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The Performance of Black Soldier Fly Larvae (BSFLs), *Hermetia illucens* L. (Diptera: Stratiomyidae), as a Function of the Substrate Used: A Review

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Abstract

Organic wastes are one of the greatest challenges that cities face worldwide. In numerous underdeveloped nations, like Cameroon, waste is often disposed of through landfills, composting, or open-air combustion. Unfortunately, the concept of waste sorting and organic waste processing is new to many individuals. This has led to an increase in the amount of organic waste and the costs connected with its management. Consequently, the majority of developing nations have sought out waste management solutions that are more cost-effective. Therefore, it has been determined that the bioconversion of organic wastes by black soldier fly larvae (BSFLs) (*Hermetia illucens*) into multifunctional prepupae is a viable alternative. Appreciation is given to the employment of the organic waste management approach in developing nations since it is not only environmentally friendly and economically viable, but also provides a means for waste valorisation through the production of diverse resources and potential economic benefits. Studies have proved the usefulness of the insect in controlling organic wastes, but countries such as Cameroon are still unfamiliar with the nuances of this method. Consequently, this timely review examined the performance of the BSFL, specifically in organic waste treatment, as well as the best practices for multiplying them to determine its viability for use in a waste treatment plant, the production of high-quality larvae as a source of protein for livestock, and the production of diesel fuel.

Keywords

Environmental Sustainability, Organic Waste Management, Waste Valorisation, Black Soldier Fly Larvae (BSFLs) Performance, Protein Source, Biodiesel

1. Introduction

The book "Limits to Growth" (Meadows et al., 2013), published over 40 years ago, emphasized that the expected exponential growth of the human population would result in increased waste generation as a result of increased consumption. Consumption could result from increased demand for industrial products and natural resources, resulting in inorganic, organic, and nutritional wastes. In rising countries, where population expansion is a social, political, and economic concern, resource availability and waste generation are affected (Dahiya, 2015). Annually, the planet accumulates 2.01 billion tonnes of municipal solid garbage, with at least 33% of that (to put it mildly) not being managed in an environmentally sustainable manner (Kaza et al., 2018). It is expected that global waste will reach about 3.40 billion tonnes by 2050, which will be more than double the rate of population growth during the same period. The East Asia and Pacific region generate the majority of the world's waste, at 23%, while the Middle East and North Africa regions generate the least, at 6% (Kaza et al., 2018). However, Sub-Saharan Africa, South Asia, the Middle East, and North Africa are the fastest developing regions, with total waste generation anticipated to be more than quadruple, double, and double, respectively by 2050.

According to available data, Africa generated 125 million tonnes of municipal solid waste (MSW) in 2012, with 81 million tonnes (65%) created in Sub-Saharan Africa (Scarlat et al., 2015). By 2025, this is predicted to increase to 244 million tonnes per year. With an average waste collection rate of only 55% (68 million tonnes) (Scarlat et al., 2015), nearly half of all MSW generated in Africa is thrown on sidewalks, open fields, stormwater drains, and waterways. The average MSW collection rate in Sub-Saharan Africa is only 44% (**Figure 1**), while coverage varies substantially between cities, ranging from less than 20% to well over 90% (Godfrey et al., 2020).

On average, 57% of MSW in Africa consists of moist, biodegradable, organic garbage (**Figure 2**). This high organic waste concentration in comparison to paper and packaging is a significant problem typified by MSW in undeveloped nations. It is simple to convert biodegradable organic waste into valuable goods such as compost or biogas. However, this resource remains mostly unexplored on the continent (Van Wyk, 2018).

Africa is confronted with an escalating waste management challenge. The standard of waste management in the majority of Sub-Saharan African countries is at an all-time low, with the most common method of waste disposal being landfilling.

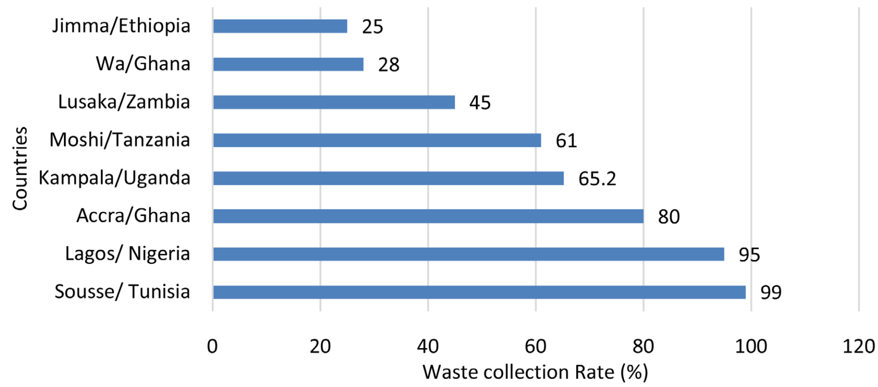

Figure 1. Coverage of MSW collection in African cities (Godfrey et al., 2020).

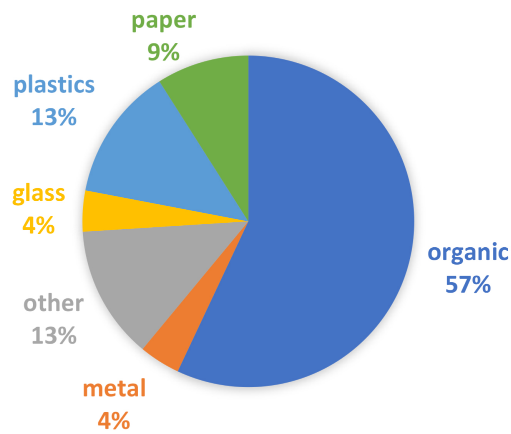

Figure 2. MSW composition in Sub-Saharan Africa (Hoornweg & Bhada-Tata, 2012).

Landfilling, which is the least preferred method of waste management on the waste management hierarchy of control, is however, associated with a long list of negative environmental and health consequences (Renou et al., 2008). With the majority of Sub-Saharan African countries and Africa still underdeveloped, more effective waste management solutions are economically unviable in these countries. While Africa generates comparatively little waste compared to developed nations, waste mismanagement in Africa is already negatively impacting human and environmental health (Godfrey et al., 2020). The biggest shortcoming in waste management originates from the inefficiency of current technology in promoting waste's beneficial application in reuse and recycling systems. Current solid or municipal waste management strategies are highly restricted in terms of collection, transportation, treatment, and disposal, and hence lack large-scale valorisation of organically-rich waste (municipal solid waste).

Researchers have attempted to sustainably decompose waste and ascertain its underlying properties (Singh & Kumari, 2019). Due to the global mismanagement of solid waste (SW) in terms of environmental contamination, social inclusion, and economic sustainability (Gupta et al., 2015; Vitorino de Souza Melaré et al., 2017), its resolution demands a holistic strategy (Bing et al., 2016). Conversion of organic waste by larvae of the BSF (**Figure 3**) into multifunctional

(a) (b)

Figure 3. Image of the adult black soldier fly (a) and the larvae (b) (Chia et al., 2019).

prepupae is an intriguing recycling technique that fits the more holistic approach because it has the ability to add value to waste.

Biowaste treatment using BSFL is a novel waste management technique (Čičková et al., 2015; Gold et al., 2018). The feeding activity of the species has the aptitude to substantially reduce vast volumes of organic biomass and concurrently supply valuable larvae having high nutrient composition (Diener et al., 2011a, 2011b). This process converts waste to larval biomass, reduces wastes and dry mass, and generates raw materials for the manufacture of soil conditioners and fertilizers (Setti et al., 2019), lubricants and biodiesel (Leong et al., 2016; Li et al., 2011), pharmaceuticals (Vilcinskas, 2013), and animal feeds (Barragan-Fonseca et al., 2017). A significant problem for BSFL biowaste treatment is the varied dependability and effectiveness of the technology when used with diverse waste substrates. The performance of BSFLs, as measured by bioconversion rate, larval weight, and larval biomass composition, varies both when the same type of biowaste is used (e.g. different vegetable wastes) and when different types are used (e.g. vegetable waste versus mill by-products) as summarized by Gold et al. (2018).

This study aims to provide information on the substrate-by-substrate performance of black soldier fly larvae in waste remediation. In addition, it investigates the suitability of various organic waste substrates for the successful multiplication of black soldier fly larvae, which is essential for assuring the continuity of the larvae-powered waste management plant. All of this is being done to establish best practices that will guarantee high-quality larvae for use as a source of protein and in biodiesel production.

2. Methodology

This analysis of BSFL performance in the valorisation of different organic waste is based on an exhaustive review of literature. The literature review employed the search terms "black soldier fly", "*Hermetia illucens*", "valorisation" and "organic waste". Additional papers were then selected using the references obtained in the database of the searched articles. This review article is solely based on secondary data that is publicly available in the scholarly domain of the Black soldier fly larvae's performance in waste treatment when exposed to various types of organic waste (substrates). A broad range of database tools and scientific domains such as Science Direct, Research Gate, Google Scholar, Web of Science, and Scopus (until May 2022) were investigated to determine *Hermetia illucens*'s (BSF) adaptability in waste composting as well as its performance in different substrates. UNEP, Eawag/Sandec, WASTE, and other environmental groups have released reports that were equally consulted. This paper is the outcome of a review of at least sixty research publications that met the inclusion criteria of the review paper regarding the BSFL treatment of various categories of organic waste. Tables of published data were used to facilitate discussion of the stated potential of BSF larvae in organic waste treatment, and their importance as value chain developers.

3. Organic Waste

3.1. Organic Waste Streams

Organic waste is defined as any biodegradable material derived from plant or animal. Organic waste decomposes into carbon dioxide, methane, or simple organic molecules. Organic wastes are ubiquitous and can be found in municipal solid waste, industrial solid waste, agricultural waste, and wastewater. Organic materials contained in municipal solid waste include food, paper, wood, sewage sludge, and yard debris (green waste) (Funk et al., 2020).

3.2. Organic Waste Problem

Globally, the continual increase in organic waste generation poses a great hazard to human health, biodiversity, and the ecology in general. Environmental threats associated organic waste include contamination of water, air, and soil (Pastor et al., 2015), as well as the potential for disease transmission (Kawasaki et al., 2020; Pastor et al., 2015). Additionally, organic waste has been found to have a negative influence on the environment due to the methane gas emitted by landfills (FAO, 2014). Organic waste is frequently disposed of in landfills, composted, or incinerated (Kim et al., 2021; Kinasih et al., 2020; Siddiqui et al., 2022), waste disposal methods that all have negative impacts on the environment. Organic waste management is a significant challenge for developing countries as there are several drawbacks linked with the main method of waste disposal practiced there (landfilling), such as their contribution to greenhouse gas emissions, the occupation of valuable space, the spread of pathogenic organisms and the production of undesirable odours (FAO, IFAD and WFP, 2013). Furthermore, this commonly used waste management method requires a long period of time before the wastes are fully decomposed (Chun et al., 2019).

4. The Use of BSFL in Waste Valorization

Numerous cities have expanded their efforts over the last decade to identify sustainable solid waste management solutions, particularly through the development of integrated solid waste management policies. To offset some of the increased expenses of waste management, it's unsurprising that activities such as valorisation and recycling have been encouraged (Diener et al., 2011b). Over the last few decades, the conversion of organic waste by saprophages (CORSs) has been offered as a solution (Barnard et al., 1998; Elissen et al., 2006). The most well-known application of CORS is vermicomposting, which is the process by which worms and microorganisms convert organic waste into black, earthy-smelling, nutrient-dense humus. Similarly, *Hermetia illucens* L. (Diptera: Stratiomyidae), more commonly known as the black soldier fly, has been propagated as an organic waste conversion (Diener et al., 2009). The BSFL characteristic of feeding veraciously on a variety of organic waste makes them suitable for organic waste treatment.

4.1. BSFL Performance

Post-waste treatment, the larvae or prepupae of the black soldier flies could be used as animal feed (Wang & Shelomi, 2017) or for the generation of biodiesel (Leong et al., 2016). As a result, the performance evaluation criteria of the BSFL was set as follow; the bioconversion rate (waste reduction capacity), larval development/weight (increment of body mass), and the composition (proteins, lipids etc) of larval biomass. For usage as feed, the larvae/prepupae protein content and amino acid composition are crucial as well as the lipids for the production of biodiesel (Gold et al., 2020). In summary, this study aims to identify best practices in the use of BSFL for waste valorisation and/or recommend new research avenues based on previous research.

4.2. The Performance of BSFL on Types of Organic Waste

4.2.1. Food Waste

Work on the valorisation of organic waste material: growth performance of wild black soldier fly larvae (*Hermetia illucens*) reared on different organic wastes carried out by Nyakeri et al. (2017) established the following findings:

Larval growth and weight

In their investigation, the total prepupal yields and average prepupal weights were found to be significantly affected by the growth substrates. Using a feeding rate of 100 mg/larva/day, restaurant food waste (RFW) produced prepupal weights that were considerably more than 0.101 ± 0.002 g ($P = 0.05$). They experienced a significant prepupal yield for restaurant food waste (RFW) that was consistent with Nguyen (2010). It was claimed, verified and established by Tschirner and Simon (2015) that the diverse character of the substrate increases its nutritional value. In addition, the protein content of the diet favorably correlates with larvae growth and weight gain (Oonincx et al., 2019). The high crude protein content may have contributed to the rapid growth rate, whereas the high carbon content may explain both the larvae's average biomass and total harvests. Therefore, the increased mean prepupal weight and yield reported for food waste could be attributed to their heterogeneity and nutritional superiority.

Biomass composition

In contrast to crude protein (CP) levels, prepupae generated on restaurant food waste RFW comprised of considerably more crude fat ($P < 0.5$): 34.9% ± 0.1%. Regardless of the substrate utilized for larval rearing, the data demonstrated that the CP concentration dropped as the larvae aged (Taufek et al., 2021).

Bioconversion rate

RFW scored as the best-reduced substrate with very little residue (11.1%) comprised primarily of the observed larval excreta. This demonstrated that, relative to waste, BSFL waste was greater. In their investigation, Kalová and Borkovcová (2013) found that plant materials provide the best substrate reduction compared to other substrate sources. Higher plant degradation rates can be related to the ability of BSF larvae to release enzymes and harbor microorganisms capable of degrading plant components.

4.2.2. Fruits and Vegetables

Lalander et al. (2019) studied the effects of feedstock on larval development and process efficiency in waste treatment with black soldier fly (*Hermetia illucens*). They investigated the BSFL performance in fruits and vegetable substrates composed of 50% Lettuce, 30% apples and 20% potatoes, and reported as follows:

Larval growth and weight

On the fruit & vegetable substrate, the larval development was slow, it took 28 days for the first prepupa to emerge and around 28 days for 50% of the prepupae to emerge. In this instance, however, the average prepupal weight was rather heavy (220 mg·larva^{-1}). The fruit and vegetable waste-reared larvae were relatively large, although their development was slower than values reported in other investigations on comparable substrates. In Spranghers et al. (2016) and Meneguz et al. (2018), the required development period for the first prepupae to emerge was 19 and 20 days respectively, days after the first feeding, compared with 28 days in this study. Spranghers et al. (2016) also discovered that feeding BSF larvae on digested vegetable waste reduced larval biomass yield by roughly 40% compared to rearing them on undigested vegetable waste, while growth time was unaffected. Fruits and vegetables are high in volatile solids (VSs) but low in protein, therefore the sluggish development could be a result of the need for a greater amount of substrate in order to obtain enough protein for development.

Bioconversion rate

BSFL composting of fruit and vegetable waste had a lower material reduction than composting of mixed food waste (Lalander et al., 2019). This is likely due to the low protein level in fruit and vegetable substrates relative to the high content of carbon with limited digestion (lignin and hemicellulose) (Gold et al., 2018; Meneguz et al., 2018; Nyakeri et al., 2017; Singh & Kumari, 2019).

4.2.3. Agricultural Waste

Agricultural waste is described as undesirable waste generated by agricultural activities. Crop residues, weeds, leaf litter, sawdust, forest waste, and livestock manure are examples of agricultural wastes (Sharma & Garg, 2019). In the majority of nations, agricultural waste is misdirected or abandoned due to a lack of awareness or a sufficient conduit for its transmission and utilization. For economic growth, the majority of agriculture-dependent nations must prioritize the reuse of agricultural and agro-industrial waste. It not only increases the local farmers' economy, but also the national economy as a whole.

1) Coconut pulp (CP) and palm oil decanter cake (DC)

Larval weight and length

Taufek et al. (2021) studied the effect or influence different substrates (coconut pulp (CP) and palm oil decanter CAKE (DC)) had on *Hermetia illucens* larvae fed on various substrates for red tilapia diet: influence on growth and body composition. At the conclusion of the trial (Week 5), CP-fed BSFL weighed a few milligrams more than DC-fed BSFL, although the difference in length was not statistically significant. They attributed the disparity in weight to a likely increase in substrate loading as the larvae's waste consumption rises. Compared to feed ration, Banks (2014) found that the frequency of food addition had a substantial effect on prepupal development.

In terms of length, BSFL in both substrates continued to grow at a steady rate from Week 1 to Week 5 (**Figure 4**), reaching around 18 mm before being harvested. The growth of BSFL in DC began slowly with a length of just 6.4 mm during the first week but quickly expanded to 18.2 mm, comparable to CP, by the fifth week. Although the length of BSFL cultivated in DC substrate decreased slightly in Week 4, no significant differences were noticed when compared to the previous week. This drop could be a result of the moulting process (the shedding or casting off of an outer layer or covering and the formation of its replacement), which resulted in weight discrepancies in selected BSFL as well.

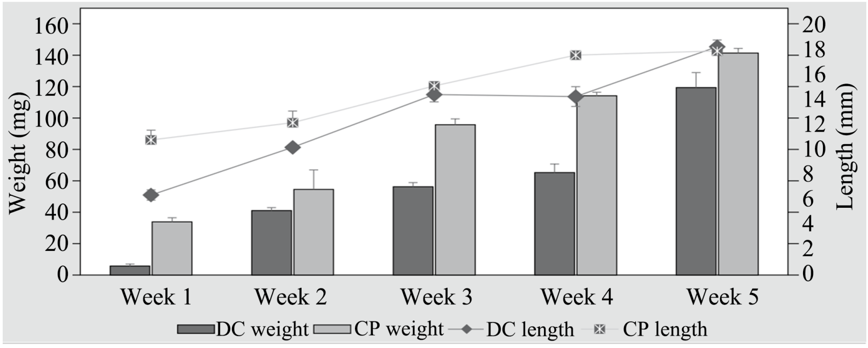

Figure 4. Length and weight gains of black soldier fly larvae fed substrates over a period of 5 weeks (Taufek et al., 2021).

They noticed a significant increase in weight of BSFL fed on DC between Weeks 4 and 5 that they attributed to the DC substrate's higher moisture content (75%) when compared to CP (52%). Numerous experiments have been conducted to determine the effect of the BSFL substrate's moisture content on dry weight and yield. According to Palma et al. (2018), raising the moisture level from 48 to 68 percent increases harvest by 56 percent, whereas Cheng et al. (2017) reported that increasing the moisture content to 80 percent reduces the capacity of sieving the residue. Nonetheless, a high moisture content may increase larvae growth but at the expense of sieving efficiency.

Biomass composition

The proximate study of nutrients for the BSFL fed on both substrates indicated that it takes up to 5 weeks for the majority of eggs to develop into pre-pupae stage before being collected, which could account for the reduced protein content. According to Aniebo and Owen (2010), increasing larval age results in the enzymatic breakdown of protein as a result of the sclerotisation action used to construct the exoskeleton's chitin. According to Rachmawati et al. (2010), crude protein levels gradually drop as larvae aged from five days (61%) to fifteen days (44%) to twenty days (42%). In DC, the BSFL lipid concentration was lower than in CP. This study's lipid percentage is within the range of 7% - 39% as reported in other studies (Barragan-Fonseca et al., 2017). The increased lipid content discovered in BSFL cultivated in CP demonstrates that BSFL are capable of assimilation and bioconversion of the feed. Additionally, extra carbohydrate in meal may be metabolized and stored as fat, increasing the larvae's lipid content (Kargbo, 2010). The high ash content of BSFL meal could be attributed to increased calcium carbonate deposition by the larvae epidermis during the moulting process (Newton et al., 1977). Increased ash concentration in BSFL-fed DC compared to CP could be a result of DC's higher weight gain. Due to the fact that the time period for BSFL harvest was set at 35 days, the larvae in DC had reached a somewhat more mature stage than those in CP, which may result in a higher weight and thus more calcium carbonate deposition. Despite the high ash content of the current BSFL larvae fed DC, the level was comparable to that reported by Shumo et al. (2019) for BSFL fed chicken manure, kitchen waste, and spent grain. Due to the presence of sand, dirt, and other inorganic debris, the composition of ash in DC substrate reported in this study is slightly greater than that reported by Dewayanto et al. (2015) (18.9%).

2) Maize straw

Wheat, rice, and corn are the three most important food crops in the world. According to FAO data, maize production in 2016 was 1038.28 million tonnes (Mt) (FAO, 2017). As a result, enormous quantities of crop straw are produced, making it the fourth most important energy source in the world after coal, oil, and natural gas (Sun et al., 2017). According to the residue-to-crop ratio (RCR) estimate, maize straw production in 2014 was around 1661 Mt, the largest among the three primary forms of crop straw (Cardoen et al., 2015; Liu et al., 2019). Straw being a significant agricultural byproduct, its efficient and comprehensive utilization is a crucial concern. Poor handling of straw results in severe environmental degradation and energy waste. Straw open burning saves labour and release nutrients (Li et al., 2016), but the particulate matter (PM) and gaseous pollutants released through straw open burning have a severe negative impact on the atmospheric environment and the ecological system (Guan et al., 2017). Thus, innovative alternatives for the disposal of straw are now being developed, and are badly required (Gao et al., 2019). The larvae of the black soldier fly, which have a voracious appetite and can ingest a wide variety of organic waste, including crop straw (Manurung et al., 2016), is one of these alternatives. Similar to its performance on other types of organic waste, its performance on corn straw is comparable.

In Gao et al.'s (2019) research in the Bioconversion performance and life table of black soldier fly (*Hermetia illucens*) on fermented maize straw during which they compared the performance of BSFL on maize straw and wheat bran, they reported

Biomass composition of larvae

There was no significant difference between maize straw and wheat bran in terms of crude protein (CPRO) and crude ash (CASH) concentration in black soldier fly larvae (control) (**Figure 5**). The wheat bran group had the greatest crude protein level at 42.74%, followed by the maize straw group at 41.76%; the crude ash content was 8.28% in the wheat bran group and 8.24% in the maize straw group.

The crude fat level was much lower in the maize straw group (30.55) than in the wheat bran group (34.26%). It was surprising that maize straw group larvae contained a larger proportion of oleic acid (23.29%) and linolenic acid (24.02%) than wheat bran group larvae (15.84% and 15.46% respectively). The maize straw-fed larvae contained less lauric acid (22.36%) than those given wheat bran (38.26%). Compared to wheat bran-fed larvae, maize straw-fed larvae had a larger proportion of monounsaturated fatty acid (24.86%) and polyunsaturated fatty acid (25.37%) but a lower proportion of saturated fatty acid (45.41%).

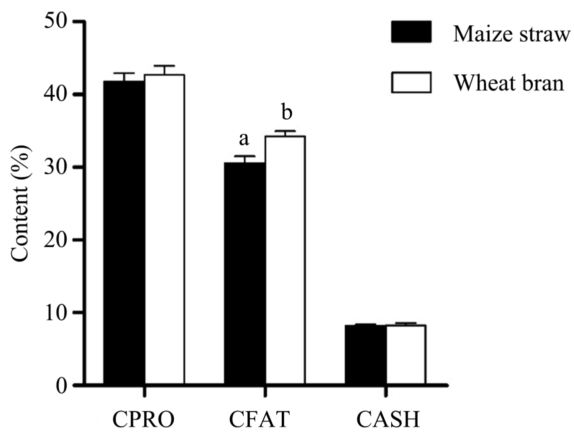

Figure 5. Primary nutritional composition of larvae fed fermented corn straw and wheat bran (Gao et al., 2019).

4.2.4. Livestock Manure

Due to characteristics such as plentiful nitrogen and high organic matter (OM), the escalating rate of organic residues from livestock manure has become a severe concern that must be disposed of properly (Liu et al., 2018; Soobhany, 2018). Although direct application of manure to farmland has a long history in agriculturally driven societies such as Africa (Sub-Saharan), it can lead to environmental contamination, including atmospheric, water, and solid pollution, and can have a significant impact on plant growth (Kong et al., 2018; Ravindran et al., 2019). Composting is an environmentally benign method for converting organic waste. However, unstable composting could result in the spread of illness, bad odors, and/or greenhouse gas (GHG) emissions, which could impede the advancement of composting technology (Hanifzadeh et al., 2017). Therefore, it is crucial to investigate a more appropriate strategy for manure management as well.

Animal manure is an abundant organic waste stream that is not directly ingested by cattle and fish, unlike by-products from the food industry, green waste, or food waste, and when not adequately handled, it is regarded as an environmental burden (Strokal et al., 2016). Surplus manure produced in livestock-dense locations where animals are intensively raised and surrounding croplands are nutrient-rich is a source of environmental pollution (Parodi et al., 2021; Yang et al., 2017) and a public health issue (Xie et al., 2018; Zhu et al., 2013).

1) Poultry manure

Manure is the primary food source for several insects in the wild, and these insects may effectively transform manure into fertilizer while keeping a low cost to the environment and recycling waste, particularly black solider fly larvae (BSFLs). According to Lalander et al. (2019), Poultry dung exhibited the maximum material reduction, with 85% on a dry matter (DM) basis, and was an excellent substrate for rapid larval development. By the fourteenth day of the experiment, the first prepupae had emerged from the substrate, and by the nineteenth day, at least fifty percent of the prepupae had emerged, all this in contrast with the development of BSF larvae on cow manure (Myers et al., 2008) that was delayed and the larvae are significantly smaller than those grown on chicken dunk (Diener et al., 2009).

2) Pig manure

Parodi et al. (2021) studied the bioconversion efficiencies, nutrients in the residual material, greenhouse gas and ammonia emissions of Black soldier flies larvae grown on pig dung. They reported the bioconversion efficiency of pig manure using BSFL to be 12.5% have primarily for dry matter (DM). Previous experiments with pig manure and BSFL indicated dry matter (DM) bioconversion efficiencies of 1.8% - 2.1% (Miranda et al., 2019), 2% (Liu et al., 2018), and 5% (Oonincx et al., 2015). They attributed these differences to the different metrics used to calculate bioconversion efficiencies (e.g. fresh vs. dry weight), the different experimental conditions (e.g. the cited studies were conducted with 100 to 450 larvae/per container and different larval densities), the different nutrient composition of manure samples, and the different feeding regimes (i.e. single vs. multiple feeding).

3) Abattoir waste

Lalander et al. (2019) abattoir waste consisted of 48% stomach contents, 16% blood (bought from a retail supplier), 12% feces, 16% meat, and 8% organs (lungs, heart). The fact that larvae developed more rapidly on abattoir waste supports the hypothesis that the protein composition of a substrate affects larval growth. They next mixed abattoir waste with fruits and vegetables in a 1:1 ratio and found the same findings for larval development, but the abattoir waste-fruits-and-vegetables mixture had a greater bioconversion rate.

4.2.5. Human Faecal Matter (FC)

Faecal sludge is broadly described as what accumulates in onsite sanitation systems (such as pit latrines, septic tanks, and container-based solutions) and is not transported by a sewer. It consists of human feces, as well as any other material that can be contained on-site, such as flush water, cleansing materials (e.g. toilet paper and anal cleansing materials), menstrual hygiene products, grey water (i.e. bathing or kitchen water, containing fats, oils, and grease), and solid waste. If faecal sludge is not properly managed, it could have adverse effects on human health and the environment (Akumuntu et al., 2017). As an example, it is estimated that 1.8 billion people utilize faecally polluted drinking water sources as a result of inadequate feacal sludge management (FSM) (United Nations, 2014). Inadequate excreta disposal is one of the principal causes of illness and a significant burden on the health of people in underdeveloped nations (UNICEF, 2005). Until very recently, the management of faecal sludge was severely overlooked in the majority of nations (Strande & Brdjanovic, 2014). In general, the faecal sludge management (FSM) on-site sanitation service supply chain involves storage, collection, transport, and safe end-use or disposal. The final phase increases the complexity of the implementation. Hence, understanding the Black soldier fly larvae performance in the valorisation of feocal sludge is crucial for FSM.

Biomass composition

Lalander et al. (2019) reported that in terms of the nutrient profile of the collected BSF larva, BSF prepupae reared on FS had a considerably higher Crude Protein level (45.4 ± 0.1). Intriguingly, BSF larvae raised on FS contained significantly ($P < 0.001$) less crude fats extracts (18% ± 0.3%) than those raised on other waste substrates. The stated values for crude fat content are comparable to those found elsewhere. 15% - 25% crude fat for larvae fed poultry manure (Gutiérrez et al., 2004), 25% for swine manure (Newton et al., 2005) and 35% for cow manure (Newton et al., 1977).

5. Recommendations

Most investigations on the efficacy and performance of BSFL in waste management focused on their suitability as protein sources and for biodiesel generation.

The capacity of BSFL frass (residue from waste processed includes dead larvae, larvae exoskeleton shreds, and excretory materials) to be used as an organic fertilizer has become an emerging area of study in recent years (Agustiyani et al., 2021; EnviroFlight, 2020; Gligorescu et al., 2020). Hence, it is recommended that the suitability of the BSFL frass post organic waste treatment to be used as an organic fertilizer.

6. Conclusion

In organic waste management, it doesn't suffice to establish BSFL as an effective waste valorisation medium; it is also necessary to assure the sustainability of such a system. While this study demonstrates that BSF larvae can be successfully raised on a variety of waste streams, it also reveals the performance of BSFL in waste treatment of specific substrates could vary thus bringing about different larval yields suitable for the various uses of the larvae post-waste treatment for instance heterogeneity and nutritional superiority of a substrate promote larval development and weight. This review also describes the factors and the best practices that influence larval growth, development, and biomass composition, allowing the larvae to meet the criteria for use as a protein source for livestock feed and the production of biodiesel. A few of the factors include: feeding rate likely being the most influential factor in determining the prepupal weight. Frequent handling of the larvae could cause stress and inhibit growth, and protein-rich substrates accelerate development, but the effect of substrate type on the amino acid profile of BSF larvae does not appear to be significant, the crude protein and lipid composition of the prepupae from various substrates often reflect the nutritious content of the feedstock utilized, Crude protein in larva drops with age. Mixtures of the two substrates could provide even higher bioconversion rate values, which was attributed to the composite substrate's better nutrient balance (C/N ratio), knowledge that is very necessary for pollution prevention. This review was conducted to determine the performance of black soldier fly larvae (BSFLs) in the valorisation of different types of organic waste to establish a precedent for the factors that facilitate the easy multiplication of the larvae to ensure the continuity of a black soldier fly larvae-powered organic waste treatment plant, especially for societies dealing with the organic waste problem for example in Sub-Saharan Africa and the production of high-quality larvae for use as a protein source in animal feed and diesel production.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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