SHORT COMMUNICATION

Rearing Methods for the Black Soldier Fly (Diptera: Stratiomyidae)

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ABSTRACT The black soldier fly, *Hermetia illucens* (L.), is a nonpest tropical and warm-temperate region insect that is useful for managing large concentrations of animal manure and other biosolids. Manure management relying on wild fly oviposition has been successful in several studies. However, confidence in this robust natural system was low and biological studies were hampered by the lack of a dependable source of eggs and larvae. Larvae had been reared easily by earlier investigators, but achieving mating had been problematic. We achieved mating reliably in a 2 by 2 by 4-m screen cage in a 7 by 9 by 5-m greenhouse where sunlight and adequate space for aerial mating were available. Mating occurred during the shortest days of winter if the sun was not obscured by clouds. Adults were provided with water, but no food was required. Techniques for egg collection and larval rearing are given. Larvae were fed a moist mixture of wheat bran, corn meal, and alfalfa meal. This culture has been maintained for 3 yr. Maintainance of a black soldier fly laboratory colony will allow for development of manure management systems in fully enclosed animal housing and in colder regions.

KEY WORDS *Hermetia illucens*, waste management, manure digestion, insect based feedstuff

THE BLACK SOLDIER fly, *Hermetia illucens* (L.), is distributed throughout the tropics and warm temperate regions (James 1935, McCallan 1974). This species has three generations a year in Georgia from April to November (Sheppard et al. 1994) and can colonize a wide variety of decomposing vegetable and animal matter (James 1935). This insect is of interest because the dense larval populations reduce house fly, *Musca domestica* L., production by 94–100% and manure dry matter by 42–56% (Sheppard 1983), and nitrogen content by 62% (Sheppard et al. 1998) when compared with same age unoccupied manure. It could solve many of the problems associated with large manure accumulations at confined animal feeding operations (Sheppard and Newton 2000).

Prepupal black soldier flies are 44% dry matter and are composed of 42% protein and 35% fat, including essential amino and fatty acids (Hale 1973). Feeding studies indicated that these prepupae are a good source of nutrition for cockerels (Hale 1973), swine (Newton et al. 1977), and tilapia (Bondari and Sheppard 1987). A recent channel catfish, *Ictalurus punctatus* L., feeding study indicated that Menhaden fish meal can be replaced with black soldier fly prepupae without loss of growth. (D.C.S., unpublished data). Menhaden fish meal is valued at about $500 per ton in most major U.S. commodity markets (Anonymous 2001). Extrapolations indicate that over 60 tons (55 MT) of prepupae could be self-harvested from a 100,000 hen caged-layer house in one summer if female black soldier flies could oviposit in the manure (Sheppard et al. 1994). A recent swine manure management trial indicated almost double the 8% conversion of manure to prepupal biomass that had been observed with layer manure (D.C.S., unpublished data).

Information on black soldier fly rearing is limited. Tingle et al. (1975) reported rearing wild collected eggs to adults in 38 d at 29.3°C. They reported that mating and oviposition were observed "often" in a 3 by 6.1 by 1.8-m cage held outdoors. In addition, mating was observed in a 0.76 by 1.14 by 1.37-m cage held outdoors, but not when held in the greenhouse. "A few" fertilized eggs were collected from adults held in this smaller cage in the greenhouse. Direct sunlight was reported to encourage mating. No mating or egg collections occurred in two smaller cages (53 by 91 by 53 cm and 38 by 46 by 38 cm). Tingle et al. (1975) was unable to establish a culture with multiple generations.

In nature, black soldier flies oviposit in dry cracks and crevices above and around moist decomposing organic matter (Copello 1926, Gonzalez et al. 1963). With this natural inclination, Booth and Sheppard (1984) found that females readily lay their eggs in small openings (flutes) in the edges of corrugated cardboard held near attractive larval media. They also reported that the black soldier fly eggs required 102–105 h (4.3 d) to hatch at 24°C with red eye spots becoming evident at 72 h and embryonic movement by 84 h. Copello (1926) wrote that in Argentina black soldier fly eggs hatched in 4–6 d. May (1961) in New

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Zealand reported black soldier fly egg hatching in 5 d in February and 7–14 d in April.

Previous manure management trials with *H. illucens* depended on wild populations to oviposit and establish a population, or larvae were moved to the study site from another facility. These methods were adequate, however reliable colonization methods are needed for the full development of this system. Our objective was to develop methods for continuous rearing of black soldier fly. This would encourage biological studies and the use of black soldier fly in value-added waste management systems. The methods are reported here.

Materials and Methods

The current colony was established in July 1998. On 21 and 30 July 1998, more than 100 BSF egg masses were collected at an open-sided caged layer house in Bacon County, GA, and taken to our laboratory at the Coastal Plain Experiment Station of the University of Georgia, Tifton, GA. Resulting larvae were reared on 15% protein layer hen feed (Flint River Mills, Bainbridge, GA) mixed with water (60–70% moisture). Subsequent rearing was done with the Gainesville house fly diet (Hogsette 1992). Layer feed and the Gainesville house fly diet are equally useful for rearing black soldier fly (Tomberlin 2001). Emerging adults were held free-flying in the 7 by 9 by 5-m greenhouse. This allowed the aerial questing by males, which precedes mating (Tomberlin and Sheppard 2001).

Adults in our colony were typically managed in a 2 by 2 by 4-m, 7.1 by 5.5-mesh per centimeter Lumite screen cage (Bioquip Products, Gardena, CA) in the greenhouse. Adults held here were watered by misting water on the cage netting and artificial plants in the cage. The two plastic plants were each a 50-cm globe of leaves, each 3.8- to 7.6-cm leaf resembled ivy. Each plant was set on a 20 by 20 by 40-cm masonry block centered under one of two Aqua Cool Fog Nozzles #WF4025 (Farm Tek, Dyersville, IA) delivering 0.8 GPH at 100 PSI. A Gilmore electronic water timer model 9400 (Gilmore, Somerset, PA) was used to deliver this mist twice daily at 1000–1100 and 1500–1600 hours. Heating was provided by a natural gas fired Dayton model 3E841 80,000 BTU/h heater (Dayton Electric, Chicago, IL). Environmental cooling was accomplished with an evaporative cooling system using wet corrugated fiber pads (Pactiv-Glacier Cor University Park, IL). Environmental conditions and associated adult emergence and oviposition within the 2 by 2 by 4-m cage were monitored for 5 and 8 mo, respectively, including the critical winter months when there was no black soldier fly adult activity locally (Sheppard et al. 1994). Eggs from the colony were collected in "egg traps" made of three layers of double-faced corrugated cardboard (Booth and Sheppard 1984) glued together, and cut into 2.5 by 5-cm blocks. There are several sizes of corrugated cardboard and experience indicated that the smaller openings were preferred. We used cardboard with three flutes per centimeter. Egg traps were taped to the inside of a 5-liter plastic bucket (L168, Plastic Packaging, West Springfield, MA) 2–5 cm above wet Gainesville House Fly Diet consisting of 50% wheat bran, 30% alfalfa meal, and 20% corn meal (Hogsette 1992). Equal volumes of this dry medium and water were mixed for an oviposition attractant or larval growth medium. Wet substrates were less attractive to ovipositing *H. illucens* (Booth and Sheppard 1984). Therefore, water was added to medium used for an oviposition attractant to near the saturation point to encourage oviposition in the dry cardboard egg traps.

Eggs and larvae were held in an insectery at 30°C and ambient humidity. Eggs were placed in a 460-ml plastic cup (MC160 Sweetheart Cup, Chicago, IL), with lid until hatched. Neonate larvae were placed on ≈80 g of moist Gainesville house fly diet in a 460-ml squat plastic cup. Placing eggs on media usually resulted in poor hatch and neonate survival, suspected to be caused by fungus. A paper towel held snugly over the cup with a rubber band to contain wandering neonates resulted in high humidity often led to fungus development. Fungus development was rarely seen if larvae were placed on fresh medium.

The neonate larvae usually consumed this first medium in 2–3 d. Large batches of larvae required another 80 g of diet before day 3. At this point the larvae were transferred to a 5-liter bucket, or a 56 by 40 by 13-cm plastic pan (Sterlite, Towsend, MA, 01469), depending on density. About 500 larvae could be reared to prepupae in the 5-liter bucket or 5,000 in the pan. Larval rearing containers were covered with muslin to reduce drying of the medium.

The following feeding regimen was typical for a pan containing ≈5,000 larvae held at 30°C. At ≈3 d when the initial diet in the 460-ml cup was depleted the larvae were moved to a pan as outlined above. Due to the variable oviposition in any given egg trap, numbers of larvae to be transferred from the initial rearing cup (460 ml) was estimated. The ≈5,000, 3-d-old larvae needed to stock a pan occupied ≈5–8 ml. These were measured after most of the depleted medium was separated from the larvae. To accomplish this separation the cup was bumped sharply to cause the larvae to burrow deeper. Then a plastic teaspoon was used to slowly skim thin layers of the depleted media from the diet/larval mass. The larvae respond to this disturbance by burrowing to the bottom of the cup, resulting in more diet being pushed to the top of the mass to be skimmed. After 2–3 min. of this process a mass consisting of ≈90% larvae remained. For experimental work aliquots of these larval masses could be weighed to calculate more exact larval numbers. Volumetric measure was adequate for general rearing.

To innoculate the 56 by 40 by 13-cm pan with ≈ 5,000 larvae we placed 5–8 ml of larvae on ≈600 g of media at one end of the pan. Three hundred to 600 g of moist medium was added each day depending on the rate of assimilation by the larvae. Depleted medium was dark and finely divided. Particularly vigorous batches of larvae were fed up to 1 kg per day when they were approaching maturity. Feeding on weekends was unnecessary for routine rearing. At 2–3 wk

Table 1. Black soldier fly, *H. illucens* (L.), emergence and oviposition rates with associated temperature and humidity in a caged colony in a greenhouse with ambient day length, Tifton, GA, USA, 1999–2000

Time interval	Mean temp, °C ± SE	% humidity ± SE	Adult emergence per day ± SE	Egg filled flutes collected per day ± SE
18–30 Nov	26.3 ± 0.20	62.7 ± 0.72	—	5.6 ± 1.1
1–31 Dec	25.2 ± 0.22	55.7 ± 0.77	312 ± 26	11.1 ± 1.5
1–31 Jan	22.4 ± 0.23	53.1 ± 0.68	124 ± 22	18.8 ± 4.1
1–29 Feb	24.2 ± 0.26	52.4 ± 0.78	494 ± 69	39.6 ± 5.1
1–29 Mar	27.8 ± 0.23	61.0 ± 0.75	330 ± 20	42.7 ± 4.7
1–30 April	—	—	478 ± 18	41.5 ± 3.9
1–31 May	—	—	466 ± 47	71.9 ± 10.1
1–13 June	—	—	300 ± 61	66.7 ± 10.7

—, Data not collected.

larvae weighed ≈0.14–0.18 g or more and some had become dark brown, rather than white. These darker individuals were prepupae (May 1961).

When prepupae accounted for ≈ 50% of the population in a pan feeding was stopped and the medium was allowed to dry. The container was covered with mosquito netting held with an elastic band to allow air flow and to contain adults when they emerged. When adult emergence began the rearing container was placed in the greenhouse and uncovered to allow mating and oviposition. Temperature and humidity were periodically monitored with a Hanna HI 9161C portable microprocessor thermohygrometer (Hanna Instruments, Woonsocket, RI).

Results and Discussion

The adults resulting from the reared larvae in 1998 emerged in the greenhouse 10–14 d after pupation. These established a continuous culture that has been maintained for 3 yr. No food was offered to adults and was not required for successful reproduction (Table 1). The large store of fat provided by the larvae apparently reduced or eliminated the necessity of adult feeding. *Hermetia illucens* pupae contain ≈35% fat (Newton et al. 1977). In contrast house fly pupae contain 9% (Teotia and Miller 1974) to 15% fat (Calvert et al. 1969) and adults require feeding for successful reproduction. The automatic water misting system was adequate to provide water to the black soldier fly adults in the cage. The mist produced droplets on the plastic plants and nearby screen. These droplets were taken in by adults. Also, numbers of adults rested on the plastic plants and became covered with dew-like drops, making no effort to avoid this accumulation.

Mating began 2 d after emergence and oviposition occurred at 4 d of age under our conditions (Tomberlin 2001). Mating and oviposition occurred during all months of the year with ambient daylength even during the shortest days of winter. More than 100 egg packed flutes in 1 d have been collected from this colony. Average eggs per flute ranged from 603 to 689 (Tomberlin 2001). Eggs held at 30°C for colony maintenance hatched in 3.5 d. At ≈2.5 d, red eye spots began to appear on the embryos (seen with the aid of a dissecting scope or hand lense). At 3 d the red eye spots were well defined. These eggs hatched within 24 h. Soldier fly larvae grew well at densities of ≈2.5 larvae per cm^2 of surface area, and required ≈1–1.5 g of media each. Daily feeding of as much fresh media as they would assimilate in 4–6 h resulted in the best growth. Beard and Sands (1973) and Morgan and Eby (1975) made similar observations concerning house fly rearing. They reported that when house fly larvae fed on older (anaerobic) manure it was lethal or at best "unsuitable" for their development. Even aerobic manure a few days old supported significantly less larval growth, which may be due to depletion of nutrients by microorganisms or other conditions detrimental to their development (Beard and Sands 1973).

Black soldier flies in our colony tolerated a wide range of temperature and humidity. Adults typically mated and oviposited at temperatures of 24°C up to 40°C or more. Booth and Sheppard (1984) reported that 99.6% of oviposition in the field occurred at 27.5–37.5°C. In our colony relative humidities of 30–90% supported mating and oviposition. Eggs and larvae were generally held at 27°C but also seemed to tolerate a range of conditions. Minimum light intensity for mating is 63 μ mol m^2s^{-1} with most mating occurring at over 200 μ mol m^2s^{-1} (J.K.T. and D.C.S., unpublished data).

The black soldier fly can be dependably cultured with these techniques, but as with any new system improvements can be made. Optimal temperatures need to be determined for each life stage and a better way to handle pupae and adult emergence would be helpful. Also, it was costly to maintain suitable temperature in the large greenhouse. If artificial lights could be found to elicit mating, then a controlled environment could be maintained with less expense.

In older open sided housing, up to 20 yr ago, dense mats of soldier fly larvae often formed under laying hens or swine when insecticides were not used (Lorimar et al. 2001). This situation was common in the southeastern United States and was also documented in California (Furman et al. 1959). Because adult *H. illucens* are reluctant to enter enclosed structures, including modern environmental animal housing, they now rarely colonize manure in these situations. Continuous culture of *H. illucens* will allow for development of value-added manure management systems in modern, fully enclosed animal housing using this insect.

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