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Biomass yield, morphometric traits, and nutrient composition of black soldier fly larvae cultivated using different food wastes

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Abstract

There is increased focus on Black Soldier Fly Larvae (BSFL) as a new source of protein in livestock and aquaculture nutrition as well as sustainable and cost-effective waste management tool. Thus, this study evaluated the biomass yield, larvae length, proximate analysis, and mineral content of BSFL grown on varied food waste substrates. The BSF eggs were incubated and resulting larvae were reared in three substrates. Rearing Substrate A (RSA) had rotten sweet orange, banana, water melon and soybean curd in a ratio (1:1:1:1), rearing substrate B (RSB) had brewers spent grain and soyabean curd at a ratio of 3:1. While rearing substrate C (RSC) consists of a mixture of rotten sweet orange, banana,, water melon and soyabean curd all mixed at a ratio of (1:1:1:3). The experiment was a completely randomized design and resulting data was analyzed using descriptive statistics. Weights of ten BSFL samples revealed that the highest fresh (0.442±0.25 g) and dried (0.133±0.08 g) weights were obtained on RSA. The larvae cultured on RSA were the longest with a mean length of 1.87±0.12 cm with 47.78±0.37% crude protein and 26.31±0.36% lipid content. The calcium (Ca) content was highest and significantly different in BSFL obtained RSA (111.39±1.09 mg/kg) as compared to RSC (66.29±0.87 mg/kg) and RSB (34.85±0.57 mg/kg). larvae reared using the different substrates have different proximate composition and BSFL contains high concentration of calcium that makes them suitable for incorporation in poultry and aquaculture feed.

Keywords: *Waste, Feed, Black Soldier Fly Larvae, Substrate, Calcium.*

Introduction

The increasing worldwide demand for protein sources to be used in animal feed has put considerable strain on traditional protein sources like fishmeal and soybean meal. To address this, scientists have found alternative and sustainable sources of protein to achieve this with less harm to the environment (Odongo et al., 2024). Insect-based protein from the Black Soldier Fly (BSF) larvae, *Hermetia illucens* is one such alternative that has been proposed to achieve this (Deshmukh et al., 2024). BSF larvae are excellent converters of organic waste to high-protein biomass and thus are the best candidates to be used in animal feeds (Matheka et al., 2022).

Aside from being a sustainable protein alternative, BSF larvae are essential in organic waste management. They break down food waste in an efficient manner, lowering landfills and greenhouse gas emissions (Msangi et al., 2021). BSF larvae can degrade different organic substrates such as vegetable waste, fruit waste, and agricultural residues (Li et al., 2021). The process of bioconversion yields larvae with high protein, fat, and essential mineral content, thus being a sustainable alternative to conventional protein feedstock in livestock and aquaculture feed (Hopkins et al., 2021).

The production of animal feed is based on fishmeal and soybean meal, which have both raised environmental and economic concerns. Overfishing is connected to the production of fishmeal, while soybean farming causes deforestation and loss of habitat (Pérez-Pacheco et al., 2022). BSF larvae present a good alternative since it is a nutrient-rich and high-protein feed ingredient that can be developed in an environmentally friendly way. Research demonstrated that it is possible to substitute fishmeal and soybean meal with BSF larvae without affecting animal growth and health (Jadhav et al., 2022). Aside from being a source of protein, BSF larvae also facilitate proper waste disposal. Organic waste, and food waste in particular, is one of the biggest issues in the environment globally. With the use of BSF larvae to break down organic waste, the waste disposal effect on the environment can be lessened significantly. BSF larvae feed on waste materials and degrade them into biomass fit for animal feed to lower the volume of waste in landfills (Dzepe et al., 2021).

BSF larvae are known to utilize low-value organic waste to produce high-value protein- and fat-rich biomass (Thongprajukaew et al., 2024). BSF larvae are fast-growing and use few resources and are thus an effective waste management solution. By-products of BSF larvae rearing such as frass (the manure of the insects) can serve to be utilized as organic fertilizer, adding to sustainability properties (Opoku et al., 2023). BSF larvae can be grown on multiple organic waste streams such as vegetable and fruit rinds, brewery waste, and agricultural waste (Ichwan et al., 2021). Their capacity to transform complex waste into nutrient-dense biomass makes them a promising candidate in sustainable feed and circular economies (Alagappan et al., 2022).

Although the prospect of BSF larvae as a renewable protein source and waste converter is well documented, there are few data on the effect of varying food waste materials on the biomass productivity, developmental characteristics, and nutritional content. Various organic waste materials can affect larval growth, nutrient utilization and conversion efficiency. Knowledge of these differences is imperative to maximize BSF-based feed processing and waste conversion systems. Thus, the objective of this study was to assess some developmental characteristics, proximate and mineral composition of BSFL reared using combination of orange waste, banana waste, water melon waste and soyabean curd as well as the nutrient and mineral composition of the resultant entomocompost.

Materials and Methods

Study Area

The growing of the larvae of black soldier fly took place at maggot laboratory in National Research Institute for Chemical Technology (NARICT), (lat 11°8'55"N long 7°41'10"E) Basawa, Zaria, Kaduna State, Nigeria.

Experimental Design

The growth performance, biomass yield, as well as nutrient content of *Hermetia illucens* (Black Soldier Fly, BSF) larvae fed on varied waste food substrates were investigated in this study. The experiment was performed within a completely randomized design (CRD) with various treatments denoting different types of waste food combination.

Description of Food Waste Substrates and the Larvae

The eggs of BSF were obtained from the BSF laboratory of National Research Institute for Chemical Technologist (NARICT). The eggs weighing 0.4g were incubated for five days in 201g of substrate which comprised of 67g rotten sweet orange, 67g of banana and 67g of watermelon. The hatched larvae were then nursed and reared in food waste substrates RSA, RSB and RSC which were prepared as follows:

Rearing Substrate A (**RSA**): This comprises of a mixture of rotten sweet orange, banana, watermelon and soyabean curd all mixed at a ratio of (1:1:1:1). Seven days after rearing, soyabean curd at a ratio of 1 was further added to the mixture and the larvae were harvested on day 15.

Rearing Substrate B (RSB): This comprises of brewers spent grain and soyabean curd at a ratio of 3:1. Seven days after rearing, soyabean curd at a ratio of 1 was further added to the mixture and the larvae were harvested on day 15.

Rearing Substrate C (RSC): This consists of a mixture rotten sweet orange, banana, watermelon and soyabean curd all mixed at a ratio of (1:1:1: 3). Seven days after rearing, soyabean curd at a ratio of 1 was further added to the mixture and the larvae were harvested on day 15 (Ebeneezar et al., 2021. modified).

The larvae obtained from the respective rearing substrates are named as:

1. **Larvae A (LA)**
2. **Larvae B (LB)**
3. **Larvae C (LC)**

Materials that can interfere with substrates homogenization such as plastics and pieces of wood were removed physically from the substrates. The substrates were then homogenized using food blender (Joseph *et al.*, 2022).

Rearing Conditions

BSF larvae were reared under controlled environmental conditions:

- **Temperature:** 27-30°C
- **Humidity:** 60-70%
- **Larvae Stocking Density:** 500 larvae per tray (20 cm × 30 cm)
- **Duration:** 12–15 days until larvae reached the prepupal stage (Pliantiangtam et al., 2021).

Data Collection

Biomass Yield Measurement

Total Weight Gain: The total weight of larvae from each rearing substrate was recorded at the end of the experimental period.

Biomass Conversion Efficiency (BCE): The efficiency of food waste bioconversion was calculated as:

$BCE\ (\%) = \left(\frac{Dry\ weight\ of\ larval\ biomass\ (g)}{Dry\ weight\ of\ substrate\ consumed\ (g)}\right) x\ 100$ (Eggink et al., 2022).

Morphometric Analysis

Larval length, segment number and weight were measured using meter rule, and precision balances of 0.001g (Deen et al., 2023).

Proximate Composition Analysis

The proximate composition of BSF larvae was determined following standard AOAC methods:

- **Crude Protein:** Determined using the Kjeldahl method.
- **Crude Fat:** Analyzed using Soxhlet extraction.
- **Moisture Content:** Measured through oven drying at 105°C.
- **Ash Content:** Assessed using a muffle

furnace at 550°C for six hours.

- **Crude Fiber:** Determined by acid and alkaline digestion (Zandi-Sohani & Tomberlin, 2024).

Mineral Composition Analysis

The mineral composition, concentrations of BSF larvae and food waste substrates was determined using atomic absorption spectrophotometry (AAS). The minerals analysed include: Calcium (Ca), Potassium (K), Magnesium (Mg), Sodium (K), Manganese (Mn), Zinc (Zn) (Fitriana et al., 2021 modified).

Characteristics of BSFL fed with the substrates

Statistical Analysis

All collected data were managed using Microsoft Excel and analyzed using descriptive statistics.

Results and Discussion

Biomass Yield and Morphometric

The fresh and dry weights of ten pieces of BSFL, total biomass obtained from different substrates, weights of fresh entomo-compost and morphometric characteristics of BSFL fed with the substrates is presented in Table 1.

Table 1. Weight of the 10 pieces of BSFL, total biomass obtained from different substrates, and morphometric characteristics of BSFL fed with the substrates.

Parameter	RSA	RSB	RSC
Fresh weight (g) of 10 pieces of BSFL	0.442±0.25[a]	0.20±0.05[c]	0.282±0.03[b]
Dry weight (g) of 10 pieces of BSFL	0.133±0.08[a]	0.06±0.01[c]	0.062±0.03[b]
Fresh total biomass of BSFL obtained from substrate (g)	176.45±66.58[b]	253.97±15.59[a]	220.03±107.52[a]
Dry total weight of BSFL obtained from substrate (g)	46.47±14.53[a]	51.76±15.88[a]	59.40±19.32[a]
Fresh entomocompost obtained after rearing the BSFL (g)	371.66±47.33[b]	875.23±161.00[a]	667.83±168.64[a]
Number of segments of BSFL	10.2±0.42[a]	10.3±0.48[a]	10.10±0.32[a]
Length of BSFL (cm)	1.87±0.12[a]	1.28±0.13[b]	1.55±0.18[c]

Mean values with same superscript are not significantly different (DMRT)

The biomass yield of BSFL differed markedly for the various food waste substrates tested in this study. Weights of ten BSFL samples revealed that the highest fresh (0.442±0.25 g) and dried (0.133±0.08 g) weights were obtained on RSA, and the lowest fresh (0.20±0.05 g) and dried (0.06±0.01 g) weights were obtained on RSB. The result shows that there are significant differences in the mean values of larvae reared using the different substrates. The highest value of fresh total biomass weight of larvae was 253.97±15.59 g for RSB, then 220.03±107.52 g for RSC, then 176.45±66.58 g for RSA.

The mean weight of the fresh entomocompost obtained after rearing the BSFL differed significantly among the samples, with RSB having the highest residue weight (857.23±161.00 g), followed by RSC (667.83±168.64 g) then RSA (371.66±47.33 g). RSB is not significantly different from RSC but they (RSB and RSC) differ significantly from RSA. The high differences in weight of fresh entomocompost indicate differences in feed conversion efficiency with the larvae being able to utilize RSA more than RSB and RSC. This implies that RSB and RSC produce more waste than RSA. The observed variation in fresh total biomass of BSFL is a result of the digestibility and composition of substrates used in food waste. The highest fresh entomocompost mean weight was obtained by RSB, this might be due to the bulky nature of spent grains contained in the substrate.

RSC, which had a lower fresh entomocompost weight compared to RSB, had the highest dry total weight of the BSFL. This implies that the substrate used for RSC could have contained a higher proportion of protein and fats that result in higher dry matter content of BSFL reared. The same trend has been observed in a previous study involving the use of high-protein diets leading to higher larval dry weight as well as protein yield (Li et al., 2021). The high fresh entomocompost weight in RSB may be indicative of higher indigestible matter content in the substrate, hence lower feed conversion efficiency by the BSFL. The lowest fresh entomocompost weight was obtained from RSA, indicating greater nutrient assimilation efficiency by the larvae. A study by Isibika et al. (2021) showed that supplementing with protein-rich food waste, including fish by-products, enhanced conversion efficiency, contributing to greater biomass of larvae.

Furthermore, a study by Karthikeyani et al. (2024) revealed that fruit-based waste produced more bioconversion compared to vegetable-based substrates, as indicated by the findings of RSB. In contrast, Fernando (2023) reported that the highest biomass yield was in substrates with high content of lipid as well as protein, in concurrence with the greater dry total weight recovery of RSC. This research thus indicates that the selection of food waste substrate is important in determining BSFL growth efficiency and biomass yield. High protein and lipid content substrates improve biomass accumulation in dry matter, whereas substrates with high fiber content or moisture content can lead to poor conversion efficiency.

The length of the BSFL cultured on various substrates differ as reflected in Table 1 but there is no significant difference in the number of segments BSFL larva possesses when they are reared using different substrates. This implies that this trait is unaffected by what the larvae consumes. This is In line with previous studies, BSFL are genetically set to a certain number of segments that are determined during early embryonic stages and are not affected by feeding or environmental conditions (Kim et al., 2010). Scientists have discovered from their studies that under different conditions, the size, weight and way of moving of larvae may differ, but their segmentation does not (Giannetti et al., 2022). Moreover, studies on genotype-by-environment interaction revealed that both genetics and nutrition play a big role in affecting growth and nutritional characteristics but not the number of segments (Sandrock et al., 2019).

The larvae fed with RSA were the longest with a mean length of 1.87±0.12 cm. The fact that they were the longest larvae implies that RSA gave a denser nutrient environment, allowing for maximum growth. On the other hand, the larvae fed with RSB had the shortest mean length of 1.28±0.13 cm**.** This may be as a result of potential nutrient limits or lower digestibility of this substrate which contains basically spent grains. The differences in morphometric characteristics of larvae indicate the effect of substrate quality on growth performance. According to a study by (Fasha et al., 2024), larvae which were fed on the waste from a slaughterhouse and rice bran showed superior growth characteristics, confirming the observations in RSA, which may contain a greater proportion of protein and lipid content.

The gross difference in length of the larvae is also consistent with prior work on BSFL cultivation. For example, Zhang et al. (2023) showed that larvae cultured on heterogeneous urban food waste streams showed pronounced phenotypic plasticity, with the larvae becoming longer and bigger in protein-rich diets. Likewise, Gyimah et al. (2021) showed that the body size of larvae was affected by substrate composition, as well as structural features, like the development of wings, indicating the importance of diet in morphometric features.

Also, Adlin (2023) found substrate nutrient content to be a determining factor in BSFL body size, with waste having a high-fat content and protein content promoting greater larval growth. This supports the current findings wherein the largest larvae were found in RSA as a result of greater macronutrient content. Overall, the morphometric differences seen here indicate the effect of substrate composition on larva growth and development. The most desirable condition for larvae growth was achieved by RSA, yielding the highest larvae mean length.

Proximate Composition of Larvae

The proximate composition of the rearing substrates and larvae are presented in tables 2 and 3.

Table 2. Proximate composition of the rearing substrates for BSFL

Parameter	RSA	RSB	RSC
MC (%)	8.65±0.41[a]	7.78±0.31[b]	8.66±0.49[a]
Ash (%)	3.66±0.50[a]	2.5±0.4[b]	3.81±0.75[a]
Crude Fibre (%)	9.11±0.70[b]	10.56±0.57[a]	9.99±0.48[a]
Lipid (%)	7.92±0.30[a]	3.2±0.23[c]	6.58±0.53[b]
Crude Protein (%)	13.43±0.61[a]	9.12±0.06[c]	12.81±0.76[b]
NFE (%)	57.24±0.53[c]	66.84±0.84[a]	58.15±1.38[b]

Mean values with same superscript are not significantly different (DMRT)

Table 3. Proximate composition of Black Soldier Fly Larvae reared on different substrates.

Parameter	Larvae A	Larvae B	Larvae C
MC (%)	7.75±0.48[a]	6.50±0.66[b]	6.98±0.19[b]
Ash (%)	5.95±0.21[b]	4.82±0.20[c]	6.72±0.12[a]
Crude Fibre (%)	7.12±0.22[c]	8.75±0.16[a]	7.80±0.32[b]
Lipid (%)	26.31±0.36[a]	15.64±0.43[c]	24.98±0.38[b]
Crude Protein (%)	47.78±0.37[a]	32.06±0.47[c]	45.45±0.49[b]
NFE	4.99±0.80[c]	32.23±0.68[a]	8.06±0.83[b]

Mean values with same superscript are not significantly different (DMRT)

When considering the substrates used for rearing (Table 2), RSA contained the highest crude protein (13.43±0.61%) as well as crude lipid (7.92±0.30%) content, corresponding to the greater protein (47.78±0.37%) and lipid (26.31±0.36%) content accumulated by larvae raised on this substrate (LA). Conversely, RSB contained the lowest protein (9.12±0.06%) as well as lipid (3.20±0.23%) content, corresponding to the lower crude protein as well as lipid value found in LB (32.06±0.47% and 15.64±0.43%) respectively. RSC, with crude protein (12.81±0.76%) as well as lipid (6.58±0.53%) content, yielded intermediate values in LC (45.45±0.49% crude protein and 24.98±0.38% lipid). This supports the correlation between substrate nutrient content as well as the consequent larvae composition, corresponding to those findings of (Zandi-Sohani & Tomberlin, 2024).

These differences in proximate composition underscore the significance of substrate selection in maximizing BSFL as a protein alternative. The absolute protein content as well as the lipid content in LA and LC points towards suitability for formulating animal feeds with high-energy content. The low protein content along with a higher content of fiber and NFE in LB, on the other hand, points towards utilization in formulations where fiber content can contribute to digestive well-being (Hopkins et al., 2021).

Earlier experiments showed that substrate quality has a direct impact on the contents of larvae protein and fat as well as on the profile of the amino acids and digestibility (Zandi-Sohani & Tomberlin, 2024). The findings of this study confirm that BSFL composition can be optimized depending on substrate choice in order to suit individual nutrient demands in poultry, aquaculture, and animal feeding. The proximate analysis of BSFL differed considerably depending on the food waste substrate used for their rearing. From Table 3, it can be observed that the moisture content (MC) of the larvae varied from 6.50±0.66% (for LB) to 7.75±0.48% (for LA) with LC being in the middle at 6.98±0.19%. The lowest moisture content of LB represents a high concentration of dry matter, which may be desirable for the production of feeds.

The highest content of crude protein (CP) was found in LA (47.78±0.37%), followed by LC (45.45±0.49%), and the lowest content was found in LB (32.06±0.47%). These differences reflect the effect of substrate composition in the protein accumulation of larvae. It has been reported that larvae raised on proteinaceous substrates, such as restaurant waste or brewery waste, accumulate higher protein content (Opoku *et al.,* 2023). The crude lipid (CL) content was highly variable, with LA and LC having a higher content of fat (26.31±0.36% and 24.98±0.38% respectively) compared to LB (15.64±0.43%). The higher lipid content in LA and LC implies that these substrates probably had a higher content of organic matter rich in fat, such as dairy waste or meat. It has already been proven through previous studies that lipid content in BSFL has a strong dependency on substrate lipid composition (Belperio *et al.,* 2024).

The highest ash content, reflecting the concentration of mineral content, was observed in LC (6.72±0.12%), followed by LA (5.95±0.21%) and LB (4.82±0.20%). An increase in ash content implies a high concentration of essential minerals like calcium, phosphorus, and magnesium, which are very important for animal nutrition (Adebayo *et al.,* 2021). The proportion of crude fibre in BSFL was in the range of 7.12±0.22% to 8.75±0.16% and this value significantly varied between different treatments. These results are in line with past studies that discovered BSFL fibre amount changes according to the kind of feed and the animal’s development. Yusoff et al. (2022) found fibre levels in BSFL of 10.1%, while Mahmud et al. (2020) noticed increases up to 10.5% during longer rearing periods. However, the result of this research disagrees with the findings of Holeh *et al.,* (2022) who reported crude fiber contents of 4.92±0.01%, 4.12±0.01%, and 4.02±0.01% for BSFL fed with market and hotel wastes, and a mixture of both respectively. In addition, Nafisah et al. (2019) proved that chitin manipulation in the larva’s exoskeleton achieved a drop in crude fibre through both physical and biological treatments. However, many studies have illustrated that lower-fibre levels (4.09–4.32%) can be found in BSFL raised on fruit and vegetable by-products, proving that more digestible and fibrous-free diet leads to less fibre in the larvae (Ahmad et al., 2024; Deshmukh et al., 2024). It is clear from this study that the fibre composition of BSFL is affected by the proximate composition of substrate used.

Mineral content of larvae and food waste substrates

The mineral composition (Ca, K, Mg, Na, Mn and Zn) of the rearing substrates and larvae are presented in tables 4 and 5.

Table 4: Mineral composition of substrates used in rearing BSFL

Mineral	RSA	RSB	RSC
Ca (mg/kg)	74.36±0.94^{a}	7.59±0.10^{c}	21.28±0.07^{b}
K (mg/kg)	16.95±0.11^{a}	18.69±3.29^{a}	18.21±1.27^{a}
Mg (mg/kg)	50.45±0.44^{a}	23.97±1.49^{c}	36.85±1.94^{b}
Na (mg/kg)	5.80±0.29^{a}	5.42±0.16^{b}	6.20±0.50^{a}
Mn (mg/kg	0.87±0.01^{a}	0.04±0.00^{b}	0.05±0.00^{b}
Zn (mg/kg)	0.54±0.07^{a}	0.43±0.02^{b}	0.51±0.02^{a}

Mean values with same superscript are not significantly different (DMRT)

Table 5: Mineral composition of BSFL reared from substrates containing various fruit and vegetable wastes

Mineral	LA	LB	LC
Ca (mg/kg)	111.39±1.09^{a}	34.85±0.57^{c}	66.29±0.87^{b}
K (mg/kg)	20.10±1.81^{a}	17.71±1.57^{a}	17.89±1.10^{a}
Mg (mg/kg)	58.26±3.17^{a}	19.41±2.17^{a}	20.39±4.26^{a}
Na (mg/kg)	5.97±0.59^{c}	20.37±0.83^{b}	28.66±1.97^{a}
Mn (mg/kg)	0.03±0.00^{b}	0.03±0.01^{b}	0.23±0.01^{a}
Zn (mg/kg)	0.01±0.00^{c}	1.42±0.05^{a}	1.30±0.05^{b}

Mean values with same superscript are not significantly different (DMRT)

The mineral composition RSA had a significantly higher calcium (74.36±0.94mg/kg) as compared to RSC (21.28±0.07 mg/kg) and RSB (7.59±0.10 mg/kg). The magnesium content of RSA (50.45±0.44mg/kg) was also significantly higher as compared to RSC (36.85±1.94 mg/kg) and RSB (23.97±1.49 mg/kg). The mineral composition of BSFL differed considerably depending on the substrate composition used for rearing. The calcium (Ca) content was highest and significantly different in LA (111.39±1.09 mg/kg) as compared to LC (66.29±0.87 mg/kg) and LB (34.85±0.57 mg/kg). Likewise, the content of magnesium (Mg) observed a similar trend, where the significantly highest content was in LA (58.26±3.17 mg/kg), compared to LB and LC, which contained 19.41±2.17 mg/kg and 20.39±4.26 mg/kg, respectively.

Potassium (K) contents were relatively constant with treatment, varying from 17.71±1.57 mg/kg (LB) to 20.10±1.81 mg/kg (LA). The sodium (Na) content varied extensively, with the highest concentration being in LC (28.66±1.97 mg/kg) as compared to LB (20.37±0.83 mg/kg) and LA (5.97±0.59 mg/kg). Manganese (Mn) and zinc (Zn) trace elements varied as well, with LC having the highest Mn content (0.23±0.01 mg/kg) and LB the highest Zn content (1.42±0.05 mg/kg) to indicate that substrates differently affect mineral bioaccumulation. The significantly high content of calcium observed in this study is an indication of the importance of calcium in the body. Chia et al., (2020) reported that although all macrominerals are important but Ca and P are the most abundant macrominerals in the body.

The high concentration of calcium and magnesium in LA indicated that larvae grown on such a substrate are especially suitable for incorporation in poultry and aquaculture feed, where such minerals are important in bone formation as well as metabolic processes (Opoku *et al.,* 2023. The potassium content found in BSFL is also useful in animal nutrition since potassium supports functional roles in nerves as well as muscle contraction (Zandi-Sohani & Tomberlin, 2024). The morphological features seen in this study validate the observations of Fasha et al., (2024) that larvae grown on nutrient-rich organic waste had better growth and segment formation.

Proximate composition of the larvae was directly affected by the nutrient content of the substrates by varying in crude protein, fat, ash, as well as fiber content. Opoku et al. (2023) reported similar trends, where varying organic waste mixtures led to notable changes in the accumulation of protein as well as lipid in BSFL. This research findings concur with other studies demonstrating the effect of food waste substrates on biomass yield, morphometric attributes, proximate analysis, as well as mineral content of BSFL. The findings of biomass yield indicated that proteinaceous as well as lipid-rich substrates led to improved larval weights as well as dry matter content. This concurs with Li et al., (2021), who indicated that proteinaceous substrates greatly improve BSFL growth performance as well as feed conversion efficiency.

Finally, findings on the mineral content highlight the significance of substrate quality as a contributor to mineral bioaccumulation. It has been affirmed by a work by Zandi-Sohani & Tomberlin (2024) that calcium and magnesium content in BSFL are directly associated with dietary mineral availability, hence substantiating the differences observed in this study.

Conclusion

Black soldier fly larvae are rich in minerals especially calcium as well as magnesium which makes them a potentially good supplement in animal diets. BSFL is a promising tool for sustainable feed production as well as organic waste management. They have the capacity for organic waste breakdown and utilization across a variety of waste types thereby supporting circular bio-economic strategies. Thus the evidence is in support of BSFL-based waste management systems integration at urban and agricultural locations where food waste accumulation is of particular concern.

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