Sustainable Agriculture Research; Vol. 15, No. 2; 2026
ISSN 1927-050X E-ISSN 1927-0518
Published by Canadian Center of Science and Education

Black Soldier Fly Larvae Meal Enhance Nutrients Composition in Diets for Nile tilapia (Oreochromis niloticus)

Anne Wambugu[1], Joy N. Riungu[1], James G. Kirimi[2] & Stephen Karanja[1]

[1] Department of Civil and Environmental Engineering, Meru University of Science and Technology, P.O. Box 972-60200, Meru, Kenya

[2] Department of Livestock and Fisheries Development, Meru County Government, P.O. Box 185-60202, Nkubu, Kenya

Correspondence: James G. Kirimi, Department of Livestock and Fisheries Development, Meru County Government, P.O. Box 185-60202, Nkubu, Kenya. E-mail: kirimijg@yahoo.com

Received: July 8, 2026 Accepted: August 29, 2026 Online Published: September 11, 2026

doi:10.5539/sar.v15n2p14 URL: https://doi.org/10.5539/sar.v15n2p14

Abstract

The study evaluated the potential of defatted black soldier fly larvae meal (BSFLM) as a sustainable alternative to fish meal (FM) in Nile tilapia (Oreochromis niloticus) diets while promoting organic waste valorisation through a circular economy approach. Black soldier fly larvae (BSFL) (Hermetia illucens) were reared on faecal sludge and organic waste, harvested at the pre-pupal stage, and defatted to produce a protein rich feed ingredient. Three isonitrogenous diets (30 % crude protein) were then formulated such that BSFLM substituted FM at 0% (control, diet 1), 50% (diet 2) and 100% (diet 3) on a protein basis. Nutritional chemical analysis on ingredients and diets were determined while diets' fatty acids profile was determined by MPA FT-NIR spectrometer. The analysis showed significant differences ($p < 0.05$) among the diet treatments for all measured parameters except dry matter. FM registered the highest crude protein, (57.89%) followed closely by defatted BSFL (54.69%). However, partial substitution of FM with defatted BSFL in diets increased crude protein levels (31.77%), registered moderate crude fat (5.26%) and moderate crude fibre (11.08%) (diet 2) levels compared to FM meal diet (diet 1). Consequently, partial substitution yielded the highest overall polyunsaturated fatty acids (ΣPUFAs) content (4.81 mg/g). Thus, the study shows that, partial replacement (50%) of FM with defatted BSFLM provides rich proximate and fatty acid profiles that can support Nile tilapia production while sustainably managing waste, promoting resource recovery within a circular economy.

Keywords: aquafeed, black soldier fly, fatty acids, fish meal, Nile tilapia, proximate composition

1. Introduction

Poor waste management and the increasing generation of organic wastes have become major environmental concerns worldwide, contributing to pollution, greenhouse gas emissions, public health risks, and loss of valuable nutrients that could otherwise be recovered and reused (United Nations Environmental Program [UNEP], 2021). Organic wastes could be sustainably managed through approaches that promote nutrient recycling and resource recovery. One promising strategy involves the conversion of organic waste into valuable products such as biofertilizers, bioenergy, and protein-rich feed ingredients through biological processes including insect bioconversion (Makkar et al., 2014; Van Huis, 2020). In particular, black soldier fly larvae (BSFL) have gained considerable attention due to their ability to efficiently convert organic waste into high quality biomass rich in protein and lipids suitable for animal and aquaculture feeds (Lu et al., 2022).

Worldwide, aquaculture sector is expanding driven by the blue economy and blue growth policy, as well as the need to provide food and nutrition security to the ever increasing population (Food and Agriculture Organisation [FAO], 2022; Obwanga et al., 2020). However, its growth and sustainability are hampered by the rising cost and limited supply of fish meal, which is the main ingredient in fish feeds (Kirimi et al., 2022; Liu et al., 2025; Lu et al., 2022).

Fish meal production relies mostly on wild caught forage fish, creating ecological concerns such as overfishing and biodiversity loss (Boakes et al., 2024; Mirzabaev et al., 2023). In addition, the fluctuating costs and limited availability of fish meal, pose economic challenges for aquafeed manufacturers and farmers alike (Lu et al., 2022). Consequently, there has been a concerted effort to identify alternative protein sources that can partially or completely replace fish meal for aquaculture feeds including insect meals, plant proteins, and animal by-products. These alternatives aim to maintain fish growth performance while reducing feed costs and environmental impact (Macusi et al., 2023; Serra et al., 2024). Black soldier fly larvae meal (BSFLM) has emerged as a promising alternative protein source for aquafeeds (Fawole et al., 2021) with recent reviews and trials indicating a proximate analysis comparable to conventional protein ingredients used in aquafeeds. (Tomberlin et al., 2020; Lu et al.,2021; Van huis, 2021).

Replacing FM with BSFLM in fish diets can alter both the proximate composition and the fatty acid profile of the formulated diet and, consequently, of fish tissues. Many trials report that partial replacement (10-50%) often maintains acceptable growth and feed use parameters for several cultured species, while higher inclusion levels or use of full fat BSFL without balancing dietary essential long-chain omega-3 fatty acids (EPA/DHA) may reduce the proportion of marine omega-3s in the diet and in fish muscle an important quality issue for human nutrition (Tippayadara et al.,2023).

Several feeding trials and reviews show BSFLM is a viable partial replacement for FM in many species (Fawole et al., 2021; Kirimi et al., 2021; Wachira et al., 2021; Maranga et al., 2025). However, there is still uncertainty about optimal inclusion levels and processing methods that maintain fish flesh quality, particularly the levels of beneficial long chain polyunsaturated fatty acids (LC-PUFAs) across species and production systems. This study therefore focuses on assessing the effects of substituting fish meal with defatted BSFLM on proximate composition and fatty acid profiles of diets formulated with partial replacement of FM with BSFL.

2. Materials and Methods

2.1 Study Site

The experiment was conducted at the Sanitation Research Institute (SRI) of Meru University of Science and Technology (MUST), located in Meru County, Kenya. The site is approximately 1,660 meters above sea level, latitude 0°08′05″ N and longitude 37°42′30″ E. The region experiences warm, temperate climatic conditions, with ambient temperatures ranging from 12 °C to 28 °C and an annual mean rainfall of approximately 1,233mm. The site provides a controlled environment suitable for BSFL production.

2.2 Black Soldier Fly Larvae Production and Processing

BSFL were obtained from the MUST-SRI production site, where they were reared in plastic lined troughs inside a climate-controlled chamber maintained at 28-30°C and 60%-70% relative humidity, using faecal sludge and organic waste as substrates (Dortmans et al., 2017; Matheka et al., 2021). Once the prepupal stage was reached, indicated by a light to dark brown cuticle (Salam et al., 2022) the larvae were harvested using a 3 mm sieve, washed with distilled water, sun dried for five days, and defatted using an electric screw oil press. The press was preheated to 55°C, and the barrel temperature maintained at 80 ± 5°C. The resulting press cake was cooled, ground, and stored at 4°C until feed formulation. Defatted BSFLM was tested using standard procedures for salmonella spp. (ISO 6579-1), Escherichia coli (ISO 16649-2), lead and cadmium (EPA 6020A) and mercury (EPA 7473) prior to diet formulation (Gold et al., 2021; Jane et al., 2023).

2.3 Preparation of Diets Formulated with BSFLM

The resulting BSFL meal (BSFLM) was used to formulate the diets. The ingredients FM, soybean, sunflower cake, wheat bran, wheat pollard meal and fish premix was procured from local feed dealers. Fish premix provided the necessary vitamins. Proximate composition of various ingredients was conducted and results used as the basis for feed formulation using an excel spreadsheet. Three isonitrogenous diets (30 % crude protein) were formulated such that BSFLM substituted FM at 0 % (control, diet 1), 50 % (diet 2) and 100 % (diet 3) on a protein basis (Table 1). Each diet feed mixture was grinded, thoroughly mixed and pelleted by adding little water. The resultant pellets were dried in a shaded environment and subsequently preserved in opaque, airtight containers throughout the duration of the experimental procedure.

Table 1

Ingredients composition (%) for diets formulated with BSFLM for Nile tilapia production

Diets	**D1 (0%)**	**D2 (50%)**	**D3 (100%)**
Ingredients			
BSFLM (defatted)	0.00	12.00	24.00
Fish meal *(Rastrionaebola argentea)*	22.00	11.00	0.00
Soyabean meal	23.00	23.00	23.00
Sunflower seed meal	9.00	9.00	9.00
Wheat bran	37.00	35.00	34.00
Wheat pollard	7.00	8.00	8.00
Fish premix	2.00	2.00	2.00
Total	100	100	100

Abbreviation: BSFLM = Black soldier fly larvae meal; D1 (0 % BSFLM); D2(50 % BSFLM); D3(100 % BSFLM)

2.4 Chemical Analyses of Feed Ingredients and Experimental Diets

Proximate analysis was carried out using standard protocols AOAC (1995) for moisture, ash, crude fibre, crude protein, ether extracts and energy content. The moisture content was determined by drying the sample in an oven at 110˚C for 24 hours and measuring the water loss. Crude protein was estimated using Kjeldahl laboratory method. Fat content was determined by the Soxhlet method by treating the sample with ether. Crude fibre was determined by boiling the sample in 1.3 % H2SO4 and then in 1.3 % NaOH. Neutral Detergent Fibre (NDF) was determined by dissolving a 100g sample in a neural detergent solution. The remaining residue was filtered, washed, dried, and weighed. Acid Detergent Fibre (ADF) was determined by boiling 100g sample in an acid detergent solution to dissolve hemicellulose and other soluble materials. The residue was then filtered, washed, dried, and weighed. The ADF residue was further treated with 72% sulfuric acid to dissolve cellulose. The remaining residue was filtered, washed, dried, and then ashed in a furnace. After subtracting ash content, the remaining material represents lignin. Amino acids determination was carried out using the high-performance liquid chromatography (HPLC) method of amino acids determination (Alhealy et al., 2022). Approximately 100 mg of finely ground sample was hydrolysed with 10 ml of 6 M HCl at 110°C for 24 h, filtered, and derivatised using the AccQ-Tag reagent. The derivatised amino acids were separated on a reverse-phase C18 HPLC column using gradient elution and detected with a fluorescence detector. Fatty acids determination was performed by MPA FT-NIR spectrometer (Bruker, Germany) which is a non-destructive method of analysis. Approximately 5 g of the sample was put into the sample cup, and absorption of electromagnetic radiation at wavelengths in the range of 780 to 2500 nm was scanned. The concentrations of individual fatty acids were calculated from the NIR spectra and expressed as g/100 g total fatty acids (Bruker, 2021).

2.5 Data Analysis

Proximate and fatty acids data was analysed statistically using SPSS version 29.0 by conducting a one-way analysis of variance (ANOVA) at 95% confidence level; to determine if there were significant differences, mean separation was done by Fisher's least significance difference (LSD) post hoc test.

3. Results

3.1 Microbial and Metal Contamination for Black Soldier Fly Larvae Meal

There was no observable microbial growth in the BSFLM samples. Selected heavy metals values were also below detection limits (Table 2).

Table 2

Microbial and heavy metal contamination for black soldier fly larvae meal

Parameter	Result	WHO limits
Microbial contaminants		
Staphylococcus aureus (cfu/swamb)	nd	Absent
Total Coliforms (cfu/swamb)	nd	Absent
E. Coli (cfu/g)	nd	Absent
Heavy metal contaminants		
Mercury	nd	0.001 mg/L
Lead	nd	0.01 mg/L
Cadmium	nd	0.03 /L

Abbreviation: nd means not detected

3.2 Proximate Analysis of Ingredients

The results of proximate analysis varied significantly ($p < 0 .05$) across all diet treatments (Table 3). FM registered the highest crude protein (57.89%) followed closely by BSFLM (54.69%). BSFLM registered the highest crude fats (14.17%) followed by sunflower (12.54%) and FM (9.55%), while FM registered the highest ash values (19.23%).

Table 3

Proximate composition of ingredients used in Nile tilapia diets formulation

Proximate (%)	**Soybean**	**Fish meal**	**Wheat Poland**	**Sunflower**	**Wheat bran**	**BSFLM**	**P value**
Dry matter	92.12±0.10^{a}	89.82±0.03^{b}	90.54±0.05^{abd}	94.59±0.09^{c}	89.98±0.07^{bd}	89.67±1.21^{bde}	0.003
Crude protein	46.56±0.24^{a}	57.89±0.77^{b}	11.89±0.39^{c}	19.95±0.29^{d}	15.22±0.10^{e}	54.69±0.12^{f}	0.000
Crude fats	2.32±0.01^{a}	9.55±0.03^{b}	2.82±0.01^{c}	12.54±0.01^{d}	3.22±0.01^{e}	14.17±0.01^{f}	0.000
Ash	7.88±0.01^{a}	19.23±0.50^{b}	3.59±0.05^{c}	7.05±0.25^{d}	4.81±0.12^{e}	5.74±0.85^{f}	0.000
Crude fibre	8.39±0.02^{a}	2.12±0.04^{b}	4.44±0.08^{c}	38.11±0.01^{d}	12.37±0.07^{e}	21.59±0.04^{f}	0.000
Neutral detergent fibre	51.7±0.04^{a}	42.01±0.12^{b}	29.04±0.13^{c}	53.54±0.53^{d}	51.57±0.13^{a}	50.40±0.03^{e}	0.000
Acid detergent fibre	15.9±0.02^{a}	10.52±0.16^{b}	4.60±0.90^{c}	35.31±0.36^{d}	15.99±0.09^{a}	21.23±2.89^{e}	0.000
Acid detergent lignin	3.21±0.02^{a}	1.68±0.02^{b}	1.13±0.03^{c}	3.21±0.06^{a}	3.44±0.03^{d}	5.86±0.04^{e}	0.000

Values are expressed as mean ± SE (n =3): Values in the same row with different superscript letters show differences ($p < 0.05$).

3.3 BSFL Fatty Acids Profile

BSFLM registered high values of lauric acid (C12:0) (294.0±0.12mg/g), myristic acid (C14:0) (52.03±.12 mg/g) and palmitic acid (C16:0) (94.67± .019 mg/g), with very low values of pentadecanoic acid (C15:0) (3.10 +0.12mg/g). For monounsaturated fatty acids (MUFAs), oleic acid (C18:1) (183.23± .027 mg/g) was the most abundant followed by palmitoleic acid (C16:1) (65.07±0.186 mg/g). BSFL was also rich in polyunsaturated fatty acid (∑PUFAs) (385.72±.260 mg/g), with eicosapentaenoic acid (EPA) (C20:5 (n-3) (184.04± .167 mg/g) being most abundant followed closely by Docosahexaenoic Acid (C22:6 (n-3) (118.23±0.120). BSFL also registered low values of C16:3 (3.23± 0.055 mg/g) and Alpha-Linolenic Acid (ω-3) C18:3(n-3) (8.12±0.009 g/mg) PUFAs (Table 4)

Table 4

BSFL fatty acids profile

Fatty Acids	Mean (mg/g)	Standard error
Saturated fatty acids (SFAs)		
C12:0	294.0	±0.120
C14:0	52.03	±0.120
C15:0	3.10	±0.120
C16:0	94.67	±0.088
C18:0	24.15	±0 .018
∑ **SFAs**	173.95	±0 .019
Monounsaturated fatty acids (MUFAs)		
C16:1	65.07	±0.186
C18:1	183.23	±0 .027
C20:1	43.32	±0 .012
C22:1	28.23	±0 .067
∑ **MUFAs**	319.85	±0 .279
Polyunsaturated fatty acids (PUFAs)		
C16:3	3.23	±0.055
C16.4	4.63	± 0.033
C18:2(n-6)	15.64	± 0.015
C18:3 (n-3)	8.12	±0.009
C18:4	21.22	±0 .017
C20:4	16.50	± 0.018
C20:5 (n-3)	184.04	± 0.167
C22:5 (n-3)	14.10	± 0.058
C22:6 (n-3)	118.23	±0.120
∑ **PUFAs**	385.72	± 0.260

3.4 BSFL Amino Acids Profile

The results for amino acids for defatted BSFLM are as tabulated in Table 5. Defatted BSFL registered relatively higher values in all amino acids as compared to the whole BSFL. Defatted BSFL was rich in Essential Amino Acids (EAAs) like leucine (4.28%), lysine (3.97%) and valine (3.78 %), with low values of histidine (2.05%) and phenylalanine (2.62%). BSFL also registered high values of aspartic acid and glutamic acids at 6.16% and 6.78% respectively, with low values of hydroxyproline (<0.2%) and ornithine (0.462%). Cysteine and tryptophan recorded very low values of 0.44% and 0.99% respectively.

Table 5

BSFL Amino acids profile

Amino acids	Whole BSFL(g/100g)	Defatted BSFL(g/100g)
Essential Amino Acids		
Histidine	1.32	2.05
Isoleucine	1.68	2.61
Leucine	2.76	4.28
Lysine	2.63	3.97
Phenylalanine	1.72	2.62
Threonine	1.57	2.46
Valine	2.38	3.78
Non-Essential Amino Acids (NEAAs)		
Alanine	2.5	4.04
Arginine	1.89	2.99
Aspartic acid	4.02	6.16
Glutamic acid	4.37	6.78
Glycine	2.03	3.24
Hydroxyproline	<0.2	<0.2
Ornithine	0.315	0.462
Proline	2.3	3.65
Serine	1.6	2.56
Tyrosine	2.43	3.95
Cystine, methionine (oxidative)		
Cystein +Cystine	0.259	0.44
Methionine	0.618	1.02
Tryptophan (Total)	0.65	0.997

3.5 Proximate Analysis of Experimental Diets

The results of proximate analysis of the experimental diets are as shown in Table 6. Dry matter and nitrogen free extracts (NFE) were not statically different ($p > 0.05$) across all diet treatments. Results of crude protein, ash, crude fat and crude fibre content varied significantly ($p < 0 .05$) across all diets. Higher crude protein was recorded in diet 2 (31.77%) than in diet 1 and diet 3 ($p = 0.01$). Diet 1 (FM diet) being superior in ash values (10.16%) as compared to other BSFL based diets (diet 2 and diet3).

Table 6

Proximate composition of experimental diets with different inclusion levels of defatted BSFLM

Proximate composition (%)	D1**(0%)**	D2**(50%)**	D3**(100%)**	P value
Dry matter	90.6 ± 0.18	90.85 ± 0.05	90.67 ± 0.08	0.483
Crude protein	30.48 ± 0.32^{a}	31.77 ± 0.12^{b}	30.93 ± 0.18^{ca}	0.014
Crude fat	4.39 ± 0.01^{a}	5.26 ± 0.10^{b}	5.77 ± 0.10^{c}	0.000
Ash	10.16 ± 0.50^{a}	8.52 ± 0.11^{b}	6.57 ± 0.39^{c}	0.004
Crude fibre	10.49 ± 0.15^{a}	11.08 ± 0.10^{b}	13.39 ± 0.15^{c}	0.000
Nitrogen free extracts	37.32 ± 2.36	36.85 ± 2.34	36.91 ± 2.39	0.989
Neutral detergent fibre	49.09 ± 011^{a}	49.06 ± 0.05^{a}	47.82 ± 0.37^{bc}	0.045
Acid detergent fibre	10.49 ± 0.15^{a}	11.08 ± 0.10^{b}	13.39 ± 0.15^{c}	0.000
Acid detergent lignin	3.41 ± 0.01^{a}	4.77 ± 0.06^{b}	3.92 ± 0.03^{c}	0.000

Values are expressed as mean ± SE (n =3): Values in the same row with different superscript letters show differences ($p < 0.05$).

Abbreviation: BSFLM = Black soldier fly larvae meal; D1 (0 % BSFLM); D2(50 % BSFLM); D3(100 % BSFLM)

3.6 Diets Formulated with Defatted BSFLM Fatty Acids Composition

Diets fatty acids varied significantly across all diet treatments (Table 7) ($p < 0 .05$) except for Tricosanoic acid (C23:0). Diet 1 registered the highest overall SFAs as well as MUFAs values. Diet 1 registered high Palmitic Acid (C16.0)

(12.157 mg/g), Oleic Acid (C18:1c9) (17.707 mg/g) as compared to diet 2 and diet 3. However, diet 2 also recorded the highest values of stearic acid (C18:0) (3.050 mg/g), Alpha-Linolenic Acid (ω-3) (C18:3 n-3) (4.81 mg/g), and vaccenic acid (C18:1c11) (1.080 mg/g) than diet 1 and diet 3. Diet 2 being superior in overall PUFAs (ΣPUFA) (4.810 mg/g).

Table 7

Experimental diets formulated with defatted BSFLM fatty acids composition

Fatty acid (mg/g)	D1(0%)	D2(50%)	D3(100%)	P-value
Saturated				
C14:0	1.093 ± 0.02^{a}	0.723 ± 0.03^{b}	0.827 ± 0.01^{c}	0.00
C15	0.07 ± 0.01	nd	nd	
C16:0	12.147 ± 0.02^{a}	11.00 ± 0.03^{b}	11.713 ± 0.01^{c}	0.00
C17:0	0.127 ± 0.01^{a}	0.070 ± 0.01^{b}	0.060 ± 0.01^{bc}	0.01
C18:0	2.797 ± 0.03^{a}	3.050 ± 0.02^{b}	2.43 ± 0.01^{c}	0.00
C22:0	0.327 ± 0.01^{a}	0.283 ± 0.01^{bc}	0.253 ± 0.01^{c}	0.01
C23:0	nd	0.047 + 0.00	0.050 +0.00	0.37
C24:0	0.057 ± 0.00^{a}	0.073 ± 0.00^{a}	0.137 ± 0.01^{b}	0.00
ΣSFAs	16.618± 0.073	15.246+0.075	15.473+0.026	
Monounsaturated				
C16:1	0.437 ± 0.01^{a}	0.250 ± 0.01^{b}	0.320 ± 0.00^{c}	0.00
C17:1	nd	nd	nd	
C18:1c9	17.707 ± 0.02^{a}	15.077 ± 0.05^{b}	16.257 ± 0.03^{c}	0.00
C18:1c11	0.973 ± 0.02^{a}	1.080 ± 0.02^{b}	0.703 ± 0.01^{c}	0.00
C20:1	0.103 +0.01	0.067 + 0.00	nd	0.09
ΣMUFAs	19.220+0.006	16.474+0.536	17.280+0.26	
Polyunsaturated				
C18:3 n-3	4.163 ± 0.01^{a}	4.810 ± 0.02^{b}	3.830 ± 0.01^{c}	0.00
C22:5	nd	nd	nd	
ΣPUFAs	4.163±0.01	4.810±0.02	3.830±0.01	

Values are expressed as mean ± SE a, b, c, d. Values in the same row with different superscript letters show differences ($p<0.05$).

Abbreviation: BSFLM = Black soldier fly larvae meal; D1 (0 % BSFLM); D2(50 % BSFLM); D3(100 % BSFLM), nd means not detected

4. Discussion

4.1 Proximate Content of Ingredients

Generally, the proximate contents registered in the study concours with many other similar studies (Belghit et al., 2018; da-Silva et al., 2024; Kirimi et al., 2021; Lu et al., 2022; Makkar et al. 2014; Saptura & Lee., 2023; Zulfiki et al., 2022) but slight differences may occur as a result of feed sources and methods of processing (Fuso, 2021; Munguti et al., 2021; Zulfiki et al., 2021). The study registered no significant differences between dry matter content of BSFLM (89.67%) to fish meal (89.82%) but lower than values recorded in soybean and sunflower meals. This suggests that BSFLM has a moisture content similar to fish meal, making it a suitable substitute without affecting feed storage stability and pellet durability (Nayak & Klüber, 2025).

Similar to many studies, FM registered the highest crude protein content (57.89%), followed closely by BSFLM (54.69%). These values were higher than plant-based proteins such as soybean (46.56%) and sunflower meal (19.95%) (Kirimi et al., 2021). Defatted BSFL recorded the highest crude fat (14.17%) as compared to FM (9.55%), indicating a high source of energy and thus feed efficiency (Spranghers et al. 2017). These crude fats trend fall within the range 7-39% (Barragan et al, 2017; Zulfiki et al., 2021). Defatted BSFL also registered lower ash content (5.74%) than that of FM (19.23%), and higher fibre content values (21.59%) than FM (2.12%), further affirming its likelihood to mineral deficiency and digestibility. Higher values of neutral detergent fibre (NDF), acid detergent fibre (ADF), and acid detergent lignin (ADL) levels in BSFLM than those registered by FM indicate a higher structural carbohydrate. This could potentially affect digestibility if used at high inclusion levels. Therefore, the BSFL proximate analysis almost mirrors that of FM making it a suitable partial substitute for FM.

4.2 BSFL Fatty Acids

BSFL registered high values of SFAs as well as MUFAs. This study concours with previous study where lauric acid (C12:0), palmitic acid (C16:0), and oleic acid (C18:1) are said to be abundant in BSFL (Bian et al., 2024: Ewald et al., 2020; Lu et al., 2022). The findings of the present study partially agree with those of Ewald et al. (2020), who reported that although the overall lipid hierarchy (SFA > MUFA > PUFA) is generally conserved, fatty acid composition can be modified through substrate selection. In contrast, the present study recorded a lipid hierarchy of SFA < MUFA, suggesting that the rearing substrate influenced the fatty acid composition. Further, in the present study, BSFL was rich in linoleic acid (C18:2n-6) and Alpha-Linolenic Acid (ALA) (C18:3n3) (the precursor for EPA and DHA) which have been found mainly in plants and marine algae (Tvrzicka et al., 2011 in Ewald et al., 2020) this could be most likely attributed to the quality of substrate used (Ewald et al., 2020). The presence of high values of overall long-chain polyunsaturated fatty acids (PUFAs) ∑(PUFAs) (385.72± 0.260mg/g) indicates that defatted BSFLM is a good source of fatty acids essential for growth and overall health of the fish (Agbohessou et al., 2024). Therefore, this BSFL rich fatty acids profile makes BSFL as suitable substitute for FM.

4.3 BSFL Amino Acids

Defatted BSFL registered relatively higher values in all amino acids as compared to the whole BSFL. Defatted BSFL was rich in EAAs like leucine (4.28 %), lysine (3.97 %) and valine (3.78 %). This results in the current study are consistent with literature showing leucine, lysine, and valine as among the most abundant EAAs in BSFL (Lu et al., 2022; Zulfiki et al., 2022). The study further concours with other studies that showed limitations in levels of methionine (1.02 %) and cystine (0.44 %) (Lu et al., 2022), but rich in histidine and isoleucine, making it superior over FM and soymeal. However, BSFL was not limited in lysine as well as arginine (Ogello et al., 2014 in Macusi et al., 2023) making BSFL a superior substitute against plant-based substitutes.

4.4 Proximate Content of Diets

The dry matter content registered across all treatment diets, ranging between 90.85% to 90.60% was relatively high with no significant differences ($p = 0.483$). A high dry matter increases nutrient density as well as storage stability in a feed (Nayak & Klüber, 2025).

Notably diet 2 emerged superior in crude protein values (31.77 %) as compared to diet 1. Crude protein is a critical dietary component in fish nutrition because it supports growth, tissue repair, metabolism, immunity, and reproduction, therefore, balanced diet formulation is essential for sustainable fish production. (Kirimi et al., 2020). The crude protein registered in the present study was relatively high, ranging from 30.48% to 30.93%. These CP values were within the range required for fish production (30 to 34 %) (Sayed, 2018; Kirimi et al., 2020; Zulkifli et al., 2022) depending on species, age and sex. Further, the findings agree with previous studies indicating that diets formulated from complementary protein sources, such as black soldier fly larvae meal combined with fishmeal or plant protein ingredients, provide a more balanced nutrient profile and support improved crude protein quality than diets based on a single protein source (Serra et al., 2024).

Diet 3 (100% replacement of FM with BSFLM) registered a high crude fat but a low ash content indicating a deficient in minerals, as well as a relatively high CF. This high crude fat and crude fibre was a reflection of its abundance in the BSFL ingredient. Notably BSFL ingredient registered a high fat content (14.17%) higher than general typical requirements to Nile tilapia (5 - 6% for juvenile and 6-8% for mature fish) (Lim et al., 2011; National Research Council [NRC], 2011), but with manipulations as in feed formulation, the crude fat reduced to 5.26 % (diet 2) which is within the range necessary for Nile tilapia production. Excessive dietary lipids can also lead to fat deposition in fish, which may negatively affect growth performance and carcass quality. A high CF accelerates gut transition time, reducing nutrient absorption (Maundu et al., 2024). However, chitin a predominant contributor to the crude fibre fraction of BSFL has been noted to improve immunity and overall gut health in fish (Alhasyani et al., 2025). Results from Nile tilapia reared on experimental diet 2 (50% substitution level) registered the highest survival rates (95.56%) in comparison to diet 1 and diet 3 (Wambugu et al., 2026). Thus, a balance as in diet 2 (50% substitution) provides the best trade off.

All diet treatments indicated relatively high NDF range (49.09 % to 47.82%). High NDF indicates greater structural fibre content, while increased hemicellulose fractions may contribute to improved digestibility compared to highly lignified materials.

This study concurs with similar studies as carried out by Ouko et al., (2025), Munguti et al., (2023) and Maina et al., (2025) where 50% substitution provided an optimal replacement balance.

4.5 Diets Fatty Acids

Fatty acids were significantly different across treatments diets ($p < 0 .05$). This indicates that the type of ingredient incorporated influenced the overall lipid profile. Myristic acid (C14:0) (1.09 mg/g) and palmitic acid (C16:0) (12.15 mg/g) values were higher for diet1 followed closely by diet3. These high levels suggests that it contained more animal-based lipid sources such as fish meal, which are naturally rich in palmitic and myristic acids (Xu et al., 2020). They could also be attributed to their abundance also in the BSFLM (Bian et al., 2024; da-Silva et al., 2024; Maranga et al., 2025). This agrees with previous studies reporting that palmitic acid and myristic acids are typically the major SFA in fish diets and fish tissues (Turchini et al., 2009; Kirimi et al., 2022). The higher stearic acid (C18:0) in diet 2 could be linked to its abundance in BSFL (da-Silva et al., 2024) since most plant oils are limited in stearic acid (Turchini et al., 2009).

Oleic acid (C18:1c9) was the dominant MUFA, with values ranging from 15.077% in diet 2 to 17.71% in diet1. This fatty acid is crucial for maintaining membrane fluidity and energy metabolism in fish (Ewald et al, 2020). The significant variation ($p = 0.00$) among treatments suggests differences in lipid sources, as oleic acid is abundant in both fish oils and plant oils such as soybean or sunflower oil (Zhou et al., 2020).

The relatively lower MUFA content in diet 2 may indicate a higher proportion of saturated or polyunsaturated fatty acids in its composition. This concours with similar studies indicating BSFL is richer in SFAs as well as PUFAs (Goda et al., 2024). The presence of vaccenic acid (C18:1 c11) was also notable, with the highest concentration observed in Diet 2 (1.08%). Vaccenic acid is a naturally occurring ruminant and insect derived monounsaturated fatty acid that can serve as a precursor of conjugated linoleic acid (CLA) in animal and fish tissues and has attracted interest because of its potential nutritional benefits (Turchini et al., 2009).

Alpha-linolenic acid (C18:3 n-3) was the primary polyunsaturated fatty acid detected, ranging from 3.83% to 4.81%. Diet 2 exhibited the highest value, possibly due to greater incorporation of plant-derived lipids rich in omega-3 fatty acids (e.g soybean) as well as high values of eicosapentaenoic acid (EPA) C20:5 (n-3) found in BSFL as an ingredient. The Omega-3 fatty acids play a vital role in fish growth, immune response, and reproduction (Agbohessou et al., 2024; Ibrahim et al., 2022). The higher PUFAs content in diet 2 suggests that BSFL inclusion enhance the nutritional quality of the feed by improving essential fatty acid supply, although it might slightly reduce saturated fatty acid content (Ibrahim et al., 2022).

Studies have shown that freshwater fish are able to synthesize Alpha-Linoleic acid into eicosapentaenoic acid (C20:5n-3) acid and docosapentaenioc Acid (C22: 9n-3) essential for overall fish growth (Tippayadara et al., 2021). Thus, the abundance of alpha-linoleic acid in diet 2 makes it rich in PUFAs. In contrast, studies conducted on African cat fish diets by Maranga et al., 2025, registered high ∑PUFAs in the control diet (FM diet) unlike in the current study where high ∑PUFAs were registered in diet 2 with 50:50 replacement ratio of FM to BSFL (Maranga et al., 2025).

The results demonstrate that altering dietary ingredients significantly affects the fatty acid composition of formulated feeds. Diet 1 appeared richer in SFAs and MUFAs, while diet 2 had elevated PUFA levels, likely attributed to lower inclusion levels of EPA and ADH in diet 2 provided by partial substitution of protein sources unlike high values in ingredients as in diet 1 with 100% FM thus, improving its nutritional quality. Therefore, maintaining a balance among SFAs, MUFAs, and PUFAs is essential for optimal fish growth, lipid metabolism, and overall health (Turchini et al., 2009). Further, growth parameters of Nile tilapia reared with 50% substitution of FM with defatted BSFL as in diet 2 recorded no significant differences with diet 1 (Wambugu et al., 2026), making partial substitution of defatted BSFL as suitable substitute for FM.

5. Conclusion

In summary, partial replacement (50%) of FM with defatted BSFLM can have minimal effects on nutrient composition for Nile tilapia feeds. However, due to BSFL fibre contents full substitution may enhance gut time and reduce nutrient absorption time as in diet 3 (100%). Further the 50 % replacement of FM with BSFL diet manipulations can provide the essential lipids and fatty acids as its proximate content and fatty acids profile meets nutritional requirements for Nile tilapia production. The 50% substitution increased levels of crude proteins as well as PUFAs. Therefore, the manipulation of lipid sources can be a viable strategy to optimize proximate and fatty acid profiles in aquafeeds while reducing reliance on traditional protein and fish oil sources. Defatted BSFL reared on organic wastes not only ease the burden of high cost of aquaculture feeds but also help in sustainably managing the ever-increasing volumes of wastes, resources recovery, thereby achieving a circular economy.

References

Agbohessou, P. S., Mandiki, R., Mes, W., Blanquer, A., Gérardy, M., Garigliany, M. M., … Kestemont, P. (2024). Effect of fatty acid-enriched black soldier fly larvae meal combined with chitinase on the metabolic processes of Nile tilapia. *British Journal of Nutrition, 131*(8), 1326-1341. https://doi.org/10.1017/S0007114523003008

Alhasyani, T., Ebeid, T., Ghonimy, M., Alharbi, S., Hassan, M. F. Y., Jarallah, A., Alkhurayji, M., Abdellatif, A. A. H., & Barakat, H. (2025). Harnessing edible insect bioactives for gut health: A comprehensive review on chitin-derived prebiotics and peptidomic insights from the black soldier fly. *Foods, 14*(21). https://doi.org/10.3390/foods14213654

AOAC (Association of Official Analytical Chemists) (1995). *Official Methods of Analysis* (17th ed.). AOAC, Gaithersburg, MD, USA

Belghit, I., Liland, N. S., Waagbø, R., Biancarosa, I., Pelusio, N., Li, Y., ... Lock, E. J. (2018). Potential of insect-based diets for Atlantic salmon (Salmo salar). *Aquaculture, 491*, 72-81. https://doi.org/10.1016/j.aquaculture.2018.03.016

Bian, H., Qiao, Y., Li, Y., Wang, Z., Zhao, L., Li, Z., Cheng, B., & Ding, G. (2024). The Growth performance and nutrient composition of black soldier fly (Hermetia illucens) larvae fed slaughtered bovine blood. *Insects, 15*(9). https://doi.org/10.3390/insects15090635

Boakes, E., Dalin, C., Etard, A., Newbold, T. (2024). Impacts of global food supply on biodiversity via land use and climate change. *Nature Communications, 15*(1), 1-16. https://doi.org/10.1038/s41467-024-49999-z

Bruker Optics GmbH. (2021). *MPA II Multi-Purpose FT-NIR Analyzer: User Manual.* Bruker Optics GmbH, Ettlingen, Germany.

Da-Silva, W. C., Silva, É. B. R. D., Silva, J. A. R. D., Martorano, L. G., Belo, T. S., Sousa, C. E. L., ... Lourenço-Júnior, J. D. B. (2024). Nutritional value of the larvae of the black soldier fly (Hermetia illucens) and the house Fly (Musca domestica) as a food alternative for farm animals; A systematic review. *Insects, 15*(8), 619. https://doi.org/10.3390/insects15080619

Dortmans, B. M. A., Diener, S., Verstappen, B. M., & Zurbrügg, C. (2017). *Black soldier fly biowaste processing: A step-by-step guide.* Eawag: Swiss Federal Institute of Aquatic Science and Technology. Retrieved from https://www.eawag.ch/en/department/sandec/projects/mswm/practical-knowhow-on-black-soldier-fly-bsf-biowaste-processing

Dortmans, B., Egger, J., & Diener, S. (2021). *Black Soldier Fly Biowaste Processing-A Step-by-Step Guide* (2nd ed.). Dübendorf, Switzerland: Eawag, Swiss Federal Institute of Aquatic Science and Technology/Sandec.

Ewald, N., Vidakovic, A., Langeland, M., Kiessling, A., Sampels, S., & Lalander, C. (2020). Fatty acid composition of black soldier fly larvae (Hermetia illucens)-Possibilities and limitations for modification through diet. *Waste management, 102*, 40-47. https://doi.org/10.1016/j.wasman.2019.10.014

Fawole, F. J., Labh, S. N., Hossain, M. S., Overturf, K., Small, B. C., Welker, T. L., Hardy, R. W., & Kumar, V. (2021). Insect (Black soldier fly larvae) oil as a potential substitute for fish or soy oil in the fish meal-based diet of juvenile rainbow trout (Oncorhynchus mykiss). *Animal Nutrition, 7*(4), 1360-1370. https://doi.org/10.1016/j.aninu.2021.07.008

Food and Agriculture Organization (FAO) (2022). *The State of World Fisheries and Aquaculture*. In The State of World Fisheries and Aquaculture. FAO, Rome, 2022. https://doi.org/10.4060/ca9229en

Fuso, A., Barbi, S., Macavei, L. I., Luparelli, A. V., Maistrello, L., Montorsi, M., Sforza, S., & Caligiani, A. (2021). Effect of the rearing substrate on total protein and amino acid composition in black soldier fly. *Foods, 10*(8), 1-15. https://doi.org/10.3390/foods10081773

Goda, A. M., El-Haroun, E., Nazmi, H., Van Doan, H., Aboseif, A. M., Taha, M. K., & Abou Shabana, N. M. (2024). Black soldier fly oil-based diets enriched in lauric acid enhance growth, hematological indices, and fatty acid profiles of Nile tilapia, Oreochromis niloticus fry. *Aquaculture Reports, 37*, 102269. https://doi.org/10.1016/j.aqrep.2024.102269

Gold, M., Ireri, D., Zurbrügg, C., Fowles, T., & Mathys, A. (2021). Efficient and safe substrates for black soldier fly biowaste treatment along circular economy principles. *Detritus, 16*, 31-40. https://doi.org/10.31025/2611-4135/2021.15116

Ibrahim, D., Arisha, A. H., Khater, S. I., Gad, W. M., Hassan, Z., Abou-Khadra, S. H., … Abd El-Wahab, R. A. (2022). Impact of omega-3 fatty acids nano-formulation on growth, antioxidant potential, fillet quality, immunity, autophagy-related genes and Aeromonas hydrophila resistance in Nile tilapia (Oreochromis niloticus). *Antioxidants, 11*(8), 1523. https://doi.org/10.3390/antiox11081523

Jane, N. M., James, N., Kobingi, N., Albert, G., & Agnes, M. (2023). An overview of heavy metal pollution in the Western Indian Ocean (WIO) region of Kenya: A Review. *Journal of Aquatic and Terrestrial Ecosystems, 1*(1), 35-41.

Kirimi, J. G., Musalia, L. M., Munguti, J. M., & Magana, A. (2022). Carcass fatty acid composition and sensory properties of Nile tilapia (Oreochromis niloticus) fed on oilseed meals with crude papain enzyme. *East African Journal of Science, Technology and Innovation, 3*(4), 1-13. https://doi.org/10.37425/eajsti.v3i4.446

Kirimi, J. G., Musalia, L. M., Magana, A., & Munguti, J. M. (2020). Protein quality of rations for Nile tilapia (Oreochromis niloticus) containing oilseed meals. *Journal of Agricultural Science, 12*(2), 82-91. https://doi.org/10.5539/jas.v12n2p82

Kirimi, J. G., Musalia, L. M., Munguti, J. M., & Magana, A. (2021). Effect of substituting fish meal with oilseed meals on diets fatty acid and proximate composition for Nile tilapia (Oreochromis niloticus). *IOSR Journal of Agriculture and Veterinary Science, 14*(9), 26-33.

Lim, C., Yildirim-Aksoy, M., & Klesius, P. (2011). Lipid and fatty acid requirements of tilapias. *North American Journal of Aquaculture, 73*(2), 188-193. https://doi.org/10.1080/15222055.2011.579032

Liu, Y., Jiang, Z., Cottrell, R. S., Tlusty, M. F., Fitzsimmons, K., & Cao, L. (2025). Unstable supply and future shortages of wild forage fish heighten risks to global fed aquaculture production. *Nature Food*, 1-11. https://doi.org/10.1038/s43016-025-01254-4

Lu, S., Taethaisong, N., Meethip, W., Surakhunthod, J., Sinpru, B., Sroichak, T., … Paengkoum, P. (2022). Nutritional composition of black soldier fly larvae (Hermetia illucens L.) and its potential uses as alternative protein sources in animal diets: A review. *Insects, 13*(9), 1-17. https://doi.org/10.3390/insects13090831

Macusi, E. D., Cayacay, M. A., Borazon, E. Q., Sales, A. C., Habib, A., Fadli, N., & Santos, M. D. (2023). Protein fishmeal replacement in aquaculture: A systematic review and implications on growth and adoption viability. *Sustainability, 15*(16), 1-15. https://doi.org/10.3390/su151612500

Maina, A. N., Osuga, I. M., Munga, L. K., Munguti, J. M., Sevgan, S., Barwani, D. K., … Tanga, C. M. (2025). Emerging insect-based aquafeed for sustainable African catfish production. *Plos one, 20*(11), e0335422. https://doi.org/10.1371/journal.pone.0335422

Makkar, H. P., Tran, G., Heuzé, V., & Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal feed science and technology, 197*, 1-33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

Maranga, B. O., Kagali, R. N., & Orina, P. (2025). Fatty acid composition of African catfish (Clarias gariepinus) fed on black soldier fly larvae (Hermitia illucens) formulated diets. *Aquaculture, Fish and Fisheries*, 1-10. https://doi.org/10.1002/aff2.70078

Matheka, R. M., Raude, J. M., Murunga, S. I., Riungu, J. N., & Wandera, S. M. (2021). Effect of fecal matter co-digestion with kitchen waste on Hermetia illucens' larval weight and protein content. *Journal of Water Sanitation and Hygiene for Development, 11*(5), 746-757. https://doi.org/10.2166/washdev.2021.077

Maundu, A., Munguti, J., Sharma, R., Kasozi, N., Liti, D., Muthoka, M., ... Mutiso, J. (2024). Apparent protein digestibility and growth performance of Nile tilapia (Oreochromis niloticus) fed on sunflower and cotton seed meal as substitutes for freshwater shrimp meal (Caridina nilotica). *Aquaculture Research, 2024*(1), 2713506. https://doi.org/10.1155/2024/2713506

Mirzabaev, A., Olsson, L., Kerr, R. B., Pradhan, P., Ferre, M. G. R., & Lotze-Campen, H. (2023). Climate change and food systems. *Science and Innovations for Food Systems Transformation*, 511-529. https://doi.org/10.1007/978-3-031-15703-5_27

Munguti, J., Wekesa, F., Osuga, I., Kariuki, M., Yossa, R., Mungai, D., … Tanga, C. M. (2023). Utilization of black soldier fly (Hermetia illucens) larvae as a potential substitute for fish meal in the production of Nile tilapia (Oreochromis niloticus). *Sustainable Agriculture Research, 13*(1), 40-45. https://doi.org/10.5539/sar.v13n1p40

National Research Council (NRC). (2011). *Nutrient Requirements of Fish and Shrimp.* Washington, DC: National Academies Press.

Nayak, A., & Klüber, P. (2025). The hidden drivers: Unraveling the impact of density, moisture, and scale on Hermetia illucens rearing. *PLoS one, 20*(1). https://doi.org/10.1371/journal.pone.0317049

Obwanga, B., Soma, K., Ingasia Ayuya, O., Rurangwa, E., Wonderen, D. van, Beekman, G., & Kilelu, C. (2020). Exploring enabling factors for commercializing the aquaculture sector in Kenya. *3R Kenya Research Report,* 1-55.

Ouko, K. O., Mboya, J. B., Mukhebi, A. W., Obiero, K. O., Ogello, E. O., Munguti, J. M., & Tanga, C. M. (2024). Effect of replacing fish meal with black soldier fly larvae meal on growth performance and economic efficiency of Nile tilapia. *Fundamental and Applied Agriculture, 9*(1), 1-9. https://doi.org/154509

Pascon, G., Opere Akinyi, R., Cardinaletti, G., Daniso, E., Messina, M., & Tulli, F. (2025). Chitin and its effects when included in aquafeed. *Aquaculture International, 33*(3), 202. https://doi.org/10.1007/s10499-025-01879-z

Salam, M., Shahzadi, A., Zheng, H., Alam, F., Nabi, G., Dezhi, S., Ullah, W., Ammara, S., Ali, N., & Bilal, M. (2022). Effect of different environmental conditions on the growth and development of black soldier fly larvae and its utilization in solid waste management and pollution mitigation. *Environmental Technology and Innovation, 28*(2022), 102649. https://doi.org/10.1016/j.eti.2022.102649

Saputra, I., & Lee, Y. N. (2023). Nutrition composition of commercial full-fat and defatted black soldier fly larvae meal (Hermetia illucens) as a potential protein resource for aquafeeds. *Biodiversitas Journal of Biological Diversity, 24*(9). 4877-4884, https://doi.org/10.13057/biodiv/d240930

Sayed, A. N. (2018). Optimum crude protein requirement of the fingerlings Nile tilapia (Oreochromis niloticus). *Biological Science, 2*(1), 1-8. https://doi.org/10.31058/j.bs.2018.21001

Serra, V., Pastorelli, G., Tedesco, D. E. A., Turin, L., & Guerrini, A. (2024). Alternative protein sources in aquafeed: Current scenario and future perspectives. *Veterinary and Animal Science, 25*, 100381. https://doi.org/10.1016/j.vas.2024.100381

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., De Meulenaer, B., & De Smet, S. (2017). Nutritional composition of black soldier fly (Hermetia illucens) prepupae reared on different organic waste substrates. *Journal of the Science of Food and Agriculture, 97*(8), 2594-2600. https://doi.org/10.1002/jsfa.8081

Tippayadara, N., Krutmuang, P., Hoseinifar, S. H., Resources, N., & Doan, H. Van. (2021). Replacement of fish meal by black soldier fly (Hermetia illucens) larvae meal: Effects on growth, hematology and skin mucus of Nile tilapia. *Animals, 11*(1), 193. https://doi.org/10.3390/ani11010193

Tomberlin, J. K., & Van Huis, A. (2020). Black soldier fly from pest to 'crown jewel' of the insects as feed industry. *Journal of Insects as Food and Feed,* 6(1), 1-4. https://doi.org/10.3920/JIFF2020.0003

Turchini, G. M., Torstensen, B. E., & Ng, W. K. (2009). Fish oil replacement in finfish nutrition. *Reviews in Aquaculture, 1*(1), 10-57. https://doi.org/10.1111/j.1753-5131.2008.01001.x

United Nations Environment Programme (UNEP). (2021). *Food Waste Index Report 2021.* United Nations Environment Programme. Retrieved from https://wedocs.unep.org/bitstream/handle/20.500.11822/35280/FoodWaste.pdf

van Huis, A. (2020). Insects as food and feed, a new emerging agricultural sector: A review. *Journal of Insects as Food and Feed, 6*(1), 27-44. https://doi.org/10.3920/JIFF2019.0017

van Huis, A. (2021). Prospects of insects as food and feed. *Organic Agriculture, 11*(2), 301-308. https://doi.org/10.1007/s13165-020-00290-7

Wachira, M. N., Osuga, I. M., Munguti, J. M., Ambula, M. K., Subramanian, S., Tanga, C. M. (2021). Efficiency and improved profitability of insect-based aquafeeds for farming Nile tilapia fish (Oreochromis niloticus). *Animals, 11*(9), 2599. https://doi.org/10.3390/ani11092599

Wambugu, A., Gikunda, G., Riungu, J. N., Kirimi, J., & Karanja, S. (2026). Growth and economic performance of Nile tilapia (Oreochromis niloticus) fed on black soldier fly larvae raised on human fecal sludge and organic waste: a circular economy approach. *Journal of Water, Sanitation and Hygiene for Development, 16*(6), 515-525. https://doi.org/1 0.2166/washdev.2026.264

Xu, H., Turchini, G. M., Francis, D. S., Liang, M., Mock, T. S., Rombenso, A., & Ai, Q. (2020). Are fish what they eat? A fatty acid's perspective. *Progress in lipid research, 80*, 101064. https://doi.org/10.1016/j.plipres.2020.101064

Zhou, Y., Zhao, W., Lai, Y., Zhang, B., & Zhang, D. (2020). Edible plant oil: global status, health issues, and perspectives. *Frontiers in Plant Science, 11*, 1315. https://doi.org/10.3389/fpls.2020.01315

Zozo, B., Wicht, M. M., Mshayisa, V. V., & van Wyk, J. (2022). The nutritional quality and structural analysis of black soldier fly larvae flour before and after defatting. *Insects, 13*(2), 1-10. https://doi.org/10.3390/insects13020168

Zulkifli, N. F. N. M., Seok-Kian, A. Y., Seng, L. L., Mustafa, S., Kim, Y. S., & Shapawi, R. (2022). Nutritional value of black soldier fly (Hermetia illucens) larvae processed by different methods. *PLoS one, 17*(2 February). https://doi.org/10.1371/journal.pone.0263924

Author Statements

Author(s) declared the statement below:

Acknowledgments

The authors appreciate Sanitation Research Institute (SRI), Meru University of Science and Technology for availing facilities to conduct this research.

Author Contributions

Anne Wambugu: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Writing – original draft. Joy N. Riungu: Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Supervision, Validation, Writing – original draft. James G. Kirimi: Conceptualization, Formal analysis, Investigation, Methodology, Supervision, Validation, Writing–original draft. Stephen Karanja: Conceptualization, Investigation, Project administration, Validation, Supervision.

Consent for Publication

All authors have read and approved the published version of the manuscript.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Informed Consent

Not applicable.

Ethics Approval

This article does not require ethical approval.

Data Availability Statement

Not applicable.

Use of Artificial Intelligence

The authors declare that no generative artificial intelligence (AI) tools were used in the conception, design, analysis, interpretation, or writing of this manuscript.

Supplementary Materials

No supplementary materials are available.

Journal Information

The Editorial Board declared the below statement on behalf of the journal and publisher.

Ethics Statement

The journal's policies adhere to the Core Practices established by the Committee on Publication Ethics (COPE).