Influence of various organic wastes on growth performance and nutrient composition of black soldier fly larvae (*Hermetia illucens*): A meta-analysis

E L Fitriana¹, E B Laconi² and A Jayanegara²

¹Graduate School of Nutrition and Feed Science, IPB University, Jl. Agatis Kampus IPB Dramaga, Bogor 16680, Indonesia
²Department of Nutrition and Feed Technology, Faculty of Animal Science, IPB University, Jl. Agatis Kampus IPB Dramaga, Bogor 16680, Indonesia

E-mail: el.fitrianal@gmail.com

Abstract. Black soldier fly (BSF) larvae (*Hermetia illucens*) is a potential protein source in animal feed. The development and nutrient composition of BSF larvae depend on its substrate. The objective of this study was to evaluate the effects of various organic wastes as substrates on growth performance and nutrient composition of BSF larvae across various studies by employing a meta-analysis method. A database was developed by integrating data from 47 studies that derived from 13 articles. The articles were derived from several electronic databases such as Science Direct and Google Scholar. Organic substrates were categorized into four groups, i.e., food waste, animal feed, faeces, and other substrates (those which could not be included into the previous three groups). These groups were statistically analyzed by using analysis of variance and continued with the Duncan multiple range test to compare among different group means. The results showed that food waste and animal feed substrates had higher percentage of waste reduction index and conversion rate as compared to those of faeces and other substrates (P<0.05). Animal feed substrate had higher prepupal yield mass of BSF larvae than that of food waste substrate (P<0.05). In regard to nutrient composition of the BSF larvae, both crude protein and ether extract of the insect species were not influenced by the different substrates and revealed relatively similar values. In conclusion, a more nutritious substrate leads to a faster growth and a higher mass yield of BSF larvae, but it does not alter nutrient composition of the insect.

1. Introduction

Black soldier fly (BSF) larvae (Diptera: Statiomyidae, *Hermetia illucens*) is an insect that rich in protein and very well-known for its ability in decomposing organic waste. BSF larvae contains more than 40% protein which is rich of essential amino acids, more than 28% lipid, and rich in calcium and phosphorus [1,2]. BSF larvae has superior adaptability for various organic substrates such as coffee industry by-product, vegetable waste, food waste, fish waste, and faeces [3–5]. Therefore, BSF has been considered as a potential feed ingredient for poultry and ruminant.

The substrate has two functions in BSF larvae production, i.e., as a growing media and feed for BSF larvae. As a media, BSF larvae production is influenced by humidity [6] and pH [7]. As a feed, BSF
larvae production is influenced by nutrient composition of substrate. The substrate influences the larvae production through its characteristic on humidity, pH, and nutrient composition. Substrate usage is dependent on the production purpose. Generally, rearing BSF larvae as a feed uses organic wastes because due to their affordable costs. Various organic wastes as substrates for BSF larvae have been studied. Although BSF larvae could be developed on almost every type of organic wastes, but the differences of substrate would considerably influence a BSF larvae production. This study aimed to evaluate the effects of various organic wastes as substrates on growth performance and nutrient composition of BSF larvae across various studies by employing a meta-analysis method.

2. Method
A database was integrated from published articles about substrate for rearing BSF larvae. The articles were obtained from several electronic databases such as Science Direct and Google Scholar. The parameters at this study consisted of two parameter groups, that are performance related parameters and nutrition related parameters. The first one consisted of waste reduction rate (WRR), waste reduction index (WRI), conversion rate (CR), feed conversion rate (FCR), growth rate (GR), fresh larva weight (FLW), dry larva weight (DLW), prepupal yield (PY), survival rate (SR), whereas the second group consisted of dry matter, ash, crude protein, and ether extract contents of the BSF. The database was developed by integrating data from 47 studies that were derived from 13 articles (table 1). The next stage was substrate categorization, in which the substrates were categorized into four groups, i.e., food waste, animal feed, faeces, and other substrates (those which could not be categorized into the previous three groups).

Table 1. Studies included in the meta-analysis of various organic wastes on growth performance and nutrient composition of BSF larvae

| References      | Substrate                          | Group         |
|-----------------|------------------------------------|---------------|
| Cai et al [8]   | Flammulina velutipes root waste    | Food waste    |
|                 | Bran                               | Animal feed   |
|                 | Kitchen waste                      | Food waste    |
| Leong et al [9] | Sewage sludge                      | Others        |
|                 | Fruit waste                        | Food waste    |
|                 | Palm decanter                      | Others        |
| Gao et al [10]  | Wheat bran                         | Animal feed   |
|                 | Fermented maize straw              | Others        |
| Ooincx et al [11]| Chicken feed                      | Animal feed   |
| Ooincx et al [12]| Chicken feed                      | Animal feed   |
| Myers et al [13]| Dairy manure                      | Faeces        |
| Nyakeri et al [14]| Banana peels                     | Food waste    |
|                 | Brewer’s waste                    | Food waste    |
|                 | Faecal sludge                     | Faeces        |
| Banks et al [15]| Fresh human faeces                | Faeces        |
| Tschirner & Simon [16]| Mixture of middling from a feed meal | Animal feed |
|                 | Dried distillers’ grains with soluble | Animal feed |
|                 | Dried sugar beet pulp             | Animal feed   |
| Jucker et al [17]| Fruit waste                      | Food waste    |
|                 | Vegetable waste                   | Food waste    |
|                 | Fruit + Vegetable waste           | Food waste    |
| Jucker et al [18]| Cricket waste                    | Animal feed   |
|                 | Locust waste                      | Animal feed   |
| Bava et al [19] | Hen diet                          | Animal feed   |
|                 | Maize distiller                   | Animal feed   |
|                 | Okara                             | Food waste    |
|                 | Brewer’s grains                   | Food waste    |
| Diener et al [20]| Chiken feed                      | Animal feed   |
The four groups of substrates were statistically analyzed by using analysis of variance and continued with the Duncan multiple range test to compare among different group means. Statistical analysis was carried out using IBM SPSS Statistics software version 20.

3. Results and discussion

All the performance parameter results are presented in table 2. Waste reduction index values showed a different group at food waste and animal feed substrates with higher waste reduction index than other substrate (p<0.05). It is indicated that the other substrate have the most unsuitable feeding rate to efficiency reduce waste. Other substrate was consisted of sewage sludge, palm decanter, and fermented maize straw. Sewage sludge waste has extra cellular polymeric substances (EPS) cell as a protective shield was formed by bacteria [9]. Hence, the EPS prevents BSF larvae to hydrolyze sewage sludge as a substrate. On the other hand, palm decanter and fermented maize straw have a high fiber content which it could be hold substrate reducing. BSF larvae were able to grow on high fiber carbohydrate substrate because cellulase enzymes that presence within the gut of BSF, although with a low growth performance and larvae biomass [21].

| Parameters                  | Food waste | Animal feed | Faeces | Others |
|-----------------------------|------------|-------------|--------|--------|
| Waste Reduction Rate (%)    | 54.5±16.8  | 45.8±12.0   | 46.3±10.8 | 48.4±0.00 |
| Waste Reduction Index (%)   | 2.81±1.43ab| 2.70±1.14b  | -      | 0.82±1.09a  |
| Conversion Rate (%)         | 7.36±8.59ab| 16.3±14.7b  | 10.7±8.53ab | 0.23±0.23a  |
| Feed Conversion Rate (%)    | 3.27±1.07  | 1.80±0.00   | 10.3±11.5 | -      |
| Growth Rate (g day⁻¹)       | 0.163±0.223| 0.005±0.000 | -      | 0.027±0.115 |
| Fresh Larvae Weight (mg)    | 388±50.2   | 42872.8     | 197±71.6 | 5.29±0.00  |
| Dry Larvae Weight (mg)      | -          | 37.9±18.9   | -      | 1.49±0.00  |
| Prepupal Yield (g)          | 1534±3.8a  | 1313±112.5b | 82.2±50.0a | -      |
| Survival Rate (%)           | 92.6±3.75  | 76.7±23.3   | -      | 93.0±0.00  |

Animal feed, food waste and faeces substrates has high conversion rate value (p<0.05). It is indicated that they have high the efficiency of conversion of substrate to biomass. The ability of the larvae to consume substrate can be attributed to diet structure, nutrient composition and moisture content [14]. All the substrates in this study have a similar moisture content (around 60–70%), but they have various nutrient composition. The animal feed substrate contained a similar range in crude protein (15–39% dry matter) and ether extract (3–17% dry matter) with the food waste and faeces substrates, whereas a higher non fiber carbohydrate has a large range (7–50% dry matter) than food waste and faeces substrates. The nutrient content ration affected growth performance and maturity of BSF larvae. The best ration for nutrient of substrate is 1:1 for protein and non-fiber carbohydrate. BSF larvae reared on balanced substrate of protein and carbohydrate developed the fastest growth performance [22]. Interestingly, the highest value of conversion rate was coupled with the lowest of feed conversion rate. In this case, it was implied that animal feed substrate not only being consumed effectively, but also highly assimilated into BSF larvae biomass. It led the animal feed as a substrate with the highest prepupal yield value (P<0.05) but were not influenced waste reduction rate, feed conversion rate, growth rate, fresh larva weight, dry larva weight, and survival rate (P>0.05).
Table 3. Influence of organic wastes on nutrient composition of BSF larvae

| Parameters       | Food waste   | Animal feed | Faeces |
|------------------|--------------|-------------|--------|
| Dry Matter (%)   | 37.0±0.64    | 32.5±6.83   | -      |
| Ash (% DM)       | 6.66±1.06    | 11.5±6.18   | -      |
| Crude Protein (% DM) | 43.9±8.66    | 46.3±6.70   | 45.4±0.00 |
| Ether Extract (% DM) | 31.1±6.09    | 27.2±11.1   | 18.1±0.00 |

The nutrient compositions of BSF larvae are presented in Table 3. Macro nutrients analyzed in this paper consist of dry matter, ash, crude protein, and ether extract. All the nutrients were not influenced by the different substrates. With regard to the substrates analyzed in this paper, the substrates have 32.5–37.0 % dry matter content, 6.66–11.5% ash content, 43.9–46.3%, crude protein and 18.1–31.1% ether extract content. These results was not coherent with previous studies about BSF larvae which stated that nutrient compositions of the substrate influenced the nutrient compositions of the BSF larvae. The level of ether extract observed in the larvae are probably due to the non-fiber carbohydrate levels found in the substrate [23]. The high level of crude protein content was due to a direct incorporation of the crude protein content in the substrate [19]. The different result could be occurred, because in this study used a different time of rearing BSF larvae data on each substrate. This is explains that the low nutrient substrate could be result a level nutrient of BSF similar with a high nutrient substrate with a long time of rearing.

4. Conclusion
The high and balanced nutrient content of the substrate is an important factor to produce BSF larvae effectively. A low nutrient content of the substrate could reduce growth performance, but it still produces BSF larvae with a high crude protein and ether extract contents.

References
[1] Balolong C J L, Jumawan B S and Taer E C 2020 Carcass quality evaluation of broilers fed with black soldier fly (Hermetia Illucens) larvae J. Environ. Sci. Computer Sci. Eng. Technol. 9 272–80
[2] Spanghers T, Ottoboni M, Klooijtjck W, Ovyn A, Deboosere S, Meulenaar B D, Michiels J, Eeckhout M, Clercq P D and Smet S D 2017 Nutritional composition of black soldier fly (Hermetia illucens) prepupae reared on different organic waste substrates J. Sci. Food. Agric. 97 2594–600
[3] Rehman K, Cai M, Zheng L, Xiao X, Somroo A A, Wang H, Li W, Yu Z and Zhang J 2017 Conversion of mixtures of dairy manure and soybean curd residue by black soldier fly larvae (Hermetia illucens L.) J. Clean. Prod. 154 366–73
[4] Rehman K, Cai M, Xiao X, Zheng L, Wang H, Soomro A A, Zhou Y, Li W, Yu Z, Zhang J 2017 Cellulose decomposition and larval biomass production from the co-digestion of dairy manure and chicken manure by mini-livestock (Hermetia illucens L.) J. Environ. Manag. 196 458–65
[5] Jiang C L, Jin W Z, Tao X H, Zhang Q, Zhu J, Feng S Y, Xu X H, Li H Y, Wang Z H and Zhang Z J 2019 Black soldier fly larvae (Hermetia illucens) strengthen the metabolic function of food waste biodegradation by gut microbiome Microb. Biotechnol. 12 528–43
[6] Cheng J Y K K, Chiu S L H H and Lo I M C C 2017 Effects of moisture content of food waste on residue separation, larva growth and larva survival in black soldier fly bioconversion Waste Manag. 67 315–23
[7] Moneguz M, Gasco L and Tomberlin J K 2018 Impact of pH and feeding system on black soldier fly (Hermetia illucens, L; diptera: Stratiomyidae) larval development Plos One 13 1–15
[8] Cai M, Zhang K, Zhong W, Liu N, Wu X, Li W, Zheng L, Yu Z and Zhang J 2017 Bioconversion-composting of golden needle mushroom (Flammulina velutipes) root waste by black soldier fly (Hermetia illucens, diptera: Stratiomyidae) larvae, to obtain added-value biomass and fertilizer Waste Biomass Valor 10 265–73

[9] Leong S Y, Kutty S R M, Malakahmad A and Tan C K 2015 Feasibility study of biodiesel production using lipids of Hermetia illucens larva fed with organic waste Waste Manag. 47 84–90

[10] Gao Z, Wang W, Lu X, Zhu F, Liu W, Wang X and Lei C 2019 Bioconversion performance and life table of black soldier fly (Hermetia illucens, diptera: Stratiomyidae) larvae, to obtain added-value biomass and fertilizer Waste Biomass Valor 10 73–84

[11] Oonincx D G A B, Laurent S, Veenenbos M E and Loon J J A 2019 Dietary enrichment of edible insects with omega 3 fatty acids Insect Sci. 27 500–09

[12] Oonincx D G A B, Broekhoven S, Huis A and Loon J J A 2015 Feed conversion, survival and development, and composition of four insect species on diets composed of by-products Ploss One 10 1–20

[13] Myers H M, Tomberlin J K, Lambert B D and Kattes D 2008 Development of black soldier fly (diptera: Stratiomyidae) larvae fed dairy manure Environ. Entomol. 37 11–15

[14] Nyakeri E M, Ogola H J O, Ayieko M A and Amimo F A 2017 Valorisation of organic waste material: growth performance of wild black soldier fly larvae (Hermetia illucens) reared on different organic wastes J. Insects as Food and Feed 3 193–202

[15] Banks I J, Gibson W T and Cameron M M 2014 Growth rates of black soldier fly larvae fed on fresh human faeces and their implication for improving sanitation Trop. Med Int. Health 19 14–22

[16] Tschirner M and Simon A 2015 Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed J. of Insects as Food and Feed 1 249–59

[17] Jucker C, Erba D, Leonardi MG, Lupi D and Savoldelli S 2017 Assessment of vegetable and fruit substrates as potential rearing media for Hermetia illucens (diptera: Stratiomyidae) larvae Environ. Entomol. 46 1415–23

[18] Jucker C, Lupi D, Moore C D, Leonardi M G and Savoldelli S 2020 Nutrient recapture from insect farm waste: bioconversion with Hermetia illucens (L.) (diptera: Stratiomyidae) Sustainability 12 1–14

[19] Bava L, Jucker C, Gislon G, Lupi D, Savoldelli S, Zucali M and Colombini S 2019 Rearing of Hermetia illucens on different organic by-products: influence on growth, waste reduction, and environmental impact Animals 9 1–16

[20] Diener S, Zurbugg C, Tockner K 2009 Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates Waste Manag. Res 27 603–10

[21] Lee C M, Lee Y S, Seo S H, Yoon S H, Kim S J, Hahn B S, Sim J S and Koo B S 2014 Screening and characterization of a novel cellulase gene from the gut microflora of Hermetia illucens using metagenomic library J. Microbiol. Biotechnol. 24 1196–06

[22] Cammack J A and Tomberlin J K 2017 The impact of diet protein and carbohydrate on select life-history traits of the black soldier fly Hermetia illucens (L.) (diptera: Stratiomyidae) Insects 8 1 – 16

[23] Meneguz M, Schiavone A, Gai F, Dama A, Lussiana C, Renna M and Gasco L 2018 Effect of rearing substrate on growth performance, waste reduction and chemical composition of black soldier fly (Hermetia illucens) larvae J. Sci. Food Agric. 98 5776–84