galls 87068 and 87069, which were collected in the end of October and in November, were brown in color.

The bases of these galls were not on the youngest shoots, but on the apices of lignified or almost lignified twigs which had undoubtedly been formed at the previous shooting. It is therefore likely that galls of *T. taiwana* are initiated on the stem of a developing shoot and become large at the time of the next shooting, as is known in *Hamiltonaphis styraci* (MATSUMURA) (AOKI & KUROSU, 1990). However, when galls are initiated remains to be investigated.

2. *Soldier*

All galls contained many soldier-like aphids with well-sclerotized tergites and protruded cornicles (Fig. 3 A). An examination of many slide-mounted immatures revealed that these aphids are 2nd-instar soldiers. The morphological differences found between the soldier and the normal 2nd-instar nymph (reproductive-to-be) (Fig. 3 B) are summarized in Table 2. Although the 1st-instar nymph of *T. taiwana*

Table 2. Main morphological differences between the soldier and the normal 2nd-instar nymph of *Tuberaphis taiwana*. Metrical data are based on 10 well-mounted specimens collected from gall 90082.

Soldier	Normal 2nd-instar nymph
Tergites sclerotized, with long setae; longest seta on 1st abdominal tergite 0.050–0.070 mm (mean 0.059 mm).	Tergites membranous, with short setae; longest seta on 1st abdominal tergite 0.020–0.024 mm (0.021 mm).
A pair of thick, spine-like setae on frons, the longer one 0.024–0.028 mm (0.027 mm) long, ca. 0.004 mm wide, the larger socket 0.010–0.012 mm (0.011 mm) wide at base.	A pair of rather thick setae on frons, the longer one 0.012–0.016 mm (0.013 mm) long, ca. 0.002 mm wide, the larger socket ca. 0.008 mm wide at base.
Apical part of ultimate rostral segment slender; distance from the apex to the nearest primary seta 0.036–0.038 mm (0.037 mm).	Apical part of ultimate rostral segment not so slender as in the soldier; distance from the apex to the nearest primary seta 0.026–0.030 mm (0.028 mm).
Cornicle protruded.	Cornicle ring-like, not so protruded as in the soldier.

has a pair of cornicles and 5-segmented antennae as the 2nd-instar aphids do, the 1st instar can be easily distinguished from the other immatures because it has only one pair of long setae on each 1st tarsal segment. We found some 1st-instar nymphs with a clear soldier cuticle developing inside and some 1st-instar nymphs with a normal 2nd-instar cuticle. The percentage of soldiers for five galls is shown in Table 1. No soldiers had the next instar cuticle developing inside. This suggests that the soldiers of *T. taiwana* are sterile.

Five of the seven lepidopterous larvae placed on galls 90082 and 92028 were attacked by one soldier or two within one min. after introduction. A lepidopterous larva placed on gall 90082 was clutched by two soldiers approximately four min. after introduction. The remaining larva was clutched by a soldier one min. 54 sec. after introduction. The use of the stylets in these attacks was seen through a hand-lens.

None of the 20 soldiers singly placed on the hand bit the skin within one min. On the other hand, at least six soldiers out of a mass of aphids placed on the hand certainly bit the skin with their stylets. TAKAHASHI (1934) already reported that aphids of *T. taiwana* bite human skin. However, unlike soldiers of *Ceratoglyphina bambusae* VAN DER GOOT (AOKI *et al.*, 1977), they caused irritation in only a slight degree. The senior author was able to stand it without patience. No aphids readily fell off the galls at the collection (cf. AOKI, 1979; AOKI & KUROSU, 1991).

Few cast-off skins were found in the galls but gall 87068 which contained many predators (see below). Soldiers of *T. taiwana* probably push cast-off skins and honeydew out of their gall; they have a pair of spine-like setae on the frons (cf. AOKI & KUROSU, 1989 a).

3. *Other insects found in galls*

Galls 90099 and 9010 contained no insects other than *T. taiwana*. Gall 90082 contained an anthocorid nymph and three, small, orange-colored beetles of the phalacrid *Stilbus* sp. They might have been on the surface of the gall. Another three beetles of the same species were found on leaves near this gall. Gall 89064 contained five small larvae of the pyralid *Assara formosana* YOSHIYASU. Gall 87068 contained various kinds of insects including 47 dipteran maggots, eight larvae and eight pupae of *A. formosana*, a chalcid wasp, two beetles of the nitidulid *Aethina* sp. (Nitidulinae), 15 nitidulid larvae (presumably of the *Aethina* sp.), three larvae of another nitiduline, two neuropterous larvae and a springtail. *Assara formosana* is known to invade galls of cerataphidines and prey on the aphids (YOSHIYASU, 1991). Larvae of the presumed *Aethina* sp. also invade galls of *Pseudoregma bambucicola* (TAKAHASHI) (AOKI & KUROSU, 1992).

4. *Notes on the life cycle*

Tuberaphis taiwana is a host-alternating species, and its secondary host is presumably a plant of Loranthaceae (see the next section). Gall 90099 collected in July contained no alates (Table 1). TAKAHASHI (1934) found "some" alates of *T. taiwana* in a gall collected on August 17. Galls of this species therefore seem to begin producing alate emigrants in August. Mature galls probably do not last until the next year. We found some dead galls but no live galls around Sun Moon Lake in December, 1990.

5. *Taxonomic position*

The galls collected in September and October contained many alates, whose characters accorded well with the original description of *Astegopteryx taiwana* given by TAKAHASHI (1934) (for the antenna, see Fig. 4 A). The 1st-instar aphids deposited by them (Fig. 4 B; for a description, see Appendix) have well-developed marginal wax plates, a long rostrum, distinct cornicles, and a pair of spine-like setae on the frons (instead of horns). In having these and other characters, they are similar to 1st-instar nymphs of the mistletoe aphid, *Tuberaphis coreana* TAKAHASHI, which has been recorded from Korea (TAKAHASHI, 1933) and Japan (SORIN, 1978), but not from Taiwan. However, the 1st-instar nymphs of *T. coreana* collected from *Viscum album* are larger than those of *taiwana*, and the frons is more distinctly protruded at the bases of the spine-like setae in *coreana*. Since 1st-instar nymphs produced by alates are usually smaller than those produced by apterae (see, *e.g.*, ARAKAKI 1989; AOKI & KUROSU, 1989 b), we cannot exclude the possibility that the two are the same species. In this paper, we tentatively use the name *Tuberaphis taiwana* (TAKAHASHI), n. comb., for this gall-forming aphid.

There is additional evidence for the close affinity between the two. Some cerataphidines are known to harbor eukaryotic, extracellular, yeast-like symbionts instead of usual, prokaryotic, intracellular symbionts (BUCHNER, 1958; KOLB, 1963;

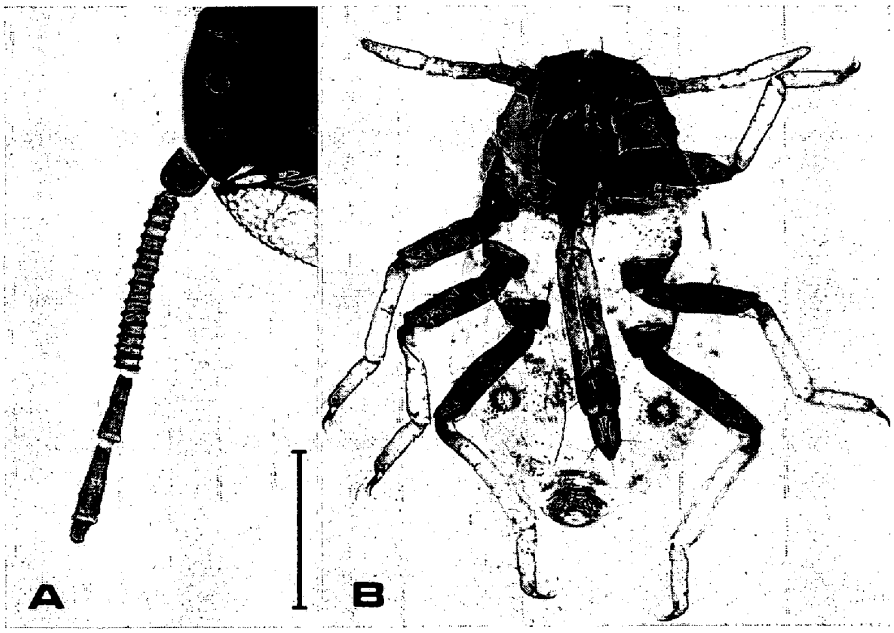

Fig. 4. *Tuberaphis taiwana*. —— A, Antenna of emigrant; B, 1st-instar exule (emigrant's offspring). Scale: 0.2 mm.

FUKATSU & ISHIKAWA, 1992). T. FUKATSU (pers. comm.) examined paraffin tissue sections of *taiwana* and *coreana*, and found that both have yeast-like symbionts. These symbionts can be seen even in slide-mounted specimens prepared for usual taxonomic purposes. (The dusky spots in aphids of Figs. 3 B and 4 B are the symbionts).

TAO (1990) proposes the unity of *T. taiwana* with "*Astegopteryx*" *vandermeermohri* HILLE RIS LAMBERS. However, as already pointed out by HSU (1980), these two are distinct species. The presumed soldiers[2] of "*A.*" *vandermeermohri* have tergal setae which are up to 0.135 mm long (HILLE RIS LAMBERS, 1931) and therefore much longer than those of the soldiers of *T. taiwana* (up to 0.080 mm long, $n=10$). The gall structure is also different between the two species (see fig. 18 in DOCTERS VAN LEEUWEN-REIJNVAAN & DOCTERS VAN LEEUWEN, 1926).

Appendix

First-instar exule (emigrant's offspring). Metrical data are indicated as mean and range, based on 10 well-mounted specimens deposited by emigrants which emerged from gall 92029. Measurements are in millimeters.

Body 0.57–0.61 (0.60) long. Head fused with prothorax, without distinct horns. Cephalothorax, abdominal tergite VIII and cauda sclerotized. Tergites

2) HILLE RIS LAMBERS (1931) regarded them as 1st-instar nymphs, but later (1933) mentioned that they are in reality of the 2nd instar. Because of their peculiar features, these nymphs are presumably soldiers.

surrounded by a number of marginal wax plates. Each wax plate composed of round cells arranged in a row; the number of cells in a plate 4–6 on abdominal tergites I and VI; total number of marginal cells excluding those on head and tergite VIII (which are indistinct) 99–116 (107). Head with 2 pairs of long, pointed setae dorsally along the frontal margin, a pair of rather thick setae ventrally between antennae, and a pair of thick spine-like setae ventrally on the frontal margin, the longer spine-like seta 0.016–0.022 (0.020) long, ca. 0.002 wide, with a socket which is ca. 0.008 wide at base. Antenna 5-segmented; segments III–V spinose; number of setae on each segment as follows: I: 2, II: 2 (rarely 3), III: 0, IV: 2, V: 1+5; basal seta on V 0.032–0.038 (0.035) long; length of each segment as follows: I: 0.030–0.036 (0.031), II: 0.038–0.040 (0.038), III: 0.046–0.052 (0.048), IV: 0.030–0.038 (0.035), V: 0.088–0.094 (0.091); primary rhinaria ciliated, on IV 0.006–0.010 (0.008) and on V 0.014–0.020 (0.017) in axial length. Rostrum long, extending beyond cornicles; ultimate segment rather short, 0.068–0.072 (0.069) long, without secondary setae. Hind femorotrochanter 0.174–0.190 (0.181) long. Tarsi 2-segmented, with some spinules; 1st segment with a pair of setae, of which the longer one is 0.054–0.058 (0.055) on hind tarsus; 2nd segment 0.084–0.090 (0.086) long on hind tarsus, with a pair of dorsal setae at apical 1/3, with 3 pairs of setae apically, and a pair of setae on empodium, the dorsoapical setae long and capitate, the empodial setae extending beyond the apices of claws and spatulate, the lateroapical setae also long and spatulate, the others pointed. Abdominal tergites I–V each with 3 pairs of setae, but one or both of the pleural setae on V often disappearing, longest seta on tergite I 0.014–0.018 (0.016); tergites VI and VII each with 2 (spinal and marginal) pairs of setae (a pleural seta rarely appearing on VI); tergite VIII and cauda each with a pair of setae; longer seta on tergite VIII 0.020–0.030 (0.024); anal plate with 2 pairs of setae. Cornicle ring-like, distinctly sclerotized around, located between pleural and marginal setae on tergite IV, 0.016–0.024 (0.021) in inner diameter.

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