

# Physiological, ethological and ecological features of *Hermetia illucen*

The Black Soldier Fly [*Hermetia illucens*] is a true fly in the family Stratiomyidae and subclass Pterygota. *H.illucens* has been a topic of interest in the ecological research world for many years. *H.illucens* possesses special physiological, ethological and ecological features that may allow *H.illucens* to become a model organism. This literature review looks at the physiological, ethological and ecological features of *H.illucens*. Existing literature about *H.illucens* has been searched and analyzed for this paper. From the literature search it was discovered that *H.illucens* is not known to have valuable impacts to the world at large. The purpose of doing this review is so that all information available on *H.illucens* can be chronicled and so the information can be used in real world applications. It provides a use of *H.illucens* as a model organism and aims to demonstrate a framework for real-world applications of *H.illucens*, such as *H.illucens* becoming a model organism for mosquitoes, Tsetse flies, and houseflies.

***An Ethological and Ecological Review of the real-world applications of *H.illucens****

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## Abstract

The Black Soldier Fly [*Hermetia illucens*] is a true fly in the family Stratiomyidae and subclass Pterygota. *H.illucens* has been a topic of interest in the ecological research world for many years. *H.illucens* possesses special physiological, ethological and ecological features that may allow *H.illucens* to become a model organism. This literature review looks at the physiological, ethological and ecological features of *H.illucens*. Existing literature about *H.illucens* has been searched and analyzed for this paper. From the literature search it was discovered that *H.illucens* is not known to have valuable impacts to the world at large. The purpose of doing this review is so that all information available on *H.illucens* can be chronicled and so the information can be used in real world applications. It provides a use of *H.illucens* as a model organism and aims to demonstrate a framework for real-world applications of *H.illucens*, such as *H.illucens* becoming a model organism for mosquitoes, Tsetse flies, and houseflies.

**Keywords:** Individual Ecology, Population Ecology, Behavioral Ecology, Mating, Ethology, Ecology

## **Main Text**

### **Anatomy/Physiology:**

*H.illucens* has various sexually dimorphic traits such as body size, features on the frons and head, abdominal spots and the shape of their abdominal terminalia to differentiate sex. Females have more whitish hairs on their face. Females only have four black frontal tubercles, and female abdomens are also more longer [Rozkosný, 1983]. The cerci has two segments [Rozkosný, 1983]. The females are also smaller than the males [Rozkosný, 1983]. The males have fewer whitish hairs on their face. [Rozkosný, 1983]. For males, the genitalia is relatively shorter than the female terminalia [Rozkosný, 1983]. The genitalia is in alignment with the syn sternum, possessing two posterolateral lobes on each side [Rozkosný, 1983]. As adults, female wing sizes are bigger than the males. Males had an average wing size of 14.24 mm, which females had an average wing size of 14.67mm [Gobbi et al, 2013]. As larvae, *H.illucens* can reach 27 mm in length and six mm in width [Rozkosný, 1983]. They are a dull, whitish color with a small, projecting head containing chewing mouthparts [Rozkosný, 1983]. Larvae pass through six instars and require 14 days to complete development [Rozkosný, 1983]. They eat a lot as larvae as when they are adults they cannot eat, as they lose their mouthparts [Rozkosny, 1983]. The energy they gain from being larvae is the energy they have for the rest of their lives [Rozkosný, 1983]. *H.illucens* as a pupa is dark brown in colour [Rozkosný, 1983]. As adults, *H.illucens* are black. [Rozkosný, 1983]. Because of its white tarsi, black legs, and elongated antenna *H.illucens* is a Batesian mimic of the wasp [Rozkosný, 1983]. They also have two transparent on their abdomen, allowing them to have a slender, wasp-like abdomen [Rozkosný, 1983]. They also have changed their behavior so that they act like wasps. This include the way they stand, move

and flight patterns [Rozkosný, 1983]. Adults range from 15 to 20 mm in length [Sheppard et al. 2002]. They live for about 5-8 days as adults [Newton, 2005].

### **Ethology:**

As larva, the flies have only one purpose and that is to eat [Tomberlin et al, 2013]. The reason why is because the energy that they get as a larva is the energy that they will use for the rest of its life [Tomberlin et al, 2002]. They move to get their food, and only eat as that is their only goal as larva. After they are ready to pupate, the larvae then move to a new area, preferably dry and cold to go through the transformations [Newton, 2005] When an adult *H.illucens* is territorial, as they follow a lekking system [Tomberlin et al. 2001]. This is because when it is time to mate, all the males try to find spots in the lekking area [Tomberlin et al. 2001]. The females only mate with the males who have territory to mate on [Tomberlin et al. 2001]. Males that do not have any territory do not have anywhere to mate [Tomberlin et al. 2001]. The more territory a male has, the greater of a chance they have or mating. If another male comes in the area, the two will fight, and the winner will take the territory [Newton, 2005]. The most popular territories are the ones that have had the most mating [Tomberlin et al. 2001]. *H.illucens* are not extremely competitive. Even if another male comes on their land, they are not going to immediately fight them, only if a female is coming will the two engage [Tomberlin et al. 2001]. Body size does not matter when it comes to mating as females mate with the first male that they see, regardless of size, [Tomberlin et al. 2001]. Also because *H.illucens* are not competitive, a smaller male can come onto lekking territory, and mate with a female on another males territory [Tomberlin et al. 2001]. Direct sunlight encourages mating for *H.illucens*, and it has rarely been

recorded mating on rainy or snowy days [Zhang et al, 2010]. Recorded in North America, mating activity begins at 8:00 am, and peaks at 10:00am CDT [Zhang et al, 2010]. Oviposition occurs on the 17th day, and has occurred without sunlight, but had a low chance [Tomberlin et al. 2001]. Females also had mating issue as females with larger wing sizes and larger bodies are more fertile than those with smaller bodies and smaller wings [Gobbi et al, 2013]. After mating, females lay their eggs on cracks and crevices near decaying matter [Zhang et al, 2010]. As larvae, *H.illucens* feed on the decaying organic material, they were born next to [Dicarlo et al. 2010]. But as adults, the flies cannot eat, they can only drink water [Tomberlin et al, 2013]. This is because their mouth cannot chew [Tomberlin et al, 2013]. Towards the end of being a larva, *H.illucens* becomes a puparium [Tomberlin et al, 2013]. A puparium is the last larval stage before pupating [Tomberlin et al, 2013]. As a puparium, they turn black from releasing melanin, a chemical into their skin that increases durability of the skin [Tomberlin et al, 2013]. They also enter a wandering stage and start to wander [Tomberlin et al, 2013]. They “wander” because they are looking for a place to pupate [Tomberlin et al, 2013]. This is a preferably a dry and cold place like an underground tunnel, and they also stop eating [Tomberlin et al, 2013]. When they find a proper habitat, they stop moving and connect to the ground vertically. [Tomberlin et al, 2013].

### **Ecology:**

*H.illucens* has a range from the Americas to South-Asia [Rozkosný, 1983]. They live in areas with lots of decaying matter [Rozkosný, 1983]. At all stages, *H.illucens* has a narrow range of temperatures they can live in, between 27-30 degrees Celsius [Rozkosný, 1983]. At 36 degrees

or higher, they die off. *H. illucens* is not active in winter months, due to the temperature, and because the adults die after breeding, leaving the eggs that will hatch in spring [Tomberlin et al, 2013]. Relative humidities of 30–90% were enough for mating, but the higher the humidity, the larger the larvae is. [Holmes et al. 2012]. As larvae, the *H. illucens* eat decaying organic material, like food scares and kitchen waste [Nguyen et al. 2012]. But as adults, the flies only drink water [Nguyen et al. 2012]. In order for *H. illucens* to achieve mating reliability, they must be in a space at least 0.76 by 1.14 by 1.37m or 10 liters [Sheppard et al, 2012]. The *H. illucens* habitat is patchily distributed, and includes various organic compositions including animal waste, spoiled fruits and vegetables, fish rendering waste, and carrion [Tomberlin et al, 2013]. These habitats can help, or hinder larval development [Tomberlin et al, 2013]. This is because the fish waste and animal waste hinder larva development, and leads to higher mortality rates [Tomberlin et al, 2013]. Fruits and vegetables decrease mortality, speed up larva development, and increase overall body size for *H. illucens* as adults [Tomberlin et al, 2013]. The main predators of *H. illucens* as both larvae and adults are other Dipterans [Peterson et al, 1960]. These include Empididae, Dolichopodidae, Ephydriidae, and Tendipedidae [Peterson et al, 1960]. Predators in other genres include Trichoptera, especially species of the genus *Hydropsyche* and Odonata [Peterson et al, 1960]. Hymenoptera is a parasitoid that only affects eggs of *H. illucens* [Peterson et al, 1960]. Non-insect predators include spiders, and leeches which only eat the larvae [Peterson et al, 1960]. Frogs are also well known predators of adult males because males go near bodies of water during mating season [Peterson et al, 1960]. *H. illucens* larvae are detritivores and have no real prey [Peterson et al, 1960]. Light affects mating because direct sunlight encourages mating for *H. illucens* [Zhang et al, 2010]. *H. illucens* has rarely been recorded mating

on rainy or snowy days because the light level is too low [Zhang et al, 2010]. In a laboratory setting, the level of light with the most amount of mating is 200 mols  $\mu/m^2$ . Insects cannot see infrared or red light [Zhang et al, 2010]. The shortest wavelength they can see up to is 700 nm [Zhang et al, 2010]. Members of Diptera only have light receptors for high blue or low green colors [480-530 nm] [Zhang et al, 2010]. Adult size is determined by pupal development [Gobbi et al, 2013]. The more energy the larvae was able to gather, the bigger the adult will be [Gobbi et al, 2013]. The amount of food that it receives as a larvae limits its growth. The diet also affects the mass of the flies, which affects fecundity [Gobbi et al, 2013]. Females with more mass had more offspring than those with a smaller amount of mass [Gobbi et al, 2013]. The temperature and gender of *H. illucens* can factor growth and fitness. At 27 and 30C, females weighed an average of 17-19% more than males [Tomberlin et al, 2009]. But males lived 20% longer [Tomberlin et al, 2009]. *H. illucens* are “r” selected [Tomberlin et al, 2009]. This is because they have about 320-620 eggs in a “big bang reproduction” and die off hours later [Tomberlin et al, 2009]. The eggs then grow up with no parental help [Tomberlin et al, 2009]. After the eggs are laid, it takes about 3-4 days for the eggs to hatch [Furman et al, 1959]. They stay as larvae for two weeks, and in the pupal stage for two weeks, but this period can increase to four months if resources are limited [Furman et al, 1959]. As adults, the flies live for 5-8 days. *H. illucens* live in random distributions [Tomberlin et al, 2002]. For larva, this is determined by the amount of supplies, and how they are spaced. In the pupal stage, this is determined by finding an adequate habitat to pupate [Tomberlin et al, 2002]. For adults, this is determined by gender, size, and territory [Tomberlin et al, 2002]. This is because males and females live in different areas before mating, and those who are bigger live in better area than those who are smaller [Tomberlin et al,



2002]. If their is better territory in a close radius, than they flies will be close [Tomberlin et al, 2002]. If it is spread out, then the flies will be spread out [Tomberlin et al, 2002]. In competition, *H.illucens* as an adult does not have any interspecific competition as they only drink water [Tomberlin et al, 2002]. They have intraspecific competition with each other for mating [Tomberlin et al, 2002]. Larvae also do not have much interspecific competition [Tomberlin et al, 2002]. This is because the larvae are detritivores and do not have competition for dead organic matter in the places that they live in [Tomberlin et al, 2002]. The larvae may compete with themselves in intraspecific competition in their are limited resources [Tomberlin et al, 2002]. And sometimes, other fly larvae may compete with *H.illucens* larvae for a resource [Tomberlin et al, 2002]. *H.illucens* is in a mutualistic relationship with some species of fungi [Brown et al, 1997]. This is because *H.illucens* put their eggs on dead fungi, giving them a food source [Brown et al, 1997]. When the eggs grow into larva, they eat the dead fungi, and other species of plants in the area [Brown et al, 1997]. This gives the fungi more room to grow. And when the adults die, they make the soil more nutritious for the fungus [Brown et al, 1997]. *H.illucens* plays a pivotal role in communities, as they regulate waste disposal [Brown et al, 1997]. *H.illucens* helps to keep ecosystems in check because they can keep the nitrogen and phosphorus levels in an ecosystem stable by eating unwanted manure that could damage the cycles [Furman et al, 1959]. Also, *H.illucens* keeps pest flies away because they eat the rotting organic matter, leaving the pest flies without a food source [Furman et al, 1959]. *H.illucens* also affected by parasitoids, especially Hymenoptera [Brown et al, 1997]. These insects put their offspring in the eggs of Dipterans , and take the nutrients away until the eggs die. After that, the Hymenoptera hatches and leaves [Brown et al, 1997].

### Connection to Wider Literature:

*H.illucens* and the knowledge that can be derived from it can be used beyond the implications of just research, to field such as forensics, commercial and medical use, to even recreational gardening. In the field of forensics, *H.illucens* could be used to find the minimum Postmortem interval [PMI] of a dead body [Nguyen et al. 2013]. Since *H.illucens* have their larvae in places with dead organic matter like a human, it could be used with the knowledge of the growth of *H.illucens* larvae in specific temperatures and with specific resources to find the date of death. For example, given a person who was killed on a 26 degree day and they have fruits and vegetables in their stomach, the information gathered about larval development could be used to find when the soldier flies deposit their larvae into the body [Nguyen et al. 2013]. This time can be used to give a date of when that person was killed, and can be used as evidence in a jury to prove or disprove innocence [Nguyen et al. 2013]. *H.illucens* can also be used to gain cheaper feed for farm animals [Tomberlin et al, 2002]. They eat a lot as larvae, and when pupating release a chemical called melatin which turns the pupal black [Tomberlin et al, 2002]. After it pupates, the vitamin count of a pupal is about that of a soybean, but cheaper and grows at a faster rate [Tomberlin et al, 2002]. And it is edible by almost every farm animal [Tomberlin et al, 2002]. *H.illucens* as a food can be grown directly at the farm [Newton, 2005] This is because as it eats decomposing organic matter, like animal feces [Newton, 2005]. This could save farms money as previously, they would have to import their food from other locations, wasting gas and transportation money [Newton, 2005]. It is estimated that *H.illucens* can could save a company \$25,000 per year per cage of livestock [Newton et al, 2005]. *H.illucens* as a larvae is used as

food for fish camps, in order to make fish bigger [Kroeckel et al, 2012]. This is because as larvae, they have a large amount of calcium which is important for fish development [Kroeckel et al, 2012]. This is not often found in a fish's diet, and helps fish become bigger [Kroeckel et al, 2012]. This brings the advantage of *H.illucens* larvae decreasing the amount of pollution from manure [Newton, 2005]. A problem of this generation is that the phosphorus, and nitrogen cycle have been corrupted by the use of artificial means of gaining these chemicals animals, especially cows. Companies make too much manure, and allow it to pile up because they cannot use it for anything else. This allows it to leak into water sources, which contaminates drinking water.

*H.illucens* as larvae are unsatisfiable eaters, and if put into manure can decrease the amount by up to 42-64% [Newton, 2005]. From the remaining compost, the adults would die on it after giving birth, making it of a higher quality [Newton, 2005]. *H. illucens* has also been used in the production of sugar and biodiesel from dairy manure [Li et al. 2011]. The use of *H.illucens* in farms can make food production safer [Newton, 2005]. *H.illucens*, when placed in manure and chicken coups lowered the amount of diseases, most notably *E.Coli* and *Salmonella* in the food [Erickson et al. 2014]. This is because the larvae alter the chemical composition in mature, making it harder for the diseases to form [Erickson et al. 2014]. This use of *H.illucens* is a cheap and accessible method that could be used to increase food safety, and save companies money from lawsuits [Erickson et al. 2014]. In the public world, *H.illucens* has more use than in the field of food and diseases [Newton, 2005]. It can be used to discourage other flies from coming to a certain area [Newton, 2005]. *H.illucens* can be used to get rid of flies because as a larvae it is a ravenous eater and eats fast [Newton, 2005]. This leaves little food for other flies [Newton, 2005]. Also, they way that it eats, churns its food and leaves it as a liquid [Newton, 2005]. This

is a state that the other flies cannot eat as larva, which kills the population overtime [Newton, 2005]. *H.illucens* can also be used in personal gardens [Newton, 2005]. They help get rid of pesky insects, and diseases in the area. Also, they are great at getting rid of unneeded compost, and make the remaining compost better [Newton, 2005]. *H.illucens* also has the potential of becoming a model organism for mosquitoes, houseflies, and Tsetse flies [Aksoy et al, 2014]. Tsetse flies spread Malaria and West Nile Disease by sucking the blood of people [Aksoy et al, 2014]. *H.illucens* have get sexual dimorphism that differentiates males and females [Rozkosný, 1983]. Mosquitos also have sexual dimorphism. Only female mosquitoes suck blood, the males do not [Aksoy et al, 2014]. This limits our focus of this problem. The next thing is that like *H.illucens*, mosquitoes are inactive in winter months due to cold temperatures [Aksoy et al, 2014]. And finally, Mosquitos locate mates because of the sound of the wings flapping [Aksoy et al, 2014]. If the females flap their wings louder, they get a mate faster. From *H.illucens*, weaknesses such as the cold weather and having to hear sound to mate could be used in order to decrease mosquito populations [Aksoy et al, 2014]. The could contribute in lowering Malaria rates and stopping Mosquito related diseases across the world. House flies can spread typhoid fever and yaws [Aksoy et al, 2014]. But like *H.illucens*, they both get advantages from humidity [Aksoy et al, 2014]. The higher the humidity, the faster the eggs will grow [Holmes et al. 2012]. So low humidity areas make it harder for the fly eggs to hatch [Holmes et al. 2012]. Both *H.illucens* and house flies also have to put their eggs in organic matter, so that they can get energy as they get older [Aksoy et al, 2014]. If mating areas are removed, then the amount of house flies in an area will decrease [Aksoy et al, 2014]. This would help to increase food and water safety, as well as stopping avoidable deaths. The Tsetse fly spreads Sleeping Disease, and

has 70 million people in Eastern Africa at risk [Aksoy et al, 2014]. Studying the fly is difficult because the females only lay one egg at a time at hundreds of locations [Aksoy et al, 2014]. The similarity with *H.illucens* and the Tsetse fly is that it has been shown that flies share the same genes that control sex development [Aksoy et al, 2014]. This means that if the the gene in *H.illucens* were controlled, the gender of the offspring could also be controlled [Aksoy et al, 2014]. This could allow us to release a strain of this onto a population, making all offspring males so that they cannot mate, eliminating a population [Aksoy et al, 2014].

### Conclusions:

From this review three conclusions were reached. They are that *H.illucens*, through its special physiological, ethological and ecological features can be used as a model organism. *H.illucens* larvae can be used in a lab setting because they are easy to take care of as they will eat decomposing matter [Tomberlin et al, 2002]. Larvae can also be put into cramped station in which hundreds of larvae can be stored [Tomberlin et al, 2002]. *H.illucens* adults will need more space to live, but will still be easy to take care of as the males no longer need to eat [Tomberlin et al, 2002]. The second conclusion of the paper is that *H.illucens* can be used in an industrial setting in order to cut costs and lower multiple types of pollutions on farms. As larvae, *H.illucens* eats the decomposing matter of the farm animals and after the larvae become pupae, the pupils can be used as food for the farm animals [Tomberlin et al, 2002]. This could save farms money as previously, they would have to import their food from other locations, wasting gas and transportation money [Newton, 2005]. The final conclusion is that *H.illucens* could be used in order to limit the diseases spread by Tsetse flies [Aksoy et al, 2014]. *H.illucens* and Tsetse flies share similar sexual dimorphisms, gender-specific behaviors and a gene that controls the sex of

the offspring [Aksoy et al, 2014]. These could be used in order to limit and decrease Tsetse fly populations [Aksoy et al, 2014]. *H. illucens* and its rise as being used could have larger implications in the fields of ecology, ethology and evolutionary biology [Aksoy et al, 2014]. These three conclusions help to expand the use of *H. illucens* into the wider scientific framework. *H. illucens* could be used in ecology to find more genes in specific organisms that can be controlled for human advantages [Aksoy et al, 2014]. *H. illucens* can also be used in ethology to study the behavior of similar organisms [Aksoy et al, 2014]. In evolutionary biology, *H. illucens* could be used by comparing the genes of *H. illucens* to other organisms [Rozkosný, 1983]. This could then be used in order to build cladograms and help expand phylogenetic theories [Rozkosný, 1983].

## **Declarations**

- Ethics approval and consent to participate: Not applicable
- Consent for publication: Not applicable
- Availability of data and material: Not applicable
- Competing interests: Not applicable
- Funding: No funding source
- Authors' contributions: SM conducted the literature research, analyzed the literature and wrote the paper. The author read and approved the final manuscript.
- Acknowledgements: Not applicable

## References:

Aksoy S, Attardo G, Berriman M, Scott M. “Genome Sequence of the Tsetse Fly [*Glossina morsitans*]: Vector of African Trypanosomiasis”. *Science*. 43: 234-235

Alock J. [1993]. The Effects of Male Body Size on Territorial and Mating Success in the Landmark-Defending Fly *Hermetia Comstocki* [Stratiomyidae]. *Ecological Entomology*. 18: 1-6

Brown B, Freeman D. 1997. Diptera as Parasitoids. *Annual Review Of Entomology*. 42: 73-97.

Diclaro II, J. W. ; Kaufman, P. E. [2010]. Black soldier fly *Hermetia illucens* Linnaeus [Insecta: Diptera: Stratiomyidae]. EENY-461, Entomology and Nematology Department, Florida Cooperative Extension Service, Institute of Food and Agricultural Sciences, University of Florida.

Erickson M, Islam M, Sheppard C, Liao J, Doyle M. [2004]. Reduction of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar enteritidis in chicken manure by larvae of the black soldier fly. *Journal of Food Protection*. 67:685–690.

FURMAN D, YOUNG R, CATTS P. 1959. *Hermetia illucens* [Linnaeus] as a factor in the natural control of *Musca domestica* [Linnaeus]. *Journal of Economic Entomology*. 52: 917–921.

Gobbi P, Martinez-Sanchez A, Rojo S. 2013. The effects of larval diet on adult life-history traits of the black soldier fly, *Hermetia illucens* [Diptera: Stratiomyidae]. *Departamento de Ciencias Ambientales y Recursos Naturales*. 110: 1-8.

Homes L, Vanlaerhoven S, and Tomberlin J. 2012. Relative Humidity Effects on the Life History of *Hermetia illucens* [Diptera: Stratiomyidae]. *Environmental Entomology*, 41:971-97

James M [1962]. Insects of Micronesia Diptera: Stratiomyidae ;Calliphoridae 13: 75-127

Kroeckel S, Harjes A. G, Roth I, Katz H, Wuertz S, Susenbeth A, Schulz C [2012]. When a turbot catches a fly: Evaluation of a pre-pupae meal of the Black Soldier Fly [*Hermetia illucens*] as fish meal substitute—Growth performance and chitin degradation in juvenile turbot [*Psetta maxima*]. *Aquaculture*. 364:345–352.

Li Q, Zheng L, Qiu N, Cai H, Tomberlin J, Yu Z. [2011]. Bioconversion of dairy manure by black soldier fly [Diptera: Stratiomyidae] for biodiesel and sugar production. *Waste Management*. 31:1316-1320.



Newton L.[2005]. Using The Black Fly, *Hermetia Illucens*, As A Value Added Tool For Swine Manure. State of the Science of Animal Manure and Waste Management. 2: 5-7.

Newton L, Sheppard C, Watson W, Burtle J, Dover., Tomberlin J, & Thelen E. [2005]. The black soldier fly, *Hermetia illucens*, as a manure management/resource recovery tool. In Symposium on the state of the science of Animal Manure and Waste Management.1: 5-7.

Nguyen T, Tomberlin J, Vanlaerhoven S. 2013. Influence of Resources on *Hermetia illucens* [Diptera: Stratiomyidae] Larval Development. Journal of Medical Entomology. 50:898-906.

Peterson B, Davies D[1960] OBSERVATIONS ON SOME INSECT PREDATORS OF BLACKFLIES [DIPTERA: SIMULIIDAE] OF ALGONQUIN PARK, ONTARIO. CANADIAN JOURNAL OF ZOOLOGY. 3: 9-18

Rozkosný, R[1983]. Subfamily Larentiinae. In A Biosystematic Study of the European Stratiomyidae [Diptera]: Volume 2-Clitelliinae, Hermediinae, Pachygaster Inae and Bibliography. 2:41

Sheppard C, Tomberlin J, Joyce J, K Barbara, Sumner S. [2002]. Rearing Methods for the Black Soldier Fly [Diptera: Stratiomyidae]. Journal of Medical Entomology, 39 :695-698

Tomberlin J, Adler P, and Myers H. 2009. Development of the Black Soldier Fly [Diptera: Stratiomyidae] in Relationship to Temperature.The Florida Entomologist. 38: 930-934

Tomberlin J, Holmes L, Valeahover S. [2013] Substrate Effects on Pupation and Adult Emergence of *Hermetia illucens*[Diptera: Stratiomyidae]. Environmental Entomology. 42. 370:374

Tomberlin J, Liu Q, Brady J, Yu Z. 2008. Black Soldier Fly [Diptera: Stratiomyidae] Larvae Reduce *Escherichia coli* in Dairy Manure. Journal Of Environmental Entomology. 37: 1525-1530.

Tomberlin J, Sheppard D, Joyce JA. 2002. Selected life history traits of *H.illucens* [Diptera: Stratiomyidae] reared on three artificial diets. Annals of the Entomological Society of America 95: 379-386.

Tomberlin J, Sheppard D. 2001. Lekking Behavior of the Black Soldier Fly [Diptera: Stratiomyidae] The Florida Entomologist. 84: 729-730

Zhang J, Huang L, He J, Tomberlin J, Li J, Lei C, Sun M, Liu Z, Yu Z. [2010]. An artificial light source influences mating and oviposition of *H. illucens*, *Hermetia illucens*. *Journal of Insect Science*. 10: 1-8.