Biotechnology application of organic waste management using black soldier fly, *Hermetia illucens*

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ABSTRACT

Nowadays, climate change attribution and improper management of waste have great attention. So, it’s necessary to use the best environmental practices (BEP) concept in waste management, especially organic type. The most affordable technology which belongs to biotechnology application is black soldier fly larvae (BSFL). So, this research aims to study the ability to use the black soldier fly, *Hermetia illucens* as a bio-recycling tool of fruit wastes. Quantitatively colorimetric analyses of the harvested BSFL fed on fruit waste were investigated with respect to the control case in this study. The results revealed a significant increase in biomolecules concentration, especially free amino acids with +2.6 x-fold in the fruit waste input with respect to control input materials of BSF colony. Besides, the elevated levels of antioxidants enzymes. These results emphasized the contribution of involving BSFL in converting non-valued input materials into highly valued products that have promising levels of antioxidants and essential biomolecules in an eco-friendly way. This research will be a willing step for getting the recognizing of investors, policymakers, and social entrepreneurs to achieve sustainability and circular economy concept through BSF technology.

Key words: Black soldier fly, Fruit waste management; Antioxidants, Circular economy;

INTRODUCTION

The challenges related to waste management especially organic one has the priority attention worldwide. The direct side effects from improper management of organic wastes leads to transmission of various diseases related to public health, increases the effect of climate change actions which associated with emission of greenhouse gases (GHG), and the indirect effects exist on the food security status due to increase population with the limited food staff availability. So, it’s necessary to apply the circular economy concept in both developing and developed countries to save our life in a good environmental condition (Vermeulen *et al.*, 2012; Kaza *et al.*, 2018; Sovacool *et al.*, 2021). On one hand, the rapid increase of overall population has prompted economic growth, with increasing the need of food, and feed (Ghisellini *et al.*, 2016). Moreover, the growth of waste generation per capita, leads to various side impacts on environment, and natural resources (Mohan *et al.*, 2016). A lot of polices and directives, have been applied to mitigate and adapt the adverse environmental effect of products or services during their whole life cycle from raw materials extraction to final disposal (Scarlat *et al.*, 2015). Within these directives’ framework, there were essential steps to introduce the circular economy concept, principles and methodology to achieve the sustainability
with its pillars environmental, social and economic, also, to develop the circular economy concept instead of linear economy concept (Bonviu, 2014). Thus, the circular economy application permits, the natural resources preservation especially in the production path (Guillard et al., 2018; Isa et al., 2021), as the circular economy concept based on the biological concept focused on the transformation of carbon reserve from organic wastes into a wide range end-products which involving biofuels, food, feed, biochemicals, and biopolymers (Székács, 2017). This shifting strategy towards bioeconomy leads to increase economic development through the availability of job creation through various innovative tools based on technology (Lainez et al., 2018). The development of desired regulations is considered as a top priority to stimulate the eco-friendly product design and encourage companies to create eco-friendly products. Also, the successful collaboration between academics, industry, private sector, governmental and non-governmental organizations, is considered as an essential factor to launch collaborations for achievement of sustainable development goals (Maina et al., 2017).

Agriculture food especially, fruits has an essential role in our food style. Therefore, there is an increase demand of these food with increasing the world population and altering nutritional habits (Schieber et al., 2001; Vilariño et al., 2017; Sagar et al., 2018). There was worldwide attention to produce fruits for example 124.73 million metric tons (MMT) of citrus, 84.63 MMT of apples, and 45.22 MMT of mangoes (Sagar et al., 2018). The increasing in fruits production levels, and the improper management practices, procedures and infrastructure, have led to fruits waste generation. For instance, the United Nations Food and Agriculture Organization (FAO) has predictable that at 1.3 billion metric tons per year and reaching up to 60% is considered as waste (Sagar et al., 2018). The fruit losses occur during all phases of fruits supply chain, which involving the harvesting process, transportation, storage, marketing, and processing (Parfitt et al., 2010). Also, many fruits, such as oranges, apples, and pineapples are applied for extraction of juice, jams, pulp and finally supplying the significant waste quantities (Rodríguez et al., 2006). These fruit wastes are considered as a source of valuable bioactive compounds, enzymes, and antioxidants which has antitumor, antimutagenic, and antiviral activities (Dilas et al., 2009; Yahia, 2017) and can be used in different industrial applications such as food, feed, pharmaceutical, and textile industries (Sagar et al., 2018).

There are a lot of techniques related to food waste management which including anaerobically digested techniques (Chiew et al., 2015), incineration, landfill, composting, bio-cell (Bjarnadottir et al., 2002; Bernstad et al., 2012), mechanical/biological treatment (PCR, 2008), dark fermentation pyrolysis, gasification, and hydrothermal carbonisation (Beylot et al., 2013; Girotto et al., 2015). Each technology has the positive and negative environment, social and economic impacts.

So, it's essential to develop a sustainable technique to recycle the food wastes especially, fruits. One of these available technologies, that used to achieve sustainability through waste management system, is called black soldier fly which is considered as a quite large insect. It has a complete metamorphosis which includes egg, larvae, pupae, and adult stages. Its larval stage has the ability to consume a variety of organic materials, which include fruits, vegetables, animal remains and manure (Nguyen et al., 2015).

The aim of the present work is to evaluate the ability of using black solider fly larvae as a bio-recycling machine of fruit waste materials. The quantitively colorimetric analysis were performed to
assess the concentration of biomolecules (proteins, free amino acids, carbohydrates, and lipids); the levels of enzymatic antioxidants (glutathione peroxidase (GPx), glutathione reductase (GR), glutathione s transferase (G-S-T), superoxide dismutase (SOD), catalase (CAT), and polyphenol oxidase (PPO)); the amount of non-enzymatic antioxidants (α,α-diphenyl-β-picrylhydrazyl (DPPH), and Reduced glutathione (GSH)); and finally, assess the concentration of essential and non-essential amino acids (aspartic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine (GLY), alanine (ALA), valine (VAL), iso-leucine (ILE), leucine (LEU), tyrosine (TYR), phenyl alanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), and proline (PRO)). All these experimental techniques were performed in the 5th instar *Hermetia illucens* which fed on fruit waste materials with comparing with control or ideal input materials.

**MATERIALS AND METHODS**  
**Waste and Insect source supplying and treatment cases design**

The fruit wastes were obtained from restaurants, focused on preparing take away juice, it is located at Cairo University campus. The black soldier fly (BSF), *Hermetia illucens* were supplied from the colony of Entomology Department, Faculty of Science, Cairo University, Egypt. About 3000 numbers of 5th instar insect larvae were divided into two groups, the first one (case A) is considered as a control group was fed on the synthetic diet contained 1% essential biomolecules (proteins, carbohydrates, amino acids, and lipids); the second group (case B) was fed on fresh fruit waste which pre-homogenized before supplied to insect larvae to facilitate larval feeding. Each experimental group was done in three times. The insects’ larvae of the two groups were supported daily feeding by 0.5 kg for 10 days. After that late 5th instar larvae were collected and were sterilized using high pressure and temperature autoclaving and finally, were stored at −20 °C until use.

**Measurements of biomolecules concentration**

The stored collected samples of BSF larvae were homogenized using mortar (30 spikes in 30 sec) at pH=7.0 and centrifuged at 1000 rpm and the supernatant was used to measure total protein, total free amino acids, total and reducing sugars. The homogenization buffer was replaced by a mixture of chloroform : ethanol (with the ratio of 2:1) and then all previous steps were done in preparing the samples for lipid test. The total protein concentration of samples was determined spectrophotometrically according to the method of Bradford (1976), using albumin as a standard. The concentration of free total amino acids was done according to Vincent (1960), and Lee et al. (2003). While, the lipids concentration was determined according to Lewis et al. (2000), using cholesterol as a standard. Finally, the total and reducing sugars were done according to the method of Mathews et al. (2004) and Hernández-López et al. (2020), respectively with slight modification using starch and glucose as a standard, respectively.

**Measurement of antioxidant enzymatic response**

The insect larvae were homogenized using mortar in ice-cold PBS at pH=7.0 and centrifuged at 1000 rpm and the supernatant was ready to be used. The activity of glutathione peroxide (GPx) was determined according to Hafeman et al. (1974) with slight modifications. While, the activity of GR was determined according to Carlberg and Mannervik (1985), with the following minor modifications; the reaction mixture contained 1750 µl oxidized glutathione...
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(GSSG), 175 µl potassium phosphate buffer (50 mM, pH =7.5), 875 µl DTNB, 175 µl NADPH, and 350 µl supernatant. The absorbance was measured at 420nm, and the GR activity was expressed as OD/mg protein/min. The activity of glutathione s transferase (GST) was determined according to the method of Seyyedi et al. (2005). The superoxide dismutase (SOD) activity was measured based on the procedure described by Misra and Fridovich (1972). While, the activity of catalase (CAT) was assessed in compliance with the method of Aebi (1984).

Measurement of antioxidant non-enzymatic response

The α,α-diphenyl-β-picrylhydrazyl (DPPH) antioxidant activity was determined according to Blois (1958). With adding 0.5M DPPH to sample and incubated for 20 min before measuring absorbance at 525 nm. DPPH assay based on scavenging capability measurement. The nitrogen atom contains old electron which is reduced by delivery a hydrogen atom from antioxidants to hydrazine (Contreras-Guzman and Srong, 1982). The procedure of Allen et al. (1984) was adapted for determining GSH concentration.

Statistical analysis

Statistical analysis was performed using IBM SPSS Statistics for Windows (Version 17.0. Armonk, NY: IBM Corp.). A non-parametric test was carried out using Mann-Whitney U test for statically comparison between case A and case B of biomolecules concentration, special amino acids amount, enzymatic and non-enzymatic antioxidants. Hierarchical Cluster Analysis (HACA) based on agglomerative statistics using Ward's Method was calculated for biomolecules concentration, special amino acids amount, enzymatic and non-enzymatic antioxidants. Principle component analysis (PCA) is a data analysis technique (variance-covariance matrix) that used as pattern seeker of data by using algorithm concept. Reproduced and residual correlations between non-enzymatic and enzymatic antioxidants of 5th instar H. illucens were done based on Pearson’s regression analysis.

RESULTS

Biomolecules concentration, non-enzymatic levels and enzymatic antioxidant activity

The percentage of biomolecules (protein, amino acid, reducing sugar, total sugar and lipid) concentration of 5th larval instars H. illucens were illustrated in Figure (1a ). The results revealed the significantly increase in biomolecules concentration especially free amino acids with +2.6 x-fold in BSF larvae feed the fruit wastes with respect to control group. In the control group (case A), the lowest concentration was showed in the reducing and total sugar concentration of 5th instar of H. illucens. The influence of potential use of animal feed products or production of biofuels was manifesting by an increase the concentration of proteins and lipids respectively, which were observed in 5th instar insect larvae (Fig. 1a ). The highest concentration of biomolecules was observed in total free amino acid of case B insects, followed by proteins and lipids (Fig. 1a ). No difference was found between case A and case B in the concentration of reducing sugars and total sugars (p value < 0.05).
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Fig. 1. The concentration of biomolecules (protein, free total amino acids, reducing sugar, total sugar, and lipid) (a); the activity of enzymatic antioxidants (glutathione peroxides (GPx), glutathione reductase (GR), glutathione s transferase (GST), superoxide dismutase (SOD), catalase CAT), and polyphenol oxidase (PPO)) (b). All data sets were expressed as median ± SED values of 5th instar *Hermetia illucens* fed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. Median values marked with the same *, no significant differences among ideal and waste feeding groups in each case separately (Mann-Whitney U, p > 0.05).

With respect to enzymatic antioxidant enzymes of 5th larval instars the results presented in Figure (1b) revealed that there were a special elevation levels of antioxidants enzymes which was found in the activity of glutathione s transferase (GST) and polyphenol oxidase (PPO) with a value of 0.7, and 0.5 x-fold, respectively, in the provided waste raw material with respect to control materials of BSF bio-machine. No difference was found between case A and case B in each activity of GPx (p value < 0.05). The lowest activity was shown in the GPx. While the increasing ascending pattern was occurred in the following arrangement GPx, SOD, CAT, GR, PPO, and GST activity (Fig. 1b).

The concentration of the non-enzymatic antioxidants of 5th larval instars *H. illucens* were presented in Table (1). The results emphasized that the highest concentration occurred in DPPH case B, however, the lowest one occurred in GSH Case B (p value > 0.05).

The results of essential and non-essential amino acid concentration (aspartic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine (GLY), alanine (ALA), valine (VAL), isoleucine (ILE), leucine (LEU), tyrosine (TYR), phenyl alanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), and proline (PRO)) were found in Table (2). The results indicated that there was a significant increase of specific amino acids concentration especially alanine, isoleucine, phenyl alanine, and histidine with the value of 2, 2.7, 2.6, and 2.1 x-fold, respectively in the provided waste raw material with respect to control materials of BSF bio-machine. However, the increase fold between case A and case B in ASP, THR, SER, GLU, GLY, VAL, LEU, TYR, LYS, ARG, and PRO were 1.4, 1.7, 1.4, 1.4, 1.9, 1.7, 1.4, 1.5, 1.4, 1.1, and 1.3 x-fold, respectively (Table 2).
Fig. 2. Dendrogram of the cluster analysis (using Ward’s Method) applied for concentration of biomolecules (protein, free total amino acids, reducing sugar, total sugar, and lipid) (a), the activity of enzymatic (glutathione peroxides (GPx), glutathione reductase (GR), glutathione s transferase (GST), superoxide dismutase (SOD), catalase CAT), and polyphenol oxidase (PPO)) and the levels of non-enzymatic (α,α-diphenyl-β-picrylhydrazyl (DPPH), and reduced glutathione (GSH)), (b), and the concentration of essential and non-essential amino acids (aspartic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine (GLY), alanine (ALA), valine (VAL), iso-leucine (ILE), leucine (LEU), tyrosine (TYR), phenyl alanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), and proline (PRO)) (c), of 5th instar *Hermetia illucens* fed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste.

Table 1. Non-enzymatic antioxidants levels (α,α-diphenyl-β-picrylhydrazyl (DPPH), and reduced glutathione (GSH)), were expressed as median ± SED values of 5th instar *Hermetia illucens* fed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. The same abbreviation as Figure 1.
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### Table 2.

The concentration of essential and non-essential amino acids concentration (aspartic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine (GLY), alanine (ALA), valine (VAL), iso-leucine (ILE), leucine (LEU), tyrosine (TYR), phenyl alanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), and proline (PRO)), were expressed as median ± SED values of 5th instar *Hermetia illucens* fed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. The same abbreviation as Figure 1.

| Amino acid | BSF (case A) | BSF (case B) | BSF* (organic waste) | White fish mealb | Corncd | Soybean meal,df | Sunflower meal,df |
|------------|--------------|--------------|-----------------------|------------------|--------|----------------|-------------------|
| ASP        | 4.5 ±0.15    | 6.6 ±0.1     | 10.3                  | 8.5              | -      | -              | -                 |
| THR        | 2.1 ±0.12    | 3.6 ± 0.2    | 4.5                   | 3.9              | 2.00   | 1.05           | 1.72              |
| SER        | 3.4 ± 0.14   | 4.8 ±0.10    | 4.1                   | 4.8              | -      | -              | -                 |
| GLU        | 5.5 ± 0.77   | 7.7 ± 0.2    | 12.2                  | 12.8             | -      | -              | -                 |
| GLY        | 4.6 ± 0.2    | 8.9 ± 0.23   | 5.4                   | 9.9              | -      | -              | -                 |
| ALA        | 4.5 ± 0.3    | 9.2 ± 0.08   | 6.2                   | 6.3              | -      | -              | -                 |
| VAL        | 4.50 ± 0.3   | 7.83 ±0.13   | 6.7                   | 4.5              | 2.78   | 1.60           | 2.07              |
| ILE        | 1.63 ± 0.2   | 4.4 ± 0.21   | 4.8                   | 3.7              | 2.45   | 1.00           | 1.96              |
| LEU        | 3.9 ± 0.31   | 5.7 ± 0.21   | 7.7                   | 6.5              | -      | -              | -                 |
| TYR        | 5.3 ± 0.14   | 8.2 ± 0.4    | 6.0                   | 2.6              | -      | -              | -                 |
| PHE        | 0.8 ± 0.15   | 2.1 ± 0.1    | 6.2                   | 3.3              | -      | -              | -                 |
| HIS        | 1.76 ± 0.2   | 3.6 ± 0.15   | 4.8                   | 2                | -      | -              | -                 |
| LYS        | 2.63 ±0.2    | 3.83 ± 0.14  | 7.4                   | 6.9              | 1.03   | 1.00           | 2.69              |
| ARG        | 3.1 ± 0.15   | 3.4 ±0.08    | 6.2                   | 6.4              | 1.82   | 2.30           | 3.14              |
| PRO        | 4.66 ± 0.12  | 6.13 ± 0.14  | 6.2                   | 5.3              | -      | -              | -                 |

*a*Müller, *et al.*, 2017; *b* FAO, 2001; *c* El-Hack, *et al.*, 2020; *d* NRC, 1994

### Interactions and correlations between studied parameters

Hierarchical Cluster Analysis (HACA) based on agglomerative statistics using Ward’s Method was calculated for biomolecules concentration, special amino acids amount, enzymatic and non-enzymatic antioxidants of 5th instar *H. illucens* (Fig. 2a-c). The results showed that amino acids concentration had a separate cluster from other biomolecules concentration. Also, the concentration of reducing sugar, total sugars, lipids and proteins had a combined cluster with low value of arm cluster dendrogram (Fig. 2a). While, the enzymatic antioxidant (SOD, CAT, GPx, and GR) activity of 5th instars BSF larvae, has a separate cluster than the other non-enzymatic and enzymatic antioxidant activity. In another hand, GST and PPO had the same highest length arm in the same cluster of the dendrogram. Also, DPPH and GSH had the similar smallest arm in the same cluster of the dendrogram (Fig. 2b). The cluster analysis results of amino acids showed that, there were a two separate cluster, the first one included GLY, ALA, GLU, TYR, VAL, ASP, PRO, SER, LEU, and LYS; the second one contained ARG, THR, HIS, ILE, and PHE. However, the largest cluster arm occurred between ALA and PRO amino acids of 5th instar *H. illucens* (Fig. 2c).

Principle component analysis (PCA) is a data analysis technique (variance-covariance matrix) that used as pattern seeker of data by using algorithm concept of each biomolecules concentration and amino acid concentration (Fig. 3a,b), thus the eigen value and chi square value ($R^2$) were...
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determined for non-enzymatic and enzymatic antioxidants (Fig. 4). The results indicated that the first principal component (PC) of proteins, lipids, free total amino acids, reducing and total sugar was 75.327% of the data variance, while the second component was 24.673% in which it had a total value of 100% (Fig. 3a). The PCA results demonstrated a positive correlation between lipids and total sugars, however, there was a negative correlation between free total amino acid and protein (Fig. 3a). yet, the results of essential and non-essential amino acid which found in Figure (3b), showed that the component 1 was 58.032%, while component 2 was 41.968%, variance value. The results demonstrated that there a positive correlation between GLY, HIS, SER, ILE, TYR, PHE, VAL, ARG, and GLU. Also, this positive correlation occurred between LYS, ASP, and ALA, despite, there were a negative correlation between GLY and these amino acids LYS, ASP, and ALA (Fig. 3b).

Fig. 3. Principal component analysis of samples from of 5th instar Hermetia illucens feed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. Data points represented the concentration of biomolecules (protein, free total amino acids, reducing sugar, total sugar, and lipid) (a), the concentration of essential and non-essential amino acids (aspartic acid (ASP), threonine (THR), serine (SER), glutamic acid (GLU), glycine (GLY), alanine (ALA), valine (VAL), iso-leucine (ILE), leucine (LEU), tyrosine (TYR), phenyl alanine (PHE), histidine (HIS), lysine (LYS), arginine (ARG), and proline (PRO)) (b).

In Figure (4) the principle component amount was two components according to the competent number and Eigen value (Fig. 4a), while R$^2$ of non-enzymatic and enzymatic antioxidants (GPX, GR, GST, SOD, CAT, PPO, DPPH, and GSH) was equal to 0.39 (Fig. 4b). Reproduced and residual correlations between non-enzymatic and enzymatic antioxidants of 5th instar H. illucens were done based on Pearson’s regression analysis and are shown in Table (3). The results demonstrated that there was a positive correlation between all antioxidant enzymes activity. The significance level < 0.01, was obtained between the following enzyme group GPx, GR, GST, CAT, and PPO, while SOD had a strong positive correlation with GPx at P value < 0.05. The non-enzymatic antioxidant (DPPH and GSH) concentration had a week positive and negative, correlation respectively with all antioxidant enzymes activity. Moreover, the residual correlation analysis indicated that there was no residual correlation between GSH and GR. However, there were a negative correlation between GSH and enzyme antioxidant group (GST, SOD, CAT, and PPO) with the values of -0.003, -0.004, -0.002, and -0.005, respectively
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Fig. 4. Eigen value and chi square value (R²) of samples from 5th instar *Hermetia illucens* feed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. The data set involved the activity of enzymatic (glutathione peroxides (GPx), glutathione reductase (GR), glutathione s transferase (GST), superoxide dismutase (SOD), catalase CAT), and polyphenol oxidase (PPO)) and the levels of non-enzymatic (α,α-diphenyl-β-picrylhydrazyl (DPPH), and reduced glutathione (GSH)).

Table 3. Pearson’s correlation coefficient between the activity of enzymatic antioxidants (glutathione peroxides (GPx), glutathione reductase (GR), glutathione s transferase (GST), superoxide dismutase (SOD), catalase CAT), and polyphenol oxidase (PPO)); and the levels of non-enzymatic antioxidants (α,α-diphenyl-β-picrylhydrazyl (DPPH), and reduced glutathione (GSH)) of 5th instar *Hermetia illucens*.

| Antioxidants | Item   | GPx   | GR    | GST   | SOD   | CAT   | PPO   | DPPH  | GSH   |
|--------------|--------|-------|-------|-------|-------|-------|-------|-------|-------|
| Co-Enzymatic |        |       |       |       |       |       |       |       |       |
| Enzymatic    | GPx    | 1     |       |       |       |       |       |       |       |
|              | GR     | 0.987**| 1     |       |       |       |       |       |       |
|              | GST    | 0.974* | 0.977**| 1     |       |       |       |       |       |
|              | SOD    | 0.913* | 0.921**| 0.832*| 1     |       |       |       |       |
|              | CAT    | 0.985* | 0.956**| 0.943**| 0.916*| 1     |       |       |       |
|              | PPO    | 0.984* | 0.963**| 0.965*| 0.882*| 0.993**| 1     |       |       |
| Non-enzymatic| DPPH   | 0.589 | 0.534 | 0.697 | 0.277 | 0.601 | 0.653 | 1     |       |
|              | GSH    | -0.476| -0.601| -0.557| -0.461| -0.375| -0.438| -0.066| 1     |

** indicates P value < 0.01; * indicates P value < 0.05

DISCUSSION

The results of the present study indicated the importance of using black solider fly larvae to enhance the proper management of wastes of fruits and As an import ecofriendly recycling technology. There were many studies clarified the ability of black solider fly larvae to be used as a waste management tool (Diener et al., 2011; Nguyen et al., 2015; Sarpong et al., 2018; Liu et al., 2019; Rhode et al., 2020; Pintowantoro et al., 2021). This will be a great opportunity for supporting the social entrepreneurs to achieve the concept of circular economy and gain extreme revenues with a little initial investment (Kim et al., 2021).

The feeding habitat of adult Black soldier fly is completely different from larva stage (Sheppard et al., 2002; Nguyen et al., 2015); the larval consumes more diets during this stage and stored more fat content within the fat body to complete the development and survive of adult stage with all necessary process (Tomberlin et al., 2002). The results of this study which includes biomolecules concentration, essential and non-essential amino acids amount approved a significant increase in these valuable molecules of 5th instar *H.*
illucens. These results indicated the importance of BSFL in waste management in various ways, the first one is its ability to reduce the amount of provided waste without any contamination or disease transmission, the second one, the ability to convert a non-value waste into a valuable sources of proteins, lipids, and chitins. Also, the present results showed the elevated activity of enzymatic antioxidants (glutathione peroxides (GPx), glutathione reductase (GR), glutathione s transferase (GST), superoxide dismutase (SOD), catalase CAT), and polyphenol oxidase (PPO)); and the levels of non-enzymatic antioxidants (α,α-diphenyl-β-picrylhydrazyl (DPPH), and reduced glutathione (GSH)) of 5th instar H. illucens. These essential antioxidants components will be used in industrial, feed production, pharmaceutical application due to the availability of enzymes and microbes in the gut tissues of BSF (Sheppard et al., 1994; Tomberlin & Sheppard, 2002; Nguyen et al., 2015; Pintowantoro et al., 2021).

Moreover, the current results set the impact of different substrates on the concentration of essential biomolecules, levels of non-enzymatic and enzymatic antioxidants of 5th instar H. illucens. There was a significant difference of the tested parameters of 5th instar fed on different substrates, case A, the ideal one contained a special concentration of biomolecules, and case B, involved fresh fruit waste. Nguyen et al. (2015), reported that the black soldier fly larvae may select kitchen waste due to its content and they can consume the fruits and vegetables waste with the greatest level consumption compared with other waste types.

The amount of kitchen waste reduction rate in this study was 74.2% which empathized that the BSF prepupae reared on organic wastes can be uses as animal feed. Liu et al., (2019) found that the conversion rate of kitchen, domestic or municipal organic waste, and crop straw have the percentage value of 60, 39-79, and 9-68, respectively. However, Nguyen et al. (2015), founded that the BSF prepupae confined less protein and lipids than previously studies (Newton et al., 2005). This may be clarified by the availability of nutrients found in the larval food supply. Li et al. (2011) calculated the waste reduction according to the equation of Dzepe et al. (2021) and they revealed that 1200 BSFL had the ability to reduce dairy manure within 21 days by 72%.

The present study indicated found that the BSF product contains valuable molecules like protein, amino acids, lipids, and carbohydrates. Similar results were reported by DeFoliart (1991) who found that the BSF product contains protein, amino acids, lipids, and carbohydrates percentage ranged from 20–70%, 30–60%, 10–50%, and 2–10%, respectively. It also contains minerals, vitamins, fatty acids, active peptides, essential and non-essential amino acids which have a health functions for living organisms. From all these valuable concentration nutrient, there were a lot of studies conclude that BSFL is considered as a hero development potential due to its ability to produce protein which can be used as animal feed, and food (Tschirner & Simon, 2015; Barragan-Fonseca et al., 2017; Schiavone et al., 2017; Wang & Shelomi, 2017; Liu et al., 2019; Soomro et al., 2021). Besides that, the lipid content in the BSFL can be used in the biodiesel extraction technology as an input material (Nguyen et al., 2017; Raksasat et al., 2021). Li et al. (2011) founded that the production of 15.8 g of biodiesel and 96.2 g sugar was obtained from the digested dairy manure treated with BSF larvae.

Additionally, these BSF larvae can be used as a natural resource of antimicrobial peptides production (Park, et al., 2015; Vogel, et al., 2018). Moreover, Li et al. (2015) showed that 97.3 % of the glucose and 93.8 % of the xylose could be produced by BSF larvae.
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Therefore, the promising technology using BSF in the waste management to produce valuable products such as proteins feed staff, enzymes, bioplastics, chitin source, biodiesel, and organic fertilizers production has to be considered as a great attention for investors, policy makers, social entrepreneurs to achieve sustainability and circular economy concept.

Similarly, to the obtained concentration of DPPH in this research study, Zhu *et al.* (2020), revealed that the scavenging rate of antiradical DPPH of black soldier fly larvae hydrolysates-invitro application (BLPHs-I) was 84.09%, which was characterized by a higher scavenging activity with the little percentage than 2 mg/mL the ascorbic acid standard, this was the same as in previous studies on different insect species, such as Asian weaver ant that had higher scavenging activity (Pattarayingsakul *et al.*, 2017). Zhu *et al.* (2020) results, approved that the scavenging capabilities of trials depend on concentration of substrate, and the highest superoxide scavenging activity was found in BLPHs-I case with the limited 50% DPPH scavenging equal to 0.88 mg/ml. These results may be due to the high levels of hydrophobic amino acids in BLPHs-I, which possibly will influence on the higher activity of superoxide scavenging, this result can be empathized by the hypothesis of superoxide radical generation could be produced through pyrogallol autoxidation process. This the same explanation that mentioned by Dong *et al.* (2017), the antioxidants ability is depend on the amino acids sequence.

Higher concentration of antioxidants was found in the present study. Li *et al.* (2017) found that the catalase activity antioxidant levels increase Jian carp which feed on BSFL with respect to control food. In 2019, Lei *et al.* reported a significant positive linear correlation between nutritional BSFL and calcium concentration, dry matter, crude protein, glutathione peroxidase, superoxide dismutase, or the food digestibility in experimental dog samples. Yet, the using of BSFL as a dog food had decrease the concentration of tumor necrosis factor-α. From these findings, this study validates the BSFL as a dog food which had the ability to improved dry matter digestibility besides to its capacity as anti-oxidative and anti-inflammatory agent. Regarding to the significant positive correlation between antioxidants enzymes group and negative correlation between GSH and enzymatic antioxidant, Abdelfattah *et al.* (2021) revealed that GSH is considered as a main thiol group inside the cell supposed to be as an essential element in the antioxidative system, besides that the scavenging ability of ROS and balancing the cellular redox state.

On conclusion, the results of the present research revealed that the using of BSFL in the management of fruit wastes and is considered as a best environmental practice (BEP) and available technology (BAT) to reduce GHG emission and avoid production of hazardous and toxic wastes which leads to overhead the waste recycling programs with the cost of landfilling and incineration. Furthermore, the valuable products from this biological technology, such as proteins, lipids, chitin and organic fertilizers are considered as a great opportunity of these manufactures. As after a simple manufacturing process, high-level-quality of biodiesel can be generated. Furthermore, it is a high protein quality animal food and feed, can be produced as a result of this technology. The ability of BSFL to be adapted in a widely worldwide regions, make the feasibility and ability to grow up of this technology.

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تطبيق التكنولوجيا الحيوية لإدارة النفايات العضوية باستخدام ذبابة الجندي الأسود، *Hermetia illucens*

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المستخلص
في الوقت الحاضر، تحظى نسب تغيير المناخ والإدارة غير السليمة للنفايات باهتمام كبير. لذلك، من الضروري استخدام مفهوم أفضل الممارسات البيئية (BEP) في إدارة النفايات، وخاصة النوع العضوي. التكنولوجيا الأكثر تكلفة التي تنتمي إلى تطبيقات التكنولوجيا الحيوية هي بركات ذبابة الجندي الأسود (BSFL). لذلك، يهدف هذا البحث إلى دراسة القدرة على استخدام ذبابة الجندي الأسود "Hermetia illucens" لطرد النفايات الفاكهة. تم فحص التحليلات الكيميائية لبركات ذبابة الجندي الأسود المحصودة والتي تتألف على فضلات الفاكهة فيما يتعلق بحالة التحكم. أظهرت النتائج زيادة معنوية في تركيز الجزيئات الحيوية وخاصة الأحماض الأمينية الحرجة مع +6.2 ضعف في مدخلات مخلفات الفاكهة فيما يتعلق بمراقبة المواد المدخلة لمستعمرة بركات ذبابة الجندي الأسود. إلى جانب مستويات مرتفعة من إنزيمات مضادات الأكسدة، أظهرت هذه النتائج على مساهمة إشراك بركات ذبابة الجندي الأسود في تحويل مواد الإدخال غير القوية إلى منتجات ذات قيمة عالية تحتوي على مستويات واعدة من مضادات الأكسدة والجزيئات الحيوية الأساسية بطريقة صديقة للبيئة. سيكون هذا البحث خطوة رائعة في الحصول على تقنيات مستدامة وصناع السياسات وأصحاب المشاريع الاجتماعية لتحقيق مفهوم الاستدامة والاقتصاد الدائري من خلال تقنية بركات ذبابة الجندي الأسود.