International Journal of Agriculture and Biosciences 2026 15(3): 1080-1087.
https://doi.org/10.47278/journal.ijab/2026.016

RESEARCH ARTICLE eISSN: 2306-3599; pISSN: 2305-6622

Utilization of Black Soldier Fly Larvae as a Substitute for Fishmeal in Koi Carp (*Cyprinus carpio*) Diets: Effects on Growth, Digestive Enzyme Activity and Color Intensity

Kittima Vanichkul [1], Wantanai Srisakda [1], Sangob Srimueang [1]*, Rungkan Klahan [2], Boontarika Thongdonphum [1], Pacharathon Simking [3], Waritpat Watcharachumsuwan [1], Jiraporn Champasri [1] and Kantika Uamphan [1]

[1]Division of Fisheries, Faculty of Agricultural Technology, Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand 12120
[2]Division of Aquacultural, Faculty of Agricultural Technology, Phetchaburi Rajabhat University, Phetchaburi, Thailand 76000
[3]Division of Veterinary Nursing, Faculty of Agricultural Technology, Rajamangala University of Technology Thanyaburi, Pathumthani, Thailand 12120
*Corresponding author: sangob_s@rmutt.ac.th

ABSTRACT

Black soldier fly larvae (*Hermetia illucens*) represent a viable, sustainable protein source for aquaculture. However, its application in ornamental species, such as koi carp, which are economically vital, requires species-specific responses to maintain market value. This study aimed to investigate the growth performance, digestive enzyme activity, and color intensity of koi carp (*Cyprinus carpio*) fed black soldier fly larvae at 0, 25, 50, and 75% of the diet instead of fish meal. The carp were conducted with a treatment diet in glass tanks for 60 days. The research concluded that black soldier fly larvae can substitute fishmeal in carp diets. However, koi carp fed a meal supplemented with over 50% black soldier fly larvae had significantly lower final body weight, average weight increase, and average daily growth rate ($P<0.05$) compared to the control group and those fed a diet with a 25% replacement diet. The fish that consumed a diet with black soldier fly larvae instead of 75% had lower protease enzyme activity than the control group ($P<0.05$) .In comparison, fish groups fed diets with black soldier fly larvae as a replacement for 50 and 75% showed considerably higher amylase and lipase activity than the control group ($P<0.05$). The L*, a*, and b* values for skin color intensity above the lateral line were not significantly different across groups ($P>0.05$). Therefore, black soldier fly larvae can replace fishmeal in carp diets not exceeding 25% without affecting growth, variations in digestive enzymes, and skin color. This information could improve koi carp culture and promote aquaculture to satisfy future sustainable demand.

Keywords: Alternative protein, Aquatic animal feed, Growth, Digestive enzyme, Skin color.

Article History
Article # 25-684
Received: 25-Oct-25
Revised: 16-Dec-25
Accepted: 28-Dec-25
Online First: 10-Jan-26

INTRODUCTION

The ornamental aquaculture industry has been continuously expanding, driven by the demand for pet fish. Advances in aquaculture have significantly improved the efficiency of production and the economic value of ornamental fish. The koi carp (*Cyprinus carpio* var. koi) market is economically important due to its worldwide popularity, especially in Asia and Europe, where demand for high-quality koi carp has driven continuous development in aquaculture (FAO, 2020). Diet plays an important role in promoting growth, color development, and efficiency of various body systems. (NRC, 2011). Moreover, carotenoid supplementation in fish diets is essential for preserving color quality, which is chiefly responsible for the vibrant hues found in ornamental fish. Coloration substantially impacts the perceived value and consumer preference of ornamental fish among aquarists (Chatzifotis et al., 2005; Elbahnaswy & Elshopakey, 2024; Tran et al., 2025). Therefore, a diet that promotes both development and pigmentation has been the main focus in ornamental aquaculture research (Linh et al., 2024).

Cite this Article as: Vanichkul K, Srisakda W, Srimueang S, Klahan R, Thongdonphum B, Simking P, Watcharachumsuwan W, Champasri J and Uamphan K, 2026. Utilization of black soldier fly larvae as a substitute for fishmeal in koi carp (*Cyprinus carpio*) diets: effects on growth, digestive enzyme activity, and color intensity. International Journal of Agriculture and Biosciences 15(3): 1080-1087. https://doi.org/10.47278/journal.ijab/2026.016

A Publication of Unique Scientific Publishers

Diets are frequently designed with high protein content, utilizing fishmeal as the primary protein source. The significant reliance on fishmeal raises issues about sustainability, price fluctuations, and environmental impacts (Zulkifli et al., 2022). Insect protein is one of the promising options and is attracting growing interest as a sustainable alternative to reduce the use of conventional fishmeal in aquaculture (Van Huis, 2013; Tippayadara et al., 2021; Gadzama, 2025; Zambrano Vera et al., 2025). The black soldier fly, *Hermetia illucens* (Linnaeus, 1758), belongs to the family Stratiomyidae. Insects serve as an alternative protein source that has garnered significant interest owing to their substantial nutritional value, particularly containing up to 8-60% protein and 18-40% fat (Barragán-Fonseca et al., 2017; Gadzama, 2025; Su et al., 2025). In addition, black soldier fly larvae contain carotenoids at 2.15mg/kg, which is important for promoting fish color (Secci et al., 2018). They can be grown from agricultural and organic waste and serve as an important tool for efficiently converting waste into protein-rich biomass, making them an essential resource for the circular bioeconomy (Anokye, 2025). This benefit has led to ongoing research on the utilization of black soldier fly larvae to develop animal feed (da Silva & Hesselberg, 2020; Salahuddin et al., 2024; Karhale et al., 2025). Considering the growing need for animal protein, expected to double by 2030, black soldier fly larvae present a viable, sustainable alternative protein source. Further research is required to elucidate the effects of black soldier fly larvae supplementation on animal responses as a substitute for conventional animal feed (Gadzama, 2025).

In the field of aquatic animal feed, a study investigates the use of black soldier fly larvae as an alternative to fish meal in formulations. It can promote the growth of various fish species, including the fighting fish (*Betta splendens*) (Kari et al., 2023), the rainbow trout (*Oncorhynchus mykiss* Walbaum) (Renna et al., 2017; Zhao et al., 2023) and the Japanese eel (*Anguilla japonica*). However, the effects may vary depending on the volume of replacement and species-specific needs, as the dietary inclusion of black soldier fly larvae has been associated with variations in digestive enzyme activity, which can affect feed efficiency and nutrient assimilation (Kuo et al., 2022).

For ornamental fish such as koi, pigmentation is a vital and fundamental attribute influencing marketability. Pigmentation is primarily affected by the consumption of carotenoids and natural pigments that accumulate in the skin and muscle tissues. Black soldier fly larvae naturally contain lipids that enhance pigment absorption (Tu et al., 2022).

Despite research on the use of black soldier fly larvae meal as a substitute for fishmeal in various economically important fish species, knowledge of its application in fancy carp (*Cyprinus carpio*), an ornamental fish with distinct nutritional requirements and significant value, remains limited. Moreover, studies on other fish species have indicated disparate effects of black soldier fly larvae, rendering it infeasible to derive definitive findings on its practical application. This study aims to evaluate the comprehensive impacts of black soldier fly larvae on growth performance, digestive enzyme activity, and skin color intensity in fancy carp, to find the optimal replacement level for use in carp feed, thereby promote sustainable and efficient carp culture development.

MATERIALS & METHODS

Black Soldier Fly Larvae and Diet Preparation

The larvae of the black soldier fly larvae from the black soldier fly larvae farm in Samut Sakhon Province of Thailand were dried in a hot air oven at 60°C for 48 hours. They were minced using a grinder into 1-2mm for use in the feed formulas. The other feedstuffs in Table 1 were ground through a 1-2mm sieve, weighed, and mixed by a mixer machine. They were taken to an extruder and then processed the feedstuffs into pellets with a diameter of 2-3mm. The diets were dried for 24 hours at room temperature and stored in sealed plastic bags at -20°C before use. The experimental diets were proximated for chemical composition, including protein, fat, fiber, ash, and moisture, according to AOAC (2000). Nitrogen-free extract (NFE) was calculated (100 - (protein + fat + ash + fiber)), and total carotenoids were analyzed following Howe & Tanumihardjo (2006). Ingredients, proximate composition and total carotenoid of experimental diets are summarized in Table 1.

Table 1: Ingredients, proximate composition and total carotenoid of experimental diets

Ingredients (g kg $^{-1}$)	BSFL 0	BSFL 25	BSFL 50	BSFL 75
Fish meal	250	187.5	125	62.5
Black soldier fly meal	0	62.5	125	187.5
Shrimp head meal	50	50	50	50
Squid liver meal	60	60	60	60
Soybean meal	150	150	150	150
Broken rice meal	140	140	140	140
Rice bran	50	50	50	50
Yeast	50	50	50	50
Wheat flour	120	120	120	120
Premix [1]	10	10	10	10
Vitamin [2]	10	10	10	10
Squid liver oil	20	20	20	20
Vegetable oil	20	20	20	20
Spirulina	50	50	50	50
Lecithin	10	10	10	10
Binders	10	10	10	10
Composition (%)				
Crude protein	33.65	33.58	31.35	30.56
Crude fat	7.33	11.18	12.05	13.98
Crude fiber	3.17	2.63	3.70	3.67
Ash	8.97	8.15	7.29	6.59
Moisture	7.20	7.07	6.63	6.36
NFE	39.68	37.99	38.98	38.84
Total carotenoid (μg/g)	0.39	1.20	1.27	1.41

[1]Premix; [2]Vitamin supplemented contains: (IU kg $^{-1}$ or g kg $^{-1}$ diet): Vitamin A 6,000,000IU, Vitamin D3 1,200,000IU, Vitamin E 6,000IU, Vitamin K3 0.45g, Vitamin B1 0.45g, Vitamin B2 3.5g, Vitamin B12 0.006g, Pantothenic Acid 5.4g, Nicotinic Acid 13.5g, Choline Chloride 85g, Copper 56g, Manganese 21g, Iron 29.6g, Zinc 33.5g, Iodine 0.3g, DL-Methionine 24.5g, L-Lysine 49g.

Fish and Experimental Procedures

Two hundred koi carp fingerlings were acquired from a commercial farm in Samut Sakhon Province of Thailand. The animals were accumulated for 7 days in cement ponds (1 cm^3), which were constantly aerated and fed commercial ornamental fish pellets twice a day at 7:30 AM and 5:30 PM before the experiment. Twelve fish were sampled and set in each glass tank measuring 80x50x50cm, for a total of 12 tanks. Each tank was continuously filtered and aerated throughout the trial. All fish were fed the treatment diet twice daily at 7:30 AM and 5:30 PM to apparent satiation, with the volume of feed recorded over 60 days. Additionally, throughout the trial, the tank was cleaned, and the water was changed every 7 days.

Growth Performance

Data were obtained by selecting at random eight fish from each tank to record their length, weight, and number of fish surviving at the beginning and throughout the trial. The growth performance has been evaluated for the average final body weight (FBW), average weight gain (AWG), average daily growth rate (ADG), feed conversion ratio (FCR) and survival rate (SR), following De Silva & Anderson (1994).

Digestive Enzyme Analysis

Three fish were randomly selected from each tank. The abdominal cavity of the fish was cut open using an aseptic procedure to obtain organ samples, including the intestines and liver. The organ sample was prepared for crude enzyme extraction by homogenizing it in Tris-HCl buffer (50 mM, pH 7.5) in a tube. The homogenate was centrifuged at 15,000g for 5min at 4°C. The supernatant has been stored in a vial at -20°C for enzyme analysis (Gimenez et al., 1999). Protease analysis was conducted in triplicate by quantifying the increase in cleavage of short-chain polypeptides, with minor modifications relative to Bezerra et al. (2005). The total protease activity was assessed using a 1% (w/v) azocasein solution prepared in buffers at different pH values (6-8). The substrate (500µL) was incubated with crude extract (20µL) and buffer solution (200mL) for 60min at 30°C. Subsequently, add 500µL of 20% (w/v) trichloroacetic acid (TCA), then centrifuge at 15,000g at 4°C for 10min. One milliliter of supernatant was combined with 1 M NaOH (1.5mL), and the absorbance was measured at 440nm using a spectrophotometer. The protease-specific activity was expressed by the change in absorbance per minute per mg of protein of the enzyme extract (ΔAbs min^{-1} mg $protein^{-1}$). The amylase enzyme was analyzed in triplicate utilizing the 3,5-dinitrosalicylic acid (DNS) method, as modified by Bernfeld (1951). A starch substrate (1% w/v) was formulated in buffers at various pH levels (6-8). The substrate (500µL) was incubated with crude extract (20µL) and buffer solution (400µL) for 60min at 30°C. Subsequently, 1.5mL of 1% dinitrosalicylic acid (DNS) solution was added and boiled for 5min. Subsequently, 1.5mL of distilled water was added to the combination and the cooled solution. The cooled solution was analyzed at 550nm utilizing a spectrophotometer. Maltose (10–100mM) was used to construct the calibration curve. The amylase-specific activity was quantified as the mmol of maltose produced per min per mg of protein. Analyses of lipase enzyme were conducted in triplicate with the modified method of Markweg-Hanke et al. (1995), 0.01M para-nitrophenylpalmitate (pNNP) dissolved in iso–isopropanol as the substrate. The substrate (100µL) was incubated with crude enzyme extract (50µL) and buffer solution (800µL) for 60 min at 30°C. Subsequently, 250µL of 0.1M Na_2CO_3 was added, and the mixture was centrifuged at 10,000g at 4°C for 15min. Absorbance was measured at 410nm using a spectrophotometer. Para–nitrophenol (pNP) was employed in a concentration of 100–1000µg/mL for the calibration curve. Lipase-specific activity was evaluated by measuring the µmol of p-nitrophenol generated per min per mg protein.

Color Measurement

The six fish were randomly selected per tank at the beginning and every 15 days thereafter until the end of the experiment to be rendered unconscious using the clove oil for color measurement. The skin above the lateral line on the left side of the koi carp was analyzed using HunterLab MiniScan EZ 45/0 (LAV) within the CIE L*a*b* color space. The obtained L*, a*, and b* values were used for presenting lightness, redness or greenness, and blueness or yellowness, respectively (Hunter and Harold, 1987)

Water Quality

Water quality in the experimental tank was measured, including water temperature, dissolved oxygen, and pH, using a Hach multivariate water quality meter (HQ40D). Total ammonia and nitrite content were measured using the titration method (APHA, 1992).

Statistical Analysis

The data in the experiment was used to determine the difference of one-way analysis in variance (ANOVA). Duncan's New Multiple Range Test (DMRT) at the 95% confidence level ($P<0.05$) was used to determine differences among treatment means. Statistical analyses were performed using SPSS Statistics software.

RESULTS

Growth Performance

Koi carp fed with experimental diets showed different growth performance, as shown in Table 2. The fish fed diets with fish meal replaced with black soldier fly larvae at 0 and 25% exhibited equivalent average final weights ($P>0.05$), which were significantly greater than those in the groups fed diets with 50% and 75% substitution ($P<0.05$). The average weight gain and average daily growth rate decreased in fish fed diets replacing over 50% of the fish meal with black soldier fly larvae. The control group has the lowest feed conversion ratio ($P<0.05$) among the other treatment groups. The fish group that was fed a diet replacing 75% of fish meal with black soldier fly larvae exhibited the highest feed conversion ratio values ($P<0.05$). The survival rate across all treatment groups ranged from 97.22 to 100% and showed no statistically significant differences ($P>0.05$).

Digestive Enzyme

The protease enzyme activity in koi carp tended to decrease in the group that was fed a diet using black soldier fly larvae as a replacement for fish meal in treatment diets. The control group of fish had significantly higher activity values than the group fed with 75% of black soldier fly larvae instead of fish meal (P<0.05). However, amylase activity tended to increase with the replacement level. The group fed with black soldier fly larvae replacing fish meal at 75% had the highest activity value and was statistically significantly different (P<0.05) from the other groups. In addition, lipase activity also increased. The control group and the group fed black soldier fly larvae replacing fish meal at 25% (P>0.05) had lower values than the groups fed 50% and 75% substitution diets (P<0.05). Both groups had statistically significant differences (P<0.05), as shown in Table 3.

Table 2: Growth performance of koi carp (*Cyprinus Carpio*) fed treatment diet for 60 days

Growth rate	BSFL 0	BSFL 25	BSFL 50	BSFL 75
IBW (g)	12.77±0.53^{a}	12.76±0.03^{a}	12.77±0.59^{a}	12.73±0.17^{a}
FBW (g)	28.49±0.18^{c}	28.14±0.34^{c}	27.01±0.01^{b}	26.54±0.07^{a}
AWG (g)	15.72±0.70^{b}	15.38±0.32^{b}	14.24±0.59^{a}	13.81±0.14^{a}
ADG (g/day)	0.35±0.02^{b}	0.34±0.01^{b}	0.32±0.01^{a}	0.31±0.0 1^{a}
FCR	2.65±0.09^{a}	2.90±0.04^{b}	3.27±0.07^{c}	3.28±0.05^{d}
SR (%)	100±0.00^{a}	97.22±4.81^{a}	100±0.00^{a}	100±0.00^{a}

Values (mean+SD) within a row with the same superscript are significantly different (P<0.05); IBW: Initial Body Weight; FBW: Initial Body Weight; AWG: Average Weight Gain ADG: Average Daily Growth Rate; FRC: Feed Conversion Ratio; SR: Survival Rate.

Table 3: Digestive enzyme of koi carp (*Cyprinus Carpio*) fed treatment diet for 60 days. (Mean±SD)

Enzyme	BSFL 0	BSFL 25	BSFL 50	BSFL 75
Protease (U/mg protein)	2.87±0.27^{b}	2.20±0.43^{ab}	2.22±0.32^{ab}	1.89±0.35^{a}
Amylase (U/mg protein)	2.54±0.33^{a}	2.00±0.54^{a}	5.41±0.55^{b}	8.47±1.37^{c}
Lipase (U/g)	27.22±0.81^{a}	33.85±1.45^{b}	35.41±1.52^{b}	38.33±0.9^{c}

Values (mean+SD) within a row with common superscript are significantly different (P<0.05).

Color Measurement

The color value of the skin above the lateral line of fancy carp is shown in Table 4. Initially, the L*, a* and b* had no significant difference between all treatment groups (P>0.05). However, the L* and b* value tended to decrease in all groups for 15 days but there was no significant difference (P>0.05). The color of a* value shown an increase remain constant until the end of the experiment (P>0.05). However, the L*, a*, and b* values exhibited no significant differences among groups throughout the trial (P>0.05).

Table 4: Color intensity of koi carp (*Cyprinus Carpio*) fed treatment diet for 60 days

Parameter	Periods	BSFL 0	BSFL 25	BSFL 50	BSFL 75
L*	Initial	57.41±4.13^{a}	60.43±3.26^{a}	60.26±3.97^{a}	59.16±3.73^{a}
	15th day	54.44±0.68^{a}	55.56±3.17^{a}	52.75±0.64^{a}	53.61±0.96^{a}
	30th day	49.76±1.62^{a}	49.07±2.72^{a}	48.79±0.51^{a}	49.72±1.83^{a}
	45th day	51.69±0.88^{a}	51.70±0.52^{a}	51.13±0.41^{a}	51.61±0.10^{a}
	60th day	55.24±1.23^{a}	54.47±0.35^{a}	55.01±0.69^{a}	54.98±0.43^{a}
a*	Initial	3.20±0.89^{a}	2.91±0.16^{a}	3.00±0.06^{a}	3.16±0.36^{a}
	15th day	7.52±0.69^{a}	7.16±0.28^{a}	7.58±1.07^{a}	7.28±0.50^{a}
	30th day	7.02±0.53^{a}	7.23±0.49^{a}	7.34±0.53^{a}	7.12±0.84^{a}
	45th day	7.48±0.40^{a}	7.29±0.14^{a}	7.48±0.24^{a}	7.33±0.28^{a}
	60th day	8.34±0.22^{a}	8.19±0.62^{a}	8.86±0.62^{a}	8.73±0.53^{a}
b*	Initial	31.66±1.84^{a}	31.20±0.37^{a}	31.54±1.17^{a}	31.52±4.63^{a}
	15th day	25.87±0.40^{a}	25.21±1.69^{a}	25.22±1.21^{a}	25.23±0.93^{a}
	30th day	22.97±0.72^{a}	22.63±0.76^{a}	22.45±0.47^{a}	23.32±0.31^{a}
	45th day	21.65±0.44^{a}	21.33±0.73^{a}	21.29±0.43^{a}	21.31±0.69^{a}
	60th day	21.06±0.38^{a}	21.08±0.24^{a}	21.32±0.54^{a}	21.40±0.17^{a}

Values (mean+SD) within a row with common superscript are significantly different (P<0.05).

Water Quality

Throughout the experimental period, water quality in the tank showed a temperature range from 28.07 to 32.75°C, a dissolved oxygen level of 6.29-7.41 ppm, a pH of 7.61-8.20, total ammonia concentrations of 0.06-0.22 ppm, and nitrite levels ranging from 0.000 to 0.078 ppm.

DISCUSSION

The growth rate of koi carp diminished in accordance with the proportion of black fly soldier larvae substituted in the experimental diet. Carp fed a diet with fish meal substituted by black fly larvae at 0% and 25% demonstrated appropriate growth, with no significant differences observed (P> 0.05). However, carp receiving a diet with 50% and 75% replacement of black soldier fly larvae demonstrated a marked decline in growth performance (P<0.05). The observed growth revealed that koi carp exhibit a reduced growth response when fish food is substituted with a higher proportion of black army fly larvae. The larvae of the black soldier fly possess a substantial fat content ranging from 7% to 39% (Barragán -Fonseca et al., 2017). The elevated fat content in food can adversely affect nutritional intake, leading to imbalances in specific essential amino acids in insects (St-Hilaire et al., 2007; Li et al., 2016). This study found fat content from 11.18 to 13.98% in the treatment diet, which (more than 60 g/kg) would inhibit weight gain and increase lipid degradation in the hepatopancreas, thus affecting growth performance and feed utilization (Fan et al., 2021). The fish ingest large quantities, adversely impacting the efficiency of protein use for development performance (Makkar et al., 2014). This is consistent with the study of Du et al. (2006), which found that increasing fat level in diets fed to *Ctenopharyngodon idella* negatively affected the growth rate by decreasing food intake, reducing growth, lowering feed efficiency, and increasing visceral adipose tissue weight. Additionally, growth performance was reduced, which may be associated with chitin, a component of insects (black soldier fly larvae). Chitin is classified as an antinutritional factor, which limits the utilization of feed during digestion (Rust, 2003). Its presence has a detrimental effect on digestive efficiency, reducing nutrient absorption (Barroso et al., 2014; Henry et al., 2015; Marono et al., 2015; Guerreiro et al., 2021). Moreover, the study similar with Kroeckel et al. (2012) found that the replacement of fish meal with dried black soldier fly larvae in the diets of flounder (*Psetta maxima*) at levels of 0, 17, 33, 49, 64, and 76% resulted in a decline in growth rate as the inclusion of black soldier fly larvae increased, attributable to the elevated chitin content in the diet. Consequently, fish in the treatment groups required more feed to convert nutrients into growth, as indicated by the feed conversion ratio.

However, research has shown varying results of black fly soldier larvae usage in fish diet. Khieokhajonkhet et al. (2022) found that using black soldier fly larvae to replace fish meal in goldfish (*Carassius auratus*) diets at 0, 10, 20, 40, 60, 80, and 100% led to an increase in growth rate that was correlated to the amount of black soldier fly larvae in the diet. Tippayadara et al. (2021) investigated diets substituting fish meal with black soldier fly larvae meal at levels of 0, 10, 20, 40, 60, 80, and 100%, and found no statistically significant differences in growth rates. The variation in growth performance outcomes is associated with species, fish size, insect types, insect consumption, and insect processing (Tschirner & Simon, 2015; Lu et al., 2020).

The survival rates in this study were more than 97% and did not significantly differ (P>0.05). Das (2023) studied the use of insects, including grasshoppers, crickets, mealworms, and black soldier flies, to raise swordtail larvae (*Xiphophorus helleri*) compared with a commercial diet. The survival rate of swordtails fed on black soldier fly larvae was statistically different from that of those maintained on commercial artificial feed (P>0.05), indicating that the replacement of black soldier fly larvae did not harm fish survival.

Furthermore, the activity of digestive enzymes in koi carp varied in response to their digestive system's adaptation to the changing nutritional composition of their diet. Protease activity tended to decrease as the black soldier fly larvae substitution level increased. It was lowest in the fish group that fed a diet substituting 75% of fish meal with black soldier fly larvae (P<0.05) and was highest in the control diet. The reduction in protease activity was associated with a lower percentage of protein in treatment diets that incorporated a higher proportion of black soldier fly larvae as a substitute for fish meal, resulting in a comparable decline in protease activity essential for protein digestion. The chitin concentration in the composition of black soldier fly larvae influences the digestion and use of protein nutrients (Alegbeleye et al., 2012; Li et al., 2016). The study of Kamalii et al. (2022) found that the replacement of fish meal with black soldier fly larvae in the diets of goldfish (*Carassius auratus*) at levels of 0, 20, 40, 60, 80, and 100% showed substitution level of 60% substitution provided optimal in growth, feed efficiency, and protease activity. However, increasing the proportion of black soldier fly larvae reduced efficiency across various parameters, suggesting the limits of high dosages on nutrient digestion and absorption, thereby reducing growth, as observed in catfish and rainbow trout (St-Hilaire et al., 2007; Anvo et al., 2017).

In contrast, the amylase and lipase activities increased with the increasing amounts of black soldier fly larvae replacement fish meal in diets that showed in the carp group fed diets that replaced fishmeal at 50 and 75% (P<0.05). The elevation of amylase activity is attributed to dietary adjustments in response to treatment, particularly the higher carbohydrate content from chitin in black soldier fly larvae, which exceeds that from fish meal. The black soldier fly larvae contain to 8.7 to 9.6% of chitin, regarded as an anti-nutritional factor in aquafeeds due to its indigestibility (Diener et al., 2009; Kroeckel et al., 2012; Jayanegara et al., 2020; Shah & Hayat, 2024), whereas fishmeal contains less than 1% chitin, which is a very low level due to the absence of chitinous exoskeletons in fish (Pascon et al., 2025). It causes the increased release of digestive enzymes (amylase) for activity. The augmentation of lipase activity correlates with the elevated fat content in the proximate composition of the experimental food, which increases as the replacement of black soldier fly larvae increases, leading to greater lipase release to facilitate fat digestion. In juvenile largemouth bass, a diet comprising up to 50% black soldier fly larvae elevated the levels of DHA, EPA, and C22:5n-3 in the liver, indicating that black soldier fly larvae could assist in the maintenance of these essential fatty acids (You et al., 2024). The fatty acid profile of black soldier fly larvae noticeably contrasts with that of fish oils containing long-chain EPA (20:5n−3) and DHA (22:6n−3). BSFL, however, has a substantial quantity of long-chain lipids, notably including lauric acid, as well as palmitic, myristic, oleic, and linoleic acids (Srisuksai et al., 2024; Dîrvariu et al., 2025). Studying on goldfish (*Carassius auratus*) and eels (*Monopterus albus*) has demonstrated that an increase in dietary fat content elevates lipase enzyme activity (Hu et al., 2020; Kamalii et al., 2022). Moreover, Muslimin et al. (2023) reported elevated levels of amylase and lipase in cork fish (Channa striata) exposed to several proportions of black soldier fly larvae as treatments, specifically at 20, 50, 80, and 100%, which is likely attributable to this study.

The ingredients in food significantly impact on the colors of ornamental fish, particularly carotenoids. These compounds are mainly natural pigments that are abundant and enhance pigmentation, giving the fish different colors such as yellow, red, and orange, thereby influencing the fish's beautiful color (Saikia & Das, 2023; Rehman et al., 2023). The study found that the total carotenoid content of all treatment diets ranged from 0.39 to 1.41 μg/g. The color intensity of koi carp in this study exhibited no significant differences in L*, a*, and b* values from the skin above the lateral line (P>0.05) among all groups. This result shows that the black soldier fly larvae level used as a replacement for fish meal in the diet is insufficient to influence the fish's coloration and aligns with the skin expression. According to Jintasataporn et al. (2005), the cultivation of fancy carp with diets containing different carotenoid levels, specifically 96.2 and 103.9μg/g, resulted in an increased redness value on the fish skin compared to the control group (P<0.05). During the 15-day investigation, the a* value exhibited an upward trend. In contrast, the b* value decreased and stabilized by the end of the experiment as the fraction of black soldier fly larvae substitution in fishmeal increased (P>0.05). In contrast, The a* value in rainbow trout fillet was negatively affected by the replacement of dietary black soldier fly larvae meal (P>0.05) in all groups (Renna et al., 2017). The incorporation of *Tenebrio molitor* larvae meal as a dietary substitute for fish meal in blackspot sea bream (*Pagellus bogaraceo*) resulted in a reduction of the a* value in the dorsal skin region. It decreased both L* and a* values in the ventral skin area (Iaconisi et al., 2017). Khieokhajonkhet et al. (2002) investigated diets with varying concentrations of black soldier fly larvae meal in goldfish, specifically 0g kg–1, 43g kg–1, 84g kg–1, 145g kg–1 and 210g kg–1 , as substitutes for fishmeal. The dietary inclusion of black soldier fly larvae meal resulted in a linear and/or quadratic reduction of a* and b* values in the head, as well as L*, a*, and b* values in the abdomen, alongside a decrease in total carotenoid content in the fin, serum, and skin. The results concerning color varied among different fish species when black soldier fly larvae were utilized as a substitute for fishmeal in aquatic animal feed. This study demonstrated that substituting fishmeal with black soldier fly larvae in carp feed did not influence the fish's coloration. Fish are unable to synthesize their own carotenoid pigments and must obtain them from their diet. Spirulina has been added into the experimental diet as an ingredient for ornamental fish to enhance color intensity through carotenoids. Numerous studies on ornamental fish have demonstrated its ability to increase pigmentation (Gouveia et al., 2003; Vernès et al., 2015). The water quality during the experiment fluctuated but remained within the acceptable range for fish culture (Svobodova et al., 1993). Therefore, the black soldier fly larvae could substitute for fish meal in the diet, and has no effect on the water quality of the cultural system.

Conclusion

This study demonstrates that black soldier fly larvae can partially replace fishmeal in koi carp feed. The extent of substitution is a pivotal factor affecting aquaculture. Integrating black soldier fly larvae into the diet at levels above 50% negatively impacts growth performance and feed efficiency, as evidenced by declines in final body weight, weight gain, and average daily growth rate, along with an increase in the feed conversion ratio. The findings indicate a notable decline in protease activity with increasing replacement levels, whereas amylase and lipase activities tend to rise as replacement rates increase. These modifications resulted from reduced protein and increased fat content in the diets that used black soldier fly larvae as a replacement for fishmeal in the trial. However, survival rates and skin pigmentation intensity were unaffected by the application of black soldier fly larvae, showing that it did not impact fish viability or aesthetic attractiveness. The research findings indicate that black soldier fly larvae can replace fish meal in koi carp diets at levels up to 25% without negatively impacting growth performance, digestive enzyme activity, or skin coloration, producing results similar to those of fish meal-based diets. This supports the use of black soldier fly larvae as a sustainable source of protein for koi carp.

DECLARATIONS

Funding: This research was supported by the National Science, Research and Innovation Fund, Thailand Science Research and Innovation (TSRI), through Rajamangala University of Technology Thanyaburi (FRB67E 0203B.3) (Grant No.: FRB670027/0168).

Acknowledgement: The authors would like to express their appreciation to the Faculty of Agricultural Technology, Rajamangala University of Technology Thanyaburi for their enormous support.

Conflict of Interest: No conflict of interest relevant to this article.

Data Availability: All the data are available inside the article.

Ethics Statement: This research was in accordance with the ethical guidelines and standards. The Animal Care Committee of Rajamangala University of Technology Thanyaburi authorized all experimental procedures (RMUTT.ARG.2024.R001) to ensure the accuracy of the study results and the welfare of the animals.

Author's Contribution: KV ,WS ,and SS performed the resources, methodology, writing the original draft, review, and editing; KV also managed project administration. RK contributed to conceptualization, methodology, supervision, writing, review, and editing. BT and PS contributed to resources, methodology, and supervision. WW provided resources and lab analyses. JC and KU contributed to resource management. Manuscript publication is approved by all authors

Generative AI Statement: The authors declare that no Gen AI/DeepSeek was used in the writing/creation of this manuscript.

Publisher's Note: All claims stated in this article are exclusively those of the authors and do not necessarily represent those of their affiliated organizations or those of the publisher, the editors, and the reviewers. Any product that may be evaluated/assessed in this article or claimed by its manufacturer is not guaranteed or endorsed by the publisher/editors.

REFERENCES

Alegbeleye, W.O., Obasa, S.O., Olude, O.O., Otubu, K., & Jimoh, W. (2012). Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings: Evaluation of the nutritive value of the variegated grasshopper. *Aquaculture Research*, 43(3), 412–420. https://doi.org/10.1111/j.1365-2109.2011.02844.x

Anokye, K. (2025). Black soldier fly larvae as a circular solution for organic waste management and sustainable livestock feed in Ghana. *Cleaner Waste Systems,* 12, 100416. https://doi.org/10.1016/j.clwas.2025.100416

Anvo, M.P.M., Aboua, B.R.D., Compaoré, I., Sissao, R., Zoungrana-Kaboré, C., Kouamelan, E.P., & Toguyéni, A. (2017). Fish meal replacement by *Cirina butyrospermi* caterpillar's meal in practical diets for *Clarias gariepinus* fingerlings. *Aquaculture Research*, 48(10), 5243–5250. https://doi.org/10.1111/are.13337

AOAC (2000). Official Methods of Analysis. (15th Ed.). The Association of Official Analytical Chemists. Virginia: USA.

APHA (1992). Standard Methods for the Examination of Water and Wastewater. (18th Ed.). American Public Health Association (APHA), American Water Works Association (AWWA), and Water Pollution Control Federation (WPCF). Washington DC: USA

Barragán-Fonseca, 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.

Barroso, F.G., de Haro, C., Sánchez-Muros, M.J., Venegas, E., Martínez-Sánchez, A., & Pérez- Bañón, C. (2014). The potential of various insect species for use as food for fish. *Aquaculture*, 422–423, 193–201. https://doi.org/10.1016/j.aquaculture.2013.12.024

Bernfeld, P. (1951). Enzymes of starch degradation and synthesis. *Advances in Enzymology and Related Areas of Molecular Biology*, 12, 379-428. https://doi.org/10.1002/9780470122570.ch7

Bezerra, R.S, Lins, E.J.F., Alencar, R.B., Paiva, P.M.G., Chaves, M.E.C., Coelho, L.C.B.B., & Carvalho, L.B., Jr. (2005). Alkaline proteinase from intestine of Nile tilapia (*Oreochromis niloticus*). *Process Biochemistry*, 40(5), 1829–1834. https://doi.org/10.1016/j.procbio.2004.06.066

Chatzifotis, S., Pavlidis, M., Jimeno, C.D., Vardanis, G., Sterioti, A., & Divanach, P. (2005). The effect of different carotenoid sources on skin coloration of cultured red porgy (*Pagrus pagrus*). *Aquaculture Research*, 36(15), 1517–1525. https://doi.org/10.1111/j.1365-2109.2005.01374.x

da Silva, G.D.P., & Hesselberg, T. (2020). A review of the use of black soldier fly larvae, *Hermetia illucens* (Diptera: Stratiomyidae), to compost organic waste in tropical regions. *Neotropical Entomology*, 49(2), 151–162. https://doi.org/10.1007/s13744-019-00719-z

Das, M. (2023). Effect of insect meals on the growth efficiency, survival and total carotenoid content of an ornamental fish *Xiphophorus maculatus* (Gunther, 1866). *Asian Journal of Fisheries and Aquatic Research,* 22 (3):1–9. https://doi.org/ 10.9734/AJFAR/2023/v22i3570

De Silva, S.S., & Anderson, T.A. (1994). Fish nutrition in aquaculture. Springer Science & Business Media. Australia. https://doi.org/10.1007/978-94-011-0199-8

Diener, S., Zurbrügg, C., & Tockner, K. (2009). Conversion of organic material by black soldier fly larvae: establishing optimal feeding rates. *Waste Management & Research,* 27(6), 603-610. https://doi:10.1177/0734242x09103838

Dîrvariu, L., Barbacariu, C.-A., Burducea, M., & Simeanu, D. (2025). Feed sources for sustainable aquaculture: Black soldier fly larvae (BSFL). *Fishes*, 10(9), 464. https://doi.org/10.3390/fishes10090464

Du, Z.Y., Clouet, P., Zheng, W.H., Degrace, P., Tian, L.X., & Liu, Y.J. (2006). Biochemical hepatic alterations and body lipid composition in the herbivorous grass carp (*Ctenopharyngodon idella*) fed high-fat diets. *British Journal of Nutrition*, 95(5), 905–915. https://doi.org/10.1079/BJN20061733

Elbahnaswy, S., & Elshopakey, G.E. (2024). Recent progress in practical applications of a potential carotenoid astaxanthin in aquaculture industry: a review. *Fish Physiology and Biochemistry*, 50(1), 97-126. https://doi.org/10.1007/s10695-022-01167-0

FAO (2020). The state of world fisheries and aquaculture 2020 (SOFIA): Sustainability in action. Food & Agriculture Organization of the United Nations (FAO). USA

Fan, Z., Li, J., Zhang, Y., Wu, D., Zheng, X., Wang, C.A., & Wang, L. (2021). Excessive dietary lipid affecting growth performance, feed utilization, lipid deposition, and hepatopancreas lipometabolism of large-sized common carp (*Cyprinus carpio*). *Frontiers in Nutrition,* 8, 694426. https://doi.org/10.3389/fnut.2021.694426

Gadzama, I.U. (2025). Black soldier fly larvae as animal feed. *Bulgarian Journal of Animal Husbandry/Životnov Dni Nauki,* 62(1), 48-64. https://doi.org/10.61308/LWHN4916

Gimenez, A.V.F., Fernandez, I., Preciado, R.M., Oliva, M., Tova, D., & Nolasco, H. (1999). The activity of digestive enzyme during the molting stage of the arched swimming *Callinectes Arcautus* orday, 1863. (Crustacea: decapoda: portunidae). *Bulletin of Marine Science*, 65, 1-9.

Gouveia, L., Rema, P., Pereira, O., & Empis, J. (2003). Coloring ornamental fish (*Cyprinus carpio* and *Carassius auratus*) with microalgal biomass. *Aquaculture Nutrition*, 9(2), 123–129. https://doi.org/10.1046/j.1365-2095.2003.00233.x

Guerreiro, I., Serra, C.R., Coutinho, F., Couto, A., Castro, C., Rangel, F., Peres, H., Pousão-Ferreira, P., Matos, E., Gasco, L., Gai, F., Oliva-Teles, A., & Enes, P. (2021). Digestive enzyme activity and nutrient digestibility in meagre (*Argyrosomus regius*) fed increasing levels of black soldier fly meal (*Hermetia illucens*). *Aquaculture Nutrition*, 27(1), 142–152. https://doi.org/10.1111/anu.13172

Henry, M., Gasco, L., Piccolo, G., & Fountoulaki, E. (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

Howe, J.A., & Tanumihardjo, S.A. (2006). Evaluation of Analytical Methods for Carotenoid Extraction from Biofortified Maize (*Zea mays* sp.). *Journal of Agricultural and Food Chemistry,* 54 (21) , 7992-7997. https://doi.org/10.1021/jf062256f

Hu, Y., Huang, Y., Tang, T., Zhong, L., Chu, W., Dai, Z., Chen, K., & Hu, Y. (2020). Effect of partial black soldier fly (*Hermetia illucens* L.) larvae meal replacement of fish meal in practical diets on the growth, digestive enzyme and related gene expression for rice field eel (*Monopterus albus*). *Aquaculture Reports*, 17, 100345. https://doi.org/10.1016/j.aqrep.2020.100345

Hunter, R.S., & Harold, R.W. (1987). The measurement of appearance. John wiley & sons.

Iaconisi, V., Marono, S., Parisi, G., Gasco, L., Genovese, L., Maricchiolo, G., Bovera, F., & Piccolo, G. (2017). Dietary inclusion of *Tenebrio molitor* larvae meal: Effects on growth performance and final quality treats of blackspot sea bream (*Pagellus bogaraveo*). *Aquaculture*, 476, 49-58. https://doi.org/10.1016/j.aquaculture.2017.04.007

Jayanegara, A., Haryati, R.P., Nafisah, A., Suptijah, P., Ridla, M., & Laconi, E.B. (2020). Derivatization of chitin and chitosan from black soldier fly (*Hermetia illucens*) and their use as feed additives: An in vitro study. *Advance in Animal and Veterinary Science*, 8(5), 472-477. https://doi.org/10.17582/journal.aavs/2020/8.5.472.477

Jintasataporn, O., Yuangsroi, B., & Smithiwong, P. (2005). Optimum levels of total carotenoids for the color intensity of carp (*Cyprinus carpio*). In the 43rd Kasetsart University Annual Conference: Fisheries, Resource and Environmental Management. Bangkok: Thailand.

Kamalii, A., Antony, C., Ahilan, B., Uma, A., & Prabu, E. (2022). Dietary protein replacement of fish meal with black soldier fly larvae meal: Effects on growth, whole-body composition, digestive enzyme activity, muscle-growth-related gene expression and haemato-biochemical responses of juvenile goldfish, *Carassius auratus*. *Turkish Journal of Fisheries and Aquatic Sciences*, 23(2). TRJFAS21837. https://doi.org/10.4194/trjfas21837

Karhale, A.V., Prasade, N.N., Kadav, V.B., Iwanate, N.T., & Tawde, R.R. (2025). Black soldier fly larvae: A sustainable protein source in animal feed. *Journal of Scientific Research and Reports*, 31(8), 37–44. https://doi.org/10.9734/jsrr/2025/v31i83348

Kari, Z.A., Téllez-Isaías, G., Hamid, N.K.A., Rusli, N.D., Mat, K., Sukri, S.A.M., Kabir, M.A., Ishak, A.R., Dom, N.C., Abdel-Warith, A.W.A., Younis, E.M., Khoo, M.I., Abdullah, F., Shahjahan, M., Rohani, M.F., Davies, S.J., & Wei, L.S. (2023). Effect of fish meal substitution with black soldier fly (*Hermetia illucens*) on growth performance, feed stability, blood biochemistry, and liver and gut morphology of Siamese fighting fish (*Betta splendens*). *Aquaculture Nutrition*, 2023, 6676953. https://doi.org/10.1155/2023/6676953

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. https://doi.org/10.1016/j.aquaculture.2022.738618

Kroeckel, S., Harjes, A.-GE, Roth, I., Katz, H., Wuertz, S., Susenbeth, A., & Schulz, C. (2012). When a turbot catches a fly: Evaluation of a pre-pupae meal of the black soldier fly (*Hermetia illucens*) as fish meal substitute - growth performance and chitin degradation in juvenile turbot (*Psetta maxima*). *Aquaculture*, 364, 345–352. https://doi.org/10.1016/j.aquaculture.2012.08.041

Kuo, I.P., Liu, C.S., Yang, S.D., Liang, S.H., Hu, Y.F., & Nan, F.H. (2022). Effects of replacing fishmeal with defatted black soldier fly (*Hermetia illucens* Linnaeus) larvae meal in Japanese eel (*Anguilla japonica*) diet on growth performance, fillet texture, serum biochemical parameters, and intestinal histomorphology. *Aquaculture Nutrition*, 2022, 1866142. https://doi.org/10.1155/2022/1866142

Li, Q.P., Gooneratne, S.R., Wang, R.L., Zhang, R., An, L.L., Chen, J.J., & Pan, W. (2016). Effect of different molecular weight of chitosans on performance and lipid metabolism in chicken. *Animal Feed Science and Technology*, 211, 174–180. https://doi.org/10.1016/j.anifeedsci.2015.11.013

Linh, N.V., Wannavijit, S., Tayyamath, K., Dinh-Hung, N., Nititanarapee, T., Sumon, M.A.A., Srinual, O., Permpoonpattana, P., Doan, H.V., & 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), 53. https://doi.org/10.3390/fishes9020053

Lu, R., Chen, Y., Yu, W., Lin, M., Yang, G., Qin, C., Meng, X., Zhang, Y., Ji, H., & Nie, G. (2020). Defatted black soldier fly (*Hermetia illucens*) larvae meal can replace soybean meal in juvenile grass carp (*Ctenopharyngodon idellus*) diets. *Aquaculture Reports*, 18, 100520. https://doi.org/10.1016/j.aqrep.2020.100520

Makkar, H.P.S., 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

Markweg-Hanke, M., Lang, S., & Wagner, F. (1995). Dodecanoic acid inhibition of a lipase from *Acinetobacter* sp. OPA 55. *Enzyme and Microbial Technology*, 17(6), 512–516. https://doi.org/10.1016/0141-0229(94)00067-2

Marono, S., Piccolo, G., Loponte, R., Di Meo, C., Attia, Y.A., Nizza, A., & Bovera, F. (2015). In vitro crude protein digestibility of *Tenebrio Molitor* and *Hermetia illucens* insect meals and its correlation with chemical composition traits. *Italian Journal of Animal Science*, 14(3), 3889. https://doi.org/10.4081/ijas.2015.3889

Muslimin, B., Yonarta, D., Heriyati, E., Helmizuryani, H., Sari, M.P., Apriyanti, D., & Kurniawan, R. (2023). Impact of black soldier fly (*Hermetia* *illucens*) fresh meal on the growth performance, digestive enzymes, hematology, and intestinal histology of cork fish (*Channa striata*). *Turkish Journal of Veterinary and Animal Sciences*, 47(4), 324–333. https://doi.org/10.55730/1300-0128.4301

NRC (2011). Nutrient Requirements of Fish and Shrimp. National Research Council. National academies press. Washington DC: USA.

Pascon, G., Opere Akinyi, R., Cardinaletti, G., Daniso, E., & Messina, M. (2025). Chitin and its effects when included in aquafeed. *Aquaculture International*, 33(22), 202-224. https://doi.org/10.1007/s10499-025-01879-z

Rehman, I., Nazim, R., Meraj, A., Ameer, A., Arshad, F., & Ali, S. (2023). Regulation and improvement of carotenoid metabolism in tomato. *International Journal of Agriculture and Biosciences,* 12, 199-207. https://doi.org/10.47278/journal.ijab/2023.065

Renna, M., Schiavone, A., Gai, F., Dabbou, S., Lussiana, C., Malfatto, V., Prearo, M., Capucchio, M.T., Biasato, I., Biasibetti, E., De Marco, M., Brugiapaglia, A., Zoccarato, I., & Gasco, L. (2017). Evaluation of the suitability of a partially defatted black soldier fly (*Hermetia illucens* L.) larvae meal as ingredient for rainbow trout (*Oncorhynchus mykiss* Walbaum) diets. *Journal of Animal Science and Biotechnology*, 8(1), 57. https://doi.org/10.1186/s40104-017-0191-3

Rust, M.B. (2003). Nutritional Physiology. In Fish Nutrition (pp. 367–452). Elsevier. Amsterdam: Netherland.

Saikia, S., & Das, J.N. (2023). Carotenoids as a dietary supplement for enhancing pigmentation and colouration in ornamental fishes: A Review. *Uttar Pradesh Journal of Zoology*, 44(13), 1–16. https://doi.org/10.56557/upjoz/2023/v44i133541

Salahuddin, M., Abdel-Wareth, A.A.A., Hiramatsu, K., Tomberlin, J.K., Luza, D., & Lohakare, J. (2024). Flight toward sustainability in poultry nutrition with black soldier fly larvae. *Animals*, 14. https://doi.org/10.3390/ani14030510

Secci, G., Bovera, F., Nizza, S., Baronti , N., Gasco, L., Conte, G., Serra, A., Bonelli, A., & Parisi, G. (2018). Quality of eggs from lohmann brown classic laying hens fed black soldier fly meal as substitute for soya bean. *Animal*, 12(10), 2191–2197. https://doi.org/10.1017/S1751731117003603

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), 2258. https://doi.org/10.18686/fsa2258

Srisuksai, K., Limudomporn, P., Kovitvadhi, U., Thongsuwan, K., Imaram, W., Lertchaiyongphanit, R., Sareepoch, T., Kovitvadhi, A., & Fungfuang, W. (2024). Physicochemical properties and fatty acid profile of oil extracted from black soldier fly larvae (*Hermetia illucens*). *Veterinary world*, 17(3), 518–526. https://doi.org/10.14202/vetworld.2024.518-526

St-Hilaire, S., Sheppard, C., Tomberlin, J.K., Irving, S., Newton, L., McGuire, M.A., Mosley, E.E., Hardy, R.W., & Sealey, W. (2007). Fly prepupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss*. *Journal of the World Aquaculture Society*, 38(1), 59–67. https://doi.org/10.1111/j.1749-7345.2006.00073.x

Su, H., Zhang, B., Shi, J., He, S., Dai, S., Zhao, Z., Wu, D., & Li, J. (2025). Black soldier fly larvae as a novel protein feed resource promoting circular economy in agriculture. *Insects*, 16(8), 830. https://doi.org/10.3390/insects16080830

Svobodova, Z., Lloyd, R., Machova, J., & Vykusova, B. (1993). Water quality and fish health. FAO. Rome: Italy.

Tippayadara, N., Dawood, M.A.O., Krutmuang, P., Hoseinifar, S.H., Van Doan, H., & Paolucci, M. (2021). Replacement of fish meal by black soldier fly (*Hermetia illucens*) larvae meal: Effects on growth, haematology , and skin mucus immunity of Nile Tilapia, *Oreochromis niloticus*. *Animals*, 11(1), 193. https://doi.org/10.3390/ani11010193

Tran, D.V., Tran, T.L.T., Doan, N.X., Dang, T.T., Hua, N.T., & Pham, H.Q. (2025). Comparative impact of synthetic and natural animal-derived carotenoids on growth, feed utilization, and pigment enhancement in *Amphiprion ocellaris*. *Fisheries and Aquatic Sciences,* 28(1), 10-20. https://doi.org/10.47853/FAS.2025.e2

Tschirner, M., & Simon, A. (2015). Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed. *Journal of Insects as Food and Feed*, 1(4), 249–259. https://doi.org/10.3920/jiff2014.0008

Tu, N.P.C., Ha, N.N., Linh, N.T.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. https://doi.org/10.1016/j.aquaculture.2022.738048

You, C.H., Li, H.W., Zhou, M., Lin, L., Dong, Y.W., Tan, X.H. & Huang, Y.H. (2024). Replacing Different Proportions of Fishmeal with *Hermitia illucens* Meal on the Growth, Health and Muscle Quality of Microp-terus Salmoides. *Acta Hydrobiologica Sinica*, 48(3), 372-383. http://dx.doi.org/10.7541/2024.2023.0159

Van Huis, A. (2013). Potential of insects as food and feed in assuring food security. *Annual review of entomology*, 58(1), 563-583. https://doi: 10.1146/annurev-ento- 120811-153704

Vernès, L., Granvillain, P., Chemat, F., & Vian, M. (2015). Phycocyanin from *Arthrospira platensis*. Production, extraction and analysis. *Current Biotechnology,* 4(4) , 481-491.

Zambrano Vera, D., Alcívar-Bazurto, M.-C., Gómez Zurita, S.N., Vinocunga-Pillajo, R.D., Romero-Vistín, A.-S., & Vallejo, C. (2025). Evaluation of the Effect of Black Soldier Fly Larvae Meal on the Growth of Aquatic Species: A Literature Review. *Revista Colombiana De Ciencias Pecuarias*. https://doi.org/10.17533/udea.rccp.e358626

Zhao, J., Pan, J., Zhang, Z., Chen, Z., Mai, K., & Zhang, Y. (2023). Fishmeal protein replacement by defatted and full-fat black soldier fly larvae meal in juvenile turbot diet: Effects on the growth performance and intestinal Microbiota. *Aquaculture Nutrition*, 2023, 8128141. https://doi.org/10.1155/2023/8128141

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), e0263924. https://doi.org/10.1371/journal.pone.0263924