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Physicochemical Properties and Fatty Acid Methyl Ester (FAME) Extract of Maggot Black Soldier Fly (*Hermetia illucens*) as Animal Feed

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Abstract

This study aimed to evaluate the physicochemical properties and fatty acid methyl ester (FAME) profile of *Hermetia illucens* (BSF) maggot extract as a potential sustainable ingredient for animal feed. Lipid extraction was performed using a modified Bligh and Dyer method by substituting chloroform with n-hexane to ensure safer and environmentally friendly processing. Proximate analysis revealed that BSF maggots contained 29.36% crude protein, 43.76% crude fat, 9.27% ash, 19.94% crude fiber, and a low moisture content of 3.06%, indicating high nutritional density and storage stability. XRF and qualitative tests confirmed significant mineral content, particularly CaO, K_2O, and P_2O_5, with no detectable heavy metals or harmful contaminants, supporting their safety for feed applications. Microscopic analysis showed particle sizes ranging from 2,000-10,000 nm, classifying the material as a nanostructured biomass. The FAME profile demonstrated a diverse composition dominated by 9-octadecenoic acid (10.92%), triacontane (8.87%), octadecanoic acid (7.65%), and heptacosanoic acid (7.17%). Key medium- and long-chain fatty acids such as dodecanoic acid (C12:0), elaidic acid (C18:1), and stearic acid (C18:0) were also detected, indicating the suitability of BSF lipids as an energy-dense feed component with oxidative stability. Overall, the biochemical and structural characteristics obtained in this study highlight BSF maggots as a promising, nutrient-rich, and environmentally sustainable ingredient for animal feed formulations.

Keywords: Black soldier fly; FAME; proximate analysis; lipid profile; animal feed.

INTRODUCTION

One of the biggest obstacles to aquaculture growth is feeding farmed fish. One of the primary issues raised regarding aquaculture is the use of large quantities of wild fish from the ocean. Increasing the sector's contribution to food security is thought to need a sustainable increase in output through scientific and technical advancements in finfish diets (Costello et al., 2020). Economically feasible and ecologically sustainable components should be used in aquafeeds that are both nutrient-dense and palatable to the farmed fish. An growing amount of research is demonstrating the significance of insect meal can improve the consumption of protein, polyunsaturated fatty acids, and a number of other nutrients that are essential for the growth and health of farmed fish (Ichwan et al., 2021). The insect meal is a good substitute for fish meal and oil because of these characteristics that make insect meal a good substitute for fish oil and meal. Larvae of the black soldier fly (BSF) (*Hermetia illucens*) have become one of the most environmentally friendly options for aquafeeds. BSFL meal is a well-balanced diet because it has a high protein content, a comparable amino acid profile to fish meal, and additional nutrients (Bondari & Sheppard, 1981); (Cummins et al., 2017).

Hermetia illucens is a possible source of protein and is found in warm and temperate climates. It is easy to reproduce and develop, and its life cycle is brief. Additionally, at some points in its life cycle, it does not need to be fed. Because BSFL can be raised on a broad range of organic waste materials, it offers a viable way to lessen the amount of this waste (Sheppard et al., 1994). If these insects were to be developed and raised, they would need less room because of their tiny size. Additionally, it was noted that raising insects results in far fewer ammonia emissions than raising domestic animals (Huis et al., 2014). According to a research by (Oonincx et al., 2010), on a weight-for-weight basis, insects release 80 times less ammonia than cattle. This is important as methane affects the earth's temperature 25 times more than carbon dioxide does. This benefit has also been emphasized by (Wang & Shelomi, 2017), specifically mentioning BSFL. In addition, BSFL has been bio-prospected for its potential as a source of lipids (Franco et al., 2021), chitin (Bessa et al., 2020); (Soetemans et al., 2020); (Triunfo et al., 2021), and antimicrobial peptides (Alvarez et al., 2019); (Manniello et al., 2021); (Moretta et al., 2020); (Xia et al., 2021).

Protein sources often need to fulfill several requirements in order to be produced, including consistent quantity availability, economic worth, non-competition with human resources, and environmental sustainability. BSF seems to meet these requirements. Currently, the BSFL meal is mostly used to produce animal feed instead of being consumed by humans (El-Hack et al., 2020); (Bessa et al., 2020). Globally, the animal feed business is looking for sustainable sources of alternative protein. Fatty acids, polysaccharides, and potentially additional nutrients are included in BSFL in addition to protein. In an attempt to lessen reliance on fish meal for protein and oil, the aquaculture feed industry is currently paying increased attention to the usage of BSFL. A thorough biochemical examination of feed ingredients is necessary to determine their nutritional worth and communicate the results to businesses and customers. Research on the body composition of insects reveals significant species-to-species variations. Furthermore, insects are cultivated and processed for feed production can have a big impact on their nutritional makeup (Fasakin et al., 2003). Thus, it is advantageous to look into the nutritional makeup of the three varieties of BSFL meals that are sold at the neighborhood store. Due to their increased quantities of EPA (eicosapentaenoic acid), DHA (docosahexaenoic acid), and other long-term omega-3 fatty acids, fruit and vegetable wastes are frequently employed as substrates for raising BSFL, these goods are readily available in quantity and the results they have been shown to produce in insects when compared to alternative substrates made from terrestrial plants (Spranghers et al., 2017).

The nutritional benefits of three distinct varieties of BSFL were examined in this study. This made it possible for us to targeted investigations for the creation of thorough data via experimental trials. To ascertain whether these chemical profiles are similar to fish-based diets and will be able to support the growth and health of the fed fish in culture systems, the approximate composition and concentrations of amino acids, fatty acids, vitamins, minerals, and nucleoside and nucleotide contents of the larvae meal were measured. This study aims to evaluate the physicochemical properties and fatty acid methyl ester (FAME) profile of *Hermetia illucens* (Black Soldier Fly, BSF) maggot extract as a potential sustainable ingredient for animal feed.

MATERIALS AND METHODS

Tool and Material

The tools used in the making an immunity booster drink include glass cups, scales, knives, containers, ovens, and packaging bags. The tools used in the proximate test are a Porcelain cup, Cruss pliers, Triangular wire, Electric balance, Oven, Exicator, Bunsen/stove, Electric furnace, 100 cc Kjedhal flask, Kjedhal flask heater, Measuring cup, 250 cc measuring flask, 100 cc and 1000 cc Erlenmeyer, Marcam Steel tools, Distillation flask, Soxhlet flask, reflux inducer, suction Erlenmeyer, Bunchner funnel, spatula, XRF instruments (PANalytical Minipal 4), UV-Vis (BK-UV1800 BK-UV1600), Microscope (Olympus BX43 Trinocular Head Microscope with Olympus DP22 Digital Camera), FTIR (Shimadzu IRPrestige 21), GC-MS (Shimadzu QP 2010 SE). Meanwhile, the ingredients used in making maggot black soldier fly. The ingredients used in the proximate test are Tablet Kjedhal, H_2SO_4, NaOH 40%, Boric Acid, Methyl Red Indicator, Brom Cresol Green Indicator, H_2SO_4 0,01 N, H_2SO_4 0.3 N, NaOH 1.5 N, HCl 0.3 N, aceton, aquademinerale, n-hexane, methanol, and aquades.

Proximate Analysis Procedure

The proximate analysis was conducted to evaluate the content of protein, fat, carbohydrates, moisture, and ash in the herbal tea formulation. The methods employed for each component are as follows:

Protein Determination (Kjeldahl Method): The protein content was determined using the Kjeldahl method (Baur & Ensminger, 1977). This involved digesting the sample with sulfuric acid to convert nitrogen present in the sample to ammonium sulfate. The digest was then neutralized with sodium hydroxide, and the released ammonia was distilled into a boric acid solution. The amount of nitrogen was quantified by titration with a standard acid, and the protein content was calculated using a conversion factor.

Fat Determination (Soxhlet Method): The fat content was extracted using the Soxhlet extraction method (Baur & Ensminger, 1977). The sample was placed in a thimble and extracted with a non-polar solvent in a Soxhlet apparatus. The solvent was evaporated, and the remaining residue was weighed to determine the fat content.

Carbohydrate Determination (By Difference): The carbohydrate content was calculated by the difference method. This involved subtracting the sum of the percentages of moisture, protein, fat, and ash from 100% (Food and Agriculture Organization, 2003)

Moisture Content (Gravimetric Method): The water content test was carried out using the gravimetric method. 10 grams of the substance are added and weighed in a container that has been measured and dried at 105 °C for 5 hours. Then, re-weighing is done. The material was dried and weighed after 1 hour until the difference between the two weighings was not more than 0.25%. Moisture content was calculated using the percentage of volume per weight. (Departemen Kesehatan RI, 2000).

Ash Content (Gravimetric Method): A total of 3 grams of extract has been ground, weighed, and put into a silicate crucible. Then incandescent and weighed again. Lighting or burning is carried out slowly until the charcoal runs out, and it is weighed after it has cooled. Added hot water, then filtered. Then re-ignited. The filtrate was put in a crucible, evaporated, and incandesced again until the weight was constant. Weighed and then calculated the ash content in the air-dried material.

Fatty Acid Methyl Ester Profile

In this study, the lipid extraction process from *Hermetia illucens* maggots was carried out by modifying the Bligh & Dyer method, namely replacing the use of chloroform solvent with n-hexane, which is safer, less toxic, and commonly used in the feed and food industry. This modification was carried out to obtain the total lipid fraction with an approach that remains efficient but more environmentally friendly. Fresh maggot samples were first cleaned of feed residues, dried at a low temperature (±60 °C) until they reached a constant weight, then finely ground to increase the surface area in contact with the solvent. The initial homogenization stage using methanol remained the same as the original (Bligh & Dyer, 1959) method, because methanol functions to denature proteins, damage cell structures, and increase lipid release from tissues. After that, n-hexane was added as the main non-polar solvent to dissolve neutral lipid fractions such as triglycerides, free fatty acids, and other lipophilic components that are predominantly found in BSF maggots. The mixture of sample, methanol, and n-hexane is then intensively homogenized using a vortex or homogenizer to maximize lipid diffusion into the solvent. The next step is the addition of air or a mild salt solution (0.9% NaCl) to allow for a two-phase acronym, where the upper phase consists of the n-hexane mixture carrying the lipids, while the lower phase contains mostly the methanol fraction rich in proteins, sugars, and other hydrophilic compounds. Phase separation is achieved by gentle centrifugation or using a separating funnel for large-scale extraction. The lipid-containing n-hexane phase is carefully removed to avoid contamination of the lower phase or the emulsion layer. To increase extraction efficiency, a backwash of the methanol-water phase using additional n-hexane can be performed and the resulting mixture combined with the first n-hexane fraction. The collected n-hexane fraction is then evaporated using a rotary evaporator at a low temperature (40°C) to prevent thermal lipid degradation, particularly unsaturated fatty acids, which are susceptible to oxidation. After all the n-hexane has evaporated, the lipid residue is dried again using a nitrogen stream or desiccator until it reaches a stable weight, then weighed using an analytical balance to determine the lipid yield.

RESULTS AND DISCUSSION

The research results show that black soldier fly (BSF) maggots are capable of converting organic waste into larval biomass with high efficiency and effectiveness. The research results from 1 kg of organic waste, such as leftover vegetables or fruits, obtained as much as 150-200 grams of dry maggot biomass shrinkage, depending on the type of substrate used. The most optimal larval growth was achieved with media based on vegetable or fruit waste which was the focus of this research which is rich in carbohydrates with a waste conversion rate reaching 15-20% within a period of 1 week. The explanatory data are as follows Table 1:

Table 1. Results of research on feeding BSF maggots.

No.	Type of BSF Maggot Feed	Feed Treatment	Maggot Composition	Treatment Results	%
1.	Organic Waste (vegetables and fruits)	1 kg	100 gram	150-200 gram	15-20
2.	Inorganic Waste (paper)	1 kg	100 gram	20-30 gram	2-3
3.	Plastic Waste	1 kg	100 gram	15-20 gram	1.5-2

On organic feed, such as vegetables and fruit, maggots can produce 150–200 grams of larval biomass from 1 kg of fresh organic waste, equivalent to a 15–20% conversion rate of the initial substrate weight. This indicates that organic feed rich in carbohydrates, vegetable protein, and high moisture is highly effective for maggot growth. This is consistent with research conducted by (Siddiqui et al., 2022), which found that BSF grows well on fruit and vegetable waste due to its balanced nutritional content. When maggots are fed paper, the biomass yield ranges between 20 and 30 grams per kilogram of feed, with a conversion rate of 2 to 3 percent. This occurs because paper consists of cellulose, which is difficult for BSF larvae to digest.

Although larvae may decompose some, the low nutrient content severely limits maggot growth. Furthermore, research conducted by (Amrul et al., 2022), shows that substrates with excessively high C/N ratios, such as paper, do not support BSF growth. The plastic treatment produced 15–20 grams of biomass with a conversion of only 1.5–2%, indicating that the plastic is barely usable as an energy source by the maggots.

Instead, the larvae's remaining energy reserves or organic contaminants attached to the plastic are responsible for this very small biomass production. Unlike certain microbes that can degrade plastic, BSF cannot degrade synthetic polymers, according to several studies (Purkayastha & Sarkar, 2022). Organic waste is clearly the most ideal feed source for all three treatments, as it produces the highest biomass and is the most efficient for maggot cultivation. Conversely, inorganic waste such as paper and plastic is unsuitable as a substrate because it has low nutritional value and is barely usable.

Samples of organic waste fed to black soldier fly (BSF) maggots were characterized using XRF to determine the elemental and compound composition of the black soldier fly (BSF) maggots. This aimed to determine the percentage of elements and oxides in the black soldier fly (BSF) maggots by ensuring that the N, P, and K elements in the black soldier fly (BSF) maggots were dominant. The characterization results of the samples are listed in Table 2. The N, P, and K content detected in black soldier fly (BSF) maggots is as follows:

Table 2. XRF data results of black soldier fly maggots.

No	Oxide	Percentage
1	P_2O_5	7.1%
2	K_2O	18.3%
3	CaO	55.6%
4	TiO_2	0.38%
5	MnO	0.59%
6	Fe_2O_3	5.80%
7	NiO	0.22%
8	CuO	0.45%
9	ZnO	0.72%
10	MoO_3	9.5%
11.	Re_2O_3	1%

BSF maggots are rich in calcium, as CaO dominates the composition with the highest percentage. This may originate from the larvae's metabolic processes, which absorb calcium from organic substrates. Organic substrates such as vegetable and fruit waste, and other organic materials are examples of organic substrates. Because calcium is essential for bone growth and various physiological systems in animals, maggot residue can be used as a base for mineral fertilizers and animal feed additives. K_2O ranks second. Plants greatly require potassium, a macronutrient that is essential for photosynthesis, water regulation, and improving crop quality. BSF maggots have a high K_2O content, indicating that they can function as a natural NPK mineral organic fertilizer. This supports previous research showing that larval biomass and frass, which are maggot waste residues, contain potassium, which helps improve soil fertility. Phosphorus in the form of P_2O_5 is essential because it is a nutrient required for root development, flower formation, and energy (ATP) production in plants. With its high P_2O_5 content, BSF maggot residue can serve as a natural source of phosphate, reducing the need for synthetic phosphate-containing chemical fertilizers. These XRF results demonstrate that BSF maggots are not only useful as high-protein animal feed but also as a source of essential minerals for organic fertilizers. Their predominance of CaO, K_2O, and P_2O_5 makes them a potential candidate to replace synthetic chemical fertilizers and support sustainable agriculture. Qualitative testing using test strips to qualitatively identify BSF maggot samples that are relatively safe as raw materials for organic fertilizer, as shown in Table 3:

Table 3. Qualitative test of BSF Maggots.

No.	Parameter	Concentration (ppm)
1.	**pH**	7.6
2.	***Alkalinity***	180
3.	***Carbonate***	40
4.	***Hardness***	250
5.	***Cyanuric Acid***	0
6.	***Copper***	0
7.	***Mercury***	0
8.	***Total Chlorine***	0
9.	***Free Chlorine***	0
10.	***Bromine***	0
11.	***Nitrate***	0
12.	***Nitrite***	0
13.	***Iron***	0
14.	***Chromium***	0
15.	***Lead***	0

Qualitative strip test data on Black Soldier Fly (BSF) maggot samples based on Table 3 provide an overview of chemical characteristics, especially pH, alkalinity, hardness, and the presence of heavy metal ions or contaminants. A pH of 7.6 indicates that the BSF maggot sample is in neutral to slightly alkaline conditions, which is in accordance with the natural nature of BSF larvae to live in a neutral-alkaline environment. This pH also indicates environmental stability that helps microbes and larvae carry out BSF maggot metabolism. High alkalinity levels indicate the presence of natural buffers in the sample, which help maintain pH stability. Carbonate (CO_3^{2-}), which usually comes from the degradation of organic matter, contributes to alkalinity. Because conditions with adequate alkalinity can suppress the activity of pathogenic microbes, this supports the maggot's ability to process organic waste. High hardness values indicate the dominance of minerals, especially Ca^{2+} and Mg^{2+}, in the sample. Previous XRF results showed a dominance of CaO in BSF maggot biomass. High hardness indicates that the maggots accumulate essential minerals, which can be used in animal feed and organic fertilizer. The proximate test data for testing the water, ash, crude protein, crude fat, crude fiber, and dry matter content in black soldier fly maggot samples are shown in Table 4:

Table 4. Proximate test results for black soldier fly maggots.

No	Code Sample	Moisture Content		DM (Dry Matter Lab)	Content Ash	Crude Protein	Crude Fat	Crude Fiber
		I (60°C)	II (105°C)					
1.	**Maggot BSF**	-	3.06%	96.64%	9.27%	29.36%	43.76%	19.94%

Analysis of Black Soldier Fly (BSF) maggots showed a low water content of 3.06%. A low water content is crucial because it can extend the shelf life of feed by suppressing the growth of spoilage-causing microorganisms. Therefore, dried BSF maggots offer advantages in terms of storage and distribution stability. The dry matter (DM) content of BSF maggots reached 96.64%, indicating that almost the entire composition consists of solid nutrients. This value indicates that the available energy in the material is quite high because the water content is very low. The higher the dry matter content, the greater the potential nutrients that can be utilized by livestock. The ash content of BSF maggots is 9.27%, which represents the total mineral content. This value is quite significant when compared to other feed ingredients such as rice bran or corn. This mineral content plays an important role in supporting metabolism, bone formation, and electrolyte balance in livestock. The crude protein content of BSF maggots was recorded at 29.36%. This figure indicates that BSF maggots are a protein-rich feed ingredient with the potential to replace fish meal or soybean meal. Protein is an essential component in the formation of body tissue, enzyme production, and supporting livestock growth. Its relatively high protein content makes BSF maggots a prime candidate for a sustainable alternative feed ingredient. In addition to protein, BSF maggots are also rich in fat, with a content of 43.76%. High crude fat provides a significant energy contribution, thereby reducing the need for energy from other sources such as vegetable oil or corn. However, high fat content also needs to be considered in ration formulation because excessive fat can affect digestibility and feed storage stability. BSF maggots contain a relatively high crude fiber content of 19.94%. Crude fiber plays an important role in maintaining the digestive health of livestock, especially ruminants, but can be a challenge for poultry or fish due to its lower digestibility.

The FTIR absorption peak at 3556.92 cm^{-1} indicates the presence of O–H groups derived from hydroxyl compounds such as alcohol, fatty acids, or water bound to the maggot's biological tissue. This group indicates that maggots contain polar compounds that can play a role in hydrogen interactions. Meanwhile, the absorption bands at 3913.03 cm^{-1} and 3855.26 cm^{-1} indicate the presence of NH_2 (amine) groups commonly found in amino acids that make up proteins. The presence of these two peaks confirms that protein is one of the main components in maggot biomass. Furthermore, strong absorption bands at 2922.11 cm^{-1} and 2853.25 cm^{-1} are associated with C–H stretching vibrations of methyl and methylene groups, which usually indicate the presence of long aliphatic chains such as in fatty acids. This indicates a relatively high lipid content in BSF maggots, which are known to be rich in oils and fats, particularly lauric acid (C12:0), which is widely used as a raw material in the feed and cosmetics industries. The absorption band at 1743.65 cm^{-1} shows the C=O (carbonyl) group typical of esters, aldehydes, or carboxylic acids, indicating the presence of esterified fats or compounds resulting from fat oxidation. This peak is very important because it illustrates the presence of complex fat structures that can be extracted and utilized for various biotechnological applications. Furthermore, the peak at 239.06 cm^{-1} (although rarely found in this region in general FTIR) is interpreted as the vibration of the nitrile group (C≡N), which may originate from complex organic nitrogen compounds. The absorption bands at 1458.18 cm^{-1} and 1507.07 cm^{-1} indicate the presence of aromatic C=C double bonds, which could indicate phenolic derivative compounds or aromatic structures of certain proteins or pigments. The presence of this aromatic group strengthens the fact that maggot biomass contains complex compounds that have the potential to be natural antioxidants or precursors for secondary metabolite biosynthesis. Overall, the FTIR results of black soldier fly maggots show that the sample contains typical functional groups of proteins (NH_2, C=O), fats (C–H, C=O), and aromatic compounds (C=C). The FTIR data can be seen in Figure 1 and Table 5 as follows:

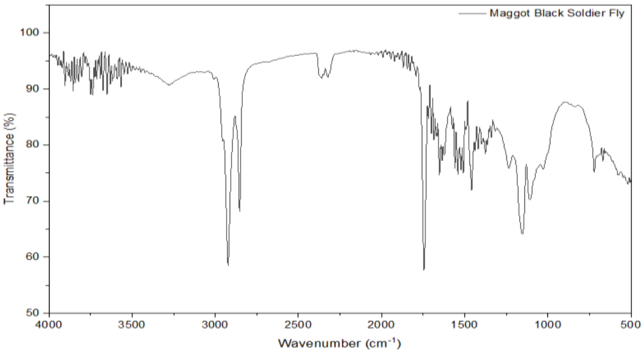

Figure 1. Infrared transmittance spectrum of black soldier fly maggots.

Table 5. IR wavelengths of black soldier fly maggots.

Wavelength (cm^{-1})	Functional Group	Vibration Type
3556.92	O-H	Stretch
3913.03	NH_2	Stretch
3855.26	NH_2	Stretch
2922.11	C-H	Stretch
2853.25	C-H	Stretch
239.06	Nitril	Stretch
1743.65	C=O	Stretch
1458.18	C=C aromatic	Stretch
1507.07	C=C aromatic	Stretch

UV-Vis test to determine the concentration of band gap, change transfer, transition metal d-d transition, purity of BSF maggot, fluoride, sulfate, ammonia, nitrite, phosphate, nitrate, color, chromium, total silica in the filtrate of the filtrate from the black soldier fly maggot sample. The sample used in this test was from the black soldier fly maggot sample. The results of the standard curve on the UV-Vis spectrophotometer were Y = 0.2655x + 0.0092 with R^2 of 0.9999. The absorbance and concentration of each parameter in the black soldier fly maggot sample using UV-Vis (Ultraviolet-Visible Spectroscopy) were Table 6:

Table 6. UV-Vis concentration data on BSF maggot sample.

Sample	Parameter	Wavelength (λ)	Absorbance (A)	Concentration Parameter (ppm)
Maggot BSF	*Band Gap*	200 nm	3.20	0,858 ± 0,01
	Change transfer	250 nm	2.80	0,752 ± 0,01
	Transition d-d	400 nm	2.46	0,662 ± 0,01
	Purity	800 nm	1.69	0,457 ± 0,01
	Flouride	570 nm	2.11	0,569 ± 0,01
	Sulphate	420 nm	2.43	0,654 ± 0,01
	Ammonia	640 nm	2.00	0,540 ± 0,01
	Nitrite	543 nm	2.14	0,578 ± 0,01
	Phosphate	400 nm	2.46	0,662 ± 0,01
	Nitrate	543 nm	2.14	0,578 ± 0,01
	Color	212 nm	3.05	0,818 ± 0,01

UV-Vis spectrophotometer data on Black Soldier Fly (BSF) maggot samples provide an overview of the organic and inorganic compounds present in the maggot's body. Absorption at a wavelength of 200-250 nm indicates the presence of electronic transitions related to the band gap and charge transfer. High absorbance values in this region (0.858 and 0.752 ppm) indicate the presence of active chromophore groups such as aromatic proteins and complex organic compounds capable of absorbing UV light. These results indicate that BSF maggots have chemical components that play a role in biological activity and bioenergy potential (Barragan-Fonseca et al., 2017). Furthermore, the absorption peak at 400 nm indicating a d–d transition and the presence of phosphate at a concentration of 0.662 ppm indicate the presence of transition metal elements such as Fe, Cu, and Zn which are important in enzymatic reactions and energy metabolism. The presence of phosphate also supports the role of maggots as a source of phosphorus nutrients for animal feed. This content is in line with research by (Siddiqui et al., 2022), who reported that BSF maggots contain important minerals and essential elements that support their growth and make them potential candidates for biomass conversion. Absorption at wavelengths of 570–640 nm reveals the presence of inorganic compounds such as fluoride, sulfate, and ammonia. Absorbance values ranging from 0.54–0.65 ppm indicate the presence of nitrogen and sulfur metabolism in the maggots. The presence of ammonia at 640 nm indicates protein deamination, while sulfate indicates the involvement of sulfur-containing amino acids such as methionine and cysteine. According to (Finke, 2013), the nitrogen and sulfur content in maggots is important for the formation of muscle tissue and strengthens their role as a natural protein source. Furthermore, the data show the presence of nitrite and nitrate (543 nm, 0.578 ppm), which illustrates the stable ammonia oxidation process, indicating the activity of microorganisms in the digestive system of BSF maggots. The presence of phosphate also supports ATP formation and other biological processes. Meanwhile, the low absorption at 800 nm (0.457 ppm) indicates a high level of purity and low levels of impurities in the sample. This indicates that the bioconversion process by BSF maggots is efficient and produces biomass with good purity. Finally, the strong absorption at 212 nm (0.818 ppm) is associated with aromatic organic compounds and conjugated double bonds that influence the maggot's natural color. This absorption indicates the presence of pigments and bioactive compounds, supporting the maggot's potential as a source of biopeptides or raw materials for high-value bioproducts. Based on the overall data, it can be concluded that the UV-Vis test successfully identified the presence of various important compounds in BSF maggots, both organic and inorganic, reflecting the chemical complexity and high nutritional value of this species.

Microscopic analysis of the black soldier fly maggots, shown in Figure 3, revealed an even distribution of particle sizes. Microscopic analysis of the black soldier fly maggot samples revealed that they tended to be short, varied, hairy, and brown in color, allowing for microscopic analysis as follows Figure 2:

Figure 2. Morphology of black soldier fly maggots (a-e) at 400x magnification.

Image (a) shows a fairly thick, layered outer cuticle, indicating that BSF maggots possess a strong exoskeleton composed of chitin. This structure functions as a protective barrier and helps maintain moisture and shape in the larvae. Brownish discoloration in certain areas indicates the deposition of melanin pigment or other organic compounds commonly found in insects. Images (b) and (c) show internal tissue that appears softer and less tightly layered, likely part of the larval epidermis or muscle tissue. The brownish to purplish discoloration in some areas indicates the interaction of microscopic dyes with proteins and lipids in the tissue. This structure indicates high metabolic activity, consistent with the maggot's function as an active organic decomposer. Meanwhile, image (d) shows a pattern of fine fibers resembling longitudinal muscle structures, which play a role in larval body movement. These fibers appear to be arranged in parallel, supporting the hypothesis that this tissue is the maggot's primary contractile muscle. Meanwhile, image (e) displays an area similar to the dorsal or ventral surface of the larva with a combination of hard and soft tissue, indicating the difference in density between the exoskeleton and the inner tissue.

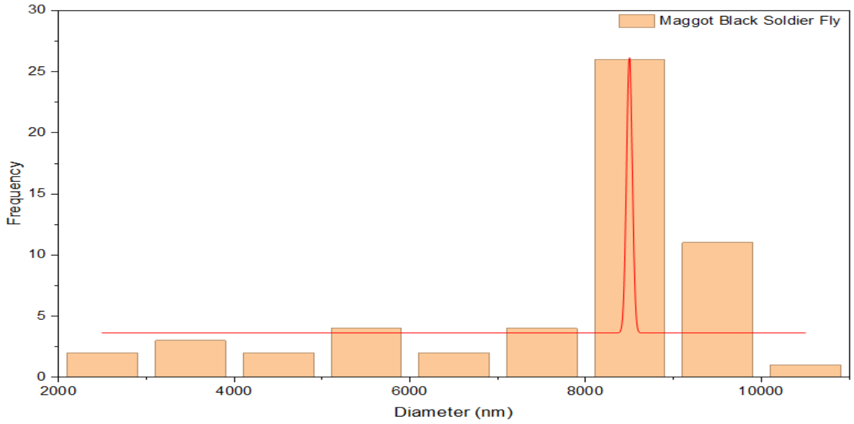

Figure 3. Particle distribution maggot black soldier fly at 400x magnification.

In particle analysis using a microscope, Figure 3 reference was performed using ImageJ to determine the particle diameter of the black soldier fly maggot sample. The graph of the microscope analysis results was performed using ImageJ reference. Based on particle testing using a microscope with ImageJ reference, the nanoscale size of the black soldier fly maggot has a size range of 2.000-10.000 nm, which can be categorized as a nanomaterial. Nanomaterials are materials with a composite size below 1000 nm or less than 1 mm. This is supported by reference (Mohanraj & Chen, 2007), which defines nanomaterials as particles with a size between 2.000-10.000 nm.

The FAME profile produced from the lipid extract of *Hermetia illucens* maggots showed a complex fatty acid composition but still followed the typical pattern of insect oils, especially the characteristics of BSF lipids which are rich in medium-chain saturated fatty acids in instrumen GC-MS followed by Table 9:

Table 9. Profile FAME Maggot Black Soldier Fly.

Peak#	Compound Name	R. Time	I. Time	F. Time	Area	Area%
1	Dodecanoic acid	12.224	12.175	12.27	38416	3.88
2	Butan-1,1-dicarbonitril	14.269	14.19	14.33	49384	4.99
3	Heptacosanoic acid	16.96	16.895	17.02	70951	7.17
4	9-octadecenoic acid	18.8	18.655	18.845	107979	10.92
5	Octadecane	19.026	18.95	19.035	44029	4.45
6	Heptadecane	19.496	19.45	19.54	40339	4.08
7	Hexadecane	19.937	19.89	19.97	43543	4.4
8	Pentadecane	20.264	20.215	20.3	64916	6.56
9	Ethyl-4-decenoate	20.345	20.33	20.445	42829	4.33
10	Octadecanoic acid	20.67	20.6	20.68	75699	7.65
11	2-cyclohexene-1-one	20.73	20.69	20.75	44526	4.5
12	1-eicosanol	20.78	20.75	20.835	53181	5.38
13	Triacontane	20.944	20.86	21	87766	8.87
14	Eicosane	21.057	21.03	21.085	42113	4.26
15	Elaidic acid	21.356	21.345	21.465	51620	5.22
16	1H-Cycloprop[e]azulen-4-ol, decahydro-1,1,4,7-tetramethyl	24.915	24.82	24.93	73522	7.43
17	Cyclohexanecarboxylic acid	25.62	25.505	25.63	58284	5.89
Total					989097	100

The FAME profile produced from the lipid extract of *Hermetia illucens* maggots shows a highly diverse compound composition, consisting of saturated and unsaturated fatty acids, long-chain alcohols, aliphatic hydrocarbons, esters, and cyclic derivatives. This diversity reflects the complexity of lipids in the body of BSF larvae, which function as energy reserves, membrane structural components, and metabolic precursors. In this dataset, the peak with the largest area percentage is 9-octadecenoic acid (C18:1) with an area of 10.92%, followed by triacontane ($C_{30}H_{62}$) at 8.87%, and octadecanoic acid (stearic acid, C18:0) at 7.65%. This composition shows that BSF has a significant proportion of saturated and unsaturated long-chain fatty acids. The main fatty acids identified include dodecanoic acid (C12:0), 9-octadecenoic acid (C18:1), octadecanoic acid (C18:0), and elaidic acid (C18:1 trans). Dodecanoic acid (lauric acid), at 3.88%, is an important component, consistent with literature indicating that BSF has a relatively high lauric content, although this varies depending on the feed substrate and larval age. Unsaturated fatty acids such as 9-octadecenoic acid and elaidic acid contribute to lipid fluidity and add nutritional value due to their bioactive properties on animal physiology. Stearic acid, a long-chain saturated fatty acid, also plays an important role in the oxidative stability of BSF oil.

In addition to the fatty acid components, this profile indicates the presence of several long-chain hydrocarbons such as heptadecane (C17), hexadecane (C16), pentadecane (C15), octadecane (C18), and triacontane (C30). The presence of significant amounts of hydrocarbons indicates a characteristic of insects, which often produce hydrocarbon compounds as part of their defense system or as cuticular components. Triacontane, with a high proportion of 8.87%, indicates that BSF contains significant amounts of waxy compounds, which may affect the melting point and physical stability of the oil. Other compounds such as 1-eicosanol (C20 alcohol) and ethyl-4-decenoate were also detected, indicating that in addition to fatty acids, BSF oil contains long-chain alcohols and volatile esters that may contribute to its characteristic aroma. 1-eicosanol has an area value of 5.38% and is part of the minor lipid fraction commonly found in insects. Cyclic compounds such as 2-cyclohexene-1-one and cyclohexanecarboxylic acid add chemical diversity to the lipid extract, suggesting the presence of secondary metabolic products or derivatives of mild oxidation.

CONCLUSIONS

The results of this study demonstrate that *Hermetia illucens* maggots possess high nutritional value, rich mineral content, and a diverse fatty acid profile that make them a strong candidate for sustainable animal feed development. The high crude fat and protein levels, coupled with the presence of essential minerals and safe chemical characteristics, confirm the maggot's suitability as an efficient feed ingredient, while the dominant C18 fatty acids and medium-chain lipids provide additional functional benefits for energy supply and metabolic health in livestock. The modified n-hexane extraction method successfully produced high-quality lipid fractions suitable for FAME profiling, strengthening the potential application of BSF maggots as an alternative to conventional protein and lipid sources in modern livestock and aquaculture nutrition.

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