Survival and Reproductive Value of *Hermetia illucens* (Diptera: Stratiomyidae) on Vegetable and Fruits Waste Rearing Substrate

U Julita¹, L L Fitri¹, R E Putra¹, and A D Permana¹

¹School of Life Sciences and Technology, Institut Teknologi Bandung, Bandung, 40132, Indonesia

agus@sith.itb.ac.id

Abstract. *Hermetia illucens*, black soldier fly has been a topic of interest in the ecological research world for many years especially in terms of its role as a bioconverter agent. Bioconversion process through black soldier fly represents a potential valuable solution to two problems: organic waste management on the one hand and on the other, the rising global demand for animal feed (transform organic waste into valuable animal feedstuff in the form of their last larval stage or prepupa). In this context, the aim of this study is to assess the survival and reproductive value of black soldier fly reared on vegetable and fruits waste. All treatments were constructed under laboratory conditions at 26±1°C temperature and 68%±0.5% relative humidity. The adult cage was placed near the window that allows sunlight to enter. Data were collected and analyzed based on an age-stage, two-sex life table. The intrinsic rates of increase (r) were 0.06877 and 0.05772 per days, finite rate of increase (λ) were 1.0712 and 1.0594 per days, net reproduction rate (R₀) were 25.88 and 19.99 offspring, and mean generation time (T) were 46.403 and 50.00 days on vegetable and fruits waste, respectively. Our results demonstrated high mortality in the larval period that probably caused by high levels of water produced by vegetables and fruits waste during the experiments.

1. Introduction

The composition of national waste in Indonesia is dominated by organic waste which is around 60% or 38.40 million tons per year which is mostly produced by household sector. Vegetables and fruits waste is one of the highest types of organic waste [1]. *Hermetia illucens*, the black soldier fly have been shown to be effective bioconverter and useful for managing large concentrations of organic waste. Black soldier fly larvae could feed on many different organic wastes, including animal manures [2][3], fruits waste [4] vegetables waste [5], and some indigestible food, such as rice straw waste [6][7], coffee pulp [8] and palm kernel meal [9]. Black soldier fly larvae contains high nutritional value of around 40% protein and 30% fat [10], that is very potential to be used as an alternative feed for livestock such as turbot [11] and broiler chicken [12]. Black soldier fly larvae can also be extracted into oil as a raw material for biodiesel production. It has lower toxicity, more biodegradable and less emissions compared to petroleum diesel [13]. Black soldier fly has high economic potential value, so many people are interested in mass production and conduct further research. However, the characteristics of development and growth of black soldier fly are strongly influenced by the growth substrate used during the larval period [14]. Therefore, the present study reported the effect of vegetable and fruit waste on the survival and
reproductive potential of the black soldier fly. In this study, an analysis of the age-stage, two-sex life table was carried out which will generate a comprehensive description in details of development, survival, fecundity and life expectancy of a population and is commonly used as a means of projecting the growth of populations.

2. Methods
The study was conducted at the laboratory of animal physiology and entomology, Biology Department, Faculty of Science and Technology, Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia.

2.1. Animal specimen
Eggs of black soldier fly obtained from adult colonies that were maintained in 60 x 60 x 60 cm screen cages in the laboratory.

2.2. Waste material
Fresh vegetable and fruits waste were collected at traditional market Ujung Berung East Bandung. The composition of vegetable waste include cabbage, mustard greens, and carrots, while fruit waste consists of papaya, banana and mango. Before being used as a substrate for black soldier fly larvae growth, all organic waste were chopped then mixed until well blended.

2.3. Treatments
Total of 100 eggs were carefully separated daily on the egg hatching medium (chicken feed). After the eggs hatch, the larvae are immediately transferred to the trial plastic cup (height 12 cm, diameter 8 cm) filled by vegetables waste or fruits waste as growing substrate. The trial was conducted with five replications. Each treatment contain 100 larvae fed with 100 mg/larvae/day daily feed rates. The experiment were carried out under room condition, temperature 26 ± 1°C, relative humidity 70 ± 5% and photoperiod Light : Dark = 12 : 12 hours. The developmental time of individuals, both male and female, the daily survival rate and fecundity were observed and recorded until the death of all individuals.

2.4. Data analysis
The data were analyzed using an age-stage, two-sex life table [15] and following the procedure described by Chi [16]. The adult preoviposition period (APOP) (the duration from adult emergence to first oviposition) and total preoviposition period (TPOP) (the duration from egg to first oviposition) were calculated. The population parameters (net reproductive rate (R₀), intrinsic rate of increase (r), finite rate of increase (λ) and mean generation time (T ) were also calculated. The age-stage life expectancy (eₓj) was calculated according to Chi and Su [17]. Because of the variation among individuals, the means and standard deviations calculated using the bootstrap method [18], it was 10,000 bootstrap to fit the normal distribution.

3. Results and discussion
The means and standard errors of the development time for each life stage, adult longevity, adult preoviposition and the fecundity of black soldier fly on vegetable and fruits waste rearing substrate are given in Table 1. Out of the cohort of 100 eggs at the beginning of each experiment, 87 and 94 eggs hatched within 5 day for vegetables waste and fruits waste rearing substrate respectively. Total development time (from egg to adult stage) of black soldier fly reared on vegetable waste and fruits waste not significantly different or about 59 days. Larva and adult period of black soldier fly reared on vegetables waste took longer to complete their development when compared with those reared on fruits waste. Whereas the pupa period was longer for fruit waste treatment than vegetable waste treatment. In this study, during the life span of female black soldier fly, the average number of eggs laid per female ranged from 98 to 204 eggs for vegetables waste treatment and 101 to 211 eggs for fruits waste treatment.
The fecundity value was smaller than the previous study, that number of eggs laid per female ranged from 236 to a maximum of 1,088 eggs [19] and ranged of 206–636 eggs per female when black soldier fly reared under artificial diet [14]. Feeding activity of black soldier fly occurs only in the larval period and maximizes the accumulation of high fat reserves so it sufficient for the needs of energy sources to the adult stage [2]. Insect larvae tend to consume a balanced and sufficient diet for their growth and development, which results in reproductive competitive adults. Thus, the quality of food available plays an important role in the subsequent development of adults [20]. The larval development of black soldier fly depends not only on temperature and humidity but also on various types and amounts of organic material and the proportion of liquid food components [21].

| Parameter                           | Stage  | Vegetable waste | Fruits waste |
|-------------------------------------|--------|-----------------|--------------|
| Developmental time (days)           | Egg    | 5.0 ± 0.0       | 5.0 ± 0.0    |
|                                     | Larva  | 16.0 ± 0.0      | 14.4 ± 0.5   |
|                                     | Prepu  | 10.0 ± 0.3      | 10.0 ± 0.5   |
|                                     | Pupa   | 10.4 ± 0.2      | 15.4 ± 0.4   |
| Adult longevity (days)              | Male   | 18.4 ± 1.5      | 15.2 ± 0.5   |
|                                     | Female | 17.4 ± 0.5      | 14.4 ± 1.2   |
| Adult preoviposition (days)         | APOP   | 4.6 ± 0.6       | 6.2 ± 0.7    |
|                                     | TPOP   | 53.8 ± 0.8      | 56.2 ± 0.2   |
| Fecundity (eggs/female)             | Female | 131 ± 18.7      | 138 ± 19.9   |

The means and standard errors of population parameters of black soldier fly in the different treatments investigated are listed in table 2. The difference in rearing substrate affects all population parameter values. Black soldier fly treated with vegetable waste has a higher intrinsic rate of increase (r), finite rate of increase (λ), and net reproductive rate (R0) than black soldier fly treated with fruits waste. The mean generation time (T) of black soldier fly reared on vegetable waste was shorter than reared on fruit waste. However, the population parameter value was lower than that reported by Samayoa et al. [19].

Table 2. Population parameters of black soldier fly reared on vegetable waste and fruits waste estimated by the bootstrap method

| Population parameter                          | Vegetable waste | Fruits waste |
|-----------------------------------------------|-----------------|--------------|
| Intrinsic rate of increase (r) (per days)     | 0.0687          | 0.0687       |
| Finite rate of increase (λ) (per days)        | 1.0712          | 1.0712       |
| Net reproductive rate (R0) (offspring)        | 25.88           | 25.88        |
| Mean generation time (T) (days)               | 46.403          | 50.000       |

Calculation of r values is useful as a concept for studying insect populations, as introduced by Huang and Chi [22]. According to life table theory a population was increasing only when R0 > 1 and r > 0 or when r < 0 the population could not increase caused by unfavorable conditions [23]. In this study, R0>1 and r > 0 for both treatment, indicating that the black soldier fly population increase in vegetable waste and fruits waste rearing substrates. In addition, the intrinsic rate of increase (r) is a critical demographic
element among other population parameters to determine the level of environmental resistance to insects [24].

The age-stage specific survival rate (S_{xj}) of black soldier fly on different rearing substrate indicates the probability that a new born will survival to age x and develop to stage j (Figure 1). Due to the variable developmental rates among individuals, there are significant overlaps between stages in the survival curves. The total developmental time was not significantly different between vegetable waste and fruits waste. The survival rates of larvae and adult on vegetable waste were lower than on fruits waste. The first females and males emerged earlier and longevity of adult was longer on vegetable waste than fruits waste.

![Figure 1](image1.png)

**Figure 1.** Age-stage-specific survival rate (S_{xj}) for individuals of age x and stage j of black soldier fly individually reared on (a) vegetable waste and (b) fruits waste

By ignoring the stage differentiation, a single age-specific survival rate (lx) gives the probability that a newborn will survive to age x (Figure 2). The age-specific survival rate (lx) and the age-specific fecundity (mx) were calculated by including all individuals of both sexes. The lx curve describes the change in the survival rate of the cohort with age. The curve of age-specific fecundity (mx) shows that reproduction began at age 45 and 50 days on vegetable waste and fruits waste, respectively.

![Figure 2](image2.png)

**Figure 2.** Age-specific survival rate (lx) and age-stage fecundity (mx) of black soldier fly individually reared on (a) vegetable waste and (b) fruits waste
Based on the age-stage survival rate, we calculate the life expectancy for each age-stage interval (Figure 3) for the prediction of the future life of the population. The life expectancy \( \text{ex}_j \) is the time that an individual of age \( x \) and stage \( j \) is expected to live. From Figure 3 it is obvious that the life expectancy of eggs, larvae, and the adult is higher on vegetable waste than fruits waste. Adult longevity of male and female on vegetable waste is much longer on vegetable waste than fruits waste.

![Figure 3](image_url)

**Figure 3.** Age-stage life expectancy \( \text{ex}_j \) for individuals of age \( x \) and stage \( j \) of black soldier fly, individually reared on (a) vegetable waste and (b) fruits waste

The contribution of an individual to the future population termed as the reproductive value. Female adult emerged earlier and has a higher reproductive value at vegetable waste than fruits waste. The reproductive value increases from egg stage to adult and significantly increases at the time of emergence of the adult females (Figure 4). In determining reproductive value, there is no curve for males because the contribution of males to the future population is not defined [25]. Egg production in adult black soldier fly may possibly be increased by adding intake of protein sources so that affect the enhancement of reproductive potential as was shown with the house fly \( (\text{Musa domestica}) \) [26].

![Figure 4](image_url)

**Figure 4.** Age-stage reproductive value \( \text{vx}_j \) of black soldier fly individually reared on (a) vegetable waste and (b) fruits waste

Black soldier fly mainly feeds during its larval stage and plays an important role as bioconverter of organic waste into edible biomass, of which the quality of biomass may depend on nutrient composition of the rearing substrate [27]. Our results demonstrated high mortality in the larval period that probably
caused by high levels of water produced by vegetables and fruits waste during the experiments. Black soldier fly larvae cannot survive in a medium that is too wet or contains a lot of water, thus creating anaerobic conditions. In such conditions, larvae will have difficulty in accessing food sources, thus inhibiting the growth rate and the bioconversion of organic waste. Black soldier fly is a highly resistant species that is able to deal with demanding environmental conditions, such as drought, lack of food or oxygen deficiency, however, waste sources that turn into anaerobes, temperatures that reach lethal values or high concentrations of heavy metals that exceed certain thresholds can be fatal to the larval population [28].

4. Conclusion
Vegetable and fruits waste are suitable for black soldier fly larvae rearing substrate and support its growth and development. However, an effective rearing system is needed to reduce the excess water produced by vegetable and fruits waste. Black soldier fly with vegetable waste treatment had better reproductive potential compared to fruit waste treatment. Proximate analysis of vegetable and fruits waste are needed to find out the correlation between nutrient content of rearing substrate and reproductive value.

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