Effects of defatted black soldier fly pupal meal on growth performance and nutrient utilization of juvenile blue swimming crab (*Portunus pelagicus*) cultured in a condo system

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Abstract
This study evaluated defatted black soldier fly (*Hermetia illucens*) pupal meal (BSFPM) as an alternative protein ingredient in diets for juvenile blue swimming crab (*Portunus pelagicus*), with emphasis on protein digestibility, growth, feed utilization, physiological responses, and body composition. *In vitro* protein digestibility of different black soldier fly preparations was first assessed using hepatopancreatic enzyme extracts from blue swimming crab. A subsequent 90-day feeding trial compared five formulated diets containing 0, 20, 30, 40, or 50% BSFPM and a trash-fish reference treatment. BSF pupa meal showed high *in vitro* protein digestibility (90.40%), comparable to fishmeal (89.75%). Dietary BSFPM produced a non-linear growth response. Crabs fed the fishmeal-based control diet showed the greatest overall growth, whereas growth was reduced particularly at 30 and 40% BSFPM. At 50% inclusion, however, specific growth rate (4.81% day^{-1}) approached that of the control (4.98% day^{-1}). Survival was unaffected by dietary treatment. Feed conversion ratio increased numerically from 1.46 in the control to 5.13 at 50% BSFPM, although differences among the formulated diets were not significant. Dietary BSFPM also altered hemolymph biochemical variables, carapace coloration, and whole-body composition. These findings demonstrate that the high *in vitro* digestibility of BSFPM does not necessarily translate into equivalent growth and feed-use efficiency in vivo. Defatted BSF pupal meal can provide digestible protein for juvenile *P. pelagicus*, but optimization of dietary nutrient balance and feed efficiency is required before a specific inclusion level can be recommended for practical feeds.

Keywords: blue swimming crab, BSF pupae meal, alternative protein, growth performance, condo culture

1. Introduction

The blue swimming crab (*Portunus pelagicus*) is one of the most commercially valuable marine crustaceans in the Indo-West Pacific region and supports important coastal fisheries and export industries. Its meat is widely marketed in North America and Europe, whereas roe and hepatopancreas are highly valued in several Asian countries (Wu et al., 2010). Despite its economic importance, continued exploitation of wild populations, together with habitat degradation, has resulted in declining stock abundance and reduced average body size, indicating increasing fishing pressure on natural resources (Yulianto et al., 2024). Expanding aquaculture production is therefore considered an important strategy to reduce dependence on capture fisheries while maintaining a stable supply for domestic consumption and export markets. However, feed remains one of the largest operating costs in crab farming and substantially influences production efficiency (Ariyati et al., 2024).

Fishmeal continues to serve as the principal protein source in aquafeeds because of its high digestibility and balanced amino acid profile. Nevertheless, its long-term use is increasingly challenged by fluctuating availability, rising prices, and concerns regarding the sustainability of marine resources (Tacon and Metian, 2015). These limitations have intensified the search for alternative protein ingredients that can maintain animal performance while reducing feed costs and environmental impacts. Among the available candidates, products derived from the black soldier fly (Hermetia illucens) have attracted considerable attention owing to their high protein content, favorable amino acid composition, and ability to be produced from organic side streams (Barragán-Fonseca et al., 2017; Henry et al., 2015; Makkar et al., 2014). Previous studies have demonstrated that black soldier fly meals can partially replace fishmeal in diets for several fish and shrimp species when appropriate inclusion levels are used (Cummins et al., 2017; Yao et al., 2024).

In blue swimming crab culture, individual rearing in stacked condo systems has become an effective management approach to minimize cannibalism, improve survival, and facilitate feeding and health management. This production

system also allows more accurate evaluation of dietary responses because feed intake and animal performance can be monitored with minimal interference among individuals. Consequently, the development of nutritionally balanced and economically viable formulated feeds is essential for maximizing the benefits of condo culture (Petersen et al., 2011). Although insect-derived ingredients have been extensively evaluated in finfish and penaeid shrimp, information regarding the nutritional value of black soldier fly products for *P. pelagicus* remains limited.

Therefore, the present study investigated the suitability of defatted black soldier fly pupal meal (BSFPM) as an alternative protein ingredient in formulated diets for juvenile blue swimming crab cultured under condo conditions. The study evaluated *in vitro* protein digestibility of BSF products together with the effects of graded dietary BSFPM inclusion on growth performance, feed utilization, molting activity, hemolymph biochemical responses, carapace coloration, and whole-body composition. The findings provide practical information for determining appropriate inclusion levels of BSFPM in formulated diets for blue swimming crab culture.

2. Materials and methods

2.1 Preparation of Black Soldier Fly (BSF) Samples

To compare the nutritional characteristics of different black soldier fly (BSF) preparations, larvae and pupae were processed using three preparation methods prior to chemical analysis. Fresh BSF samples were first cleaned and separated into three groups: (1) fresh samples stored at -20°C before analysis, (2) defatted fresh samples obtained by mechanical oil extraction after freezing at -20°C, and (3) defatted dried samples, in which the insects were oven-dried at 105°C for 2 h before mechanical oil extraction. Following processing, all defatted products were weighed and analyzed for proximate composition according to AOAC (2000). Chitin content was determined using the method described by Khantaphant and Akkarachaneeyakorn (2017).

2.2 Protein Digestibility Analysis

In vitro protein digestibility of black soldier fly (BSF) preparations and conventional protein ingredients was evaluated using crude hepatopancreatic enzyme extracts prepared from adult blue swimming crabs (120-150 g). Hepatopancreas tissues were homogenized in ice-cold 50 mM phosphate buffer (pH 7.5; 1:5, w/v), and the homogenates were centrifuged at 15,000 × g for 20 min at 4°C. The resulting supernatant was collected as the crude enzyme extract and stored at -20°C until analysis following the procedure of Giménez et al. (1999). Protease activity was determined using the azo-casein method described by Bezerra et al. (2005).

Prior to the digestibility assay, fishmeal, soybean meal, and the different BSF preparations were finely ground (<200 μm). Protein digestibility was determined following the *in vitro* procedure of Vu et al. (2017). Digestion reactions were conducted in triplicate at pH 9.0 and 30°C for 240 min under continuous agitation (150 rpm).

2.3 Feed Preparation

Five formulated diets were prepared to evaluate graded levels of defatted black soldier fly pupal meal (BSFPM). The fishmeal-based control diet contained no BSFPM, whereas the remaining four diets contained BSFPM at 20, 30, 40, or 50% (Table 1). Ground trash fish (blackchin tilapia) was included as an additional reference treatment representing a non-formulated feed.

For preparation of the formulated diets, dry ingredients were ground through a 50-mesh screen and thoroughly mixed before water was added at 30% to obtain a uniform dough. The mixture was then extruded, cut into uniform strips, and dried at 60°C for 12 h. Drying was continued for a further 6 h at the same temperature to improve pellet stability. The finished diets were kept under dry conditions until used in the feeding trial.

2.4 Experimental Procedure

The feeding trial was conducted using a completely randomized design with six dietary treatments: the fishmeal-based control, four diets containing 20, 30, 40, or 50% BSFPM, and the trash-fish reference treatment. Each treatment consisted of three replicates, with 10 juvenile blue swimming crabs per replicate. Crabs had an initial body weight of 2.45 ± 0.88 g and were maintained in box-condo units (30 × 4 × 20 cm) for 90 days in seawater at a salinity of 30 ppt. Crabs were fed twice daily at 08:00 and 17:00 h. The daily feeding rate was adjusted according to the stage of the trial, corresponding to 10% of biomass during days 0–30, 5% during days 31–60, and 3% during days 61–90. Uneaten feed was removed 4 h after feeding. Growth, survival, and molting were monitored throughout the experiment. Growth performance and feed utilization indices were calculated at the end of the feeding trial. Feed conversion ratio (FCR) was calculated on an as-fed basis for all dietary treatments.

Following completion of the feeding trial, hemolymph samples were collected for biochemical analysis. Exoskeleton samples were retained for chitin determination, and whole-body samples were collected for proximate composition analysis.

2.5 Blood Biochemical Analysis

Crabs were anesthetized by lowering the water temperature to below 10°C before hemolymph collection. Hemolymph (1 mL) was withdrawn from the walking legs using sodium citrate as an anticoagulant. Hemolymph osmolality was determined using an osmometer, whereas total protein, glucose, and triglyceride concentrations were measured using an automated biochemical analyzer.

2.6 Whole-body composition, chitin content, and carapace color

Whole-body samples were dried at 105°C and ground before chemical analysis. Moisture, crude protein, lipid, and ash were determined according to standard AOAC (2000) procedures.

Chitin content was determined following Khantaphant and Akkarachaneeyakorn (2017). Dried and ground samples were subjected to acid demineralization with HCl followed by alkaline deproteinization with NaOH. The recovered chitin was dried to constant weight and expressed relative to the initial dry weight of the sample.

For carapace color assessment, six crabs from each dietary treatment were randomly selected at the end of the feeding trial and immobilized in an ice slurry before measurement. Color was measured at four points on the carapace using a portable colorimeter and expressed according to the CIE Lab* color system.

2.7 Statistical analysis

Data were analyzed by one-way analysis of variance (ANOVA) to determine the effects of dietary treatment. When significant differences were detected, treatment means were compared using Duncan's multiple range test. Data are presented as mean ± standard error (SE), and differences were considered significant at $P < 0.05$.

3. Results

3.1 In vitro protein digestibility

In vitro protein digestibility differed among the tested protein sources ($P < 0.05$; Table 2). BSF pupa meal had the highest value (90.40%), although it did not differ significantly from BSF larval meal (88.93%) or fishmeal (89.75%). Fresh BSF larvae and dried BSF pupae showed intermediate digestibility values of 88.45 and 88.33%, respectively. Lower values were recorded for fresh BSF pupae (86.26%), dried BSF larvae (85.14%), and soybean meal (85.50%).

3.2 Growth performance, survival, and molting

Growth responses of juvenile blue swimming crabs were affected by dietary treatment during the 90-day feeding trial ($P < 0.05$; Table 3). Initial body weight did not differ among treatments. Crabs fed the fishmeal-based control diet attained the greatest final weight, weight gain, and specific growth rate. Growth was reduced at 20–40% BSFPM inclusion, with the lowest responses generally observed at 30 and 40%. At 50% BSFPM, growth improved relative to the 30 and 40% treatments, and specific growth rate did not differ significantly from that of the control group.

Survival was unaffected by dietary treatment ($P > 0.05$), ranging from 70 to 90%. Yield differed significantly among treatments, with the highest values recorded in the control and 50% BSFPM groups, whereas the 30% BSFPM treatment produced the lowest yield.

A total of 11 molting events was recorded in the control group during the feeding period. The corresponding values were 10, 8, 9, 10, and 9 events for crabs receiving 20, 30, 40, and 50% BSFPM and trash fish, respectively. Molting data were pooled observations and were therefore not subjected to statistical analysis.

3.3 Feed utilization and economic performance

Feed utilization differed among dietary treatments ($P < 0.05$; Table 4). Crabs receiving trash fish consumed substantially more feed than those receiving the formulated diets, with total feed intake reaching 159.31 g/crab compared with 15.15–26.41 g/crab for the formulated diets. Daily feed intake showed a similar response.

Feed conversion ratio (FCR) was markedly higher in the trash-fish group (34.28) than in all formulated-diet treatments ($P < 0.05$). Among the formulated diets, FCR increased numerically from 1.46 in the control to 5.13 at 50% BSFPM inclusion; however, these differences were not statistically significant.

Feed cost per crab increased with BSFPM inclusion, from USD 0.23 in the control treatment to USD 0.66 at 50% BSFPM. The trash-fish treatment had the highest feed cost per crab (USD 0.74). Overall economic indices differed among treatments, with the fishmeal-based control showing the most favorable production cost, whereas diets containing BSFPM showed lower economic performance.

3.4 Hemolymph biochemical parameters

Hemolymph biochemical responses differed among dietary treatments ($P < 0.05$; Table 5). Osmolality was higher in crabs fed the fishmeal-based control diet than in those receiving BSFPM-containing diets. Hemolymph glucose and triglyceride concentrations were generally higher in BSFPM-fed crabs than in the control and trash-fish groups. Total protein also differed among treatments.

3.5 Carapace color

Dietary treatment affected carapace color (Table 6). The b* value differed significantly among treatments ($P < 0.05$), with crabs fed the fishmeal-based control diet showing a higher value than those receiving BSFPM-containing diets. In contrast, L* and a* values were not significantly affected by dietary treatment ($P > 0.05$).

3.6 Whole-body composition

Whole-body composition varied among dietary treatments ($P < 0.05$; Table 7). Crabs receiving trash fish had higher body moisture than those fed the formulated diets. Whole-body crude protein was highest in the fishmeal-based control group and was generally lower in crabs receiving BSFPM-containing diets. Higher lipid content was recorded in the 20% BSFPM and trash-fish groups relative to most other treatments. Crude fiber, ash, and chitin contents tended to be greater at the higher BSFPM inclusion levels, particularly at 30–50%.

4. Discussion

The present study showed that defatted black soldier fly pupal meal (BSFPM) was readily digested by enzymes derived from the hepatopancreas of blue swimming crab, but its high *in vitro* protein digestibility did not consistently translate into improved growth or feed utilization in vivo. BSF pupa meal showed the highest numerical digestibility value among the tested protein sources and was comparable with fishmeal and BSF larval meal. This finding agrees with

previous reports describing the generally high nutritional value and protein availability of black soldier fly-derived ingredients (Barragán-Fonseca et al., 2017; Henry et al., 2015; Makkar et al., 2014). However, the discrepancy between *in vitro* digestibility and growth performance indicates that protein digestibility alone does not determine the nutritional value of BSFPM for *P. pelagicus*. Other dietary characteristics, including chitin content, mineral concentration, lipid composition, and amino acid balance, may influence nutrient utilization once the ingredient is incorporated into a complete diet (Soetemans et al., 2020; Le Boucher et al., 2024; Weththasinghe et al., 2021).

Growth responses to increasing BSFPM inclusion were not linear. The fishmeal-based control produced the greatest overall growth, whereas lower responses were observed particularly at 30 and 40% BSFPM. In contrast, growth improved again at 50% inclusion, with specific growth rate approaching that of the control treatment. This pattern suggests that the effect of BSFPM cannot be explained solely by increasing inclusion level. Variation in the balance among available protein, lipid, minerals, and indigestible fractions may have contributed to the observed response. Studies in other aquatic species have similarly shown that the nutritional value of insect meals depends not only on inclusion rate but also on processing method and the composition of the final diet (Henry et al., 2015; Makkar et al., 2014; Wang et al., 2024).

Feed utilization provided a different response from growth. Although FCR did not differ significantly among the formulated diets, it increased numerically as BSFPM inclusion increased. Thus, the relatively high growth observed at 50% BSFPM was accompanied by a less favorable feed conversion ratio than that of the control diet. This distinction is important because similar growth performance does not necessarily indicate equivalent nutrient-use efficiency. The progressive increase in FCR may be associated with changes in dietary nutrient balance and with greater proportions of components that are less efficiently utilized by the crab. Chitin, in particular, has been identified as a potential constraint on nutrient utilization when insect meals are included at high levels, although its effect varies among species and dietary conditions (Henry et al., 2015; Makkar et al., 2014; De los Santos-Romero et al., 2017).

Molting activity generally followed the variation in growth, although the pooled nature of the molting observations prevents statistical comparison among treatments. The control group recorded the greatest number of molting events, whereas somewhat fewer molts occurred in the 30 and 40% BSFPM groups. Because somatic growth in crustaceans is closely associated with the molting cycle, differences in nutrient and energy availability may influence both intermolt growth and the frequency of molt events (He et al., 2017; Yuan et al., 2022). Nevertheless, the present molting data should be interpreted cautiously because they were not analyzed statistically and therefore provide only descriptive support for the growth response.

Hemolymph biochemical variables were also affected by diet. Crabs fed BSFPM-containing diets generally showed lower osmolality but higher glucose and triglyceride concentrations than those receiving the fishmeal-based control. These changes indicate that replacement of fishmeal with BSFPM altered circulating metabolites and osmotic status. Hemolymph glucose and triglycerides are closely associated with energy metabolism in crustaceans, whereas osmolality reflects the balance between internal fluids and the surrounding medium (Cheng et al., 2005; Huang et al., 2019; Yao et al., 2021). The higher circulating energy metabolites observed in BSFPM-fed crabs may therefore reflect differences in nutrient metabolism or energy allocation. However, because metabolic flux and enzyme activities associated with these pathways were not quantified, the present data do not allow a specific physiological mechanism to be identified.

Dietary effects were also evident in carapace coloration. The b* value was higher in crabs receiving the fishmeal-based control than in those fed BSFPM-containing diets, whereas L* and a* were not significantly affected. Differences in b* may be related to the type and availability of dietary pigments, particularly carotenoids originating from marine ingredients (Maoka, 2011; Chaiyawat et al., 2009; Haque et al., 2023). Black soldier fly meals generally contain lower concentrations of marine carotenoids than fishmeal-based ingredients, which may partly explain the lower yellowness values observed in the BSFPM treatments (Hender et al., 2021; Ukwela et al., 2024; Sangsawang et al., 2024). Because L* did not differ significantly among treatments, the present results are better interpreted as a change in color tone rather than overall darkening or lightening of the carapace.

Whole-body composition further reflected differences among the dietary treatments. Crabs fed the fishmeal-based control had the highest body protein content, whereas BSFPM-containing diets generally resulted in lower protein deposition. Higher body lipid was observed in the 20% BSFPM and trash-fish treatments, while fiber, ash, and chitin increased at the higher BSFPM inclusion levels. These responses are consistent with compositional characteristics of insect-derived ingredients, particularly their chitin and mineral fractions (Soetemans et al., 2020). The increase in body ash and chitin at higher dietary BSFPM levels suggests that increasing inclusion altered not only nutrient intake but also the composition of deposited tissues.

Economic performance closely reflected feed utilization. Although BSFPM offers potential as an alternative protein ingredient, the diets containing BSFPM did not improve economic efficiency under the conditions of the present study. The numerical increase in FCR with greater BSFPM inclusion increased feed input relative to biomass gain, while the formulated control maintained the most favorable production cost. These results indicate that ingredient substitution should be evaluated on the basis of both biological performance and feed-use efficiency rather than ingredient digestibility alone.

Overall, defatted BSF pupal meal can contribute digestible protein to diets for juvenile *P. pelagicus*, but its nutritional value depends on the composition of the complete diet and cannot be predicted solely from *in vitro* protein digestibility. The non-linear growth response, together with the numerical deterioration in FCR and changes in hemolymph

metabolites and body composition, indicates that increasing BSFPM inclusion produces multiple nutritional responses rather than a simple dose-dependent effect. Further work should therefore focus on improving the nutrient balance of BSFPM-based diets and identifying which compositional factors limit feed efficiency at higher inclusion levels.

5. Conclusion

Defatted black soldier fly pupal meal (BSFPM) was efficiently digested by proteolytic enzymes from the hepatopancreas of juvenile blue swimming crab, with *in vitro* protein digestibility comparable to that of fishmeal. However, this high digestibility was not consistently reflected in growth performance or feed utilization. Dietary BSFPM produced a non-linear growth response, with reduced performance particularly at intermediate inclusion levels, whereas growth at 50% inclusion approached that of the fishmeal-based control. Feed conversion ratio nevertheless increased numerically with increasing BSFPM inclusion, indicating that growth response and feed-use efficiency were not closely aligned. Dietary BSFPM also affected hemolymph biochemical variables, carapace coloration, and whole-body composition. Overall, BSFPM represents a digestible alternative protein source for juvenile *Portunus pelagicus*, but its inclusion in formulated diets requires further optimization of dietary nutrient balance and feed efficiency before a specific replacement level can be recommended for practical production.

Research Ethic Approval

The procedures have been authorized by the Animal Ethics Committee for Experiments on Animals of Phetchaburi Rajabhat University and implemented in accordance with the experiment animal welfare regulation formulated by the Institute of Animals for Scientific Purposes Development (IAD) Thailand (Approval No. IACUC PBRU 270367002)

CRediT authorship contribution statement

The authors' responsibilities were as follows: RK conceptualized the study; RK, KK, JB and BY analyzed the data; RK, MA,PK wrote the manuscript; RK and BY review and edit. All authors took part in the study design, read the final manuscript, and provided comments and suggestions for improvements.

Declaration of Competing Interest

The authors declare that they have no conflict of interest.

Declaration of generative AI use

The authors used ChatGPT (OpenAI) solely to assist with English-language editing and to improve the clarity and readability of the manuscript. The authors reviewed and verified the revised text and take full responsibility for the scientific content, data, analyses, interpretations, and references.

Data availability

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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Table 1. Ingredients and proximate composition of experimental diets

Ingredients (%)	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
Fishmeal (60% CP)	30	27	27	27	25	-
Soybean meal (44% CP)	42	34	24	14	6	-
Defatted BSFPM	0	20	30	40	50	-
Shrimp meal	2	-	-	-	-	-
wheat gluten	17	12	12	12	12	-
Soybean oil	1.5	1.5	1.5	1.5	1.5	-
Fish oil	1.5	1.5	1.5	1.5	1.5	-
Lecithin	2	2	2	2	2	-
Alpha - starch	1	1	1	1	1	-
Premix[1]	1	1	1	1	1	-
Trash fish	-	-	-	-	-	100
Total	100	100	100	100	100	100
Feed cost (USD/Kg)	1.56	1.91	2.16	2.40	2.62	0.26
Proximate composition by analysis (%)						
Moisture	5.10 ± 0.08	4.13 ± 0.41	3.29 ± 0.09	3.54 ± 0.05	3.81 ± 0.09	73.86 ± 0.95
Protein	45.05 ± 0.21	45.36 ± 0.63	45.22 ± 0.25	45.05 ± 0.20	45.45 ± 0.65	12.18 ± 0.83
Fat	12.40 ± 0.06	14.74 ± 0.26	15.93 ± 0.53	13.54 ± 0.29	15.14 ± 0.52	19.59 ± 0.77
Fiber	11.26 ± 0.53	11.12 ± 0.36	11.39 ± 0.87	11.67 ± 0.65	11.64 ± 0.47	0.31 ± 0.09
Ash	10.65 ± 0.81	11.69 ± 1.87	12.53 ± 0.06	14.30 ± 0.72	15.01 ± 0.64	7.20 ± 0.66
NFE*	15.54 ± 0.34	12.96 ± 0.68	11.64 ± 0.35	11.9 ± 0.38	8.95 ± 0.47	7.86 ± 0.65

*NFE = 100- (moisture%+Crude protein%+Crude fiber % + Ether extract % + Ash %)

Note : Premix (1 kg) = vitamin A, 3000000 mg kg^{-1}; vitamin B1-Thiamin, 15000 mg kg^{-1}; vitamin B2-Riboflavin, 12500 mg kg^{-1}; vitamin B3-Niacin, 50000 mg kg^{-1}; vitamin B5-Pantothenic acid, 40000 mg kg^{-1}; vitamin B6-Pyridoxine, 20000 mg kg^{-1}; vitamin B7-Biotin, 750 mg kg^{-1}; vitamin B9-Folic acid, 3000 mg kg^{-1}; vitamin B12, 100 mg kg^{-1}; vitamin D, 1000000 µg kg^{-1}; vitamin E, 90000 mg $kg^{-1}$and vitamin K, 20000 mg kg^{-1};Ca, 150 mg kg^{-1}; P, 150 mg kg^{-1}; Cu, 20000 mg kg^{-1}; Fe, 40000 mg kg^{-1}; Mn, mg kg^{-1}; Se, 280 mg kg^{-1}; Zn, 40000 mg $kg^{-1}$and I, 2200 mg kg^{-1}.

Table 2. *in vitro* protein digestibility (%) of different preparations of BSF larvae and pupae using protease enzymes from the hepatopancreas of juvenile blue swimming crabs

Feedstuff	Protein digestibility of young crab
Dried Black Soldier Fly (BSF) pupa	88.33 ± 0.56[b]
Fresh Black Soldier Fly (BSF) pupa	86.26 ± 2.25[c]
Dried Black Soldier Fly (BSF) larvae	85.14 ± 1.00[c]
Fresh Black Soldier Fly (BSF) larvae	88.45 ± 1.23[b]
Black Soldier Fly (BSF) pupa meal	90.40 ± 0.68[a]
Black Soldier Fly (BSF) worm meal	88.93 ± 1.32[ab]
Fishmeal	89.75 ± 0.38[ab]
Soybean meal	85.50 ± 0.50[c]

Note: mean ± standard error (SE) in the same column, different letters indicate statistically significant differences. (P<0.05)

Table 3. Growth performance of juvenile blue swimming crabs fed experimental diets for 90 days

Parameter	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
Initial weight (g/crab)	2.45 ± 0.88 [a]	2.50 ± 0.93 [a]	2.50 ± 0.87 [a]	2.42 ± 0.91 [a]	2.49 ± 0.84 [a]	2.51 ± 0.87 [a]
Final weight (g/crab)	20.10 ± 3.50 [a]	15.73 ± 3.30 [b]	11.85 ± 1.92 [c]	11.96 ± 1.80 [c]	19.04 ± 3.10 [a]	14.27 ± 3.01 [b]
Weight gain (g/crab)	17.65 ± 2.95 [a]	13.23 ± 2.50 [b]	9.35 ± 1.18 [c]	9.54 ± 1.36 [c]	16.55 ± 2.42 [a]	11.76 ± 2.53 [b]
Percent weight gain (%)	778.01 ± 214.24 [a]	561.98 ± 107.66 [b]	401.17 ± 91.12 [c]	434.98 ± 141.40 [bc]	706.74 ± 153.44 [a]	504.00 ± 140.17 [bc]
Average daily gain (g/crab/day)	0.19 ± 0.03	0.14 ± 0.02	0.10 ± 0.01	0.10 ± 0.01	0.18 ± 0.02	0.13 ± 0.02
Specific growth rate (%/day)	4.98 ± 0.60 [a]	4.36 ± 0.40 [bc]	3.71 ± 0.44 [d]	3.82 ± 0.63 [d]	4.81 ± 0.46 [ab]	4.11 ± 0.59 [cd]
Survival rate (%)	70.00 ± 0.00 [a]	80.00 ± 0.00 [a]	80.00 ± 0.00 [a]	70.00 ± 0.00 [a]	70.00 ± 0.00 [a]	90.00 ± 0.00 [a]
Yield (g/replication)	20.28 ± 2.96[a]	14.84 ± 2.49 [b]	11.68 ± 2.14 [c]	12.31 ± 1.79 [bc]	18.63 ± 3.54 [a]	15.28 ± 2.02 [b]

Note: Values are presented as mean ± SE. Means within the same row with different superscript letters differ significantly (P < 0.05).

Table 4. Feed utilization and economic performance of juvenile blue swimming crabs fed experimental diets for 90 days

Parameter	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
Total feed intake (g/crab)	15.15 ± 1.69 [c]	25.92 ± 3.44 [b]	23.11 ± 2.87[bc]	21.05 ± 5.07[bc]	26.41 ± 2.19[b]	159.31 ± 14.70 [a]
Feed intake (g/crab/day)	0.33 ± 0.03 [b]	0.57 ± 0.07 [b]	0.53 ± 0.08 [b]	0.41 ± 0.12[b]	0.52 ± 0.10[b]	3.38 ± 0.40[a]
Feed conversion ratio	1.46 ± 0.22 [b]	2.63 ± 0.81[b]	3.31 ± 0.70 [b]	4.50 ± 1.02 [b]	5.13 ± 1.22[b]	34.28 ± 10.53 [a]
Feed cost (USD/crab)	0.23 ± 0.05 [d]	0.50 ± 0.08[c]	0.54 ± 0.08[c]	0.58 ± 0.09[bc]	0.66 ± 0.10[ab]	0.74 ± 0.09 [a]
Total cost (USD/ Kg.	10.05 ± 0.66 [d]	23.06 ± 0.82[c]	35.72 ± 0.71 [b]	43.74 ± 0.89 [a]	45.65 ± 0.70 [a]	43.08 ± 0.83 [ab]
B/C ratio	1.09 ± 0.23[a]	0.62 ± 0.17 [b]	0.31 ± 0.06 [b]	0.26 ± 0.06 [b]	0.29 ± 0.09 [b]	0.23 ± 0.06 [b]

Note: Values are presented as mean ± SE. Means within the same row with different superscript letters differ significantly (P < 0.05).

Table 5. Hemolymph biochemical parameters of juvenile blue swimming crabs fed experimental diets for 90 days

Blood biochemical	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
Osmolarity (Osm)	637.00 ± 0.04^{a}	559.50 ± 0.76^{ab}	520.75 ± 14.08^{bc}	531.50 ± 21.25^{b}	300.00 ± 42.91^{d}	437.50 ± 37.61^{c}
Triglyceride (mg/dL)	6.02 ± 2.75^{d}	20.25 ± 2.21^{b}	7.90 ± 1.93^{d}	24.13 ± 3.01^{a}	11.09 ± 0.52^{c}	12.84 ± 0.15^{c}
Glucose (mg/dL)	5.88 ± 0.93^{b}	3.730 ± 0.25^{c}	3.87 ± 0.54^{c}	13.64 ± 1.97^{a}	4.09 ± 1.05^{c}	1.05 ± 0.15^{d}
Protein (mg/ml)	8.66 ± 0.42^{d}	22.56 ± 3.67^{a}	16.42 ± 1.35^{b}	13.51 ± 0.60^{bc}	12.56 ± 1.10^{c}	15.80 ± 2.61^{b}

Note: Values are presented as mean ± SE. Means within the same row with different superscript letters differ significantly ($P < 0.05$).

Table 6. The carapace color of blue swimming crabs fed with experimental diets for 90-day

Parameter	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
L*	46.45 ± 4.17	38.85 ± 3.97	40.12 ± 1.91	39.33 ± 2.51	39.96 ± 3.33	38.29 ± 3.06
a*	13.69 ± 1.90	10.39 ± 1.26	10.68 ± 1.43	10.33 ± 1.68	10.41 ± 0.94	11.28 ± 1.52
b*	18.22 ± 3.50^{a}	9.25 ± 2.68^{b}	8.38 ± 2.41^{b}	8.47 ± 4.36^{b}	8.79 ± 0.92^{b}	8.37 ± 3.21^{b}

Note: Values are presented as mean ± SE. Means within the same row with different superscript letters differ significantly ($P < 0.05$).

Table 7. Whole-body chemical composition and carapace chitin content of juvenile blue swimming crabs fed experimental diets for 90 days

Chemical composition and Chitin (%)	Defatted BSFPM inclusion levels (%)					Trash fish
	0	20	30	40	50	
Moisture	5.08 ± 0.16^{c}	6.27 ± 0.49^{b}	2.04 ± 0.00^{e}	2.84 ± 0.40^{d}	5.12 ± 0.35^{c}	9.21 ± 0.57^{a}
Protein	33.36 ± 1.46^{a}	28.95 ± 0.03^{c}	28.73 ± 0.22^{c}	21.37 ± 1.77^{c}	23.19 ± 1.13^{c}	30.48 ± 1.20^{b}
Fat	7.73 ± 0.03^{c}	11.10 ± 1.69^{a}	8.77 ± 0.09^{bc}	9.17 ± 0.10^{b}	8.95 ± 0.57^{bc}	10.53 ± 0.39^{a}
Fiber	4.57 ± 0.20^{d}	6.75 ± 0.63^{bc}	9.18 ± 1.10^{a}	5.51 ± 0.80^{cd}	5.97 ± 0.05^{cd}	7.61 ± 1.29^{b}
Ash	44.54 ± 0.81^{c}	53.66 ± 3.20^{b}	58.83 ± 0.99^{a}	44.47 ± 1.94^{c}	54.58 ± 1.61^{ab}	42.27 ± 2.73^{c}
Chitin	17.25 ± 2.01^{d}	17.56 ± 0.76^{d}	15.84 ± 0.74^{d}	26.24 ± 1.64^{b}	28.93 ± 0.46^{a}	23.71 ± 0.44^{c}

Note: Values are presented as mean ± SE. Means within the same row with different superscript letters differ significantly ($P < 0.05$).

Figure 1. Different preparations of BSF larvae and pupae; A: Fresh BSF larvae, B: Fresh BSF pupae, C: Dried BSF larvae, D: Dried BSF pupae, E defattedBSF larvae, F defatted BSF pupae

Figure 2. Condo system for the rearing of blue swimming crabs and feeding regimes: (A) box condo culture system, (B) crab fed with trash fish, and (C) crab fed with experimental diet