

Taxonomic review and morphometric analysis of the genus *Melanaphis* van der Goot (Hemiptera: Aphididae) in Korea

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Seven species of the genus *Melanaphis* van der Goot are recognized in Korea, including *M. sorini* Halbert and Remaudière new to Korea. Morphometric analysis is performed based on 27 major characteristics to determine the morphometric correlation between species and to suggest useful diagnostic characters in this species complex. We provide the identification key based on the results of the morphometric analysis.

Keywords: aphids; canonical discriminant analysis; host plant; identification; taxonomy

Introduction

The genus *Melanaphis* van der Goot 1917 is one of the major aphid taxon of the tribe Aphidini in the subfamily Aphidinae, containing 24 valid species in the world (Remaudière and Remaudière 1997; Favret 2011). However, the majority of species are distributed in the Palearctic region, especially in East Asia (Zhang et al. 2001; Blackman and Eastop 2006). Currently, seven species have been recognized from Korea: *M. bambusae* (Fullaway 1910), *M. japonica* (Takahashi 1919), *M. koreana* (Sorin 1972), *M. pyrararia* (Passerini 1861), *M. sacchari* (Zehntner 1897), *M. siphonella* (Essig and Kuwana 1918), and *M. sorini* (Halbert and Remaudière 2000). Of the seven species, *M. sorini* is newly recorded in Korea.

Most species of *Melanaphis* live on herbaceous plants such as Poaceae as their secondary hosts (Zhang et al. 2001; Blackman and Eastop 2006). It is ecologically similar to *Rhopalosiphum* Koch or *Hyalopterus* Koch in that a few species alternate their hosts between Rosaceae and Poaceae (Blackman and Eastop 2000). *Melanaphis* is characterized for relatively small body size, truncated conical shape of siphunculi, and antenna shorter than body length (Heie 1986). Although several species of *Melanaphis* have been reported as utilizing *Pyrus* as their primary hosts and alternating two heterogeneous hosts, most species live on *Miscanthus* or other monocots without host alternation, where they usually are attended by ants (Blackman and Eastop 2006). However, monoecious species on secondary hosts seem to have lost their primary hosts. It is suggested that *Melanaphis* is the most basal group of Rhopalosiphina and is thus regarded to

provide some clues to the evolution of host alternation in the subfamily Aphidinae (Kim and Lee 2008).

In this study, we review the seven *Melanaphis* species (Table 1), and provide the identification key, host plants, measurement data, and the photo plates from the macerated specimens. In addition, we try to analyze the morphological relationships using morphometrics based on the measured characters to understand the morphometric relationships between species, and to determine the major characteristics that differentiate *Melanaphis* species.

Materials and methods

Aphid samples were preserved in 80% alcohol, and slide-glass specimens were mounted on Canada balsam, following Blackman and Eastop's (2000) methods.

Table 1. Sample list of the apterous viviparous females used in morphometric analysis.

Species	No. of specimens	Host plant
<i>M. bambusae</i>	8	<i>Pseudosasa japonica</i>
<i>M. sorini</i>	16	<i>Miscanthus sinensis</i>
<i>M. japonica</i>	30	<i>Sorghum bicolor</i> and <i>M. sinensis</i>
<i>M. koreana</i>	22	<i>M. sinensis</i>
<i>M. pyrararia</i>	16	<i>Pyrus ussuriensis</i>
<i>M. sacchari</i>	22	<i>S. bicolor</i> and <i>Zea mays</i>
<i>M. siphonella</i>	20	<i>Pennisetum alopecuroides</i>

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Abbreviations used for descriptions are as follows: al., alate viviparous female (alata); ap., apterous viviparous female (aptera); ny., nymph; Ant.I, Ant.II, Ant.III, Ant.IV, Ant.V, Ant.VI and Ant.VIb, antennal segments I, II, III, IV, V, VI and base of VI, respectively; Ant.IIIBD, basal diameter of antennal segment III; PT, processus terminalis; URS, ultimate rostral segment; 2HT, second segment of hind tarsus; AbdT.I, AbdT.II, AbdT.III, AbdT.IV, AbdT.V, AbdT.VI, AbdT.VII, and AbdT.VIII, Abdominal tergum I, II, III, IV, V, VI, VII, and VIII, respectively; MT, marginal tubercle; SIPH, siphunculi(-us); GP, genital plate.

Materials and methods for description and morphometric analysis are shown in the supplementary data section "Materials and methods"¹

Materials and methods

Results

The canonical discriminant analysis (CDA) identified the first three canonical variables (CVs) that collectively explained 84.12% of the total variance (Table 2). *M. bambusae*, *M. sacchari*, and *M. sorini* in group A were closely related to one another, whereas *M. japonica* was close to *M. koreana* or *M. siphonella* in group B based on the two CDAs (Figure 1 and 2). In the plot of CV1 and CV2, the distributions of *M. bambusae*, *M. sacchari*, and *M. sorini* overlapped with each other on the mid-left side, and the distributions of *M. japonica* and *M. koreana* also overlapped with each other (Figure 1). However, the distribution of *M. siphonella* was exclusively located in the middle, and the distribution of *M. pyraria* was remotely located on the upper right, far from the rest of the congeneric species. Nevertheless, the seven *Melanaphis* species were nicely clumped based on the plot of CV1 and CV3 (Figure 2). The result of total-sample standardized canonical coefficients showed that the lengths of SIPH and cauda significantly contributed to species separation on the first three canonical variables, and the length of PT had a large influence on the axis of CV2. In addition, the length of 2HT was the main variable causing the separation in both CV1 and CV2, and the length of setae on AbdT.III also affected both the CV2 and CV3. Except for the five characters, the lengths of URS and Ant.V similarly contributed to each axis in the two plots. Statistical analyses using Tukey's honestly significant difference (HSD) test in ANOVA (Table 3) also showed that the characters largely contributing to the three CVs could be significant in separation of the species in each group of A and B (Figure 1, 2). In particular, the characters acting as major elements in the CDA (for example, length of

Table 2. The first three CVs (standardized coefficients) based on 27 morphological characters for apterae of the seven *Melanaphis* species.

Part	CV1	CV2	CV3	
Length (mm)	Body	0.5050	-0.4395	0.5788
	Whole antennae	0.2659	-0.3513	-0.5107
	Ant.I	-0.2587	0.1301	-0.1612
	Ant.II	0.0664	0.9457	-0.0246
	Ant.III	-0.0290	0.3120	-0.1128
	Ant.IV	0.4394	-0.1299	-0.2086
	Ant.V	0.5481	0.6944	0.4977
	Ant.VIb	0.5044	-0.0988	-0.0165
	PT	-0.2135	-1.6197	0.0013
	URS	0.6167	-0.5454	-0.0216
	Hind femur	0.2268	-0.1592	-0.4041
	Hind tibia	-0.3552	0.7499	0.7056
	2HT	1.0922	0.9719	0.0247
	SIPH	-1.5564	1.1223	1.3331
	SIPH (basal width)	-0.3818	0.5573	-0.6858
	Cauda	-0.7795	-1.3455	-1.8174
	Cauda (basal width)	0.4638	-0.0930	-0.3571
	Setae on Ant.III	0.3185	0.2732	0.6075
	Ant.IIIBD	0.4238	-0.0932	-0.1224
	Setae on AbdT.III	0.5187	-1.0503	1.2197
No. of setae on	Ant.I	-0.1871	-0.2600	0.0777
	Ant.II	-0.0747	0.1285	0.2829
	Ant.III	-0.0743	0.1137	0.4068
	URS (subsidiary)	0.1455	-0.0123	-0.1952
	AbdT.VIII	0.0736	-0.0415	0.6329
	GP	0.1973	-0.4633	0.0610
	Cauda	0.1190	0.0459	-0.0700
	Eigenvalue	19.2437	17.1290	8.8601
	% of the total variance	35.79	31.85	16.48

cauda, SIPH, and Ant.V) have better statistical power to distinguish similar species than others.

Discussion

In the two CDA plots (Figure 1 and 2), *M. pyraria* was morphologically differentiated from the other species. This may be because the *M. pyraria* samples used in the analysis had been solely collected from the primary host, *Pyrus ussuriensis*. Stroyan (1984) reported that the body length of *M. pyraria* (maximum 2.4 mm long) collected from the primary host, *Pyrus communis*, was larger than that (maximum 1.7 mm long) on the

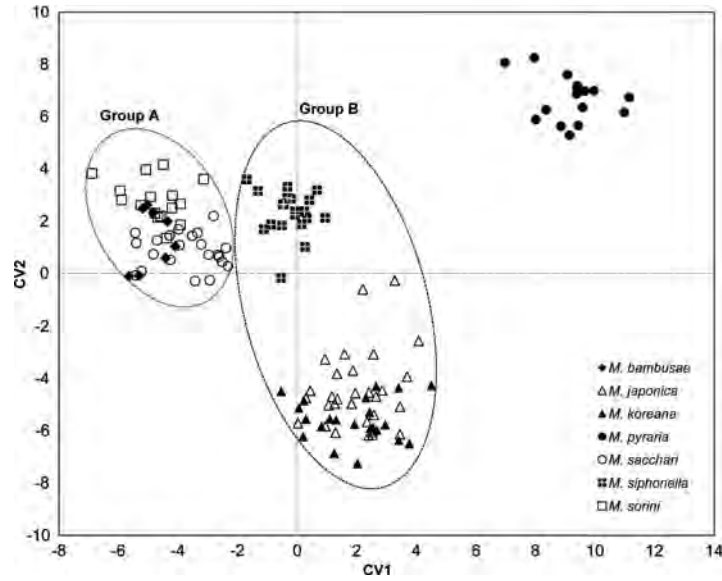


Figure 1. Plot of the mean scores on the CV1 vs CV2 of *Melanaphis* specimens based on the analysis of 27 morphological characters.

secondary host. In our study, the mean length of PT in *M. pyrarria* was shortest among the seven species (Additional file 4. Table S-1¹). In addition, the mean ratio of PT versus Ant.VIb in *M. pyrarria* (1.68) was much smaller than those in the other species (2.93–4.18), even though the samples were not fundatrices based on the short URS and the sparse setae on cauda (Stroyan 1984; Heie 1986). The previous taxonomic findings of the genus *Melanaphis* revealed that

the apterous or alate viviparous females collected from the primary host generally are bigger than those on the secondary host in host alternating species (Stroyan 1984; Heie 1986; Blackman and Eastop 2006). In fact, according to Heie’s description (1986) of *P. pyrarria*, the body size of the apterous viviparous females on the secondary host is very similar to that of the other *Melanaphis* species. Consequently, the large difference of *M. pyrarria* in the morphometric analysis was likely

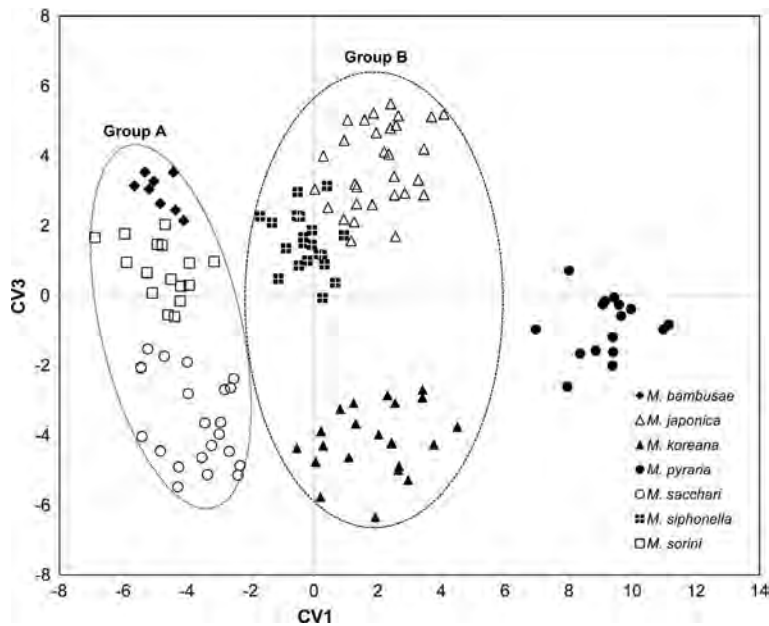


Figure 2. Plot of the mean scores on the CV1 vs CV3 of *Melanaphis* specimens based on the analysis of 27 morphological characters.

Table 3. Multiple comparisons of character differences of the seven *Melanaphis* species in groups A and B (Figures 1, 2) by Tukey's HSD tests.

Part		Group A			Group B			Statistical power ($P < 0.01$)
		<i>M. bambusae</i> vs <i>M. sorini</i>	<i>M. bambusae</i> vs <i>M. sacchari</i>	<i>M. sorini</i> vs <i>M. sacchari</i>	<i>M. japonica</i> vs <i>M. koreana</i>	<i>M. japonica</i> vs <i>M. siphonella</i>	<i>M. koreana</i> vs <i>M. siphonella</i>	
Length	Body	0.000*	0.000*	0.713	0.048	0.053	0.000*	***
	Whole antennae	0.001*	0.020	0.159	0.001*	0.000*	0.000*	****
	Ant. I	0.529	0.179	0.007	0.843	0.824	0.698	—
	Ant.II	0.210	0.275	0.843	0.038	0.015	0.000*	*
	Ant.III	0.441	0.411	0.924	0.255	0.160	0.778	
	Ant.IV	0.020	0.952	0.001*	0.276	0.000*	0.000*	***
	Ant.V	0.000*	0.002*	0.051	0.002*	0.000*	0.000*	*****
	Ant.VIb	0.000*	0.000*	0.037	0.637	0.000*	0.000*	*****
	PT	0.000*	0.000*	0.745	0.010	0.000*	0.000*	*****
	URS	0.000*	0.000*	0.940	0.000*	0.010	0.000*	*****
	Hind femur	0.049	0.005*	0.182	0.111	0.454	0.448	*
	Hind tibia	0.713	0.844	0.816	0.003*	0.004*	0.987	**
	2HT	0.000*	0.000*	0.908	0.336	0.219	0.781	**
	SIPH	0.825	0.006*	0.000*	0.000*	0.356	0.000*	*****
	SIPH (basal width)	0.845	0.000*	0.000*	0.209	0.107	0.711	**
	Cauda	0.001*	0.000*	0.000*	0.000*	0.000*	0.000*	*****
	Cauda (basal width)	0.029	0.000*	0.031	0.013	0.603	0.073	*
	Setae on Ant.III	0.301	0.120	0.000*	0.000*	0.000*	0.980	***
	Ant.III BD	0.853	0.011	0.000*	0.000*	0.069	0.000*	***
	Setae on AbdT.III	0.000*	0.000*	0.333	0.000*	0.000*	0.027	*****
No. of setae on	Ant.I	0.086	0.055	0.722	0.000*	0.000*	0.599	**
	Ant.II	0.186	0.608	0.263	0.005*	0.080	0.322	*
	Ant.III	0.182	0.092	0.000*	0.000*	0.523	0.000*	***
	URS (subsidiary)	1.000	0.240	0.096	0.199	0.754	0.380	—
	AbdT.VIII	0.498	0.120	0.200	0.000*	0.000*	0.644	**
	GP	0.830	0.406	0.141	0.051	0.465	0.267	—
	Cauda	0.000*	0.058	0.000*	0.000*	0.000*	0.082	***

*Statistically significant ($P < 0.01$) Statistical power means the number of cases in which statistical significance is detected.

to be caused by the difference between the primary-host and the secondary-host generations. However, we included this species in the analysis in order to clarify the morphometric relationships with other species collected from the secondary hosts in Poaceae.

The seven *Melanaphis* species except for *M. pyrraria* were morphologically very close to each other, but they could be differentiated by some combination of the characters examined in the CDA. For example, the plot of CV1 and CV2 reflects the morphological closeness between *M. japonica* and *M. koreana*, but

these two species could be discriminated by the other variable, CV3, where the length of setae on AbdT.III, hind tibia, width of SIPH, and the number of setae on AbdT.VIII were responsible for their separation as the valuable elements. Corresponding to the traditional view of the diagnostic characters (Sorin 1970; Stroyan 1984; Heie 1986), the length of SIPH and cauda may be good candidates for species identification in the CDA. In addition, the length of 2HT, PT, and setae on AbdT.III may be used secondarily for species identification in this genus,

even though they individually were not effective to separate the species in Tukey's HSD tests (Table 3). Therefore, the multivariate morphometric analysis can be a useful diagnostic tool for the closely related *Melanaphis* species.

Systematic accounts

Order Hemiptera

Family Aphididae

Subfamily Aphidinae

Genus *Melanaphis* van der Goot 1917

Type species: *Aphis bambusae* Fullaway, 1910.

Diagnosis. Specialized on monocotyledons, especially bamboo species and *Miscanthus*, in Poaceae. However, host alternation between woody and herbaceous hosts occurs in a few species. Ant.IV sometimes fused with Ant.III. Dorsum pigmented with irregular sclerotized patches on spinal area in most species. SIPH truncated conical and mostly shorter than cauda. Cauda usually constricted near at base.

Key to the seven species of the genus *Melanaphis* in Korea (based on the apterous viviparous female)

1. Antennal segments wholly/partially pale except Ant.VI. Tibia pale except apical area..... 2
 - Antennal segments and tibia wholly black *Melanaphis siphonella* (Figure S-VI)
2. Thorax and abdomen pale, without sclerotized patches on spinal area. Cauda with 6 setae or less. SIPH as long as or slightly longer than cauda. Ratio of antenna / body 0.89–1.06 *M. bambusae* (Figure S-I)
 - Thorax and abdomen colored with sclerotized patches on spinal area. Cauda with 8 setae at least or more. SIPH shorter than cauda. Ratio of antenna / body 0.41–0.82 3
3. Thorax and AbdT.I-V colored with dark broad sclerotized patches. PT shorter than $2.0 \times$ Ant.VIb *M. pyraria* (Figure S-III)
 - Thorax pale or barely dark sclerotized, AbdT.I-V colored with dark irregular and small fragmented sclerotized patches. PT longer than $2.0 \times$ Ant.VIb & 4
4. Number of setae on GP less than 15. AbdT.II-VI without MT except AbdT.I, VII *M. sacchari*

- Number of setae on GP more than 20. AbdT.II-VI occasionally with 2-10 MTs except AbdT.I, VII 5

5. AbdT.II-VII each with 1–2 marginal setae on each side. Longest seta on head vertex shorter than Ant.I-IIBD. Longest seta on hind tibia shorter than $0.5 \times$ its middle diameter. Longest setae on AbdT.III 0.02–0.03 mm *M. sorini* (Figure 3)

- AbdT.II-VII each with 4–8 marginal setae on each side. Longest seta on head vertex shorter than Ant.I-IIBD. Longest seta on hind tibia longer than its middle diameter. Longest setae on AbdT.III 0.03–0.07 mm 6

6. AbdT.II-VI as well as AbdT.I, VII with 8–14 MTs. Setae on both dorsal head and Ant.III as long as $0.3 \times$ Ant.IIIBD. Longest setae on AbdT.III 0.05–0.07 mm *M. japonica* (Figure S-II)

- AbdT.II-VI as well as AbdT.I, VII with 5–8 MTs. Setae on both dorsal head and Ant.III as long as $0.5 \times$ Ant.IIIBD. Longest setae on AbdT.III 0.02–0.06 mm *M. koreana*

Morphological characters, specimens examined, host plants, and distribution of species are shown in the supplementary data section “Species description”¹ Photos (Figures S-I, S-II, S-III, S-VI) and biometric data (Table S-I, S-II) are also shown in supplementary data¹

1. *Melanaphis bambusae* (Fullaway 1910) (Figure S-I and Table S-I)¹
Aphis bambusae Fullaway 1910: 34-35; Takahashi 1921. *Yezabura sasae* Matsumura 1917. *Yezaphis sasicola* Matsumura 1917. *Yezabura photinia* Matsumura 1918. *Melanaphis bambusae*: van der Goot 1917; Paik 1972; Eastop and Hille Ris Lambers 1976; Remaudière and Remaudière 1997; Lee et al. 2002; Lee and Kim 2006.
2. *Melanaphis japonica* (Takahashi 1919) (Figure S-II and Tables S-I, S-II)¹
Brachysiphum japonicum Takahashi 1919: 194-201. *Melanaphis japonica*: Remaudière and Remaudière 1997; Lee et al. 2002; Lee and Kim 2006.
3. *Melanaphis koreana* (Sorin 1972) (Tables S-I, S-II)¹
Longiunguis koreana Sorin 1972: 76-77. *Melanaphis koreana*: Eastop and Hille Ris Lambers 1976; Lee and Seo 1992; Lee et al. 2002; Lee and Kim 2006.

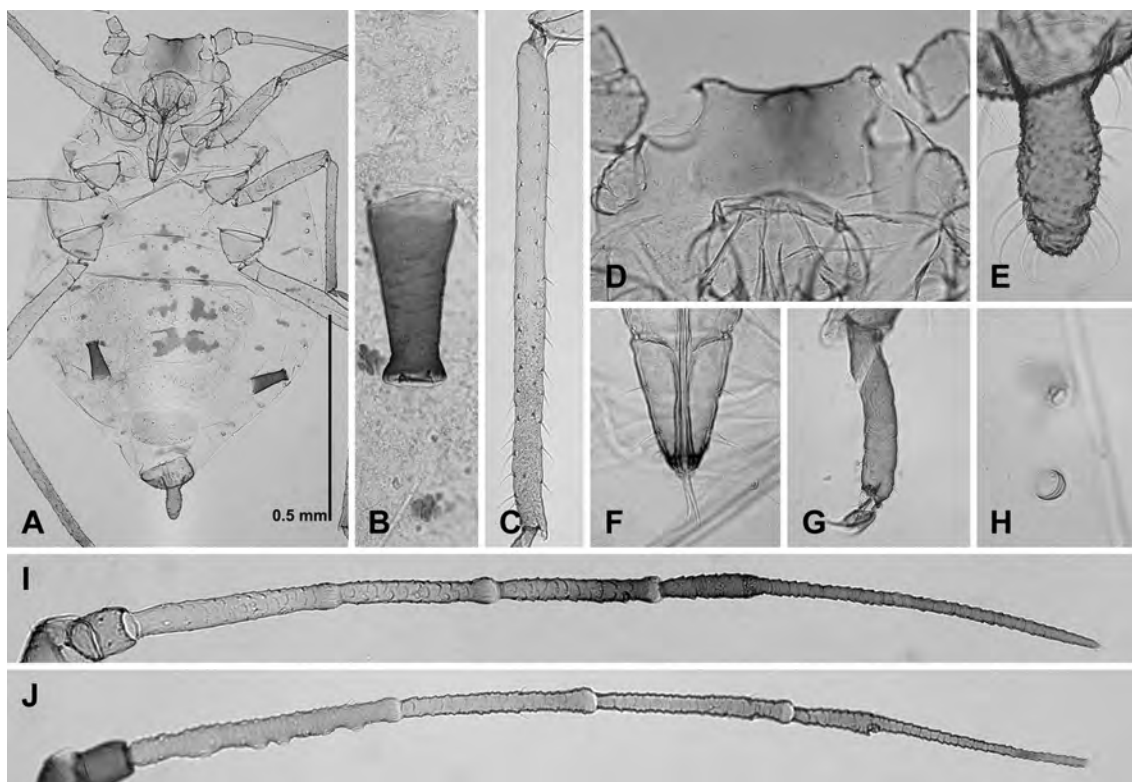


Figure 3. *Melanaphis sorini*; apterous viviparous female (A-I) and alate viviparous female (J). (A) body; (B) SIPH; (C) hind tibia; (D) head; (E) cauda; (F) URS; (G) 2HT; (H) MT on AbdT.I; (I) Ant.II-V; (J) Ant.II-V. Each pair of F-G and I-J in the same magnification to compare relative size.

4. *Melanaphis pyraria* (Passerini 1861) (Figure S-III and Table S-I)¹

Myzus pyraria Passerini 1861: 399; (l.c. Remaudière and Remaudière 1997).

Schizaphidiella quinquarticulata Hille Ris Lambers 1939. *Melanaphis pyraria*: Remaudière and Remaudière 1997; Lee and Kim 2006.

5. *Melanaphis sacchari* (Zehntner 1897) (Tables S-I, S-II)¹

Aphis sacchari Zehntner 1897: 551; Takahashi 1933.

Aphis formosana Takahashi 1921: 54. (syn.) *Aphis sorghi* Theobald 1914: 321. (syn.)

Melanaphis sacchari: Eastop and Hille Ris Lambers 1976; Remaudière and Remaudière 1997; Lee et al. 2002; Lee and Kim 2006.

6. *Melanaphis siphonella* (Essig and Kuwana 1918) (Figure S-VI and Tables S-I, S-II)¹

Aphis siphonella Essig and Kuwana 1918: 73-75.

Longiunguis siphonella: Takahashi 1966.

Pergandeidia siphonellus: Okamoto and Takahashi 1927.

Melanaphis siphonella: Paik 1972; Remaudière and Remaudière 1997; Lee et al. 2002; Lee and Kim 2006.

7. *Melanaphis sorini* Halbert and Remaudière 2000 (Figure 3 and Tables S-I, S-II)

Melanaphis sorini Halbert and Remaudière 2000: 112; Blackman and Eastop 2006.

Melanaphis formosana sensu Sorin 1970 nec Takahashi 1921.

Morphological characters. Color in life: (ap., al.) Body color varies; wine red, purple, or dark brown. Nymph slightly covered with wax. Macerated specimen: (ap.) Body ovoid and round, 1.41–1.87 mm long. Body and appendages pale, but AbdT.I–V spinally with some irregular dark patches. Head smooth dorsally and ventrally, with three pairs of acuminate setae on dorsum, longest seta as long as or slightly shorter than Ant.I–IIBD; frons w-shaped, median tubercle of frons slightly developed (Figure 3D). Antennae 0.52–0.67 times as long as body length without secondary rhinarium; Ant.I smooth with 3–5 setae; Ant.II smooth with 2–4 setae; Ant.III smooth, weakly imbricate with short 2–7 setae, longest one 1.1 times as long as basal diameter of the same segment; Ant.IV weakly imbricate with approximately 3 setae; Ant.V imbricate with approximately 3 setae; Ant.VI strongly imbricate with 3 short setae on Ant.VIb and 3–4 apical setae on PT, PT 3.13–4.54 times

as long as Ant.VIb (Figure 3I). URS barely reaching to middle coxae, as long as or slightly shorter than 2HT (Figure 3A). Legs smooth and pale; hind femora 0.25–0.40 mm; hind trochanter 0.48–0.68 mm. SIPH truncated conical, black, slightly shorter than cauda (Figure 3B). Marginal tubercles present on AbdT.I and VII, and occasionally present on AbdT.II–VI with 4–14 MTs. Cauda black, slightly constricted, with about 10–15 setae (Figure 3E). (al.) Body 1.39–1.79 mm long. Head, Ant.I, and Ant.II, thorax, SIPH black; apical area of Ant.III–V gradually darker; Ant.VI dark (Figure 3J). Ant.III, IV with 7–11, 0–2 secondary rhinaria, respectively. Other characters as in apterous female.

Specimens examined. 16 ap., Saribong, Jeju city, Jeju, 25.x.2000. on *Miscanthus sinensis* var. *purpurascens*, Coll.#001023 SH70-1; 6 al., 3 ny., Halla Arboretum, Jeju city, Jeju, 25.x.2000 on *Miscanthus sinensis* var. *purpurascens*, Coll SH56. **Host plants.** *Miscanthus* spp. **Distribution.** Korea (middle, south, Jeju), Japan, China, and Taiwan.

Remarks. Based on Halbert and Remaudière (2000), the identifications of *M. formosana* samples previously collected from *Miscanthus* var. *purpurascens* (Lee et al. 2002; Lee and Kim 2006) are revised for *M. sorini* in this study. Our specimens apparently correspond to the materials identified as *M. sorini* by Halbert and Remaudière (2000) because of the ratio of URS and 2HT as 0.99–1.17 smaller than that of *M. miscanthi* (Takahashi 1921) as 1.22–1.44. In addition, Halbert and Remaudière (2000) pointed out that the material identified as *M. formosana* by Sorin did not correspond to the specimens identified as *M. miscanthi*. Correspondingly, *M. miscanthi* has not been found yet in Korea.

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Note

1. Supplementary material can be found by clicking on the Supplementary Content tab at <http://dx.doi.org/10.1080/19768354.2011.620621>.

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