Global Journal of Fisheries Science
Volume 7(3), pages 81-90, August 2025
Article Number: A374C1A43
ISSN: 2782-750X
https://doi.org/10.31248/GJFS2025.084
https://integrityresjournals.org/journal/GJFS

Full Length Research

Composition of black soldier fly larvae (*Hermetia illucens*): A comparative study across three different rearing substrates and two different drying methods

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Received 10th June 2025; Accepted 8th August 2025

ABSTRACT: The development of the aquaculture sector in Nigeria has been slowed by the growing cost of feed ingredients, particularly fish meal. It is becoming more and more common to produce Black Soldier Fly (*Hermetia illucens*) larvae (BSFL) as insect meal and a sustainable substitute for conventional animal feed sources. However, there is limited information on the best suited substrate for the commercial production of BSFL. Hence, the nutrient composition of BSFL meal was assessed utilizing several substrates and drying methods. The BSFL were grown on three distinct organic wastes of wheat bran (WB), maize bran (CB), and varied fruit wastes (FW) for 13 days, at UI-FAO insectarium, Department of Aquaculture and Fisheries Management, University of Ibadan. Oven and sun-drying techniques were used to process the reared BSFL. Compositions of the larvae raised on three distinct types of organic garbage were assessed and statistically examined. Larvae raised on wheat bran/sundried (WB/SD) had the maximum protein content (60.78%), whereas those raised on fruit waste/oven dried (FR/OD) had the lowest value (29.70%). Larvae raised on fruit waste/oven dried (FR/OD) had higher levels of vitamin A, C, and D, whereas those raised on wheat-bran/oven dried (WB/OD) had the lowest levels. Larvae raised on wheat-bran substrate had significantly different ($p<0.05$) levels of alanine. No statistical differences were observed in copper values of the larvae reared on the three substrates. The larvae raised on a wheat-bran substrate had greater levels of potassium and zinc compared to the larvae reared on assorted fruit waste and corn-bran substrates. The results revealed wheat bran as the best substrate, and black soldier fly larvae were identified as a possible sustainable supply of protein in aquaculture. Consequently, it is advised that black soldier fly larvae (BSFL) be raised on wheat bran substrate and processed via the sun-drying method, which is a preferable substrate and drying method.

Keywords: Aquaculture, insect meal, organic substrates, sustainable protein source, wheat bran.

INTRODUCTION

Aquaculture's current fish production has not been able to keep up with demand due to issues with climate change, using wild fish for feed (Naylor *et al.,* 2021), and population growth (Belghit *et al.,* 2018). Fish require a balanced diet including protein, lipids, carbohydrates, vitamins, and minerals to ensure optimal growth, health, and productivity. The nutritional needs of fish vary depending on factors such as species, life stage, and environmental conditions (Limbu *et al*., 2022). Fishmeal is a crucial component of fish feed formulation for cultured fish, mostly made from tiny pelagic species, such as herring, sardines, and anchovies (Lorenzen *et al*., 2022). Fishmeal is becoming more expensive due to the growing demand for it as a key source of protein in animal diets. Additionally, feed expenses account for almost 70% of the entire aquaculture production (Chia *et al*., 2020). Therefore, finding sustainable and alternative sources of protein for aquaculture is needed (Makokha *et al*., 2023; Lu *et al*., 2022; Chia *et al.,* 2020; Belghi *et al.,* 2018). Both public organizations and researchers are interested in the possibilities of insect-based protein (Iyapo *et al.,* 2025; Iyapo *et al.,* 2024; Lu *et al*., 2022; Chia *et al*., 2020; Shumo *et al*., 2019).

The black soldier fly (BSF) (*Hermetia illucens*) larvae are one of the insect species with the greatest potential for large-scale production among those suggested for animal feed. BSF larvae provide a novel approach to waste valorization by converting low-grade organic waste streams into high-quality protein (Iyapo *et al.,* 2025; Addeo *et al.,* 2024; Gebremichael *et al.,* 2022; Oliva-Teles *et al.,* 2022; Chia *et al*., 2020). The Food and Agricultural Organization (FAO) recommends that insect species acceptable for feed are those that can be produced in large quantities on an industrial scale, with a minimum reach of 1,000 kg per day of insect fresh weight (Chia *et al*., 2020). However, meeting this recommendation requires a considerable amount of substrate for insect feeding. Moreover, the nutritional composition of BSF larvae is influenced by the substrate used. Accessibility of abundant feedstock is crucial for the sustainability of insect production. Substrates such as corn bran, wheat bran, and assorted fruit waste have been investigated for BSF larvae rearing because of their availability and possible nutritional values. They are nutrient-dense and high in fiber and protein, which enable high larvae development rates and biomass output. They are economical and environmentally friendly (Iyapo *et al.,* 2025; Siddiqui *et al.,* 2024). Corn bran and wheat bran were chosen based on their nutritional diversity, while assorted fruit waste was selected because of its availability as local waste. One common technique for increasing the shelf life of edible insect larvae is the drying technique. This method includes roasting, sun drying, smoke drying, oven drying, microwave drying, hot-air drying, and freeze drying (Thanasakran *et al*., 2025). Drying process reduces moisture-mediated deteriorative biochemical processes, stops microbial growth and reproduction, maintains nutritional values, and brings the moisture content down to a safe level (Iyapo *et al*., 2024). Oven drying and sun-drying are the most widely used methods for dehydrating whole edible insects due to their affordability and historical use (Akullo *et al*., 2025). The substrates used in the production and processing technique of the BSFL is a great way to evaluate its acceptability for animal and human consumption, and this can affect the nutritional value of the finished product of black soldier fly larvae meal (BSFLM) (Iyapo *et al*., 2025). Therefore, the purpose of this study was to investigate the chemical composition and quality of black soldier fly larvae raised on three distinct substrates and processed using oven-dried and sun-dried processes, as a source of protein for the aquaculture sector.

MATERIALS AND METHODS

Experimental site

The production and rearing of black soldier fly larvae (BSFL) were performed inside the insectarium in conducive conditions (39°C and 60% relative humidity) provided by the FAO-UI unit, Department of Aquaculture and Fisheries Management, Faculty of Renewable Natural Resources, University of Ibadan, Ibadan, Oyo State, Nigeria.

Experimental materials

Ten (25 litre) yellow kegs were cut vertically into two equal parts (17 x 11 x 4 inches) for rearing of the black soldier fly larvae. The wheat bran and maize bran were purchased from a commercial feed mill in Ibadan, while the assorted fruit wastes were obtained from the fruit sellers at Agbowo market in Ibadan, Oyo State. The assorted fruit wastes were blended into fine particles, kept in an air-tight plastic container to prevent contamination of other insects. A 2 by 2 wooden planks were bought from Bodija Sawmill Market, cut into 10 inch sizes to serve as eggies, where the black soldier fly laid their eggs. 650 ml covered bowls, face towel size, spraying bottle, 12 width by 5 inch depth bowls, and glucose were all bought from Bodija Market in Ibadan, Oyo State. Poultry drops were collected from the departmental poultry farm, mixed with water (20 g: 5 litres) inside an air-tight plastic container, covered for 2-3 days to produce foul smell as attractant for the black soldier fly.

Preparation of the feeding substrates

Three substrates were used to raise the BSFL. These substrates included wheat bran (WB), corn bran (CB), and assorted fruit waste (FW). The dried substrates (wheat bran and corn bran) were mixed with water (200 g of substrate mixed in 2 litres of water) inside the rearing trays. The fruit waste comprises pineapple rinds, orange pith, and watermelon rinds, blended and kept in an air-tight plastic container. Each substrate was measured inside the rearing tray, and a caliber net was spread on the prepared substrates to prevent the BSFL from drowning when newly hatched.

Experimental set-up

The experiment was in two segments: the production of black soldier fly larvae inside the love nest using attractant, and the rearing of black soldier fly larvae using different organic substrates (wheat bran, corn bran, and assorted fruit waste).

Figure 1. Experimental set-up for production of the Black Soldier Fly Larvae (A= Black Soldier Fly Lavae Insectarium; B = Arrangement of the Love Net; C = Active Emerged Black Soldier Fly; D = Eggies containing laid Black Soldier Fly Eggs; E= Scrapped Black Soldier Fly Eggs; F = Arrangement of the prepared rearing trays in triplicates inside shelves in an insectarium for nurturing hatched larvae).

Production of black soldier fly larvae

One kilogram of black soldier fly pupae (starter) was collected from a reputable farm in Ibadan. Four bowls containing 100g of starter each and two bowls of attractant each were arranged inside the love nest. A towel soaked in glucose water bowl was placed inside the love nest for the flies to suck and to prevent them from dehydration because the BSF did not eat at this stage. The only stage of black soldier fly that eats is the larvae stage. 2-3 eggies were arranged on each attractant bowl for the emerged female black soldier fly to lay their eggs after mating.

The black soldier fly started emerging from the pupae stage to the adult fly stage after 3 days, and they copulate after two days of emerging. The female BSF laid eggs through their ovipositor inside the eggies arranged on the attractant bowls. Glucose water was also sprayed on the love nest to cool their environment. The BSF died after laying their eggs. After 4-6 hours of laying eggs, the eggies were collected and scraped using a sharp knife. The scrapped eggs were weighed and transferred to the second phase (rearing phase) of production.

Rearing of black soldier fly larvae

Five grams of eggs were weighed using a sensitive weighing scale (Cen-Tech,12.7 x 8.1x 2.6 inches) and gently placed on the caliber net spread on the prepared substrates to prevent drowning of the larvae when hatched, then the prepared eggs were covered with another caliber net to prevent other flies from laying eggs. The substrate trays were covered with fine nets, fastened with rope to prevent escape of the larvae. Each treatment was replicated thrice, labeled, and arranged inside the array shelves, in an insectarium. The eggs hatched after 4-6 days, depending on the environmental conditions. The hatched larvae started consumption of the substrates (wheat bran and corn bran, and fruit waste) immediately they hatching. The rearing larvae substrates were checked daily, moistened with neat water, and replaced every four days with freshly prepared substrates to remove exuvia and frass, to provide adequate food for the proper development of the larvae. The larvae growth and development were monitored through weight and length. The mature larvae were harvested by mechanical sieving using different sizes of sieves on the 13th day of rearing, to separate the larvae from frass (residue of the substrates).

Processing of the reared larvae

After harvesting, the larvae from each substrate (wheat bran, corn bran, and fruit waste) in triplicate were rinsed with water, killed by blanching (immersion for 1–5 min in boiling water), drained, and divided into two parts; then processed by two different drying methods (oven-dried and sun-dried). The oven-dried larvae were dried at 100ºC for 24 hours, while the sun-dried larvae were sun-dried for 96 hours, respectively. The dried larvae were milled to black soldier fly larvae meal (BSFLM) for chemical analysis (proximate, vitamin, fatty acids profile, and amino acid profiles).

Chemical analysis

The proximate analysis of the processed BSFL meal were done for their composition using Iyapo *et al*. (2025) method (Table 1); mineral analysis (Table 2) BSFLM were analysed using Atomic Absorption Spectrophotometer machine as described by Addeo *et al*. (2024) method; vitamins (Table 3) and amino acid (Table 4) were quantified using High-Performance Liquid Chromatography (HPLC) method; and fatty acid using Gas Chromatography-Mass Spectrometry (GC-MS) method (Table 5) following standard method.

Statistical analysis

The data generated were analyzed using one-way ANOVA and Descriptive. The Duncan Multiple Range Test (DMRT) was used for posthoc analysis and expressed as mean ± SE (standard error). The significance level adopted was 95% ($P \leq 0.05$). Statistical analyses were performed using the software SPSS version 20 (SPSS Inc., Chicago, IL).

RESULTS

Proximate Composition

The crude protein value of Black Soldier Fly Larvae (BSFL) reared on wheat bran (WB) was significantly higher ($p<0.05$) compared to those reared on corn bran (CB) and assorted fruit waste (FW) substrates, but the value of larvae reared on wheat-bran substrate and dried via sundried (WB/SD) (60.78±0.04%) was higher than the value of larvae reared on wheat-bran substrate and dried via oven-dried larvae (WB/OD) (57.66±0.50%). The same trend was also reported from carbohydrate (CHO) values of the black soldier fly larvae reared on the three substrates. The highest ash value was reported from BSFL reared on assorted fruit waste substrate and dried via oven-dried (FW/OD) (19.05±0.07%) while the least value (4.00±0.14%) was recorded from BSFL reared on corn-bran substrate and dried via oven-dried (CB/OD). The ether extract value was highest (23.95±0.21%) from BSFL reared on corn-bran substrate and dried via oven-dried (CB/OD) and least value (3.60±0.14%) from BSFL reared on wheat-bran substrate and oven dried (WB/OD). Crude fibre was highest (9.00±0.14%) from BSFL reared on assorted fruit waste substrate and dried via oven-dried (FW/OD), while the lowest value (5.65±0.21%) was reported from BSFL reared on corn-bran substrate and dried via oven-dried (CB/OD). This result indicated that wheat-bran substrate is the leading substrate out of the three substrates examined, and the sun-drying method is the better method between the chosen drying methods to keep the proximate composition of black soldier fly larvae (Table 1).

Vitamins composition

Vitamin A was significantly higher ($p<0.05$) than vitamin C and vitamin D across the treatment. Vitamin A was highest (7.17 ± 0.03mg) in BSF larvae raised on assorted fruit waste oven-dried (FW/OD) followed (15.28 ± 0.02mg) by the BSF larvae reared on assorted fruit waste substrate and dried through sun-dried method (FW/SD), then (9.10 ± 0.02mg) BSFL reared on corn bran substrate and sundried (CB/SD) while the least value of vitamin A (7.17 ± 0.03mg) was recorded from BSFL raised with wheat bran substrate and oven-dried (WB/OD). The highest vitamin D value (2.07 ± 0.03mg) was recorded from BSFL reared on assorted fruit waste substrate and dried via oven-dried method (FW/OD), while the least value was recorded from BSFL reared on wheat bran substrate and oven-dried (WB/OD). There was no significant difference ($p>0.05$) between the vitamin C value of BSFL reared on corn-bran substrate and dried via sundried (CB/SD) and BSFL reared on assorted fruit waste substrate and dried via oven-dried method (FW/OD). This result revealed assorted fruit waste substrate as the best substrate that maintained vitamin A, C, and D of the reared black soldier fly larvae irrespective of the drying methods (oven and sun drying) (Table 2).

Minerals Composition

The mineral analysis reported that calcium values ranged from 0.26% to 3.05%; magnesium ranged from 0.33mg to 0.48mg. The highest value of potassium (1.13 mg) was reported from BSFL reared on wheat bran substrate and dried via sundried method (WB/SD), and the least value (0.61 mg) was reported from BSFL reared on corn bran

Table 1. Proximate composition of the reared and processed black soldier fly larvae.

Proximate (%)	WB/OD	WB/SD	CB/OD	CB/SD	FW/OD	FW/SD
Crude protein	57.66±0.50[a]	60.78±0.04[a]	35.74±0.51[b]	33.46±0.78[c]	29.70±0.28[d]	30.35±0.35[d]
Ash content	7.04±0.57[b]	6.85±0.07[c]	4.00±0.14[d]	6.25±0.21[c]	19.25±0.07[a]	19.05±0.07[a]
Ether extract	3.60±0.14[e]	4.25±0.21[d]	23.95±0.21[a]	23.35±0.21[a]	17.55±0.21[c]	18.10±0.28[b]
Crude fibre	6.70±0.14[c]	7.25±0.07[b]	5.65±0.21[f]	6.00±0.14[d]	9.00±0.14[a]	8.45±0.07[b]
Dry matter	61. 90±0.28[c]	59.46±0.04[d]	91.76±0.21[a]	91.20±0.02[a]	88.20±0.42[b]	88.95±0.35[b]
Carbohydrate	38.10±0.28[c]	40.55±0.04 [a]	30.66±0.65[d]	30.95±0.22[b]	24.50±0.14[d]	24.05±0.07[d]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05). **Legend:** WB/OD = Wheat bran/Oven dried; WB/SD = Wheat bran/Sun dried; CB/OD = Corn bran/Oven dried; CB/SD = Corn bran/Sun dried; FW/OD = Fruit waste/Oven dried; FW/SD = Fruit waste/Sun dried.

Table 2. Vitamins profile of the reared and processed black soldier fly larvae.

Treatments	Vitamin A (mg/100g)	Vitamin C (mg/100g)	Vitamin D (mg/100g)
WB/OD	7.17 ± 0.03[e]	6.47 ± 0.03[d]	0.45 ± 0.02[d]
WB/SD	8.78 ± 0.03[d]	7.25 ± 0.02 [c]	0.65± 0.02[c]
CB/OD	7.37± 0.08[e]	6.95 ± 0.21[d]	0.75± 0.01 [c]
CB/SD	9.10 ± 0.02[c]	9.17± 0.02[a]	1.02 ± 0.02[b]
FW/OD	16.51 ± 0.02[a]	9.75 ± 0.01[a]	2.07 ± 0.03[a]
FW/SD	15.28 ± 0.02[b]	8.02 ± 0.01[b]	1.51 ± 0.01[b]

Means ± SE along the same column with similar superscripts are not significantly different (p>0.05). **Legend:** WB/OD = Wheat bran/Oven dried; WB/SD = Wheat bran/Sun dried; CB/OD = Corn bran/Oven dried; CB/SD = Corn bran/Sun dried; FW/OD = Fruit waste/Oven dried; FW/SD = Fruit waste/Sun dried.

substrate and dried via oven dried method (CB/OD). Phosphorus was highest in BSFL reared on assorted fruit waste substrate and dried via sundried method (FW/SD) as well as BSFL reared on wheatbran and oven dried (WB/OD) with a value of 0.95mg while the least value (0.61mg) was recorded from BSFL reared on corn bran substrate and dried via oven dried method (CB/OD). There were no significant differences (p>0.05) in phosphorus values of the larvae reared on the three substrates. Sodium was significantly higher (2.11mg) in BSFL reared on assorted fruit waste substrate and dried via the sundried method (FW/SD) compared to others. Some micro minerals were not detected across the treatment, including Lead, Cadmium, Mercury, Cobalt, Chromium, Nickel, Selenium, and Vanadium. Nitrogen was not detected in BSFL reared on wheat bran substrate (WB), but was present in BSF larvae reared on assorted fruit waste (FW) and corn-bran (CB) substrates. Zinc was observed across the treatments. Highest value (0.20mg) of zinc was recorded from BSFL reared on wheat bran substrate and oven dried (WB/OD) while the least value (0.13mg) was recorded from BSFL reared on corn-bran substrate and oven dried (CB/OD) together with BSFL reared on assorted fruit waste substrate and dried via oven dried method (FW/OD). This result discloses the sun-drying method as the better drying method that stabilizes the body needed minerals irrespective of the substrate used in rearing the black soldier fly larvae (Table 3).

Amino acid composition

No significant variations were recorded in the amino acid profile of the BSF larvae reared on fruit waste, corn bran, and wheat-bran substrates. All non-essential amino acids profiles were higher in BSFL reared on wheat bran substrate and dried via sundried method (WB/SD), except glycine, which was higher in BSFL reared on wheat bran substrate and dried via oven dried method (WB/OD). In addition, the essential amino acid profile was reported to be highest from BSFL reared on wheat bran substrate and dried via the sundried method (WB/SD). Lysine, Phenylalanine, and Valine were highest in BSFL reared on wheat bran substrate and dried via oven-dried method (WB/OD) and BSFL reared on corn-bran substrate and dried via sundried method (CB/SD). This symbolized that wheat-bran substrate is the best substrate out of the three experimented substrates, and the sun-drying method is the better drying BSFL that maintained the Amino acid profiles of the black soldier fly larvae examined (Table 4).

Fatty acid composition

A noticeable difference was observed in fatty acid profiles of the larvae reared on the three substrates. Lauric acid ranged from 9.96 ± 03% to 12.60 ± 00% with the highest value recorded from BSFL reared on wheat bran substrate

Table 3. Mineral profile of the reared and processed black soldier fly larvae.

Mineral (g/kg)	WB/OD	WB/SD	CB/OD	CB/SD	FW/OD	FW/SD
Ca	0.25 ± 0.00[c]	0.29 ± 0.00[c]	0.20 ± 0.00[c]	0.26 ± 0.04[c]	2.51 ± 0.01[b]	3.05 ± 0.01[a]
Mg	0.36 ± 0.00[c]	0.33 ± 0.01[c]	0.33 ± 0.00[c]	0.41 ± 0.00[b]	0.41 ± 0.00[b]	0.48 ± 0.01[a]
K	1.07 ± 0.00[b]	1.13 ± 0.00[a]	0.61 ± 0.00[c]	0.68 ± 0.00 [c]	0.88 ± 0.00 [c]	0.98 ± 0.00[c]
P	0.95 ± 0.00[a]	0.93 ± 0.03[a]	0.61 ± 0.00[a]	0.80 ± 0.00[a]	0.83 ± 0.00[a]	0.95 ± 0.00[a]
Na	0.21 ± 0.01[d]	0.21 ± 0.00[d]	1.33 ± 0.02[c]	1.54 ± 0.00[b]	1.96 ± 0.01[b]	2.11 ± 0.00[a]
Mn	0.41 ± 0.00[b]	0.48 ± 0.00 [a]	0.15 ± 0.00[c]	0.18 ± 0.00[c]	0.39 ± 0.00 [c]	0.43 ± 0.00[b]
Fe	0.16 ± 0.00[b]	0.19 ± 0.00 [b]	0.30 ± 0.00[a]	0.43 ± 0.00[a]	0.28 ± 0.09[a]	0.32 ± 0.00[a]
Cu	0.01 ± 0.00[a]	0.01± 0.00[a]	0.01 ± 0.00[a]	0.01 ± 0.00[a]	0.01 ± 0.00[a]	0.01 ± 0.00[a]
Zn	0.20 ± 0.01[a]	0.18 ± 0.00[b]	0.13 ± 0.00[c]	0.16 ± 0.00[b]	0.13 ± 0.00[c]	0.16 ± 0.00[b]
Ni	ND	ND	ND	0.01 ± 0.00[a]	ND	0.01 ± 0.00[a]
N	ND	ND	5.67 ± 0.00[a]	5.27 ± 0.00[b]	4.73 ± 0.01[c]	4.82± 0.00s[c]
Co	ND	ND	ND	ND	ND	ND
Cr	ND	ND	ND	ND	ND	ND
Cd	ND	ND	ND	ND	ND	ND
Pb	ND	ND	ND	ND	ND	ND
Se	ND	ND	ND	ND	ND	ND
V	ND	ND	ND	ND	ND	ND
As	ND	ND	ND	ND	ND	ND
Hg	ND	ND	ND	ND	ND	ND

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05). **Legend:** WB/OD = Wheat bran/Oven dried; WB/SD = Wheat bran/Sun dried; CB/OD = Corn bran/Oven dried; CB/SD = Corn bran/Sun dried; FW/OD = Fruit waste/Oven dried; FW/SD = Fruit waste/Sun dried; ND: Not detected.

Table 4. Amino acid profile of the reared and processed black soldier fly larvae.

Amino acids (%)	WB/OD	WB/SD	CB/OD	CB/SD	FW/OD	FW/SD
Non-essential amino acid						
Arginine	5.47 ± 0.03[a]	5.58 ± 0.04[a]	5.03 ± 0.01[b]	5.13 ± 0.02[b]	4.72 ± 0.04[c]	4.86 ± 0.06[c]
Alanine	7.72 ± 0.01[a]	7.90 ± 0.01[a]	6.34 ± 0.02[b]	6.29 ± 0.01[b]	5.96 ± 0.08[c]	6.10 ± 0.01[b]
Aspartic	5.79 ± 0.01[c]	6.48 ± 0.04 [a]	6.15 ± 0.02[b]	6.24 ± 0.02[a]	6.08 ± 0.01[a]	6.02 ± 0.01[b]
Cysteine	1.07 ± 0.01[a]	1.17 ± 0.02 [a]	0.94 ± 0.01[b]	0.91 ± 0.01[b]	0.85 ± 0.01[c]	0.82 ± 0.01[c]
Glutamic	12.48± 0.01[b]	13.17± 0.05[a]	11.53 ± 0.11 [c]	11.76± 0.06[c]	9.73 ± 0.05[d]	9.96 ± 0.05[d]
Glycine	5.14 ± 0.01[a]	5.09 ± 0.01[a]	4.64 ± 0.01[b]	4.72 ± 0.01[b]	4.44 ± 0.03[c]	4.52 ± 0.03[c]
Pyrolysine	0.85 ± 0.01 [b]	1.03 ± 0.01[a]	0.92 ± 0.01[b]	0.85 ± 0.01 [b]	0.86 ± 0.01 [b]	0.81 ± 0.01[c]
Proline	5.38 ± 0.01[a]	5.46 ± 0.03[a]	5.17 ± 0.01 [b]	5.23 ± 0.02[a]	5.02 ± 0.01[b]	5.06 ± 0.01[b]
Ornithine	0.10 ±0.01 [a]	0.57 ± 0.01 [a]	0.75 ± 0.01 [a]	0.05 ± 0.01 [a]	0.07 ± 0.01 [a]	0.05 ± 0.01 [a].
Tryptophan	0.28 ± 0.02 [b]	0.36 ± 0.01 [d]	0.24 ± 0.01 [b]	0.30 ± 0.01 [c]	0.17 ± 0.01 [a]	0.18 ± 0.01 [a]
Serine	2.52 ± 0.17[a]	2.62 ± 0.03[a]	2.43 ± 0.02[b]	2.34 ± 0.01[b]	2.33 ± 0.01[b]	2.28 ± 0.03[b]
Essential amino acids						
Histidine	2.48 ± 0.02[a]	2.42 ± 0.04[a]	2.30 ± 0.02[b]	2.27 ± 0.01[b]	2.15 ± 0.01[c]	2.22 ± 0.01 [b]
Isoleucine	3.59 ± 0.01[a]	3.67 ± 0.02[a]	3.25 ± 0.01[b]	3.19 ± 0.01[b]	2.93 ± 0.03[c]	3.09 ± 0.01[b]
Leucine	6.46 ± 0.02[b]	6.67 ± 0.02[a]	6.35 ± 0.04[b]	6.24 ± 0.01[b]	6.20 ± 0.02 [b]	6.08 ± 0.04[c]
Lysine	5.70 ± 0.01[a]	5.62 ± 0.01[b]	5.60 ± 0.02 [a]	5.90 ± 0.03[a]	5.57 ± 0.02 [c]	5.62 ± 0.01[b]
Methionine	2.37 ± 0.18[ab]	2.51 ± 0.01[a]	2.30 ± 0.14[ab]	2.16 ± 0.01[c]	2.04 ± 0.01[d]	2.09 ± 0.01[d]
Phenylalanine	6.23 ± 0.01[a]	6.19 ± 0.01[a]	5.64 ± 0.01[b]	5.57 ± 0.03[b]	5.38 ± 0.01[c]	5.46 ± 0.01[c]
Threonine	4.30 ± 0.14 [a]	4.90 ± 0.14 [a]	4.24 ± 0.03 [a]	3.39 ± 1.43 [a]	4.10 ± 0.03 [a]	4.01 ± 0.01[a]
Tryptophan	0.28 ± 0.02 [b]	0.36 ± 0.01 [d]	0.24 ± 0.01 [b]	0.30 ± 0.01 [c]	0.17 ± 0.01 [a]	0.18 ± 0.01 [a]
Valine	5.00 ± 0.04[c]	5.20 ± 0.01[c]	6.37 ± 0.05[a]	6.55 ± 0.08 [a]	5.60 ± 0.14[b]	5.31 ± 0.13[c]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05. **Legend:** WB/OD = Wheat bran/Oven dried; WB/SD = Wheat bran/Sun dried; CB/OD = Corn bran/Oven dried; CB/SD = Corn bran/Sun dried; FW/OD = Fruit waste/Oven dried; FW/SD = Fruit waste/Sun dried.

Table 5. Fatty acid profile of BSF larvae cultured in different substrates and different drying methods.

Fatty acid (%)	WB/OD	WB/SD	CB/OD	CB/SD	FW/OD	FW/SD
Lauric	12.50 ± 01[a]	12.60 ± 00[a]	11.10 ± 00[b]	10.88 ± 02[c]	9.96 ± 03[c]	10.50 ± 00[c]
Palmitic	2.08 ± 00 [c]	2.11 ± 00[c]	6.10 ± 00 [a]	5.94 ±00 [a]	4.90 ± 01[b]	4.96 ± 00 [b]
Arachidonic	0.04± 04 [a]	0.03 ± 04 [a]	0.05 ± 00[a]	0.05 ± 00 [a]	0.05 ± 00 [a]	0.03 ± 00 [a]
Oleic	3.11 ± 00[c]	3.12 ± 00 [c]	5.89 ± 01[a]	6.04 ± 00 [a]	5.74 ± 01[b]	5.61 ± 00[b]
Margaric	0.06 ± 00[a]	0.07 ± 00[a]	0.06 ± 00[a]	0.06 ± 00[a]	0.07 ± 00[a]	0.08 ± 00[a]
Stearic	0.57 ± 00[a]	0.57 ± 00[a]	1.00 ± 00[e]	0.97 ± 00 [d]	0.90 ± 00 [c]	0.89 ± 00 [b]
Linoleic	2.11 ± 00[a]	2.08 ± 00[b]	2.28 ± 00[a]	2.30 ± 00[a]	2.26 ± 00[a]	2.26 ± 00[a]
Lignoceric	0.03 ± 00[a]	0.03 ± 00[c]	0.02 ± 00[a]	0.02 ± 00[a]	0.03 ± 00[a]	0.02 ± 00[a]
Myristic	2.13 ± 00 [b]	2.10 ± 00 [a]	2.35 ± 00 [e]	2.42 ± 00 [f]	2.29 ± 00 [c]	2.30 ± 00 [d]
Behenic	0.01 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]	0.04 ± 04 [a]
Butyric	0.01 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]	0.00 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]
Valeric	0.02 ± 00 [a]	0.02 ± 00 [a]	0.01 ± 00 [a]	0.02 ± 00 [a]	0.01 ± 00 [a]	0.01 ± 00 [a]
Palmitoleic	0.44 ± 0.5 [a]	0.82 ± 00 [a]	0.87 ± 00 [a]	0.89 ± 00 [a]	0.84 ± 00 [a]	0.85 ± 00 [a]
Caprylic	0.04 ± 00 [a]	0.03 ± 00 [a]	0.03 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [b]
Propionic	0.02 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [a]	0.02 ± 00 [a]
Acetic	0.05 ± 00 [a]	0.06 ± 00 [a]	0.05 ± 00 [a]	0.05 ± 00 [a]	0.04 ± 00 [a]	0.04 ± 00 [a]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05). **Legend:** WB/OD = Wheat bran/Oven dried; WB/SD = Wheat bran/Sun dried; CB/OD = Corn bran/Oven dried; CB/SD = Corn bran/Sun dried; FW/OD = Fruit waste/Oven dried; FW/SD = Fruit waste/Sun dried.

and dried via sundried method (WB/SD), while the least value was recorded from BSFL reared on assorted fruit waste substrate and dried via oven-dried method (FW/OD). Palmitic acid was recorded highest (6.10 ± 00%) from BSFL raised on corn-bran substrate and dried via oven-dried method (CB/OD), while the least value (2.08 ± 00%) was recorded from BSFL reared on wheat bran substrate and dried via oven-dried method (WB/OD). There were no significant differences (p>0.05) among the values of Arachidonic acid, Margaric acid, Valeric acid, Behenic acid, Butyric acid, Palmitoleic acid, Caprylic acid, and Propionic acid. This report indicated that the fatty acid profiles of BSFL raised on corn-bran substrate are biologically impacted compared to those of BSFL reared on wheat-bran (WB) and assorted fruit waste (FW) substrates (Table 5).

DISCUSSION

Composition and sources of substrates have effect on the final composition of the reared larvae because they help in providing the needed nutrients for the rearing larvae during developmental stages in the rearing medium (Iyapo *et al*., 2024). Results from earlier studies indicated the use of different substrates in rearing insects (Sohani *et al*., 2024; Iyapo *et al*., 2024; Langston *et al*., 2023; Gold *et al*., 2022; Spranghers *et al*., 2017). This study is aligned within the range of substrate feed diet for culturing black soldier fly larvae. The variation in protein values in this study was within the range reported by Iyapo *et al*. (2024), who reared mealworm on three different substrates. The reason behind this result could be the similarity in substrates used in rearing the larvae. The protein content of this study is lower than the protein values reported by Spranghers *et al*. (2017), who reared black soldier fly larvae on three different organic waste substrates. The authors also concluded that black soldier fly larvae could be an interesting protein source for animal feeds. But contrary to Chia *et al*. (2020), who reported closely related results of protein yield in BSF larvae fed agro-industrial by-products. The differences in the crude protein values could be due to the differences in the rearing substrates and the composition of the substrates. Chemical compositions of substrates influence the larvae's feeding behavior and nutrient uptake (Iyapo *et al*. 2024). The protein values of BSF larvae reared on fruit waste in this research are within the range reported by Nguyen *et al.* (2015), who reared BSFL on fruit and vegetable waste. Purnamasari *et al*. (2021) also reported similar crude protein results for BSFL processed through oven-dried techniques. In addition, crude protein values of BSFL raised on wheat-bran substrate from this research are higher than those reported by Zandi-Sohani *et al*. (2024), while crude protein values of BSFL raised on assorted fruit waste and corn-bran substrates are within the range values reported by the author.

The ash content levels of the BSFL in this research ranged from 4.00 to 19.05% which aligns with the ranges reported in the literature (Sohani *et al*., 2024; Chia *et al*., 2020; Makkar *et al*., 2014). The variation in the ash contents highlighted the impact of substrate makeup on the composition of black soldier fly larvae and the drying procedure. The ash value is attributed to the quantity and quality of various minerals, including iron, calcium, phosphorus, zinc, copper, etc, present in the black soldier fly larvae. This research discovered the highest percentage of ash value from BSFL reared on assorted fruit waste substrate and dried via the oven-drying method (FW/OD). Additionally, the BSFL reared on assorted fruit waste and oven-dried (FW/OD) showed the highest crude fibre value, which might be an indicator of high nutritional values of the substrate used in rearing the BSFL. On the other hand, dry matter ranged between 61. 90 and 91.76%, which is quite high and means the drying process of larvae would be easy and cost-effective.

This research reported the highest value of vitamins A, C, and D from BSFL reared on assorted fruit waste and oven-dried. This result could relate to the variations in the combination of the fruit waste. The result was similar to the study of Zulkifli *et al*. (2022) that used spraying and oven drying methods for BSFL processing, but the author didn't detect vitamin A in BSFL processed via the oven drying method. Vitamin C was found in BSFL reared on the three different substrates from this study, which helps in supporting normal growth performance and feed utilization of farmed animals (Adewolu and Aro, 2009).

This report clearly indicated that the mineral content of BSF larvae is influenced by the rearing substrates. Among the minerals evaluated in this study, the potassium (K) value of BSF larvae reared on wheat-bran substrate, irrespective of the drying procedure, was significantly higher than those reared on corn-bran and assorted fruit waste substrates. This result is consistent with the findings of Chia *et al.* (2020); Shumo *et al.* (2019), Tschirner and Simon (2015), and Finke (2013). The calcium contents of BSFL reared on the three substrates in this study were lower than the result of Makokha *et al*. (2023), who raised BSFL on barley spent grains. Performance differences may be caused by the composition of the substrates and the drying method. The mineral compositions of BSFL in this study were lower than the results of Romano *et al*. (2023), who reported higher mineral values in black soldier fly larvae reared on different fruit peels. However, the mineral profile from this study was within the range reported by Iyapo *et al*. (2025). Furthermore, substrates fed and processing techniques have been reported to affect the mineral profile of BSFL (Iyapo *et al*., 2025; Weko *et al*., 2023).

Most of the amino acid values were higher in BSF larvae reared on wheat bran substrates and processed via the sundried (WB/SD) method, indicating that wheat-bran substrate as well as the sun drying technique effectively impact the amino acid profiles of the raised BSFL. Protein was more concentrated in larvae reared on wheat bran substrates and processed through the sun drying method (WB/SD), thereby making both essential and non-essential amino acid profiles of BSFL higher, improved, and richer protein source. Both essential and non-essential amino acid profiles of BSF larvae reared on wheatbran substrate in this study were higher than those reared with cereal by-products in the study of Schiavone *et al*. (2017). Variation in this report could be the differences in the rearing substrates and environmental factors. The non-essential (dispensable) amino acids profiles were higher in BSFL reared on wheat-bran and processed via the sun-drying method (WB/SD), except in glycine and ornithine, which were higher in WB/OD and CB/OD, indicating that removing the lipid content by sundrying significantly impacts the amino acid composition of BSF larvae.

The fatty acid composition of BSFL is significantly influenced by the substrates used in rearing them. Observable variations in the level of various fatty acid profiles were noticed in this study. Linoleic acid, which helps in supporting skin health and regulating various physiological processes, is higher in BSFL reared on corn-bran substrate and dried via the sun-drying method (Iyapo *et al*., 2025). The fatty acid profile of this experiment was within the range published by Schreven *et al*. (2021), who fed black soldier fly larvae oilseed by-products. Fatty acid composition of BSFL varies and depends on the diet fed or substrate reared on, and the processing methods (Iyapo *et al*., 2025; Tognocchi *et al*., 2024; Lu *et al*., 2022; Schreven *et al.*, 2021; Shelomi, 2020; Ewald *et al.*, 2020; Danieli *et al.*, 2019). The results obtained in this study indicated that the rearing substrates, rearing conditions, and drying procedure significantly contribute to the nutrient composition of black soldier fly (BSF) larvae, which may impact aquafeed formulation, palatability, digestibility, and feed conversion efficiency of the fish fed.

Conclusion

This research demonstrated that wheat bran can be effectively used as a rearing substrate for BSFL, offering a sustainable solution for agricultural waste because the larvae grew better on wheat bran than on other tested substrates. The nutrient composition of the larvae makes them a promising alternative protein source for animal feed, potentially reducing dependency on conventional protein sources like soybean meal, fishmeal, etc., by utilizing waste streams like plant-based waste and animal-based waste. In addition, the proximate and amino acid profiles of BSFL in this research revealed the sun-drying method as a better drying method that biologically impacted the nutrient composition of BSFL. Additionally, BSFL farming can contribute to more sustainable animal feed production, aligning with circular economy principles and promoting environmental sustainability. Future research should continue to analyze the microbial load of the larvae to ascertain the health status of the black soldier fly larvae before incorporated into aquafeed production.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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