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Nutrition composition of commercial full-fat and defatted black soldier fly larvae meal (*Hermetia illucens*) as a potential protein resource for aquafeeds

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Abstract. *Saputra I, Lee YN. 2023. Nutrition composition of commercial full-fat and defatted black soldier fly larvae meal* (Hermetia illucens) *as a potential protein resource for aquafeeds. Biodiversitas 24: 4877-4884.* Black Soldier Fly or BSF (*Hermetia illucens*) is one of the most researched insect species for its potential as a protein source in aquafeeds. In the present study, two commercially available full-fat and defatted BSF larvae were analyzed in terms of nutrition profiles including proximate composition, amino acids, fatty acids, and mineral contents. The defatted BSF was in the form of a meal and the full-fat BSF was in the form of overdried. The full-fat BSF larvae were ground using a food-grade milling machine and strained to obtain small particles. BSFL meals were then sent for laboratory analysis. Results indicated that the defatted BSFL have higher crude protein content than full-fat BSF, with crude protein value of 47.70% and 30.72%, respectively. In contrast, the crude lipid in the full-fat BSFL was 36.20%, higher than in defatted BSFL, with only 8.11% lipid content. The amino acids analysis indicated that only histidine was the amino acid that was higher in defatted BSF than in full-fat BSF. The availability of fatty acids in defatted BSFL was lower than in full-fat BSF. On the contrary, the Ca, Na, mg, Zn, Fe, Mn, and Cu in defatted BSF were higher than in the full-fat BSFL. In conclusion, full-fat and defatted BSF have comparable nutrition value to fishmeal sourced from bycatch fishes and the defatting process of BSFL improves the nutritional composition of BSFL including protein and amino acids. Therefore, it can be used as information for the correct choice of BSFL used in aquafeeds.

Keywords: Amino acids, aquafeeds, BSF, fatty acids, minerals, proximate composition

Abbreviations: BSF: Balck Soldier Fly; DF: Defatted; FF: Full Fat; HPLC: High Performance Liquid Chromatography

INTRODUCTION

In recent years, the black soldier fly (*Hermetia illucens*) has been massively explored as a sustainable source of nutrition (Riddick 2014; Sánchez-Muros et al. 2016; Hasan et al. 2019). Although it was considered a nutritious food source for human consumption (Bessa et al. 2020), further investigation on its positive and drawback effects is important (Bessa et al. 2021). The BSF become an ideal source of nutrition that can be used as animal feed. They have an important role in the agricultural field, including natural fertilizers, sources of feed and oil for livestock, sources of chitin (Soetemans et al. 2020) and sources of antimicrobial peptides (Xia et al. 2021). Along with the rapid development of technology, BSF can not only be used as a protein source for animal feed but also as a protein source for fish and shrimp feed (Riddick 2014; Henry et al. 2015). The reason behind this is that the nutritional content of BSF is comparable to fishmeal and sufficient to support the growth of the fish and shrimp. Apart from being used as an alternative source of protein in fish feed, the BSF is also considered a candidate for providing a source of lipids (Franco et al. 2021). Several final products of BSF are available but not limited to live form, overdried, BSFL meal powder and frass (Yildirim-Aksoy et al. 2020; Zulkifli et al. 2022).

BSF larvae contain various nutrients such as protein, lipids or fat, minerals, vitamins, amino acids, and fatty acids. Many reports said that the protein content of BSF ranges from 30-40% depending on the stage, substrate and processing and has a potential function as a fishmeal substitute in aquafeeds (Devic et al. 2018; Fisher et al. 2020; Hu et al. 2020; Zozo et al. 2022; Zulkifli et al. 2022) supporting the future of aquaculture. That level of protein content is suitable as the protein source for cultured fish and crustacean species which require moderate crude protein. The effort to improve the nutrition quality of BSF is demanding. Reports have shown that the whole BSF larvae have a high lipid content and that become a major concern in its utilization as alternative protein sources in aquafeeds. The removal of excessive lipid content in the BSF is expected to increase the crude protein content through the defatting process (Hender et al. 2021; Zozo et al. 2022). The defatting process of BSF larvae using hexane and isopropanol solution has successfully removed approximately 80% of total fat content and improved the crude protein content by about 22.4% (Zozo et al. 2022). The increasing crude protein content also increases the availability of amino acids. Schiavone et al. (2017) reported that all amino acids of the highly defatted BSF were higher than partially defatted BSF and affected the amino acid contents of the tested diets.

Apart from the success of full-fat BSF larvae in replacing fishmeal, it has been reported that the defatted BSF larvae can also be used as fishmeal replacers in the diets of several fish with mixed results (Senlin et al. 2017; Hu et al. 2020; Hender et al. 2021). In barramundi (*Lates calcarifer*), the inclusion of defatted BSF as much as 30% did not impair their growth but instead improved the immune capability of the fish (Hender et al. 2021). A higher inclusion level of defatted BSF reaching as much as 75% was reported to be suitable for Jian carp (*Cyprinus carpio*) (Senlin et al. 2017). On the contrary, the lower amount of fishmeal substitution with BSF was reported to be optimum for rice field eel, *Monopterus albus* (Hu et al. 2020). Research has found that the crude fat content of full-fat BSF larvae is up to 32% (Hu et al. 2020; Weththasinghe et al. 2021). That nutritious lipid is believed as a sustainable source for future aquafeeds due to the simplicity of its production (Ewald et al. 2020; Franco et al. 2021). Like the protein content, the lipid content from BSF larvae depends on the type of substrate or food source (Barragan-Fonseca et al. 2017). In addition, stage and age are also crucial factors that determine the nutritional content of BSF. BSF raised using household waste substrate is known to have a high fat content. Whereas BSF reared using fruit and vegetable substrates has a lower protein content when compared to those cultivated using animal materials. Lan et al. (2022) reported that the protein content of BSF grown using fruit and vegetable substrates had a crude protein value of 38.5% lower than the protein content of BSF cultivated using fish or ruminant liver substrates.

Both full-fat and defatted BSF have been reported to have a prospective function as fishmeal substitutes. Many sources discuss the nutritional content of BSF as a sustainable and promising future nutrition source (Rabani et al. 2019; Xu et al. 2020; Hender et al. 2021; Weththasinghe et al. 2021; Lu et al. 2022) and each type of BSF meal has their unique characteristics. Each type of BSF meal also has pros and cons on the physiology and immunology of the cultured animal. Therefore, it becomes important to know the nutritional content of BSF to obtain precise nutrition content information, particularly BSF products that are available on the market and are sold commercially. In this study, a comparison will be made between commercial full-fat BSF and defatted BSF meal, which is available in the local market and will be used as an alternative protein source in aquafeeds. By knowing the value of the BSFL meal nutritional content, the feed formulation for fish feed will be more appropriate according to the needs of the fish species. The aim of the present study is to evaluate the nutritional composition of defatted and full-fat BSF meals available in the market as protein sources in aquafeeds.

MATERIALS AND METHODS

In the present study, commercial BSF larvae were purchased from the marketplace and locally produced in Indonesia. The defatted BSF was purchased in the form of a meal, while the full-fat BSF was in oven-dried form. The BSF were grown in the organic food leftover substrates. The defatted BSF meal was produced by several processes, including steaming, drying and grinding. The full-fat oven-dried BSF larvae were then ground using a food processor (Chence CH-250A, China) several times until fine particles were achieved. The product was also sieved using an industrial-grade sieve (Retsch Test Sieves, US). For proximate composition and mineral analysis, the BSF samples were sent to the Fish Health Environmental Test Centre (Serang-Indonesia). While the amino and fatty acids analysis were performed at IPB University Nutrition Laboratory (Bogor-Indonesia).

Proximate composition

The crude protein content was analyzed using the Kjeldahl method where the availability of protein is determined by multiplying the nitrogen by factor 6.25. The moisture content was tested using the gravimetry method, where approximately 2 g of samples were placed in a heat-treated ceramic cup and placed in an oven at 105°C for 16 hours. After the process was completed, samples were then moved into a desiccator for 30 minutes and weighed. The ash content was tested using heat treatments of the samples at 550°C for 6 hours. The sample was then further processed with another 550°C for 1 hour or until it reached the constant weight. The amino acid composition in the commercial BSFL meal was analyzed using the High-Performance Liquid Chromatography method (AOAC 2000) where the protein is released by hydrolysis with HCl 6N. The hydrolyzate is dissolved in sodium citrate buffer and each of those amino acids was separated using an HPLC machine. The mineral content analysis, including calcium, sodium, magnesium, zinc, iron, manganese and copper was performed using atomic absorbance spectroscopy (Agilent 200 series AA systems, US) according to an established protocol (Paul et al. 2014). Prior to the analysis, the BSF samples were prepared by dry destruction. The nitrous oxide flame method was used for calcium analysis and the acetylene flame method was used for natrium, magnesium, zinc, iron, manganese and copper analysis.

Data analysis

The proximate composition, amino acids, fatty acids and minerals were analyzed in terms of differences among the defatted and full-fat BSF according to an established calculation (Cummins et al. 2017) as follows:

$$\% \text{ Differences} = \frac{(TP_{DF} - TP_{FF})}{TP_{FF}} \times 100$$

Where:
TP : Value of tested parameters
DF : Defatted BSF larvae meal
FF : Full-Fat BSF larvae meal

The collected data were then compared to reliable references that have similar topics in it. The search for the related paper was conducted by looking at reputable sources such as Scopus and Web of Science database. Papers with sufficient information related to the nutritional composition of BSF were chosen and used as references.

RESULTS AND DISCUSSION

The proximate composition of tested BSF meal indicated that higher crude protein and ash content were observed in defatted BSFL than in full-fat BSFL. On the contrary, the crude lipid contents in the defatted BSFL were lower than in full-fat BSFL meal (Table 1). Meanwhile, the moisture of full-fat BSFL was relatively like the ash content in defatted BSFL meal.

In general, the content of amino acids in the full-fat BSFL was higher than the amino acids in the defatted BSF. Exception for threonine and histidine where their content in the full-fat BSF is lower (Table 2).

The comparison of tested fatty acids composition is presented in Table 3. All of the fatty acids content tested were higher in defatted BSFL meal than in full-fat BSFL meal. Both capric (C10:0) and caprylic (C8:8) were not detected in both BSFL meal types. The arachidic acid (C20:4 n6) was detected in defatted BSFL meal but not in full-fat BSFL meal. Large portions of palmitic acid (C16:0), oleic acid (C18:1 n9) and linoleic acid (C18:2) were observed in both BSFL meal types. The highest differences in fatty acid content were found in lauric acid, where the content of lauric acid in full-fat BSF was higher, more than 80%, than lauric acid in defatted BSF. In addition, arachidic acid was not found in defatted BSFL, while only a small amount was found in full-fat BSFL.

The minerals analysis from the full-fat and defatted BSF indicated that defatted BSF has a higher amount of all mineral types tested than full-fate BSF. The complete mineral analysis results can be seen in Table 4. Calcium is the largest proportion of minerals from both BSFL meal, followed by magnesium and natrium, respectively. In contrast, only a small amount of copper was found in both BSFL meal. Copper and zinc were the minerals that have a noticeable difference compared to others.

Table 1. The proximate composition of commercial full-fat and defatted BSF meal (g/100 g dry weight basis)

Proximate composition (%)	FF BSFL	DF BSFL	% differences*
Crude protein	30.72	47.70	55.3
Crude lipid	36.20	8.11	-77.6
Ash	11.97	18.90	57.9
Moisture	6.56	6.02	-8.2

Note: *% differences represent the magnitude of proximate composition differences between the ingredients and was calculated as ($PC_{DFBSFL}-PC_{FFBSFL}$) / PC_{FFBSFL} *100, where PC_i is the proximate composition in ingredient *i* as described by Cummins et al. (2017)

Table 2. Amino acids composition of commercial full-fat and defatted BSF (g/100 g dry weight basis)

Amino acid	FF BSFL	DF BSFL[a]	(%) differences
Aspartate	2.35	1.84	-21.7
Glutamine	3.21	3.12	-2.8
Serine	1.65	0.71	-57.0
Glycine	1.85	0.84	-54.6
Histidine	0.43	0.72	67.4
Arginine	1.23	0.70	-43.1
Threonine	0.77	0.82	6.5
Alanine	1.28	0.72	-43.8
Proline	1.82	0.84	-53.8
Tyrosine	0.78	0.71	-9.0
Valine	1.27	0.61	-52.0
Methionine	0.61	0.52	-14.8
Cysteine	0.74	0.62	-16.2
Isoleucine	1.18	0.88	-25.4
Leucine	2.13	1.30	-39.0
Phenylalanine	0.88	0.69	-21.6
Lysine	2.16	1.26	-41.7

Note: [a]Amino acid profile of defatted BSFL from Saputra and Fotedar (2023). *% differences represent the magnitude of amino acids concentration differences between the ingredients and was calculated as ($AA_{DFBSFL}-AA_{FFBSFL}$) / AA_{FFBSFL} *100, where AA_i is the amino acids concentration in ingredient *i* as described by Cummins et al. (2017)

Table 3. Fatty acids composition of commercial full-fat and defatted BSFL (g/100 g dry weight basis)

Fatty acids	FF BSFL	DF BSFL	(%) differences
Caprylic acid (C8:0)	ND	ND	-
Capric acid (C10:0)	ND	ND	-
Lauric acid (C12:0)	7.21	1.23	-82.9
Myristic acid (C14:0)	10.23	7.52	-26.5
Palmitic acid (C16:0)	26.45	15.23	-42.4
Stearic acid (C18:0)	4.12	1.85	-55.1
Arachidic acid (C20:4 n6)	0.23	ND	0.0
Oleic acid (C18:1 n9)	23.45	17.12	-27.0
Linoleic acid (C18:2)	34.32	26.12	-23.9
Linolenic acid (C18:3 n3)	2.12	1.05	-50.5
∑ PUFA**	2.35	1.05	-55.3
∑ MUFA*	25.57	18.17	-28.9
∑ SFA***	48.01	25.83	-46.2

Note: ND: Not Detected. *% differences represent the magnitude of fatty acids concentration differences between the ingredients and was calculated as ($FA_{DFBSFL}-FA_{FFBSFL}$) / FA_{FFBSFL} *100, where FA_i is the fatty acids concentration in ingredient *i* as described by Cummins et al. (2017)

Table 4. Mineral composition of commercial full-fat and defatted BSFL

Minerals	FF BSFL	DF BSFL	(%) differences
Ca (calcium) g/kg	37.0	57.7	55.9
Na (Natrium) g/kg	1.3	1.7	30.8
Mg (Magnesium) g/kg	4.2	6.2	47.6
Zn (Zinc) mg/kg	61.71	138.08	123.8
Fe (Iron) mg/kg	341.35	529.57	55.1
Mn (Manganese) mg/kg	90.28	128.26	42.1
Cu (Copper) mg/kg	5.61	26.6	374.2

Note: *% differences represent the magnitude of mineral concentration differences between the ingredients and was calculated as ($MN_{DFBSFL}-MN_{FFBSFL}$) / MN_{FFBSFL} *100, where MN_i is the mineral concentration in ingredient *i* as described by Cummins et al. (2017)

Discussion

The potential use of BSFL meal as a protein source in aquafeeds is demanding and therefore the evaluation of the nutrition composition of commercial BSFL meal was conducted. The nutrition composition of full-fat and defatted BSFL meal was different and in agreement with the previous reports (Cummins et al. 2017; Biasato et al. 2019; Fisher et al. 2020; Zozo et al. 2022). While the defatting process reduces the fat content, it increases the crude protein content in the BSFL meal. Zozo et al. (2022) reported that the process of defatting reduces the fat content of BSFL substantially. In comparison, the fat content of defatted BSFL was 81.11% (recalculated) lower than full-fat BSFL. It means that the process of defatting is beneficial to BSFL meal quality, particularly in terms of fat content. In contrast, that process improves the crude protein content within the BSFL meal by up to 19.6%. The defatting process yielded crude protein as much as 56.11% of total dry matter. In previous research, Biasato et al. (2019) included the defatted BSF meal as a protein resource with a crude protein content of 55.9%. The high crude protein content in those defatted BSF explains the results of the present study.

In several previous reports presented in Table 5., the crude protein content ranged between 32.1% to 48.2% and the type of BSF meal used in their experiments seems to be full-fat BSF (Devic et al. 2018; Adeoye et al. 2020; Hu et al. 2020; Rawski et al. 2020; Weththasinghe et al. 2021; Zulkifli et al. 2022). Those results indicated that the full-fat BSF meal can only have a crude protein content of as much as 50% of total dry matter without the defatting process and vice versa. Apart from improving the crude protein content, the defatting process also significantly reduced the fat content in the BSF meal. The fat or lipid content in aquafeed ingredients becomes a limiting factor for certain fish and crustaceans. The excessive lipid in aquafeed leads to suboptimal growth and increases the potential disease occurrence in fish aquaculture. While the lipid content of full-fat BSFL meal reached as much as 30% of the total dry matter (Hu et al. 2020; Rawski et al. 2020; Weththasinghe et al. 2021), the defatting process decreases the amount of fat to only 10% of total dry matter (Zozo et al. 2022). That explains the results in this study, where the fat content of the defatted BSFL meal was only 9% of total dry matter, lower than full-fat BSFL meal.

The defatting process of BSF larvae has been reported to influence the major nutritional composition (Schiavone et al. 2017; Hender et al. 2021; Zozo et al. 2022). In the present study, the amino acid content of defatted BSFL meal is constantly higher than the full-fat BSFL meal. It may be affected by the process of defatting. Various results of the amino acids analysis in BSF have been reported (Table 6 and 7). The dispensable amino acids in BSF meal where alanine was ranged between 1.3 to 7.7, aspartate1.7 to 9.3, cysteine 0.1 to 2.4, Glutamine 3.4 to 11.6, Glycine 0.2 to 3.9, proline 1.1 to 5.9, Serine 1.2 to 7.1, Tyrosine 0.8 to 5.8. It was not clear of the BSF meal type used in those studies, which make it difficult for further analysis. However, all reports agreed that glutamine has the largest portions among the dispensable amino acids in the BSF meal. Those facts are also found in tested BSFL meals in this study.

The indispensable amino acid content of both types of BSFL meal in this study also has a similar pattern to dispensable amino acids, where the composition of in defatted BSFL meal was higher than in the full-fat BSFL meal. However, the value of indispensable amino acids was lower than in previous reports (Magalhães et al. 2017; Rawski et al. 2020; Zulkifli et al. 2022). The amino acids profile of the defatted BSF meal in the present study has the closest value to the frass product from BSF reported by Yildirim-Aksoy et al. (2020). This result questioned the purity of tested commercial BSFL meal. Since the defatted BSFL was bought in the form of a meal or powder, it was difficult to assess its original form. In contrast, the full-fat BSF was in the form of oven-dried. The most possible reason for the contradicted results is the substrate of commercial BSF used in this study. That is because the substrate plays an important role in the nutrition content of harvested BSF (Spranghers et al. 2017).

The process of defatted process is expected to yield more protein than the lipid content within the BSF meal. However, the defatted BSF used in the experiment conducted by Senlin et al. (2017) and Biasato et al. (2019) seems to have a similar proportion of amino acids compared to the full-fat BSF meal (Devic et al. 2018; Lan et al. 2022; Zulkifli et al. 2022). That evidence indicated that even after the defatting process, the amino acids of the BSF meal may still have a similar profile. In contrast, Schiavone et al. (2017) reported the amino acid content changes in the BSF after the defatting process. In their work, the high-defatted BSF resulted in a higher amino acid content than partially defatted BSF which confirms the results of the present study.

In aquafeeds, the sufficient availability of lipids or fat is essential in providing balanced nutritional requirements for the cultured species. More than just the lipid, the composition of fatty acids in it is important. With the appropriate amount, the BSF meal is known as a good source of lipids for fish (Xu et al. 2020). There is not many research analyzing the fatty acids composition in BSFL meal, because the fatty acids composition in the is highly varies depending on the age of BSF larvae (Ewald et al. 2020), substrate (Ewald et al. 2020; Lan et al. 2022) and also the processing type (Hender et al. 2021). Several fatty acids analysis of BSF is presented in Table 8. Hender et al. (2021) reported that the defatting process of BSFL improves the crude protein content per kg of dry matter. On the contrary, the composition of the fatty acid contents in the partially defatted BSFL meal decreased after the defatting process. A similar result was also obtained in this study where the fatty acids of full-fat BSFL meal are higher than the defatted BSFL meal. The decrease of total crude lipid is positively correlated with the reduction of fatty acid content. Thus, the method of defatting process can be considered according to the desired final nutritional contents. For instance, a partial defatting process can be applied in order to achieve moderate fat content and a highly defatting process is used for high lipid removal from the BSFL.

In addition, both BSFL meal types tested have a rich composition of palmitic acid (C16:0), oleic acid (C18:1) and linoleic acid (C18:2) and close to the BSFL meal tested (Lan et al. 2022; Zulkifli et al. 2022). Since the substrate of commercial BSF larvae in this study is unknown, the similar pattern of fatty acids composition may explain that situation. While Lan et al. (2022) used tofu as substrate, Zulkifli et al. (2022) used agro-industry waste in growing the BSF larvae, which resulted in the comparable fatty acids aforementioned.

Minerals are important chemical compounds that are required by animals, including fish, to support optimal growth. Among several minerals, calcium is known as the most abundant mineral found in animal bodies. In this study, the quantities of calcium, natrium/sodium and magnesium were larger than other minerals and in agreement with previous reports (Spranghers et al. 2017; Biasato et al. 2019; Fisher et al. 2020; Zulkifli et al. 2022). Those mineral compounds are known as major elements. The calcium carbonate in the exoskeleton is responsible for the high calcium constituted in BSFL. In addition, a small amount of zinc, iron, and manganese was also found in BSFL meal, with copper having the least amount. The minerals substances tested in commercially defatted BSF in this study were higher than in the full-fat BSF. Thus, the defatting process might improve the availability of minerals in BSFL. A similar finding was also reported by Zozo et al. (2022) except for natrium composition. In their report, the natrium composition of defatted BSF was lower than the natrium in the whole BSF after the defatting process. That anomaly only occurs in natrium substances and is possibly caused by the mineral bound to the fat component during the defatting (Zozo et al. 2022). The defatting process should increase the availability of mineral composition which is in line with the increase of ash. That is because mineral is one of the constituents of ash content. In this study, the nutritional composition of the defatted BSF increased following the defatting process. The calcium composition was almost doubled than previous reports in Table 9 (Spranghers et al. 2017; Biasato et al. 2019; Boykin et al. 2020; Zulkifli et al. 2022). The calcium composition of full fat and defatted BSF in this study was 37.1 g/Kg and 57.7 g/Kg, respectively. The most possible reason behind the results might be associated with the fact that apart from the defatting process, the origin of the BSF substrate also has a high impact on its nutritional composition.

Table 5. Proximate composition of several types of BSF meal (g/100 g of dry matter basis)

Proximate composition						References
Protein	**Lipid**	**Fibre**	**Moisture**	**Ash**	**NFE**	
48.2	25.7	9.9	7.1	8.3	7.9	Zulkifli et al. (2022) ¶
32.1	32.2	NA	8.5	13	NA	Hu et al. (2020) ¶
42.0	32.0	NA	NA	9.25	NA	Weththasinghe et al. (2021) ¶
56.0	11.8	NA	NA	NA	NA	Fisher et al. (2020) *
41.6	23.2	7.6	NA	11.6	10.8	Devic et al. (2018) ¶
52.0	15.1	NA	10	7.3	NA	Cummins et al. (2017) *
42.6	23.0	10.8	8.2	10.5	4.9	Adeoye et al. (2020) ¶
35.0	29.8	7.9	NA	5.3	22.1	Rawski et al. (2020) ¶
55.9	8.5*	NA	NA	7.6	NA	Biasato et al. (2019) †
45.8	25.8	NA	4.4	NA	NA	Zozo et al. (2022) ¶
56.1	4.8	NA	6.5	NA	NA	Zozo et al. (2022) †

Note: †: Defatted BSFL meal, ¶: Full-fat BSFL meal, *: Most likely defatted BSFL meal, NA: Data are not available

Table 6. The indispensable amino acid compositions of several types of BSF meal (g/100 g of dry matter basis)

Indispensable amino acids										References
Arg	**His**	**Iso**	**Leu**	**Lys**	**Met**	**Phe**	**Thr**	**Try**	**Val**	
1.3	1.7	2.4	3.4	3.9	1.1	2.1	1.8	0.9	2.9	Adeoye et al. (2020) ¶
1.0	1.5	0.6	1.2	0.8	1.5	1.2	1.1	1.3	0.5	Yildirim-Aksoy et al. (2020) ¶¶
2.5	2.8	2.4	3.6	3.6	1.1	2.1	1.9	3.1	3.1	Zulkifli et al. (2022) ¶
2.0	1.4	1.7	2.9	2.3	0.7	1.7	1.6	0.6	2.4	Spranghers et al. (2017) ¶
2.3	1.5	1.9	3.2	2.7	0.6	1.6	1.7	0.5	2.6	Cummins et al. (2017) *
2.0	1.2	2.7	2.9	2.7	0.7	1.7	1.7	NA	2.6	Devic et al. (2018) ¶
3.0	1.9	2.2	4.2	3.8	1.2	2.3	2.4	0.9	3.7	Fisher et al. (2020) *
2.5	3.1	3.0	1.4	2.6	0.7	0.7	2.0	3.5	2.2	Biasato et al. (2019) †
2.4	0.9	2.2	3.5	3.6	2.1	1.7	2.5	NA	3.9	Lan et al. (2022) ¶
2.6	1.6	2.2	3.6	3.7	1.2	2.3	2.2	NA	3.7	Senlin et al. (2017) †
5.0	3.0	4.9	7.2	4.8	1.9	3.9	4.6	NA	5.9	Magalhães et al. (2017) ¶
5.4	3.2	4.7	7.8	6.8	2.1	7.7	4.4	NA	6.7	Rawski et al. (2020) ¶
1.6	0.8	1.5	2.9	2.1	0.6	1.5	1.3	0.7	1.9	Weththasinghe et al. (2021) ¶
2.2	1.2	1.9	2.9	2.1	6.5	1.7	1.7	NA	2.7	Schiavone et al. (2017)†
2.7	1.6	2.4	3.7	2.5	8.7	2.2	2.2	NA	3.5	Schiavone et al. (2017) ††

Note: †: Defatted BSFL meal, ††: Highly defatted BSFL, ¶: Full-fat BSFL meal, ¶¶: BSF frass, *: Most likely defatted BSFL meal, NA: Data are not available

Table 7. The dispensable amino acid compositions of several types of BSF meal (g/100 g of dry matter basis)

Dispensable amino acids								References
Ala	**Asp**	**Cys**	**Glu**	**Gly**	**Pro**	**Ser**	**Tyr**	
3.9	4.6	2.4	5.6	2.6	2.8	2.2	4.3	deoye et al. (2020) ¶
3.1	5.1	0.2	6.1	0.2	2.9	2.1	3.1	ulkifli et al. (2022) ¶
2.5	3.7	0.3	4.2	2.3	2.3	1.7	NA	pranghers et al. (2017) ¶
3.7	NA	0.8	6.4	3.5	3.4	2.4	3.8	isher et al. (2020) *
2.4	4.5	0.5	6.8	2.4	3.1	2.2	NA	an et al. (2022) ¶
3.3	5.3	NA	5.6	2.6	NA	2.0	3.4	enlin et al. (2017) ¶
7.7	9.3	2.4	11.6	5.1	5.9	7.1	5.8	Iagalhães et al. (2017) ¶
2.4	3.2	0.2	4.2	1.5	1.9	1.2	1.8	/eththasinghe et al. (2021) ¶
3.6	3.7	0.1	4.9	2.4	3.1	2.0	2.6	chiavone et al. (2017) †
4.4	4.9	0.2	6.4	3.0	3.3	2.7	3.4	chiavone et al. (2017) ††

Note: †: defatted BSFL meal, ††: highly defatted BSFL, ¶: full-fat BSFL meal, ¶¶: BSF frass, *: Most likely defatted BSFL meal, NA: data are not available

Table 8. The fatty acid compositions of several types of BSF meal (g/100 g of dry matter basis)

Fatty acid	References									
	(1a)	**(1b)**	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
C12:0	53.8	47.3	17.8	21	36.4	45.9	57.3	19.5	14.7	34.5
C14:0	8.9	8.6	5.2	3.7	6.8	8.7	7.3	4.5	3.1	39.9
C16:0	20.5	14.1	20.6	5.3	15.4	12.2	9.6	21.0	19.4	16.3
C16:1 n7	6.2	4.4	1.7	1.6	2.4	1.9	1.9	2.5	3.5	2.6
C18:0	4.6	3.1	2.9	0.8	1.4	2.5	1.4	3.9	4.1	2.1
C18:1 n7	NA	NA	ND	6.1	0.6	ND	2.4	24.0	21.7	0.4
C18:2 n6	0.1	ND	24.8	3.8	11	14.1	11.5	19.6	28.6	9.9
C18:3 n6	0.2	0.1	ND	0.5	0	1.6	0.7	1.1	1.9	NA
C20:0	0.1	ND	ND	<0.1	0.1	0.1	0	0.2	0.3	NA
C20:2	NA	NA	ND	0.1	ND	ND	ND	NA	0.4	NA

Note: 1. Hender et al. (2021), 2. Zulkifli et al. (2022), 3. Rawski et al. (2020), 4. Rabani et al. (2019), 5. Daszkiewicz et al. (2022), 6. Spranghers et al. (2017), 7. Chen et al. (2021), 8. Lan et al. (2022), 9. Schiavone et al. (2017). NA: Data are not available, ND: Not Detected

Table 9. Mineral composition of several BSFL

Minerals	References					
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Ca (g/kg)	8.2	16.0	28.7	21.4	18.5	26.5
Na (g/kg)	1.1	8.0	0.7	1.3	-	5.2
Mg (g/kg)	4.5	2.0	2.7	3.9	2.8	3.3
Zn (mg/kg)	172.0	22.5	160.0*	131.0	110.0*	303.07
Fe (mg/kg)	154.0	-	350.0*	204.0	150.0*	300.7
Mn (mg/kg)	203.0	185.1	220.0*	232.0	120.0*	140.1
Cu (mg/kg)	-	7.8	10.0*	11.2	-	13.7

Note: 1. Biasato et al. (2019), 2. Fisher et al. (2020), 3. Spranghers et al. (2017), 4. Boykin et al. (2020), 5. Campbell et al. (2020), 6. Zulkifli et al. (2022). *: Values are converted from the original data, -: Data is not available

In conclusion, the present study indicated that the nutritional value, including proximate composition, amino acids, fatty acids, and minerals of commercial full-fat and defatted BSFL meal meet the requirement for aquafeeds. In addition, our findings showed that the nutritional value of BSF meal is influenced by the processing type. The original full-fat BSFL meal has a low protein content and a high fat level, while the defatted BSFL meal has a high protein content and low fat content. The results can be used as valuable information in improving our knowledge of the exploitation of BSF meal and their suitability for specific aquatic species.

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