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Composition of Defatted and Non-Defatted Black Soldier Fly Larvae Meal: Alternative for Fish Feeds

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ABSTRACT

Black soldier fly (Hermetia illucens) larvae meal has been considered as a great source of animal protein for animals. Nutrient composition of the larvae varies according to the substrate used in rearing the larvae and the processing techniques. This study was conducted to investigate the nutrient composition of full-fatted and processed (defatted and non-defatted) black soldier fly larvae meal. The larvae reared on wheat bran substrate were collected from Food and Agriculture Organization, University of Ibadan (FAO/UI) black soldier fly larvae culturing unit, sacrificed with hot water, rinsed and divided into full-fatted and processed (defatted and non-defatted) groups. The defatted group was mechanically pressed by squeezer to remove the fat content and the non-defatted group was not contacted. Both defatted and non-defatted groups were independently subjected to oven and sundried procedures. Chemical compositions of the full-fatted larvae meal, defatted oven-dried larvae, defatted sun-dried larvae, non-defatted oven-dried larvae and non-defatted sun-dried larvae were determined and statistically analysed. The research revealed black soldier fly larvae meal as a viable alternative to use as an animal protein source in fish feed formulation. Additionally, the nutritional composition revealed sun-dried processing method as the best method to remove the black soldier fly larvae lipid.

Keywords: *Animal protein, Defatted and Non-defatted, Fish feed, Drying method, Black soldier fly larvae*

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INTRODUCTION

Fishmeal is a great source of protein for aqua-feeds because of its great flavor, easy digestion, superior mineral, fatty acid, and essential amino acid composition (Rathipriya and Kannan, 2018). Additionally, the actual price of fish meal has increased over the last three decades and still expected to continue as the product's demand increases (Cottrell *et al*., 2020). It is now necessary to find substitute protein sources for use in fish feed formulation due to the high price and inconsistent quality of imported fish meal (Alfiko *et al*., 2022). A variety of locally produced fish feeds have been produced from various sources to provide more affordable, accessible, and sensible substitute for foreign commercial fish meals (Munguti *et al*., 2021). Black soldier fly (*Hermetia illucens*) larvae (BSFL) are presently the most promising candidates that have attracted a lot of attention as a possible substitute for replacing fish meal due to their capacity to transform organic and inorganic waste into biomass that is rich in protein and fat, their quick rearing period, and potential for bioremediation (Siddiqui *et al*., 2022). The amount of healthy, high-quality proteins, fatty acids, and micronutrients in BSFL varies, depending on the processing and defatting techniques used (Salahuddin *et al*., 2024). The mechanical pressing method is economical, labor-efficient, required little initial investment and low-cost (Zozo *et al*., 2022). Additionally, it may also be used on a small scale and greatly lower microbial hazards during extended storage, while preserving the purity and quality of the nutrients (Yan *et al*., 2023). Drying is a popular method for extending the shelf life of edible insects. This includes hot-air drying, microwave drying, freeze drying, roasting, sun drying, smoke drying and oven drying (Hernández-Álvarez *et al*., 2021). Drying removes the moisture content to a safe level, prevent the growth and reproduction of microbial proliferation, mitigate moisture-mediated deteriorative biochemical reactions and preserves the nutritional values (Alp and Bulantekin, 2021). The most popular techniques for dehydrating entire edible insects are oven and sun-drying because they are cost-effective and have been used traditionally (Parniakov *et al*., 2022). Processing method of BSFL is an excellent approach to determine its suitability for animal and human consumption (Khaemba *et al*., 2022) and this can impact on the nutritional content of the final product of black soldier fly larvae meal (BSFLM) (da-Silva *et al*., 2024). This study was therefore designed to investigate the chemical components of full-fatted and processed (defatted and non-defatted; and drying (oven and sun-drying)) methods of BSFL reared on wheat bran substrate.

MATERIALS AND METHODS

Collection, preparation and processing of black soldier fly larvae

Black soldier fly larvae were source from Food and Agriculture Organization University of Ibadan, (FAO/UI BSFL) culturing unit at the Department of Aquaculture and Fisheries Management Farm, University of Ibadan, Oyo State, Nigeria. The BSFL was starved for 48 hours to empty their bowel, sacrificed with hot water to removed dirt, rinsed with cleaned water and sieved.

The cleaned larvae were divided into full-fatted and processed (defatted and non-defatted) larvae groups.

Defatting procedure

The defatted BSFL group were packed in a small size mesh, pound lightly with pestle and pressed mechanically by squeezer tool for 20 minutes (Rozali *et al*., 2022) while the non-defatted group were not contact. The two groups were independently subjected to two different drying procedure of oven and sundried procedures.

Drying condition

Oven-air dried procedure

The defatted and non-defatted BSFL groups were separately subjected to oven-air dried at 85^{0}C for 5 hours (Rozali *et al*., 2022). Care was taken to ensure equal drying rate for each sample to ascertain no larvae sample overlapped.

Firstly, the trays were dried in the oven and weighed using an electronic scale (Cen-Tech, 12.7 x 8.1x 2.6 inches); the defatted and non-defatted larvae were placed on each weighed tray, weighed together with the trays and placed in an electric oven (Model 10-D1398) at 85°C for 5 hours. At every 30 minutes, the BSFL in the trays were removed from the oven and weighed to determine the moisture content. The drying process was terminated when the BSFL dried completely; and the percentages of the moisture content of dried BSFL were calculated using the formula below:

$$MC\ (\%) = 100 - \frac{(M_1 - M_2)}{(M_1 - M_0)} \times 100 \qquad (1)$$

Where:

M_0 = weight of an empty tray (g)

M_1 = weight of tray with BSFL before dried (g)

M_2 = weight of tray with BSFL after dried (g)

Sun-air dried procedure

The moisture contents of defatted and non-defatted BSFL were removed by spreading on a tray surface and sundried for four days (Son *et al*., 2023).

The trays were dried with clean napkin and weighed on electronic scale (Cen-Tech, 12.7 x 8.1 x 2.6 inches); BSFL were spread on the weighed trays, weighed together with the tray, covered with net to avoid contaminated by flies and rodents; and placed on height surface. Every 3 hours, the BSFL spread were checked by turning and weighed, to determine the moisture content.

The drying processes were terminated once the calculated moisture contents were constant. Care was taken to ensure same drying rate for each BSFL to assure no BSFL overlapped.

The resultant products of dried defatted and non-defatted black soldier fly larvae were milled to black soldier fly larvae meal (BSFLM) with a standard blender (VTCL, 750W, 230V).

Thereafter, chemical analysis were carried out to select the better drying method based on the nutritional quality and to know the effect of defatting process on the composition of the BSFL.

Chemical analysis

Proximate analysis of the full-fatted and processed BSFL meals were done for their composition using Fatima *et al*., (2023) method (Table 1); mineral analysis (Table 2) of the BSFLM were determined by the Atomic Absorption Spectrophotometer machine as described by Shumo *et al*., (2019); Vitamins (Table 3) and amino acid analysis (Table 4) by method of Nascimento *et al*., (2020); and fatty acid analysis (Table 5) by gas chromatography using Ewald *et al*., (2020) method .

Table 1: Proximate composition of black soldier fly larvae reared on wheat bran substrates

Parameters (%)	FFLM	Treatments			
		DODLM	DSDLM	NDODLM	NDSDLM
Crude protein	49.01±0.29[b]	57.84±0.27[d]	60.79±0.02[e]	41.61±0.11[a]	55.49±0.05[c]
Ash content	6.89±0.05[c]	7.05±0.02[d]	6.86±0.03[c]	5.30±0.06[b]	4.61±0.06[a]
Ether extract	34.90±0.05[e]	3.69±0.11[a]	4.27±0.09[b]	24.10±0.15[d]	22.47±0.19[c]
Crude fiber	5.52±0.06[c]	6.71±0.06[d]	7.30±0.06[e]	4.79±0.05[b]	4.38±0.04[a]
Moisture content	70.00±0.07[e]	62.07±0.20[c]	59.47±0.02[b]	53.10±0.09[a]	67.61±0.07[d]
Dry matter	46.91±0.09[e]	38.00±0.15[c]	40.57±0.02[d]	29.97±0.05[a]	32.34±0.04[b]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05).
Legend
FFLM: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

Table 2a: Macro mineral content of black soldier fly larvae reared on wheat bran substrates

Macro Minerals (mg)	FFLM	Treatments			
		DODLM	DSDLM	NDODLM	NDSDLM
Calcium	0.33±0.02[a]	0.27±0.01[a]	0.34±0.03[a]	0.29±0.03[a]	0.26±0.02[a]
Magnesium	0.37±0.02[b]	0.38±0.02[b]	0.36±0.02[b]	0.33±0.02[ab]	0.28±0.02[a]
Potassium	1.16±0.02[c]	1.10±0.02[bc]	1.14±0.01[c]	1.06±0.02[b]	0.86±0.02[a]
Phosphorus	0.66±0.28[a]	0.97±0.01[a]	0.93±0.01[a]	0.83±0.01[a]	0.67±0.01[a]
Sodium	0.22±0.01[a]	0.21±0.01[a]	0.24±0.01[a]	0.22±0.01[a]	8.8±8.60[a]
Nitrogen	0.00 ± 0.00[a]	9.18±0.01[c]	9.81±0.07[d]	8.92±0.01[e]	5.93±0.02[b]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05)
Legend: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

Table 2b: Micro mineral contents of black soldier fly larvae reared on wheat bran substrates.

Micro mineral (mg)	FFLM	Treatments			
		DODLM	DSDLM	NDODLM	NDSDLM
Iron	0.2±0.01[c]	0.17±0.01[b]	0.2±0.01[c]	0.17±0.01[b]	0.15±0.01[a]
Copper	0.03±0.01[a]	0.03±0.01[a]	0.03±0.01[a]	0.03±0.01[a]	0.02±0.00[a]
Zinc	0.21±0.01[c]	0.19±0.00[b]	0.19±0.00[b]	0.18± 0.00[b]	0.15± 0.00[a]
Manganese	0.49±0.01[c]	0.42±0.01[b]	0.49±0.01[c]	0.42±0.01[b]	0.39±0.01[a]
Nickel	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.02±0.01[b]	0.03±0.01[b]
Vanadium	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.00 ± 0.00[a]	0.02±0.01[b]	0.03±0.01[b]
Cobalt	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Chromium	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Cadmium	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Lead	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Selenium	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Mercury	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05).

Legend: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

Table 3: Vitamin Profiles of black soldier fly larvae reared on wheat bran substrates

Vitamins (mg)	FFLM	Treatments			
		DODLM	DSDLM	NDODLM	NDSDLM
Vit A	8.8±0.01[b]	7.19±0.03[a]	8.8±0.02[b]	13.01±0.10[c]	14.64±0.03[d]
Vit C	7.26±0.01[b]	6.49±0.02[a]	7.26±0.02[b]	9.81±0.02[c]	10.02±0.03[d]
Vit D	0.66±0.01[b]	0.46±0.01[a]	0.66±0.02[b]	1.24±0.02[c]	1.41±0.01[d]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05)
Legend: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

Table 4: Amino acid profile of black soldier fly larvae reared on wheat bran substrates

Parameters (%)	FFLM	Treatments			
		DODLM	DSDLM	NDODLM	NDSDLM
Non-essential Amino Acid					
Arginine	4.38±0.01[b]	5.49±0.023[d]	5.60±0.03[e]	4.65±0.01[c]	4.29±0.02[a]
Alanine	6.29±0.015[c]	7.72±0.01[d]	7.91±0.01[e]	6.11±0.01[b]	5.95±0.01[a]
Aspartic Acid	6.06±0.02[c]	5.81±0.02[a]	6.50±0.03[d]	5.91±0.02[b]	6.09±0.03[c]
Cysteine	0.93±0.02[b]	1.07±0.01[c]	1.19±0.02[d]	1.02±0.01[c]	0.80±0.02[a]
Glutamic Acid	12.10±0.07[b]	12.49±0.01[c]	13.21±0.05[d]	12.17±0.18[bc]	11.43±0.01[a]
Glycine	4.93±0.15[ab]	5.14±0.01[b]	5.09±0.01[b]	4.88±0.01[ab]	4.72±0.02[a]
Pyrolysine	0.9±0.02[b]	0.86±0.01[b]	1.03±0.01[c]	0.79±0.01[a]	0.76±0.02[a]
Proline	5.11±0.02[a]	6.39±1.01[a]	5.48±0.02[a]	5.243±0.02[a]	5.19±0.01[a]
Ornithine	0.08±0.01[a]	0.11±0.01[ab]	0.18±0.01[c]	0.13±0.01[b]	0.09±0.01[a]
Tyrosine	5.43±0.03[a]	5.94±0.02[d]	6.16±0.02[e]	5.77±0.01[c]	5.59±0.02[b]
Serine	2.59±0.01[c]	2.52±0.01[b]	2.64±0.02[c]	2.45±0.01[a]	2.40±0.01[a]
Essential Amino Acid					
Histidine	2.67±0.03[a]	2.48±0.01[a]	2.44±0.03[a]	2.35±0.01[a]	2.75±0.36[a]
Isoleucine	3.66±0.03[d]	3.60±0.01[c]	3.68±0.02[d]	3.46±0.00577[b]	3.32±0.02[a]
Leucine	6.69±0.03[b]	6.47±0.02[b]	6.69±0.03[b]	5.93±0.02[a]	5.92±0.17[a]
Lysine	5.31±0.02[a]	5.70±0.01[b]	5.63±0.01[b]	5.43±0.02[b]	5.29±0.01[a]
Methionine	2.31±0.02[a]	2.38±0.01[b]	2.53±0.02[c]	2.34±0.01[ab]	2.29±0.01[a]
Phenylalanine	5.95±0.02[a]	6.24±0.01[b]	6.21±0.02[b]	5.96±0.12[a]	5.88±0.03[a]
Threonine	4.06±0.02[a]	4.40±0.12[b]	5.00±0.12[c]	3.93±0.15[a]	4.39±0.04[b]
Tryptophan	0.41±0.03[b]	0.30±0.02[a]	0.37±0.01[b]	0.23±0.01[a]	0.24±0.01[a]
Valine	5.06±0.04[b]	5.01±0.02[b]	5.23±0.02[c]	4.74±0.02[a]	4.81±0.03[a]

Means ± SE along the same row with similar superscripts are not significantly different (p>0.05).
Legend: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

Statistical analysis

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

RESULTS

The proximate composition (Table 1) of full-fatted and processed BSFLM reported highest crude protein value of 60.79% from defatted sundried larvae meal (DSDLM) followed by defatted oven-dried larvae meal (DODLM) with crude protein value of 57.84% while the lowest crude protein value of 41.61% was reported from non-defatted oven-dried larvae meal (NDODLM). There were significant differences ($p<0.05$) among the crude protein values across the treatments. On the contrary, the highest ash value was recorded from DODLM with a value of 7.05% while the least value was recorded from non-defatted sundried larvae meal (NDSDLM) with a value of 4.61%. There was no significant difference ($p>0.05$) between the ash values of DSDLM and FFLM.

The value of ether extract in full-fatted larvae meal (FFLM) was significantly difference ($p<0.05$) across the treatment. The crude fiber values ranged from 4.38% to 7.30%. Moisture value ranged from 53.10% to 70.00% with highest value obtained from FFLM while the least value from the NDODLM. The mineral analysis (Table 2a & b) showed that calcium values ranged from 0.26% to 0.34%; magnesium ranged from 0.28mg to 0.37mg. Highest value (1.16 mg) of potassium was reported from FFLM and least value (0.86 mg) from NDSDLM. Phosphorus was highest in DODLM with a value of 0.97mg while the least was from NDSDLM recorded 0.67mg. Macro minerals needed for the body functioning are present in the processed larvae. Some micro minerals were not detected across the treatment including lead, cadmium, mercury, cobalt, chromium, and selenium. Some minerals were present in a minute value among the processed BSFL but absent in FFLM such as Nickel and Vanadium. The highest value (9.81mg) of Nitrogen was revealed from DSDLM while least value (5.74mg) was recorded from NDSDLM but not detected in FFLM.

Noticeable significant variations were recorded in the vitamin contents of the processed BSFLM (Table 3). Highest values of Vitamin A (14.64 mg), C (10.02 mg) and D (1.41 mg) were recorded from NDSDLM with the least values of Vitamin A (7.19 mg), C (6.49 mg) and D (0.46 mg) recorded from DODLM. There were no significant differences ($p>0.05$) among the vitamin contents of FFLM and DSDLM across the treatment.

Noticeable significant variations were recorded in amino acid profile of the processed BSFL (Table 4). All non-essential amino acids profiles were recorded higher in DSDLM except in proline and glycine that were recorded higher in DODLM. This symbolized that defatted sundried process had significant impacts to the non-essential profiles of black soldier fly larvae reared on wheat bran substrates. There was no significant difference ($p>0.05$) between histidine values of FFLM and the processed BSFL, highest histidine value (2.75%) was recorded from NDSDLM followed by FFLM (2.67%) then DODLM (2.48%) while the lowest value (2.35%) was recorded from NDODLM. There was no significant difference ($p>0.05$) between the isoleucine value of FFLM and DSDLM. Highest isoleucine value (3.68%) was recorded from DSDLM followed by FFLM (3.66%) then DODLM (3.60%) while the lowest value (3.46%) was recorded from NDODLM. Highest value of essential amino acid were recorded from processed BSFLM except leucine and tryptophan that were recorded higher from FFLM, indicated that the processing method had significant impact ($p<0.05$) to essential amino acid composition of black soldier fly larvae reared on wheat bran substrate.

The processing techniques appeared to improve the composition of both non-essential and essential amino acid profiles across the treatment, signified that the processing methods add positive impacts to amino-acid composition of the BSFLM reared on wheat bran substrate.

A noticeable significant difference of fatty acids profiles was revealed in FFLM compared to the processed BSFLM (Table 5). All of the fatty acids values were higher in FFLM excepts behenic acid, butyric acid and acetic acid that were recorded higher in NDSDLM, implies that the processing methods did not had positive impacts on fatty acid profiles of the black soldier fly larvae reared on wheat bran substrate. In addition, there was no significant difference ($p>0.05$) between the values of lignoceric acid of FFLM and NDODLM, as well as the behenic value of NDSDLM and FFLM

Table 5: Fatty acids profiles of black soldier fly larvae meal

Fatty Acids (%)	FFLM	Processed Treatments DODLM	DSDLM	NDODLM	NDSDLM
Lauric	16.97 ± 0.12^{c}	12.51 ± 0.02^{a}	12.61 ± 0.00^{a}	15.10 ± 0.00^{b}	15.31 ± 0.00^{b}
Stearic	1.00 ± 0.00^{d}	0.57 ± 0.00^{a}	0.58 ± 0.01^{a}	0.91 ± 0.00^{c}	0.88 ± 0.00^{b}
Palmitic	3.95 ± 0.03^{b}	2.38 ± 0.29^{a}	2.11 ± 0.00^{a}	3.59 ± 0.00^{b}	3.71 ± 0.00^{b}
Arachidonic	0.12 ± 0.00^{d}	0.07 ± 0.00^{c}	0.01 ± 0.00^{a}	0.09 ± 0.00^{c}	0.09 ± 0.00^{c}
Oleic	4.21 ± 0.01^{d}	3.11 ± 0.00^{a}	3.12 ± 0.00^{a}	4.11 ± 0.00^{b}	4.13 ± 0.00^{c}
Margaric	0.95 ± 0.00^{c}	0.06 ± 0.00^{a}	0.07 ± 0.00^{b}	0.11 ± 0.00^{e}	0.10 ± 0.00^{d}
Linoleic	2.90 ± 0.03^{c}	2.10 ± 0.00^{a}	2.08 ± 0.00^{a}	2.67 ± 0.00^{b}	2.71 ± 0.00^{b}
Lignoceric	0.04 ± 0.00^{b}	0.03 ± 0.00^{a}	0.03 ± 0.00^{a}	0.04 ± 0.00^{b}	0.05 ± 0.00^{c}
Myristic	2.92 ± 0.02^{b}	2.13 ± 0.00^{a}	2.44 ± 0.33^{ab}	2.66 ± 0.00^{ab}	2.51 ± 0.00^{ab}
Behenic	0.04 ± 0.00^{c}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.03 ± 0.00^{b}	0.04 ± 0.00^{c}
Butyric	0.03 ± 0.00^{c}	0.01 ± 0.00^{a}	0.01 ± 0.00^{a}	0.02 ± 0.00^{b}	0.03 ± 0.00^{c}
Valeric	0.04 ± 0.00^{c}	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.03 ± 0.00^{b}	0.04 ± 0.00^{c}
Palmitoleic	1.02 ± 0.02^{b}	0.56 ± 0.24^{a}	0.82 ± 0.00^{ab}	0.87 ± 0.00^{ab}	$0.91\pm0.00a^{b}$
Caprylic	0.07 ± 0.00^{b}	0.04 ± 0.00^{a}	0.03 ± 0.00^{a}	0.05 ± 0.00^{a}	0.05 ± 0.00^{a}
Propoinic	0.05 ± 0.00^{c}	0.02 ± 0.00^{a}	0.02 ± 0.00^{a}	0.03 ± 0.00^{b}	0.04 ± 0.00^{b}
Acetic acid	0.08 ± 0.00^{c}	0.05 ± 0.00^{a}	0.06 ± 0.00^{a}	0.07 ± 0.00^{b}	0.09 ± 0.00^{c}

Means ± SE along the same row with similar superscripts are not significantly different ($p>0.05$)

Legend: FFLM= Full-fatted larvae meal; DODLM= Non-defatted oven-dried larvae meal; DSDLM= Defatted sun-dried larvae meal; NDODLM= Non-defatted oven-dried larvae meal; NDSDLM= Non-defatted sun-dried larvae meal.

DISCUSSION

A critical analysis of the result revealed both the benefits and implications of various treatment methods on BSFL meal's chemical compositions, providing information into how specific processing techniques might be tailored to optimize aquafeed formulations. The compositional data of this study showed that the BSFL meals obtained after defatting irrespective of the drying method are good sources of dietary protein. The processed BSFLM showed a higher crude protein value than full-fatted larvae meal. Research by Xing *et al.* (2018) and Zhou *et al.* (2018) supported these findings, reported that defatting process improved the protein profile and decrease fat content when protein and fat are separated, beneficial for controlling lipid intake in fish sensitive to high-fat diets particularly for species such as tilapia, which may experience metabolic stress with high-fat feeds. Furthermore, the protein values of BSFLM of both FFLM and processed meals in this experiment were lower than the values reported by Cullere *et al*. (2016) and Schiavone *et al*. (2017) but higher than the values reported by Munguti *et al*. (2024). These differences could be due to the insect rearing substrate and the defatting process.

Defatted larvae meals (DSDLM and DODLM) exhibited the highest crude protein values, highlighted the effect of fat removal on protein concentrations. Defatting essentially reduces non-protein components, which concentrated the protein and essential nutrients (Navarro del Hierro *et al*., 2021). However, this increased protein concentrations through defatting process also presented considerations regarding balance nutritional needs. Apart from improving the nutritional values, the defatted procedure also significantly reduced the lipid content of the BSFLM which can likely to promote the growth and reproduction of microbial proliferation (Alp and Bulantekin, 2021), the defatted process can minimized the lipid content to about 10% (Zozo *et al.,* 2022).

The EE content found in this experiment was significantly higher than those reported by Zhao *et al*. (2022), who fed defatted BSFL different diets. The EE value of FFLM was significantly higher than the values of the processed larvae meal. This could be the result of defatting process which can influence the variability in the amounts of EE.

Drying (either oven dried or sun dried) technique had positive impact to the BSFL nutrient composition (Sangsawang *et al*., 2024). The significant decrease in EE values for defatted BSFLM treatments, as compared with non-defatted reflected how defatting could help to regulate energy levels in aquafeeds. High fat contents, as seen in FFLM, can be problematic in diets for species that do not efficiently utilize excessive lipids, leading to lipid accumulation and reduced feed efficiency (Dumas *et al*., 2018). Research by Zainorahim *et al*. (2024) supported these findings, that defatted BSFLM diets improved the protein profiles and decreased fat contents, and thus beneficial for controlling lipid intake in fish sensitive to high-fat containing diets. This is particularly important for species like *Scortum barcoo*, which may experience metabolic stress with high-fat feeds (Hancz *et al*., 2024).

The reduction in moisture contents of the processed BSFLM treatments, compared to higher moisture levels in FFLM had notable implications for feed stability and storage (Howieson *et al* 2023). Lower moisture levels in defatted BSFLM can prolong shelf life by reducing susceptibility to microbial growth, as noted by Shati *et al*. (2022), who found defatted BSFLM to be a stable protein source with low spoilage risk in aquafeeds. This reduction in moisture value enhanced the feed's resistance to mould and bacterial contamination, which is especially valuable for long-term storage in regions with high humidity or in feed production areas where bulk storage is necessary (Mgbeahuruike *et al*., 2023).

Nevertheless, a critical aspect of reduced moisture is that may influence the feed texture (Wang *et al*., 2023), and possibly impacted the palatability. Fish are sensitive to feed texture, and high moisture content could lead to pellet breakages, which may deter feed intake in certain species (Andriani *et al*., 2025). Incorporating moisture management strategies, such as partial rehydration or blending with other ingredients, may help in optimizing feed texture without compromising the storage benefits of reduced moisture (Russo *et al*., 2025).

The observed increase in Ash content in DODLM compared to other treatments suggested that defatted and drying processed can enhanced the mineral retention, which is essential for trace mineral supplementation in aquafeeds. This finding aligned with Elahi *et al.* (2020) that reared yellow mealworm on vegetal feed material.

Minerals are essential chemical substances that are needed by animals including fish to maintain healthy growth (Alagawany *et al.,* 2021). The mineral and vitamin profiles of BSFLM revealed how different processing methods, such as defatting and drying techniques, influenced its nutrient compositions. (Vasilopoulos *et al*., 2024), which in turn affects its suitability for aquaculture feeds. This study showned that calcium contents in BSFLM tends to be stable across the processed larvae, which aligned with the findings in fish nutrition, that adequate but not excessive calcium levels are essential for skeletal health (Lall and Kaushik, 2021). Therefore the results of calcium contents of BSFLM diets in this study were lower than the reported values by Makokha *et al*. (2023), that raised BSFL on barley spent grains. Performance differences may be caused by the composition of the substrates.

The calcium value of DSDLM (0.34%) was closer to the value of FFLM (0.33%). The reason behind this result might be associated to drying method. The mineral profiles of this study was lower to the study of Romano *et al*. (2023) that reported higher values of mineral value in black soldier fly larvae reared on different fruit peels. Furthermore, substrates fed have been reported to affect the mineral profile of BSFL (Weko *et al*., 2023).

Among the minerals is the potassium which helps nerves, muscle heart to function well and also helps moving nutrient and waste around the body system (Jomova *et al.,* 2022). In this study, the value of potassium is higher in FFLM than processed BSFLM; this could be related to the processing involved during lipd removal. The micro mineral including calcium, magnesium, phosphorus and sodium values of the processed BSFLM in this study were significantly higher than the values of FFLM except in potassium that was significantly higher in FFLM and nitrogen that was not detected in FFLM. The reason behind this result might be associated with the applied pressure, hour and their interaction during defatting process as well as the drying method used in drying the larvae. Thus, the defatting process might improve the availability of the minerals in BSFLM.

Phosphorus requirement must be satisfied through the diet as the fish cannot readily obtain it from the environment, which contains a low amount of phosphorus. Phosphorus levels, on the other hand, were notably higher in DODLM. Higher phosphorus availability is beneficial for fish species like *C. gariepinus* and *O. niloticus* (Diatta *et al.,* 2023), which required significant phosphorus intake or availability for bone formation and cellular metabolism (Gagelonia *et al.,* 2024). Therefore, the phosphorus values reported in this study were within the values given by Crosbie *et al.* (2024) that fed full fatted and defatted black soldier fly larvae meals to growing pigs but lower to the values reported by Munguti *et al* (2025) that fed black soldier fly larvae meals to Nile tilapia. Research by Sajid *et al*. (2023) supported these findings, showing that increased phosphorus in insect-based meals aided bone development in juvenile fish. Thus, defatted, phosphorus-rich BSFLM can be a valuable addition to feeds aimed at supporting growth and skeletal health.

In terms of vitamin contents, defatting processed tends to reduce the levels of fat-soluble vitamins such as Vitamins A and E in BSFLM. Non-defatted sun-dried larvae meal retained the highest concentrations of these vitamins; this may be due to the fact that fat-soluble vitamins are stored in the lipids that are partially removed during defatting process. The water soluble vitamins (vitamin C) of full-fatted and processed BSFLM of this study were higher than the values reported by Munguti *et al* (2025) that fed black soldier fly larvae meals to Nile tilapia; and Zulkifli *et al.* (2022) who used three different processed methods of treatment for black soldier fly larvae. However, vitamin A were not detected in the report of Zulkifli *et al.* (2022) but detected in this report of both full-fatted and processed BSFLM. The values of vitamin D (fat soluble vitamins) of DODLM in this study was within the range values reported by Shumo *et al*. (2019) who reared black soldier fly larvae on common organic waste streams in Kenya.

Akhtar and Ramzan (2024) and Karjee *et al*. (2023), observed similar trends in fish feed, where diets rich in fat-soluble vitamins enhanced immune functions and overall health in fish. Thus, for diets that required high vitamin A, C, or D levels, non-defatted BSFLM may be preferable. However, if the primary goal is to boost protein and essential amino acids, defatted BSFLM would be more suitable, especially given the protein concentration benefits of defatting BSFLMs.

This findings showed that the amino acid value of defatted oven and sun dried larvae meal were higher than the FFLM indicated that the processed method had influenced on the amino acid profile. Protein was more concentrated in defatted meals thereby making amino acid values higher and improved the concentration of amino acid mostly the essential amino acids, such as leucine, Isoleucine, methionine, phenylalanine and threonine making it richer protein source.

High levels of isoleucine, an amino acid that needed for muscle metabolism, glucose transportation, energy production and immune functions in fish (Sharf and Khan, 2023), was particularly abundant in DSDLM. Study by Vala *et al*. (2024) demonstrated that protein-rich feeds with balanced amino acid profiles supported optimal growth in aquaculture species by meeting their specific amino acid requirements. This aligned with the idea that defatted BSFLM, with its improved amino acid profiles, could serve as a high-quality protein source that could enhanced fish growth and healthy outcomes, thus making it an ideal component for species with high amino acid demands (Munguti *et al,* 2024).

Amino acid in both FFLM and processed BSFLM used in this trial were at higher levels than those fed with cereal by-products reported by Schiavone *et al*. (2017), which could be the differences in substrates used in rearing the larvae. The non-essential (dispensable) amino acids profiles were higher in DSDLM except in proline and glycine that were higher in DODLM, indicated that removing the lipid content by sundried add values to the amino acid composition. Although, all the non-essential amino acids profiles of defatted larvae were significantly difference compare to FFLM indicated that the processing technique improved the composition of non-essential amino acid profiles. However, the values of essential (indispensable) amino acid profile was not aligning with non-essential amino acid because the histidine, leucine and tryptophan values were recorded higher in FFLM. The most possible reason for this result could be the applied pressure during defatting process and the substrate used in rearing the larvae because the substrate has a significant impact on nutritional value of the collected BSFL (Deng *et al*., 2022).

Considerable differences were found in the fatty acid composition of the BSFLM. NDSDLM was enriched in lignoceric acid and acetic acid compared to the other meals. Similar values of behenic, butyric and valeric acid were recorded for FFLM and NDSDLM. However, fat contents in feeds do contributed to essential fatty acids and energy (Xing *et al*., 2018), so complete fat removal could reduce the nutritional composition of the feed. The choice of defatting level should thus aligned with the specific dietary needs of the target species, balancing protein concentrations with adequate lipid levels to provide necessary energy and essential fatty acids (Mahfoud *et al.,* 2023).

Lauric acid, stearic acid, palmitic acid, arachidonic acid, oleic acid, linoleic acid, margaric acid, myristic acid, propoinic acid, palmitoleic acid and caprylic acid occurred in all BSFLM but were most abundant in FFLM. The reason could be due to defatting process and temperature applied during processing of the larvae meal regarding the sacrificing and drying methods of the larvae, which may have significant impacts on the fatty acid profiles. Research by Saputra and Lee,(2023) was similar to this findings, revealing that the composition of the fatty acid contents of full-fat BSFL meal are higher than the defatted BSFL meal.

The fatty acid profiles of this experiment was within the ranged published by Schreven *et al*. (2021) that fed black soldier fly larvae oilseed by-products. Fatty acid composition of BSFL varies and depend on the diet fed or substrate reared on; and the processing methods (Lu *et al*., 2022; Tognocchi *et al*., 2024; Schreven *et al*., 2021;

Shelomi, 2020; Ewald *et al*., 2020; Danieli *et al*., 2019).

Conclusion and Recommendation

The current study demonstrated that the nutritional values encompassing proximate composition, amino acids, fatty acids, and minerals of full-fatted and processed BSFL, are comparable to that of fishmeal, and the defatting process of BSFL enhanced its protein and amino acid content. This result revealed that the nutritional value of BSFLM influenced by the processing techniques. Additionally, the nutritional composition of BSFLM from this research revealed sun-drying method as the best method to remove black soldier fly larvae lipid. Consequently, it can provide information for selecting the appropriate BSFL for aquafeeds. Composition of black soldier fly larvae reared on other substrates should be conducted, thereby guide farmers on best substrate to reared black soldier fly larvae before incorporates into fish feeds.

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