UMT PRESS

Planetary Sustainability
Journal Homepage: https://journal.umt.edu.my/index.php/planetsust/
eISSN: 3009-0105
DOI: http://doi.org/10.46754/ps.2025.07.004

GROWTH, REPRODUCTION AND PIGMENTATION PERFORMANCES OF RED CHERRY SHRIMP (*Neocaridina davidi*) FED WITH BLACK SOLDIER FLY LARVAE (*Hermetia illucens*) MEAL

MOHD HAFIZI AZHAR[1], SHARIFAH RAHMAH[1], MOHAMAD JALILAH[2], SUHAIRI MAZELAN[2], JASSIM ABDULLA AL-KHAYAT[3], PONNUMONY VETHAMONY[3], VICTOR TORRES ROSAS[3], WEE KONG VIC-PUI[4] AND LIEW HON JUNG[2,5]*

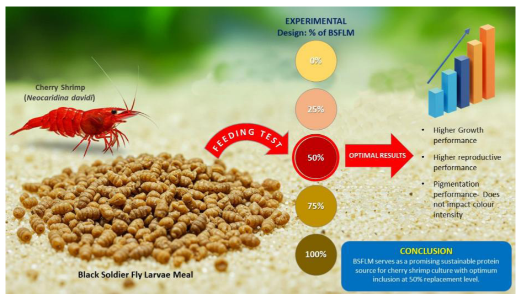
[1]Faculty of Fisheries and Food Science, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [2]Higher Institution Center of Excellence, Institute of Tropical Aquaculture and Fisheries, Universiti Malaysia Terengganu, 21030 Kuala Nerus, Terengganu, Malaysia. [3]Environmental Science Center, Qatar University, Doha, Qatar, [4]Entomal Biotech Sdn. Bhd., 57000 Kuala Lumpur, Malaysia. [5]Heilongjiang River Fisheries Research Institute, Chinese Academy of Fishery Sciences, Harbin, China.

**Corresponding author: honjung@umt.edu.my*

HIGHLIGHTS

- BSFLM inclusion level at 50% shown an improvement of overall growth performances.
- BSFLM also improved reproductive performances.
- BSFLM is a promising alternative protein source for cherry shrimp culture.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article History:
Received: 22 May 2025
Revised: 17 June 2025
Accepted: 17 June 2025
Published: 15 July 2025

Keywords:
Alternative protein, aquaculture sustainability, ornamental aquarium, dietary inclusion, crustacean nutrition.

ABSTRACT

The increasing demand of cherry shrimp (*Neocaridina davidi*) is driven by their vibrant colouration, making it a popular pet in aquariums. Nevertheless, the efficacy of using insect protein as an alternative to stimulate growth and reproductive performances in cherry shrimps remains unknown. Therefore, this study is designed to investigate the effects of using Black Soldier Fly Larvae Meal (BSFLM) on the growth, reproductive and pigmentation performances of cherry shrimps. Five iso-nitrogenous diets (42% protein) with varying BSFLM inclusion levels (0%, 25%, 50%, 75% and 100%) were formulated. The results showed that growth performance, including length gain, weight gain, specific growth rate and moulting rate were improved significantly at 50% BSFLM inclusion, which could be attributed to an optimal balance of nutrients and protein digestibility. Reproductive performances including ovary development and larvae production remained stable across all diets, demonstrating the robustness of BSFLM for reproductive performance. Similarly, pigmentation was also unaffected. This study highlights BSFLM as potential sustainable protein source for cherry shrimp culture.

Introduction

The ornamental aquarium industry has experienced significant growth in recent years, with cherry shrimps (*Neocaridina davidi*) emerging as a popular pet among enthusiasts due to their vibrant colouration. Originally found in diverse inland water habitats across Asia, these small freshwater crustaceans, measuring 15 mm to 30 mm in length (João *et al*., 2015), have gained market value ranging from RM2 to RM200 depending on grade, colour, size and lineage (Wong, 2022). The red morph, commonly known as red cherry shrimp, is particularly prized, though various colour morphs exist like orange, yellow, green, blue and stripped (Suen *et al*., 2020).

Diet plays a crucial role in maintaining the vibrant colouration of cherry shrimps (Lupton, 2020; Sussman, 2021), as well as both ecological and physiological adaptations influenced by temperature, photoperiod, background substrate, light intensity and dietary carotenoid content (Tomas *et al*., 2019). The reproductive biology of cherry shrimps is characterised as “direct development”, with females carrying fertilised eggs (21 to 51 per clutch) in a brood pouch for 25 to 35 days before releasing the hatched juveniles called “shrimplets” (Weber *et al*., 2016; Michael, 2019). Sexual dimorphism is evident, with females displaying a wider, more rounded abdomen compared to the narrower, streamlined abdomen of males (Michael, 2019).

The growing popularity of ornamental shrimp has prompted research into sustainable and cost-effective feed alternatives. Black Soldier Fly Larvae (BSFL) (*Hermetia illucens*) have emerged as a promising sustainable protein source for aquaculture applications (Linh *et al*., 2024). This globally distributed insect species, found across Asia, Europe and south eastern United States (Marshall *et al*., 2015). Its larvae consumes a wide range of organic matter, including rotting fruits, vegetable scraps, animal waste and municipal organic waste (Liu *et al*., 2017). Their life cycle progresses through five main stages: Egg, larva, pre-pupa, pupa and adult (Maglangit *et al*., 2021).

BSFL offers significant nutritional benefits, containing approximately 40-55% protein and 9-30% lipid (Seyedalmoosavi *et al*., 2022), making it comparable or even superior to traditional protein sources like fishmeal. Studies have shown that BSFL meal can enhance growth performance, intestinal health and immunity in various aquatic species (Verma, 2023). Additionally, BSFL production represents a sustainable approach by converting organic waste into high-value biomass, potentially reducing the environmental impact and cost of aquaculture feeds (Kim *et al*., 2021).

Previous research have explored BSFL application in commercially important aquaculture species, such as Pacific white-leg shrimp (*Litopenaeus vannamei*) (Cummins *et al*., 2017; Usman *et al*., 2021), juvenile lobster (*Panulirus ornatus*) (Saputra *et al*., 2023) and various fish species including goldfish

(*Carassius auratus*) (Khieokhajonkhet *et al*., 2022), juvenile Jian carp (*Cyprinus carpio*) (Li *et al*., 2017) and discus (*Symphysodon sp.)* (Tu *et al*., 2022). These studies have generally shown positive outcomes with BSFL inclusion levels ranging from 20% to 75%, with optimal performance typically observed at around 50% replacement of fishmeal.

Despite extensive research on BSFL applications in various aquaculture species, there is a notable gap in knowledge regarding its effects on ornamental shrimp, particularly the cherry shrimp. While similar studies have been conducted on other crustaceans, such as Pacific white-leg shrimp (Chen *et al*., 2023) and giant freshwater prawn (*Macrobrachium rosenbergii*) (Zarantoniello *et al*., 2023), as well as ornamental fish like zebrafish (*Danio rerio*) (Chemello *et al*., 2021), the specific impacts of BSFL on growth, reproduction and pigmentation, particularly, in cherry shrimps remain unexplored.

This study aims to address this research gap by investigating the effects of black soldier fly larvae meal (BSFLM) on the growth, reproduction and pigmentation of cherry shrimps. This research seeks to determine the optimal BSFLM incorporation rate for cherry shrimp culture and evaluate its potential as a sustainable alternative protein source for the ornamental aquaculture industry.

Materials and Methods

Source of Specimen and Management

A total of 50 adult cherry shrimps measuring 1.5 cm to 1.8 cm were sourced from the Institute of Tropical Aquaculture Hatchery, University Malaysia Terengganu (AKUATROP, UMT). The cherry shrimps were divided randomly into 25 experimental aquariums with a capacity of 3 L. Two shrimps were housed in one aquarium, with Java moss provided to create a secure environment for the shrimps. Feeding was done twice a day at 9 a.m. to 10 a.m., and in the evening at 5 p.m. to 6 p.m., to satiation with a predetermined quantity of food. Water parameters such as pH, temperature, ammonia, nitrite and nitrate levels in each tank were checked daily between 9 a.m. and 10 a.m., Water exchange was done every three days by 20% and once a week by 50%. The project duration was two months.

Experimental Diet Formulation and Development

The proximate analysis process for BSFL meal was done to identify the nutritional content. The proximate analysis was carried out according to AOAC Standard Method (AOAC, 2000) for moisture, ash, lipid and protein. There were five iso-nitrogenous experimental diets (42% of protein) which served as a control (Diet 1); 25% BSFLM (Diet 2); 50% BSFLM (Diet 3); 75% BSFLM (Diet 4); and 100% BSFLM (Diet 5). The composition of the experimental diets is shown in Table 1, while the proximate composition is shown in Table 2.

Table 1: Composition of experimental diets based on 100 g per volume content.

Ingredients	Experimental Diets				
	Control (Diet 1)	**25% (Diet 2)**	**50% (Diet 3)**	**75% (Diet 4)**	**100% (Diet 5)**
FM	33.96	25.55	17.09	8.58	0
BSFLM	0	10.8	21.68	32.62	43.64
Wheat gluten meal	10	10	10	10	10
Soybean meal	17	17	17	17	17
Corn meal	14	13	12	11	10
Fish oil	1.8	1.3	0.9	0.4	0
Wheat flour	10	10	10	10	10
Soy lecithin	1	1	1	1	1
Squid oil	2	2	2	2	2
Spirulina	0.5	0.5	0.5	0.5	0.5
Choline chloride	0.5	0.5	0.5	0.5	0.5
Mineral premix	1	1	1	1	1
Vitamin premix	2	2	2	2	2
Vitamin C	1	1	1	1	1
Vitamin E	0.1	0.1	0.1	0.1	0.1
Yeast concentrate	0.1	0.1	0.1	0.1	0.1
Astaxanthin	0.05	0.05	0.05	0.05	0.05
Cellulose	4.99	4.1	3.08	2.15	1.11
Total (%)	**100**	**100**	**100**	**100**	**100**

Table 2: Proximate composition of the experimental diets (Control, 25%, 50%, 75% and 100% BSFLM)

Parameter	Proximate Analysis				
	Control (Diet 1)	**25% (Diet 2)**	**50% (Diet 3)**	**75% (Diet 4)**	**100% (Diet 5)**
Protein (%)	41.33 ± 1.04	42.03 ± 0.34	42.01 ± 0.34	41.65 ± 0.71	41.28 ± 0.46
Lipid (%)	9.09 ± 0.04	9.26 ± 0.34	8.98 ± 0.65	7.36 ± 0.43	7.02 ± 1.61
Moisture (%)	4.75 ± 0.09	4.88 ± 0.06	5.14 ± 0.15	4.75 ± 0.22	4.83 ± 0.08
Ash (%)	8.34 ± 0.04	8.05 ± 0.02	7.87 ± 0.03	7.45 ± 0.03	6.70 ± 0.03

All dietary ingredients were added and mixed thoroughly with a feed binder, and water was added to pelletiser for final mixing to produce proper feed dough. The dough was pelletised with a customised heavy-duty meat grinder with 0.5 mm die size and dried in the oven at 60°C for 12 hours.

Experimental Design

A total of 50 red cherry shrimps (25 males and 25 females) were distributed randomly into 25 experimental aquariums with two shrimps of the opposite sex in each aquarium. The experimental replication arrangement was designed according to completely randomise distribution. The experiment tanks set up is illustrated in Figure 1 and 2.

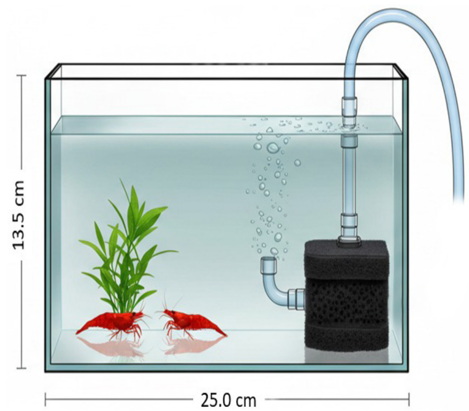


Figure 1: Aquarium design for each replicate

Figure 2: The experimental design arrangement of replicates in the Institute of Tropical Aquaculture Hatchery, UMT

Growth and Reproduction Determination

Growth and reproductive performances cherry shrimps were calculated based on the equations below:

$$\text{Survival Rate (\%)} = \frac{\text{(Initial no. shrimp} - \text{No of mortality shrimp)}}{\text{Total number of shrimp}} \times 100\%$$

(Chowdhury *et al*., 2020)

$$\text{Feed intake} = \frac{\text{Feed given} - \text{Remaining feed}}{\text{Number of cherry shrimp}}$$

(Suyitman *et al*., 2020)

$$\text{Length gain (cm)} = \text{Final legth (cm)} - \text{Initial length (cm)}$$

(Mengumphan *et al*., 2015)

$$\text{Weight gain (g)} = \text{Final weight (g)} - \text{Initial weight (g)}$$

(Hassan *et al*., 2021)

$$\text{Specific Growth Rate (\%)} = \frac{\text{(In final average weight} - \text{In initial average weight)}}{\text{Experimental days}} \times 100\%$$

(Chowdhury *et al*., 2020)

$$\text{Moulting frequency (\%)} = \frac{\text{Number of cherry shrimp moults}}{\text{Initial number of cherry shrimp}} \times 100\%$$

(Zhou *et al*., 2023)

$$\text{Ovary size (cm)} = \text{Length of ovary} \times \text{Wide of ovary}$$

(Usha & Sandya, 2013)

$$\text{Number of larvae} = \frac{\text{Average larvae count in (10ml)}}{\text{beaker (10ml)}} \times \text{water volume (ml)}$$

(Zhou *et al*., 2023)

Pigmentation Analysis

A comprehensive pigmentation analysis was conducted at the beginning and end of the experiment. High-resolution images of the shrimp were captured using a digital camera under standardised lighting conditions to ensure consistency in visual comparison. In addition, a Konica Minolta CR-400 colorimeter was used to quantitatively assess coloration. The colour measurements were recorded using the CIE Lab* system, focusing on the a* (red-green) and b* (yellow-blue) values, which are indicative of pigmentation intensity. The RGB values obtained were converted to Lab* values for analysis (Nhan *et al*., 2019).

$$\text{Colour intensity} = \sqrt{(a*)^2 + (b*)^2}$$

(Nhan *et al*., 2019)

Data Analysis

All the data collected including moulting frequency, Specific Growth Rate (SGR), Survival Rate (SR), length gain (cm), weight gain (g), survival rate (%), feed intake, moulting rate, ovary size (cm), number of larvae and pigmentation performance (colour intensity) among the different dietary groups were assessed using one-way ANOVA. Prior to the analysis, the Shapiro-Wilk test was performed to ensure that the data followed a normal distribution. I If necessary, the data would be subjected to log[10] transformation to achieve a normal distribution. If the one-way ANOVA revealed significant differences, the Tukey's post-hoc test was conducted to identify which specific differences existed among treatment groups (Frost, 2019). This approach was also used for the analysis of pigmentation performance, in which a* and b* values obtained from colorimetric measurements served as the dependent variables. All significant confident limit was set at 95% ($p < 0.05$).

Results

Feeding and Growth Performance

Table 3 presents the feed intake across five experimental diets (Control, 25%, 50%, 75%, and 100% BSFLM), revealing that diets 1, 2, and 3 (Control, 25% and 50% BSFLM) had the highest feed intakes, which were significantly higher compared with Diet 5 (100% BSFLM), which had the lowest feed intake ($p < 0.05$). Survival rates remained insignificant among the diets, although lowest survival rate was noted in 100% BSFL ($p > 0.05$). In term of growth performances, the highest length gain (0.30 cm ± 0.03 cm) and weight gain (0.11 g ± 0.01 g) was found in 50% BSFLM diet, whereas the lowest was found in 100% ($p < 0.05$). Similarly, highest SGR was found in 50% BSFLM (0.58% ± 0.13) and the lowest was observed in the 100% (0.35% ± 0.08). Nevertheless, higher moulting rates were observed in cherry shrimps fed with Control diet, 25% and 50% BSFLM diets at 7.0% ± 0.18, 7.0% ± 0.15 and 7.6% ± 0.20, respectively, and lowest at 100% (4.8% ± 0.23) ($p < 0.05$).

Table 3: Feeding and growth performances of cherry shrimp, *Neocaridina davidi* fed with the five experimental diets (one control, four BSFLM) for 60 days

Parameter	Experiment Diets				
	Control (Diet 1)	**25% (Diet 2)**	**50% (Diet 3)**	**75% (Diet 4)**	**100% (Diet 5)**
Feed intake (g)	3.13 ± 0.11^{b}	3.06 ± 0.25^{b}	3.23 ± 0.14^{b}	2.72 ± 0.08^{ab}	2.49 ± 0.11^{a}
Survival rate (%)	80.0 ± 0.16	90.0 ± 0.08	90.0 ± 0.08	80.0 ± 0.16	70.0 ± 0.15
Length gain (cm)	0.27 ± 0.02^{ab}	0.23 ± 0.02^{ab}	0.30 ± 0.03^{b}	0.19 ± 0.02^{a}	0.18 ± 0.01^{a}
Weight gain (g)	0.10 ± 0.01^{ab}	0.10 ± 0.01^{ab}	0.11 ± 0.01^{b}	0.07 ± 0.01^{a}	0.06 ± 0.00^{a}
SGR (%)	0.53 ± 0.17^{ab}	0.53 ± 0.15^{ab}	0.58 ± 0.13^{b}	0.37 ± 0.15^{a}	0.35 ± 0.08^{a}
Moulting rate (%)	7.0 ± 0.18^{b}	7.0 ± 0.15^{b}	7.6 ± 0.20^{b}	6.2 ± 0.23^{ab}	4.8 ± 0.23^{a}

Reproductive Performance

Table 4 shows the effects of BSFLM inclusion levels on ovary development and larvae production of cherry shrimps. Ovary development remained stable among experimental diets with no significant differences compared with control diet ($p > 0.05$). Similarly, larvae production of cherry shrimps fed with different BSFLM inclusion levels were not significantly different ($p > 0.05$), where cherry shrimps produced about 22-27 larvae, peaking at 50% BSFLM (27.6 ± 3.97), followed closely by control (26.0 ± 2.06) and 25% BSFLM (25.4 ± 2.56). Ovary development of male and female cherry shrimp fed the five experimental diets for 60 days is shown in Figures 3 and 4.

Table 4: Reproductive performances of cherry shrimp, *Neocaridina davidi* fed the five experimental diets (one control, four BSFLM) for 60 days

Parameter	Experiment Diets				
	Control (Diet 1)	**25% (Diet 2)**	**50% (Diet 3)**	**75% (Diet 4)**	**100% (Diet 5)**
Ovary development (cm)	0.032 ± 0.01	0.031 ± 0.01	0.033 ± 0.02	0.027 ± 0.01	0.028 ± 0.01
Number of larvae	26.00 ± 2.06	25.40 ± 2.56	27.60 ± 3.97	24.25 ± 2.58	22.00± 2.05

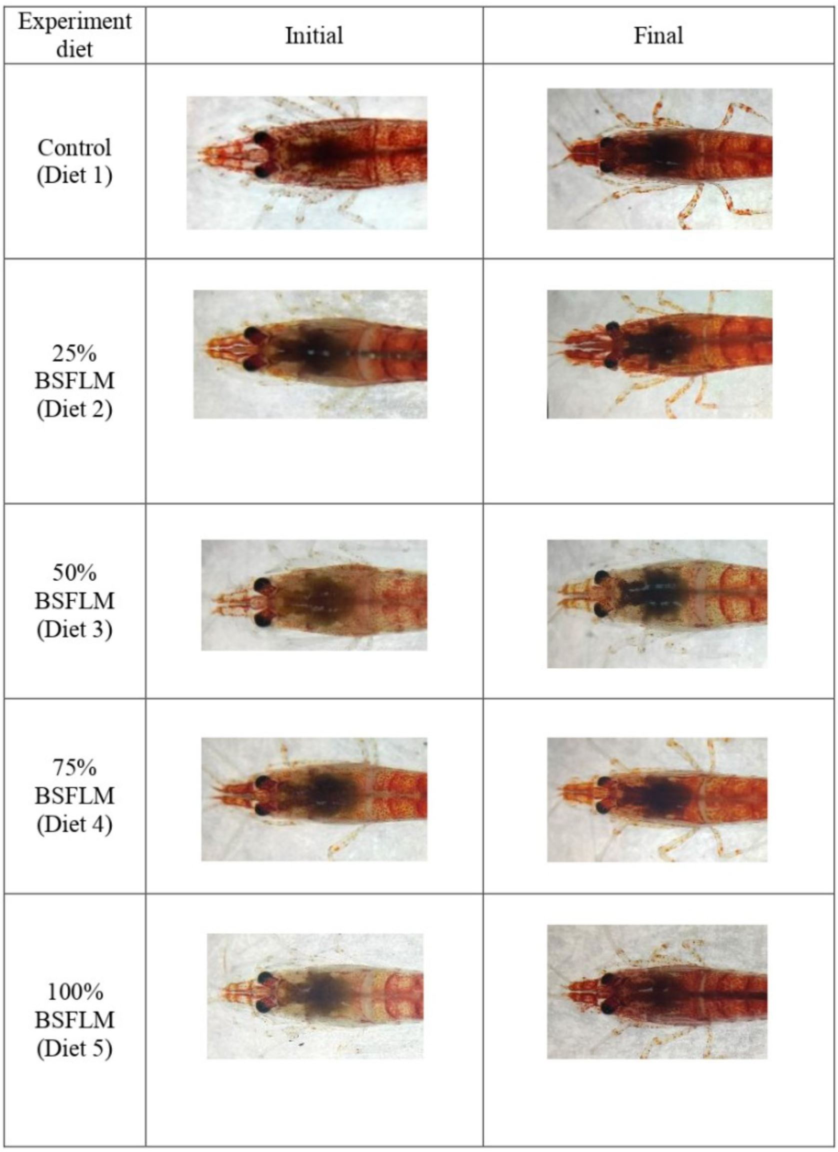


Figure 3: Ovary development of male cherry shrimps, *Neocaridina davidi* fed the five experimental diets for 60 days

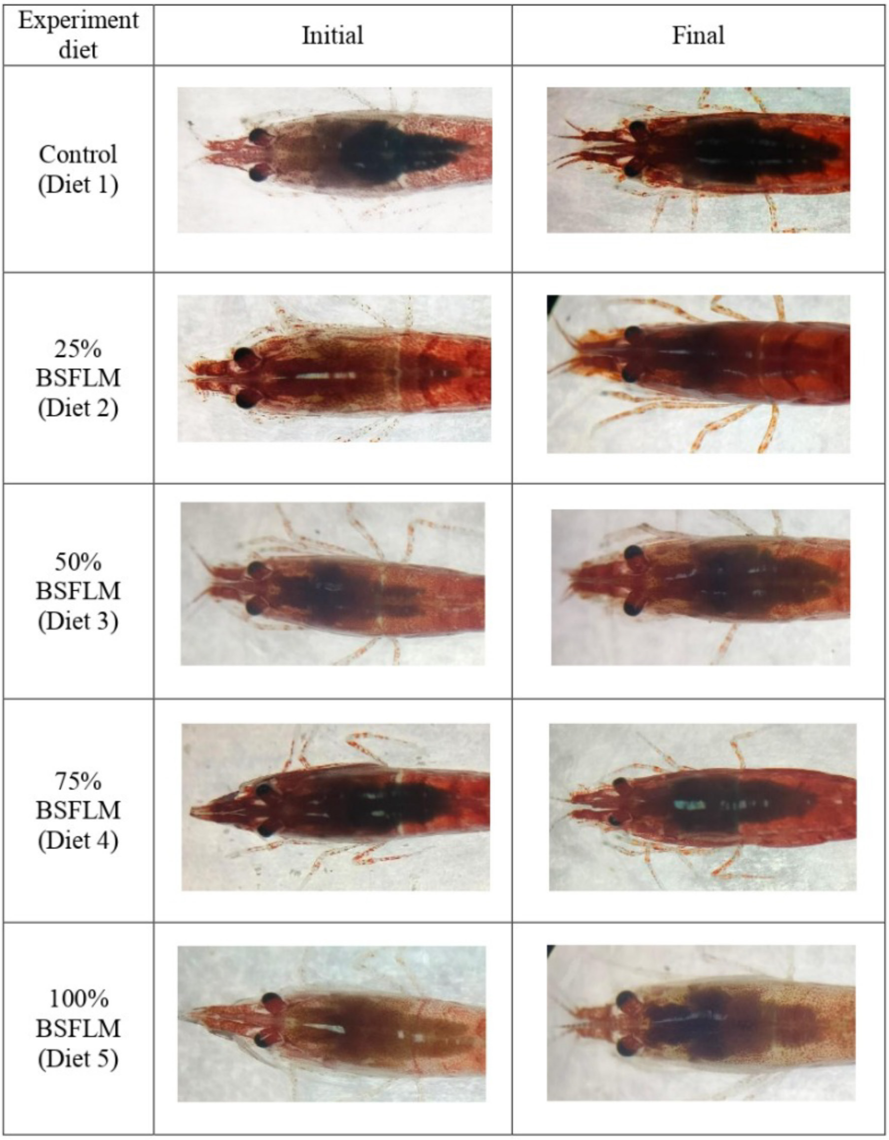


Figure 4: Ovary development of female cherry shrimps, *Neocaridina davidi* fed the five experimental diets for 60 days

Pigmentation Performance

Table 5 shows the effects of different BSFLM inclusion levels (25%, 50%, 75% and 100%) on colour intensity compared to a control diet. The mean colour intensity values obtained from all experiment diets groups was not significantly different ($p > 0.05$), which ranging from 43.34 ± 11.68 to 50.84 ± 13.33. This indicates that incorporating BSFLM into diets did not impact colour intensity. Colour intensity of male and female cherry shrimp fed the five experimental diets for 60 days is shown in Figures 5 and 6, respectively.

Table 5: Colour intensity of cherry shrimps, *Neocaridina davidi* fed the five experimental diets (one control, four BSFLM) for 60 days

Parameter	**Experiment Diets**				
	Control (Diet 1)	**25% (Diet 2)**	**50% (Diet 3)**	**75% (Diet 4)**	**100% (Diet 5)**
Colour intensity	50.84 ± 13.33	43.34 ± 11.68	49.57 ± 8.68	47.04 ± 12.66	48.41 ± 14.25

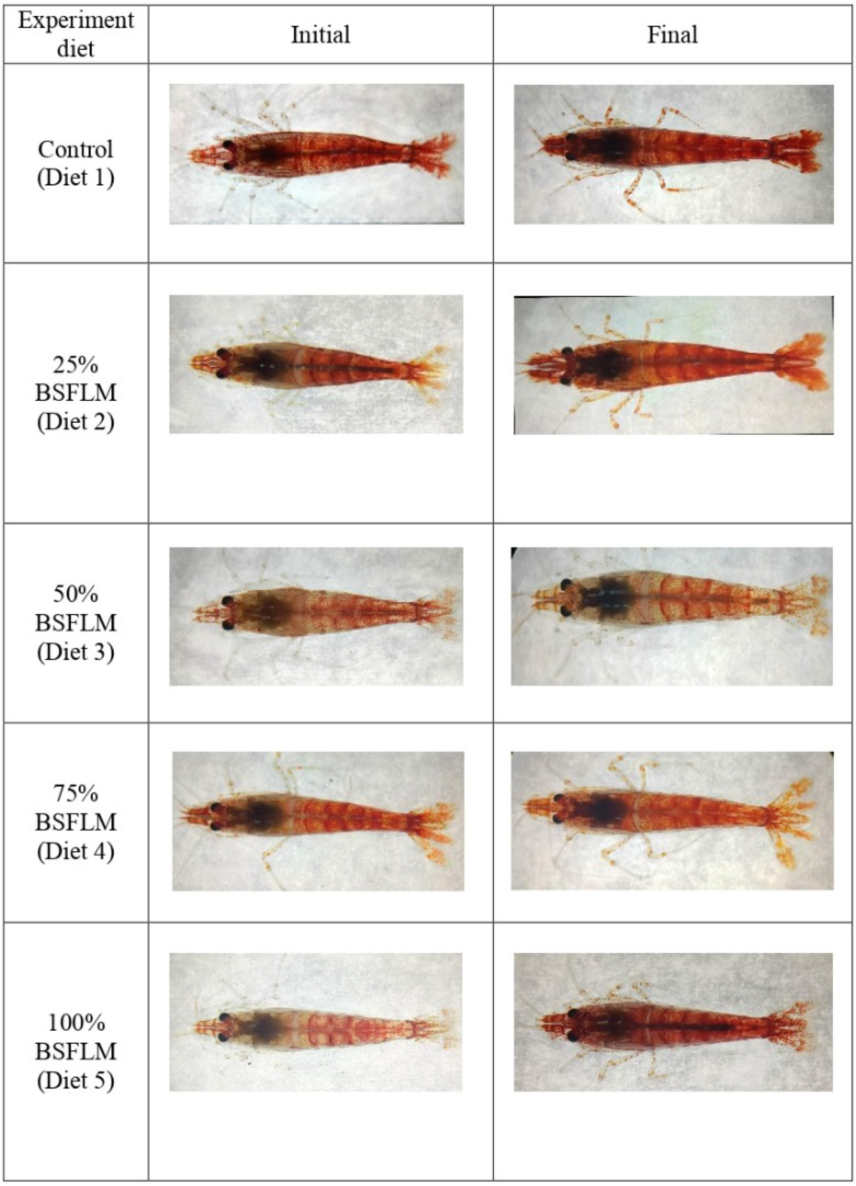


Figure 5: Colour intensity of male cherry shrimps, *Neocaridina davidi* fed the five experimental diets for 60 days

Experiment diet	Initial	Final
Control (Diet 1)		
25% BSFLM (Diet 2)		
50% BSFLM (Diet 3)		
75% BSFLM (Diet 4)		
100% BSFLM (Diet 5)		

Figure 6: Colour intensity of female cherry shrimps *Neocaridina davidi* fed the five experimental diets for 60 days

Discussion

Feeding and Growth Performances

The palatability of feed is an important factor of consideration when formulating diets for aquaculture species coupled with well-enriched and balance nutritional (Tantikitti, 2014). In this study, the palatability of dietary BSFLM was clearly demonstrated with an increase in feed intake of cherry shrimps for all BSFLM inclusion diets, although low consumption rate was noted for diet 4 and diet 5 (75% BSFLM and 100% BSFLM). These results proved the potential of using BSFLM as an insect protein meal for cherry shrimp culture. They were also in line with a study on Pacific white shrimps (Chang *et al*., 2024), where the shrimps were able to consume BSFL diets up to 75% as the optimum inclusion rate (Ling *et al*., 2024).

However, this study found that the highest feed intake were observed in 25%, and 50% BSFLM diets, which suggested that these levels provided an optimal balance of palatability and nutrient composition for cherry shrimps. This aligned with a previous study that demonstrated the efficacy of partial BSFLM substitution in aquatic feeds was due to its high digestible protein and lipid contents (Henry *et al*., 2015). The reduced feed intake in diets with higher BSFLM levels (75% and 100%) could be attributed to the indigestible chitin components that negatively affected feed acceptability (Fonseca *et al*., 2017). The highest growth performances such as length gain, weight gain and SGR of cherry shrimp was noted in shrimps fed with 50% BSFLM, this high growth performance was proven with high moulting rate shown that nutrition intake from BSFLM diet was sufficient to support all growth metabolism.

These findings were in parallel with other previous findings and emphasised BSFLM as a protein-rich digestible meal to be used for commercial feed ingredients (Henry *et al.* 2015; Fonseca *et al.* 2017). The decline in growth performance observed at higher BSFLM inclusion levels (75% and 100%) could also be attributed of nutrient imbalances. Although BSFLM is rich in protein and other essential nutrients, but it might lack certain amino acids, such as methionine and lysine, that are important for growth and tissue development in shrimp (Zhou *et al.* 2018), and this might impair protein synthesis, leading to stunted growth (Hu *et al.* 2023). Thus, depleted feed intake could be caused by lower palatability at higher BSFLM inclusion levels (Lock *et al.*, 2015).

Reproductive Performance

Both ovary development and the number of larvae produced by cherry shrimps remained stable in all dietary treatments irrespective of BSFLM inclusion levels. The ovary sizes were recorded ranging from 0.027 cm to 0.033 cm, and the number of larvae produced was between 22 and 27. BSFLM's rich nutritional profile, including essential amino acids and fatty acids, could support shrimp reproductive health by providing the nutrients necessary for gonadal development and larval viability (Kawasaki *et al*., 2023).

This consistency reproductive performances suggested that BSFLM inclusion, even at higher levels (BSFLM 75% and 100%), did not impair the structural development of reproductive tissues or the ability to produce viable larvae (Shah & Hayat, 2024). To the best of our knowledge, most studies on BSFLM had focused on growth and immune development for fish and shrimps. There were studies that examined the reproductive performance of zebrafish (*Danio rerio*) feed with BSFLM, where their experimental designs were similar with this study. They found that increasing BSFLM inclusion levels (from 0%, 25%, 50%, 75% to 100%) had no effect on zebrafish reproductive performance (Chemello *et al*., 2021) and long-term physiological stability (Sangiacomo *et al*., 2024).

Pigmentation Performance

The colour intensity of all cherry shrimps found in this study remained consistent with influenced by different BSFLM inclusion levels (25%, 50%, 75%, and 100%) (Table 8 and Figure 8). Although, BSFLM might lack natural pigments such as carotene or astaxanthin, nevertheless, inclusion levels at even 100% did not significantly enhance or detract from the colour intensity of shrimp. Additionally, the nutrition and carotenoid content in BSFLM were highly dependent on their feed ingredients used during larval rearing (Nor *et al*., 2022). Carotenoids, such as lutein and beta-carotene, were not synthesised de novo by the larvae, but bioaccumulated from the substrates they consumed (Bonelli *et al*., 2020).

This meant that the nutritional profile of BSFLM, particularly its lipid-soluble vitamins and pigments, directly reflected the nutritional quality and composition of their feed (Leni *et al*., 2022). In this study, astaxanthin was added into the feed formulation as a pigment enhancer. Previous studies had shown that substrates enriched with plant-based carotenoid sources or supplemented with commercial carotenoids could significantly improve the pigment concentration in BSFLM (Liland *et al*., 2017). This ability to bioaccumulate carotenoids highlighted the versatility of BSFLM as an easy feedstock in aquafeed application. Therefore, the quality of BSFLM as an alternative protein source and its value as a dietary pigment source would depend on tailoring the feed substrate to match the nutritional and pigment requirements of the target species (Ratti *et al*., 2023).

Practical and Economic Feasibility of using BSFLM

The use in ornamental shrimp aquaculture presents both practical and economic promise, though further evaluation is needed. As a sustainable and protein-rich alternative to traditional Fish Meal (FM), BSFLM effectively supported shrimp growth; for instance, in white-leg shrimps (*Penaeus vannamei*), diets of up to 75% BSFLM achieved comparable or enhanced daily weight gain and feed conversion ratios (Nunes *et al*., 2023). Its amino acid profile also aligned with requirements observed in other species, such as the Nile tilapia (Shati *et al*., 2022; Kariuki *et al*., 2024) and Siberian sturgeon (Rawski *et al*., 2021), where gains in growth and feed efficiency had been reported.

Economically, BSFLM could offer cost savings, particularly when FM prices were elevated. A favourable return on investment had been documented when BSFLM was priced below USD3.04/kg (Nunes *et al*., 2023), a finding supported by similar experiences in other aquaculture systems (Limbu *et al*., 2022). Environmentally, BSFLM could contribute to sustainability by reducing dependency on marine-sourced ingredients and enabling production from organic waste, such as shrimp by-products (Moore & Drewery, 2024; Hu *et al*., 2024). Nonetheless, its wider adoption hinged on addressing key constraints, namely supply consistency (Supreetha *et al*., 2023), price fluctuations (Sutopo *et al*., 2012), production scale (Veldkamp *et al*., 2022), processing methods (Nugroho *et al*., 2020; Supreetha *et al*., 2023) and regional market dynamics (Vega *et al*., 2014; Veldkamp *et al*., 2022). While our study confirmed the biological suitability of BSFLM at a 50% inclusion level, future research should focus on detailed feed formulation trials, cost-benefit analyses and market integration assessments to verify its feasibility and commercial viability in ornamental shrimp farming.

Study Limitation

One of the limitations of this study is the absence of detailed amino acid and fatty acid profiles of the experimental diets. These profiles were crucial for a more comprehensive understanding of the nutritional value of BSFLM, particularly in relation to essential amino acids such as methionine and lysine, which were known to influence growth performance in aquatic species. Unfortunately, due to resource constraints, we were unable to conduct these analyses. Long-term experiments should be conducted to evaluate the physiological and reproductive impacts for sustainable performance. Future studies should also include a complete nutritional profile of the diets to better elucidate the role of specific nutrients in supporting optimal growth, reproduction, and pigmentation in ornamental shrimp.

Conclusions

The result of this study demonstrated the potential of BSFLM as a potential sustainable alternative insect protein source for cherry shrimp culture with optimum inclusion level at 50% to achieve higher growth performances. However, the feed had no impact on the reproductive system and pigmentation of cherry shrimps. Future studies should focus on optimising BSFLM-based diets by addressing micro-nutrient balance, such as through amino acid (e.g., methionine, lysine) and essential fatty acid (DHA, EPA) supplementation to achieve maximum growth and reproductive performances. In addition, BSFLM shows strong potential as a sustainable and cost-effective alternative protein source in ornamental shrimp aquaculture, but its successful commercial application would require further studies on economic feasibility, optimal inclusion levels and market acceptance.

Acknowledgments

This work is supported by the Ministry of Higher Education, Malaysia, under the Higher Institution Centre of Excellence (HICoE) programme at the Institute of Tropical Aquaculture and Fisheries (AKUATROP), Universiti Malaysia Terengganu (Vot 63933 and 56065). The authors also like to acknowledge the Qatar National Research Fund and the Ministry of Municipality and Environment for awarded this research grant to Qatar University (MME-02 – 0921–200026).

Conflict of Interest Statement

The authors declare that they have no conflict of interest.

References

Addo, P., Fosu-Gyasi, S., Oduro-Kwarteng, S., Armstrong, D. G., & Awuah, E. (2024). Assessing egg deposition behaviour of female black soldier fly (*Hermetia Illucens*) in Kumasi, Ghana using MOSW as bait. *Journal of Asia-Pacific Entomology/ Journal of Asia Pacific Entomology*, *27*(1), 102168-102168.https://doi.org/10.1016/j.aspen.2023.102168

Adeoye, A. A., Akegbejo-Samsons, Y., Fawole, F. J., & Davies, S. J. (2020). Preliminary assessment of black soldier fly (*Hermetia illucens*) larval meal in the diet of African catfish (*Clarias gariepinus*): Impvdact on growth, body index, and hematological parameters. *Journal of the World Aquaculture Society*, *51*(4), 1024-1033. https://doi.org/10.1111/jwas.12691

Adetunmbi, T. (2023). The potential of insects as alternative animal protein source for livestock feeding. *Global Journal of Agricultural Sciences*, *22*(1), 47-61. https://doi.org/10.4314/gjass.v22i1.6

Admin, L. N. (2023). Unveiling the mysteries of cherry shrimp growth in your aquarium! Swimming creatures; swimming creatures. https://www.swimmingcreaturesinc.com/post/unveiling-the-mysteries-of-cherry-shrimp-growth-in-your-aquarium

Barragan F., K. B., Dicke, M., & van Loon, J. J. A. (2017). Nutritional value of the black soldier fly (*hermetia illucens l.*) and its suitability as animal feed – a review. *Journal of Insects as Food and Feed*, *3*(2), 105-120. https://doi.org/10.3920/jiff2016.0055

Bonelli, M., Bruno, D., Brilli, M., Gianfranceschi, N., Tian, L., Tettamanti, G., Caccia, S., & Casartelli, M. (2020). Black soldier fly larvae adapt to different food substrates through morphological and functional responses of the midgut. *International Journal of Molecular Sciences*, *21*(14), Article 4955. https://doi.org/10.3390/ijms21144955

Chemello, G., Zarantoniello, M., Randazzo, B., Gioacchini, G., Truzzi, C., Cardinaletti, G., Riolo, P., & Olivotto, I. (2021). Effects of black soldier fly (*Hermetia illucens*) enriched with *Schizochytrium* sp. on zebrafish (*Danio rerio*) reproductive performances. *Aquaculture*, *550*, 737853. https://doi.org/10.1016/j.aquaculture.2021.737853

Chen, Y., Zhuang, Z., Liu, J., Wang, Z., Guo, Y., Chen, A., Chen, B., Zhao, W., & Niu, J. (2023). Effects of *Hermetia illucens* larvae meal on the Pacific white shrimp (*Litopenaeus vannamei*) revealed by innate immunity and 16S rRNA gene sequencing analysis. *Comparative Biochemistry and Physiology. Part D, Genomics & Proteomics*, *46*, 101080-101080. https://doi.org/10.1016/j.cbd.2023.101080

Chowdhury M. A., & Roy, N. M. (2020). Probiotic supplementation for enhanced growth of striped catfish (*Pangasianodon hypophthalmus*) in cages. *Aquaculture Reports*, *18*, 100504-100504. https://doi.org/10.1016/j.aqrep.2020.100504

Cummins J. V. C., Rawles, S. D., Thompson, K. R., Velasquez, A., Kobayashi, Y., Hager, J., & Webster, C. D. (2017). Evaluation of black soldier fly (*Hermetia illucens*) larvae meal as partial or total replacement of marine fish meal in practical diets for Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture*, *473*, 337-344. https://doi.org/10.1016/j.aquaculture.2017.02.022

Frost, J. (2019). *Using post hoc tests with ANOVA*. Statistics by Jim. https://statisticsbyjim.com/anova/post-hoc-tests-anova/

Goncalves, R., Lund, I., Sousa, D., & Skov, P. V. (2022). Shrimp waste meal (*Pandalus borealis*) as an alternative ingredient in diets for juvenile European lobster (*Homarus gammarus, L*.). *Animal Feed Science and Technology, 294,* 115478-115478. https://doi.org/10.1016/j.anifeedsci.2022.115478

Hassan, H. U., Ali, Q. M., Ahmad, N., Masood, Z., Hossain, M. Y., Gabol, K., Khan, W., Hussain, M., Ali, A., Attaullah, M., & Kamal, M. (2020). Assessment of growth characteristics, the survival rate and body composition of Asian sea bass *Lates calcarifer* (Bloch, 1790) under different feeding rates in closed aquaculture system. *Saudi Journal of Biological Sciences*, *28*(2), 1324-1330. https://doi.org/10.1016/j.sjbs.2020.11.056

Henry, M., Gasco, L., Piccolo, G., & E. Fountoulaki. (2015). Review on the use of insects in the diet of farmed fish: Past and future. *Animal Feed Science* *and Technology*, *203*, 1-22. https://doi.org/10.1016/j.anifeedsci.2015.03.001

Hu, X., Zhang, H., Pang, Y., Cang, S., Wu, G., Fan, B., Liu, W., Tan, H., & Luo, G. (2024). Performance of feeding black soldier fly (Hermetia illucens) larvae on shrimp carcasses: A green technology for aquaculture waste management and circular economy. *Science of the Total Environment*, 172491. https://doi.org/10.1016/j.scitotenv.2024.172491

Hu, Z., Li, H., Liu, S., Xue, R., Sun, J., & Ji, H. (2023). Assessment of black soldier fly (*Hermetia illucens*) larvae meal as a potential substitute for soybean meal on growth performance and flesh quality of grass carp *Ctenopharyngodon idellus*. *Animal Nutrition*, *14*, 425-449. https://doi.org/10.1016/j.aninu.2023.06.006

João A. F. P, Gregati, R. A., da, C., López, L. S., & Negreiros, M. L. (2015). Post-hatching development of the ornamental “Red Cherry Shrimp” *Neocaridina davidi* (Bouvier, 1904) (Crustacea, Caridea, Atyidae) under laboratorial conditions. *Aquaculture Research*, *48*(2), 553-569. https://doi.org/10.1111/are.12903

Kariuki, M. W., Barwani, D. K., Mwashi, V., Kioko, J. K., Munguti, J. M., Tanga, C. M., Kiiru, P., Gicheha, M. G., & Osuga, I. M. (2024). Partial replacement of fishmeal with back soldier fly larvae meal in Nile Tilapia diets improves performance and profitability in earthen pond. *Scientific African*, *24*, e02222. https://doi.org/10.1016/j.sciaf.2024.e02222

Kawasaki, K., Zhao, J., Takao, N., Sato, M., Ban, T., Tamamaki, K., Kagami, M., & Yano, K. (2023). Sustenance trial to analyze the effects of black soldier fly larvae meal on the reproductive efficiency of sows and the hematological properties of suckling and weaning piglets. *Animals*, *13*(21), 3410. https://doi.org/10.3390/ani13213410

Khieokhajonkhet, A., Uanlam, P., Ruttarattanamongkol, K., Aeksiri, N., Tatsapong, P., & Kaneko, G. (2022). Replacement of fish meal by black soldier fly larvae meal in diet for goldfish *Carassius auratus*: Growth performance, hematology, histology, total carotenoids, and coloration. *Aquaculture*, *561*, 738618-738618. https://doi.org/10.1016/j.aquaculture.2022.738618

Kim, C. H., Ryu, J., Lee, J., Ko, K., Lee, J.Y, Park, K.Y., & Chung, H. (2021). Use of Black Soldier Fly larvae for food waste treatment and energy production in Asian countries: A Review. *Processes*, *9*(1), 161-161. https://doi.org/10.3390/pr9010161

Leni, G., Maistrello, L., Pinotti, G., Sforza, S., & Caligiani, A. (2022). Production of carotenoid-rich *Hermetia illucens* larvae using specific agri-food by-products. *Journal of Insects as Food and Feed*, *9*(2), 171-182. https://doi.org/10.3920/jiff2022.0016

Liland, N. S., Biancarosa, I., Araujo, P., Biemans, D., Bruckner, C. G., Waagbø, R., Torstensen, B. E., & Lock, E. (2017). Modulation of nutrient composition of black soldier fly (*Hermetia illucens*) larvae by feeding seaweed-enriched media. *PLOS One*, *12*(8), e0183188. https://doi.org/10.1371/journal.pone.0183188

Limbu, S. M., Shoko, A. P., Ulotu, E., Luvanga, S. A., Munyi, F., John, J., & Opiyo, M. A. (2022). Black soldier fly (Hermetia illucens, L.) larvae meal improves growth performance, feed efficiency and economic returns of Nile tilapia (Oreochromis niloticus, L.) fry. *Aquaculture, Fish and Fisheries*, *2*(3), 167-178. https://doi.org/10.1002/aff2.48

Limbu, S. M., Shoko, A.P., Ulotu, E. E., Luvanga, S. A., Munyi, F.M., John, J. O., & Opiyo, M. A. (2022). Black soldier fly (*Hermetia illucens, L.*) larvae meal improves growth performance, feed efficiency and economic returns of Nile tilapia (*Oreochromis niloticus,* L.) fry. *Aquaculture, Fish and Fisheries, 2(3),* 167-178. https://doi.org/10.1002/aff2.48

Ling, S. Y., Shafiee, M., Longworth, Z., Vatanparast, H., Tabatabaei, M., & Jung, L. H. (2024). Black Soldier Fly Larvae Meal (BSFLM) as an alternative protein source in sustainable aquaculture production: A scoping review of its comprehensive impact on shrimp and prawn farming. *Animal Feed Science and Technology*, *319*, Article 116174. https://doi.org/10.1016/j.anifeedsci.2024.116174

Linh, N. V., Wannavijit, S., Tayyamath, K., Dinh-Hung, N., Nititanarapee, T., Sumon, M. A. A., & Srinual, O., Permpoonpattana, P., Doan, H., & Brown, C. L. (2024). Black Soldier Fly (*Hermetia illucens*) larvae meal: A sustainable alternative to fish meal proven to promote growth and immunity in koi carp (*Cyprinus carpio* var. koi). *Fishes*, *9*(2), Article 53. https://doi.org/10.3390/fishes9020053

Liu, Z., Liu, Q., Zhang, D., Wei, S., Sun, Q., Xia, Q., Shi, W., Ji, H., & Liu, S. (2021). Comparison of the proximate composition and nutritional profile of by products and edible parts of five species of shrimp. *Foods*, *10*(11), 2603-2603. https://doi.org/10.3390/foods10112603

Lock, E. R., Arsiwalla, T., & Waagbø, R. (2015). Insect larvae meal as an alternative source of nutrients in the diet of Atlantic salmon (*Salmo salar*) postsmolt. *Aquaculture Nutrition*, *22*(6), 1202-1213. https://doi.org/10.1111/anu.12343

Lu, S., Nittaya, T., Weerada, M., Jariya, S., Boontum, S., Thakun, S., Pawinee, A., Sorasak, T., Siwaporn, P., Rayudika, A., Pramote, 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), 831-831. https://doi.org/10.3390/insects13090831

Lukhaup (2020). *Neocaridina davidi "Bloody Mary" crustacea*. Fishpedia. https://www.fishi-pedia.com/crustacea/neocaridina-davidi-bloody-mary

Lupton, A. (2020). *Cherry shrimp guide*. Flip Aquatics Setting the Standard. https://flipaquatics.com/blogs/news/cherry-shrimp-guide

Maglangit, F., Alosbanos, R. S., & Akeed, M. (2021). *Black soldier fly*. https://encyclopedia.pub/entry/7597

Marshall, S. A., Woodley, N. E., & Hauser, M. (2015). The historical spread of the Black Soldier fly, *Hermetia illucens* (L.) (Diptera, Stratiomyidae, Hermetiinae), and its establishment in Canada. *JESO*, *146*, 51-54. https://journal.lib.uoguelph.ca/index.php/eso/article/download/3696/3745

Mengumphan, K., & Panase, P. (2015). Growth performance, length-weight relationship and condition factor of backcross and reciprocal hybrid catfish reared in net cages. *International Journal of Zoological Research*, *11*(2), 57-64. https://doi.org/10.3923/ijzr.2015.57.64

Michael (2019). *Breeding and life cycle of red cherry shrimp - shrimp and snail breeder*. Aquarium Breeder. https://aquariumbreeder.com/breeding-and-life-cycle-of-red-cherry-shrimp/

Mohan, K., Rajan, D. K., Muralisankar, T., Ganesan A. R., Sathishkumar, P., &

Revathi, N. (2022). Use of black soldier fly (*Hermetia illucens* L.) larvae meal in aquafeeds for a sustainable aquaculture industry: A review of past and future needs. *Aquaculture*, *553*, 738095-738095. https://doi.org/10.1016/j.aquaculture.2022.738095

Mohd, L., Ishak, A. R., Hua, P. W., Mohd, N., Dom, N. C., Shafie, F. A., Abdullah, A. M., Kari, Z. A., & Edinur Hisham Atan. (2022). Growth and development of black soldier fly (*Hermetia illucens* (L.), Diptera: Stratiomyidae) larvae grown on carbohydrate, protein, and fruit-based waste substrates. *Malaysian Applied Biology*, *51*(6), 57-64. https://doi.org/10.55230/mabjournal.v51i6.2386

Moore, E., & Drewery, M. L. (2024). Pelagic fish spared from ocean catch by integrating Black Soldier Fly Larvae in U.S. aquaculture production. *Frontiers in Sustainable Food Systems*, *8*, Article 1297414. https://doi.org/10.3389/fsufs.2024.1297414

Nhan, H. T., Minh, T. X., Liew, H. J, Hien, T. T. T., & Jha, R. (2019). Effects of natural dietary carotenoids on skin coloration of false Clownfish (*Amphiprion ocellaris* Cuvier, 1830). *Aquaculture Nutrition*, *25*(3), 662-668. https://doi.org/10.1111/anu.12887

Nor, Seok-Kian, A. Y., Seng, L. L., Mustafa, S., Kim, Y.-S., & Rossita Shapawi. (2022). Nutritional value of black soldier fly (*Hermetia illucens*) larvae processed by different methods. *PLOS ONE*, *17*(2), e0263924-e0263924. https://doi.org/10.1371/journal.pone.0263924

Nugroho, D. S., Shen, C. Y., Chou, T. H., Hartini, N., & Chiu, H. Y. (2020). Antifungal lotion as value-added product for harvested BSFL processing: Simple process design and economic evaluation. *Jurnal Bahan Alam Terbarukan*, *8*(2), 124-132. https://doi.org/10.15294/JBAT.V8I2.22794

Nunes, A. J. P., Yamamoto, H., Simões, J. P., Pisa, J. L., Miyamoto, N., & Leite, J. S. (2023). The Black Soldier Fly (*Hermetia illucens*) larvae meal can cost-effectively replace fish meal in practical nursery diets for post-larval *Penaeus vannamei* under high-density culture. *Fishes*, *8*, Article 605. https://doi.org/10.20944/preprints202310.1034.v1

Raman, S. S., Stringer, L. C., Bruce, N. C., & Chong, C. S. (2022). Opportunities, challenges and solutions for black soldier fly larvae-based animal feed production. *Journal of Cleaner Production*, *373*, 133802-133802. https://doi.org/10.1016/j.jclepro.2022.133802

Ratti, S., Zarantoniello, M., Chemello, G., Giammarino, M., Palermo, F. A., Cocci, P., Mosconi, G., Tignani, M. V., Pascon, G., Cardinaletti, G., Pacetti, D., Nartea, A., Parisi, G., Riolo, P., Belloni, A., & Olivotto, I. (2023). Spirulina-enriched substrate to Rear Black Soldier fly (*Hermetia illucens*) prepupae as alternative aquafeed ingredient for rainbow trout (*Oncorhynchus mykiss*) diets: Possible effects on zootechnical performances, gut and liver health status, and fillet quality. *Animals*, *13*(1), Article 173. https://doi.org/10.3390/ani13010173

Rawski, M., Mazurkiewicz, J., Kierończyk, B., & Józefiak, D. (2021). Black Soldier Fly full-fat larvae meal is more profitable than fish meal and fish oil in Siberian Sturgeon Farming: The effects on aquaculture sustainability, economy and fish GIT development. *Open Access Journal*, *11*(3), Article 604. https://doi.org/10.3390/ANI11030604

Salam, M., Shahzadi, A., Zheng, H., Alam, F., Nabi, G., Shi D., Ullah, W., Sumbal A., Ali, N., & Bilal, M. (2022). Effect of different environmental conditions on the growth and development of Black Soldier Fly Larvae and its utilisation in solid waste management and pollution mitigation. *Environmental Technology & Innovation*, *28*, 102649-102649. https://doi.org/10.1016/j.eti.2022.102649

Sangiacomo, C., Trombetta, L., Susini, F., Brogi, L., Licitra, R., Marchese, M., Falabella, P., Franco, A., Scieuzo, C., Del Vecchio, G., Verri, T., & Fronte, B. (2024). *Hermetia Illucens meal from different substrates for replacing fishmeal: Study on zebrafish as fish model* (Pre-print). SSRN. https://doi.org/10.2139/ssrn.5000812

Saputra, I., & Fotedar, R. (2023). The effect of defatted black soldier fly meal (*Hermetia illucens*) inclusion in the formulated diet on the growth, gene expression, and histopathology of juvenile lobster (*Panulirus ornatus* Fabricius, 1798). *Aquaculture International*, *32*(1), 11-29. https://doi.org/10.1007/s10499-023-01151-2

Seyedalmoosavi M., Mielenz, M., Veldkamp, T., & Cornelia C. G. D. (2022). Growth efficiency, intestinal biology, and nutrient utilisation and requirements of black soldier fly (*Hermetia illucens*) larvae compared to monogastric livestock species: A review. *Journal of Animal Science and Biotechnology*, *13*(1), Article 31. https://doi.org/10.1186/s40104-022-00682-7

Shah, S. R. A., & Hayat, Z. (2024). Nutritional composition and processing methods of black soldier fly larvae for fish feeding. *Probe - Fishery Science & Aquaculture*, *6*(1), Article 2258. https://doi.org/10.18686/fsa2258

Shati, S. M., Apiyo, M. A., Nairuti, R. N., Shoko, A. P., Munyi, F., & Ogello, E. O. (2022). Black soldier fly (*Hermetia illucens*) larvae meal improves growth performance, feed utilisation, amino acids profile, and economic benefits of Nile tilapia (*Oreochromis niloticus*, L.). *Aquatic Research*, *5*(3), 238-249. https://doi.org/10.3153/ar22023

Sudha, C., Ahilan, B., Nathan, F., Uma, A., & Prabu, E. (2022). Effects of dietary protein substitution of fishmeal with black soldier fly larval meal on growth and physiological responses of juvenile striped catfish, *Pangasianodon hypophthalmus*. *Aquaculture Research*, *53*(6), 2204-2217. https://doi.org/10.1111/are.15739

Suen, C., & Gillett-Kaufman, J. L. (2018) University of Florida cherry shrimp. Ufl.edu. https://entnemdept.ufl.edu/creatures/MISC/cherry_shrimp.html

Supreetha, S., Sonarthi, H., & Mall, S. (2023). Food processing and management of food supply chain: From farm to fork. In Malik, J. A., Goyal, M. R., Kumari, A. (Eds.), *Food process engineering and technology* (pp. 119-134). https://doi.org/10.1007/978-981-99-6831-2_6

Surendra, K. C., Tomberlin, J. K., Van H. A., Cammack, J. A., Heckmann, L. H. L., & Khanal, S. K. (2020). Rethinking organic wastes bioconversion: Evaluating the potential of the black soldier fly (*Hermetia illucens*) (BSF). *Waste Management*, *117*, 58-80. https://doi.org/10.1016/j.wasman.2020.07.050

Sussman, G. (2021, March 7). *Neocaridina shrimp care and breeding guide*. Windy City Aquariums. https://www.windycityaquariums.com/blogs/blog/neocaridina-shrimp-care-and-breeding-guide?srsltid=AfmBOorsdqsgC0-iWqUS9-Mmb_JftTLA_EiwKqVS0dzjVDF408Qw_Yke

Sutopo, W., Bahagia, S. N., & Cakravastia, A. (2012). A buffer stock model to ensure price stabilisation and availability of seasonal staple food under free trade considerations. *Journal of Engineering and Technological Sciences*, *44*(2), 128-148. https://doi.org/10.5614/ITBJ.ENG.SCI.2012.44.2.3

Suyitman, S., Warly, L., Rahmat, A., & Pazla, R. (2020). Digestibility and performance of beef cattle fed ammoniated palm leaves and fronds supplemented with minerals, cassava leaf meal and their combinations. *Advances in Animal and Veterinary Sciences*, *8*(9). https://doi.org/10.17582/journal.aavs/2020/8.9.991.996

Tantikitti, C. (2014). Feed palatability and the alternative protein sources in shrimp feed. *DOAJ (DOAJ: Directory of Open Access Journals)*. https://doaj.org/article/cf76484253264f94bb4551daf1ad0fa6

Tomas, A. L., Sganga, D. E., & Susana, L. (2019). Effect of background color and shelters on female pigmentation in the ornamental red cherry shrimp *Neocaridina davidi* (Caridea, Atyidae). *Journal of the World Aquaculture Society*, *51*(3), 775-787. https://doi.org/10.1111/jwas.12660

Tu, Ha, N. N., Thuy, T., & Tri, N. N. (2022). Effect of astaxanthin and spirulina levels in black soldier fly larvae meal-based diets on growth performance and skin pigmentation in discus fish, *Symphysodon* sp. *Aquaculture*, *553*, 738048-738048. https://doi.org/10.1016/j.aquaculture.2022.738048

Usha, B. S., & Sandya, S. (2013). Measurement of ovarian size and shape parameters. In *2013 Annual IEEE India Conference (INDICON), Mumbai, India, 2013, pp. 1-6.* https://doi.org/10.1109/INDCON.2013.6726079

Usman, U., Fahrur, M., Kamaruddin, K., & Fahmi, M. R. (2021). The utilisation of black soldier fly larvae meal as a substitution of fish meal in diet for white shrimp, *Litopenaeus vannamei*, grow-out. *IOP Conference Series. Earth and Environmental Science*, *860*(1), 012023-012023. https://doi.org/10.1088/1755-1315/860/1/012023

Vega, S. H., & Elhorst, J. P. (2014). Modelling regional labour market dynamics in space and time. *Papers in Regional Science*, *93*(4), 819-841. https://doi.org/10.1111/PIRS.12018

Veldkamp, T., Meijer, N. P., Alleweldt, F., Deruytter, D., Van Campenhout, L., Gasco, L., Roos, N., Smetana, S., Fernandes, A., & van der Fels-Klerx, H. J. (2022). Overcoming technical and market barriers to enable sustainable large-scale production and consumption of insect proteins in Europe: A SUSINCHAIN Perspective. *Insects*, *13*(3), Article 281. https://doi.org/10.3390/insects13030281

Verma, A. (2023, May 26). Boosting shrimp feed with BSFL meal: An excellent supplement for enhanced nutrition. *Think Grain Think Feed*. https://benisonmedia.com/boosting-shrimp-feed-with-bsfl-meal-an-excellent-supplement-for-enhanced-nutrition/

Weber, S., & Traunspurger, W. (2016). Influence of the ornamental red cherry shrimp *Neocaridina davidi* (Bouvier, 1904) on freshwater meiofaunal assemblages. *Limnologica*, *59*, 155-161. https://doi.org/10.1016/j.limno.2016.06.001

Wong, D. (2022). *The neocaridina story*. Madshrimp. https://madshrimp.com/blogs/news/the-neocaridina-story

Zarantoniello, M., Chemello, G., Ratti, S., Pulido-Rodríguez, L. F., Daniso, E., Freddi, L., Salinetti, P., Nartea, A., Bruni, L., Parisi, G., Riolo, P., & Olivotto, I. (2023). Growth and welfare status of giant freshwater prawn (*Macrobrachium rosenbergii*) post-larvae reared in aquaponic systems and fed diets including enriched Black Soldier fly (*Hermetia illucens*) prepupae meal. *Animals*, *13*(4), Article 715. https://doi.org/10.3390/ani13040715

Zhou, C., Yang, G., Sun, L., Wang, S., Song, W., & Guo, J. (2023). Counting, locating, and sizing of shrimp larvae based on density map regression. *Aquaculture International*, *32*(3), 3147-3168. https://doi.org/10.1007/s10499-023-01316-z

Zhou, D., Liu, L. H., Xinliang, & Fang, W. (2023). Effects of different shelters on feeding, molting, survival, and growth of *Scylla paramamosain*. *Frontiers in Marine Science*, *10*, Article 1191025. https://doi.org/10.3389/fmars.2023.1191025

Zhou, J. S., Liu, S. S., Ji, H., & Yu, H. B. (2017). Effect of replacing dietary fish meal with black soldier fly larvae meal on growth and fatty acid composition of Jian carp (*Cyprinus carpio var*. Jian). *Aquaculture Nutrition*, *24*(1), 424-433. https://doi.org/10.1111/anu.12574

Zulkifli, N. M. F. M., Seok-Kian, A. Y., Seng, L. L., Mustafa, S, Yang-Su, K., & Shapawi, R. (2022). Nutritional value of black soldier fly (*Hermetia illucens*) larvae processed by different methods. *PLOS One*, *17(2)*, e0263924-e0263924. https://doi.org/10.1371/journal.pone.0263924