Int. J. Indust. Entomol. Vol. 21, No. 2, 2010, pp. 185~187

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International Journal of *Industrial Entomology*

The Larval Age and Mouth Morphology of the Black Soldier Fly, *Hermetia illucens* (Diptera: Stratiomyidae)

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(Received 27 October 2010; Accepted 30 November 2010)

Most studies of the black soldier fly, *Hermitia illucens*, widely distributed throughout Southeast Asia and America focused on the use of larvae for recycling various organic materials and feed for fish and livestock. To recognize the instars of the soldier fly's larvae, we examined the number of exuviae originated from each larva from 1st instar to pupa. The weight and the head capsule width of the black soldier fly larvae also confirmed that the black soldier fly was passed through 6th instars. In addition, we found that the black soldier fly larvae had a well developed mandibular-maxillary complex, similar to those reported from the larvae of scavengers including *Odontomyia cincta*, *Neopachygaster maculicornis*, *Ptecticus brunettii* and *Stratiomys ruficornis*.

Key words: *Hermitia illucens*, Larval duration, Morphology of mouthpart, BSF

Introduction

The black soldier fly, *Hermitia illucens* L., is distributed throughout Southeast Asia and America (Kim, 1997) and thought to be introduced in Korea before 1990 from America (Kim, 1997). Its superior abilities in digesting and consuming organic materials derived from plants, animals and human give the reputation of the black soldier fly as a beneficial scavenger (Diener *et al*., 2009). Most commonly reported studies of the black soldier fly are focused on the use of the black soldier fly larvae for recycling various organic materials and feed for fish and livestock (Diener *et al*., 2009; Heo *et al*., 2008). Recently, the ecological and developmental characteristic of the black soldier fly in Korea was reported (Kim *et al*., 2008). However, it is not still clearly the characteristic of larval stage and mouth morphology of larvae. For effective utilization of them as resources, the recognition of the instars and the morphology of mouth part of the soldier fly's larvae is critical. Thus, we investigated the number of molting and the duration of larval development, the larval weights, the larval head capsule width and the larval mouth morphology.

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Materials and Methods

Insect rearing

Hermetia illucens (the black soldier fly) was maintained and reared at 27 ± 1°C and 60 ± 1% humidity with *Drosophila* standard medium (9.2 g of agar, 62.4 g of dry yeast, 40.8 g of corn meal, 84 g of dextrose anhydrous, 5 ml of honey-due, 14.6 ml of mold inhibitor composed of 50 ml of 10% *p*-hydroxybenzoic acid methyl ester in ethanol and 23 ml of propionic acid, and 1 L of distilled water; Cuc *et al*., 2009).

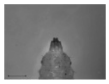
Determine the larval instar

To determine larval instars, the 30 hatched 1st instar larvae of the black soldier fly were transferred and maintained in the individual Petri-dish (diameter 35 mm, SPL life sciences) containing food. The determination of instars was when the exuviae of each instar larva was observed. All larvae examined were completed their development (data not shown).

Morphological characteristic of larval stage

The larval head capsule width was measured by ocular

Table 1. The larval and pupal developmental characteristics of the black soldier fly

N = 30 (mean ± SD)	Larval instars						Pupa
	1st	2nd	3rd	4th	5th	6th	
Duration (days)	1 ± 1	2 ± 1	2 ± 1	5 ± 1	6 ± 1	12 ± 3	22 ± 2
Weight (mg)	NM	NM	3.9 ± 1.31^{e}	22.1 ± 9.61^{d}	66.3 ± 29.42^{c}	185.3 ± 33.99^{a}	134.5 ± 27.49^{b}
Head capsule width (mm)	0.1 ± 0.02^{g}	0.2 ± 0.04^{f}	0.4 ± 0.06^{e}	0.6 ± 0.08^{d}	0.9 ± 0.06^{b}	1.1 ± 0.05^{a}	0.8 ± 0.06^{c}
Head capsule image							

"NM" means "not measured" in the study. Different superscript letters mean significant difference (*Duncan's test*, *alpha* = 0.05). Scale bar in head capsule images indicates 0.5 mm.

micrometer using stereo microscope (SZ-ST, Olympus, Japan). Larval weight was examined on electronic scales (AB104-S, Mettler Toledo, Switzerland).

SEM of mouth parts of the black soldier fly larvae

For electron microscope image, third-instar black soldier fly larvae were preserved in 70% ethanol, dehydrated in a graded series of ethanol solutions, and dried with CO_2 by the critical point technique. The specimens were coated with gold using a sputter coater (SC7620 mini sputter coater, Polaron, East Sussex, UK) and were examined on a Leo 1420 scanning electron microscope (LEO Electron Microscopy, Cambridge, UK) that was operated with accelerating voltages between 5 and 20 kV.

Results and Discussion

The larval age

Even though several studies have been made on the ecological characteristic of the black soldier fly in Korea, there is little agreement on larval instars of them. Different from the report that the black soldier fly larvae pass through 6 instars in America (Hall and Gerhardt, 2002), the black soldier fly larvae in Korea was reported to pass through only 5 instars (Kim *et al*., 2008). In Korea, there was no effort to confirm larval instars of the black soldier fly, using the individual exuviae of larvae while the larval instars were distinguished by the naked eye based on the larval size. However, it was hard and inaccurate to distinguish 1st instar and 2nd instar based on the larval size because the sizes of 1st instar and 2nd instar larva were very similar. Since the black soldier fly in Korea was thought to be originated from America and the correct recognition of the instars of the black soldier fly larvae could increase the effective usages of them, we examined the individual exuviae of the 30 black soldier fly larvae and found that each larva molted 6 times before pupation. This result suggested that the black soldier fly was passed through 6th instars (data not shown).

Morphometric analysis of larval head capsules

To verify the 6 instars in the black soldier fly larvae, the head capsule width of the black soldier fly larvae were examined. Consistent with our observation, the head capsule width of the black soldier fly larvae could be divided into 6 significantly different sizes (Table 1). The head capsule widths of the black soldier fly larvae were consistently increased from the 1st to the 6th instar larvae, but decreased in the pupal stage (Table 1). Similarly, the weight of larvae also dramatically increased from the 3rd to 6th instar larvae. These results suggested that developmental stage of the black soldier fly larvae is significantly related to the head capsule width and body weight.

Mouth morphology of the black soldier fly

To gain further information regarding the superior abilities of the black soldier fly larvae as scavengers, the morphology of the mouthpart of the black soldier larvae were examined by scanning electron microscopy. The black soldier larvae possess a hemicephalic head with a well developed labrum and mandibular-maxillary complex (Fig. 1). In the dorsal view of a mouth part, the labrum is oriented anteriorly and has a pointed apex; the labrum is also much longer than the distal part of the general lobes. In the ventral view of mouth part, the mandibular-maxillary complex is visible; from this view, the mandibular brush, apical maxillary lobes, and maxillary palps can be observed. The mandibular brush has the appearance of a duster with long hairs. The apical maxillary lobes each have the appearance of a finger with three lobes. The maxillary palps are long and conical and contain a group of apical sensilla. The molar part of the mandible was behind a maxillary palp and had the appearance of a large,

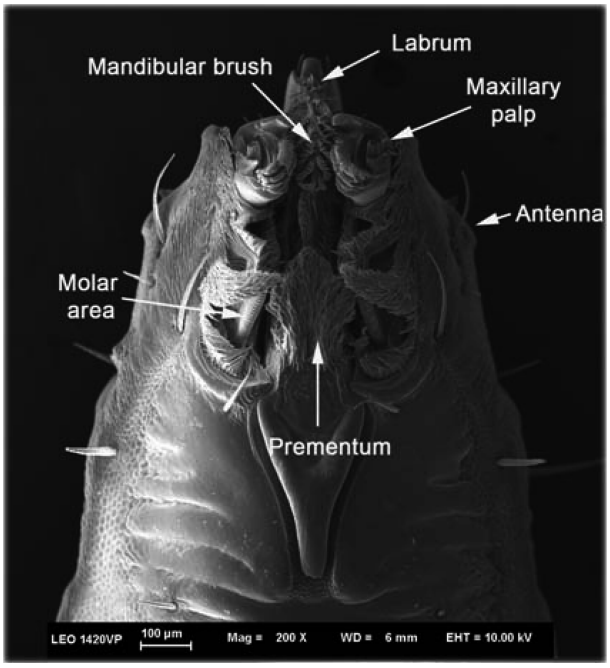


Fig. 1. The dorsal view of the mouth part of the black soldier fly larva. The black soldier fly larvae had a hemicephalic head with a well developed labrum and mandibular-maxillary complex. A molar area, a prementum, and antennae were present.

pleated bag. The mandibular-maxillary complex swings vertically when the black soldier larvae are feeding (data not shown). Thus, the repetitively vertical movements of the mandibular-maxillary complex of the black soldier larva might have the purpose of gathering fragments of decaying organic matter. The head of the black soldier larva is different than that of the house fly larva in that it is tightly connected to the thorax and the mouth part is not retracted into the thorax. Instead, the black soldier larvae have a well developed mandibular-maxillary complex, similar to those reported from the larvae of scavengers including *Odontomyia cincta* and *Neopachygaster maculicornis* (James, 1981), *Ptecticus brunettii* (Rozkošný and Kovac, 1998), and *Stratiomys ruficornis* (Nerudová and Kovac, 2008), suggesting that the black soldier larvae have a mouth part that contains a sweeping apparatus that was transformed from the biting mouth part that is typical in other insects (Rozkošný and Kovac, 1998) to improve the efficiency of uptake with respect to organic materials. Collectively, the black soldier fly larvae passed through 6 instars and had a mouthpart with characteristics of scavenger insects.

Acknowledgements

The authors thank Kyung Su Ahn, Suen gi Hwang, In Im Kim and Young Ja Kim for their valuable help in rearing the black soldier fly. This work was supported by a grant from RDA (PJ0068932010).

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