Yuzuncu Yil University
Journal of Agricultural Sciences
(Yüzüncü Yıl Üniversitesi Tarım Bilimleri Dergisi)
https://dergipark.org.tr/en/pub/yyutbd

ISSN: 1308-7576 e-ISSN: 1308-7584

Research Article

Effects of Crab Shellmeal Inclusions to Fishmeal Replacement on the Survival, Growth, and Feed Utilization of Mangrove Crab *Scylla serrata* (Forsskal 1775)

Melodina D. HAIROL[1], Cherry T. NIAN[2], Ainulyakin H. IMLANI[3], Jurma A. TIKMASAN[4] Jurmin H. SARRI*[5]

[1,2,3,4,5]Mindanao State University-Tawi-Tawi College of Technology and Oceanography, College of Fisheries, Sanga-Sanga, Bongao, 7500, Tawi-Tawi, Philippines

[1]https://orcid.org/0000-0002-2800-667X, [2]https://orcid.org/0000-0001-5013-2739, [3]https://orcid.org/0000-0002-6123-4711
[4]https://orcid.org/0000-0002-6736-4664, [5]https://orcid.org/0000-0002-4798-0566

*Corresponding author e-mail: jurslink@gmail.com

Article Info

Received: 15.06.2022
Accepted: 01.11.2022
Online published: 15.12.2022
DOI: 10.29133/yyutbd.1131220

Keywords

Crab shellmeal,
Fishmeal,
Growth,
Mangrove crab,
Survival

Abstract: Mangrove crab *Scylla serrata* is associated with mangroves throughout the Indian and Pacific oceans. This species is crucial to aquaculture and fishing. As wild stocks decline and demand rises, mangrove crab aquaculture has become increasingly popular. However, feed development research and its quality are still meager in the industry. This study examined the interactive effects of different levels of crab shellmeal (CSM) to fishmeal (FM) replacement on proximate composition, feed utilization, carcass composition, growth, and survival performance of mangrove crab *S. serrata*. Four formulated diets were prepared, and one for chopped trash fish (TF) supplement: 30% FM and 0% CSM (Diet 1) as a negative control, 20% FM and 10% CSM (Diet 2), 10% FM and 20% CSM (Diet 3), 0% FM and 30% CSM (Diet 4), and TF as a positive control (Diet 5). Experiments were conducted in each group for 30 days with ten replicates. Results revealed that formulated diets using different levels of CSM and FM did not significantly affect mangrove crabs' growth and survival rates as well as feed utilization. However, the proximate composition of Diet 4 was significantly higher among other experimental diets. Moreover, the crab's whole body composition (ash, moisture, carbohydrates, crude protein, crude fat, and calories) with different levels of CSM and FM was significantly improved. Hence, it is possible to enhance the carcass composition and proximate composition by supplementing CSM; however, it has no effect on feed utilization, as well as the growth and survival rates of mangrove crab *S. serrata*.

To Cite: Hairol, M. D., Nian, C. T., Imlani, A. H., Tikmasan, J. A., Sarri, J. H., 2022. Effects of Crab Shellmeal Inclusions to Fishmeal Replacement on the Survival, Growth, and Feed Utilization of Mangrove Crab *Scylla serrata* (Forsskal 1775). *Yuzuncu Yil University Journal of Agricultural Sciences*, 32(4): 714-726. DOI: https://doi.org/10.29133/yyutbd.1131220

1. Introduction

Mangrove crab *S. serrata* (Forsskal, 1775), also known as green crab or mud crab, is one of the largest portunid species that lives along the coast and in mangrove swamps all along the Indo-Pacific coastline (Barnes et al., 2002; Le Vay et al., 2007; Shelley and Lovatelli, 2011). It has become increasingly popular in aquaculture due to its economic importance and is currently admired seafood all over the world because of its savory sweet flesh, larger size, and nutritional value (Sathiadhas and Najmudeen, 2004; Ali et al., 2011). As a matter of fact, mangrove crab is one of the most commonly

used ingredients in a number of dishes (Mirera, 2011). Together with shrimp and mollusks, it already ranks among the top most in-demand aquaculture products globally (Sathiadhas and Najmudeen, 2004). In 2020, crustacean production accounted for nearly 11 237 metric tons in world aquaculture, of which 159.4 metric tons came from crabs (FAO, 2022). Furthermore, aside from the delicious and nutritious crab meat, its shells are also demanded in the pharmaceutical industry for its high levels of chitin, which has a variety of applications such as water-repellent adhesive, oral mucoadhesive liquid, and wound dressings (Kato et al., 2003). Aquaculture is also exploring the possibility of using shells as a formulated feed ingredient because they contain chitin like krill (Ringo et al., 2012).

Mangroves' crabs are initially harvested in the wild (Agbayani, 2011; Mirera, 2011; Quinitio, 2017; Hasanuzzaman et al., 2014; Basu and Roy, 2018). Mangroves provide a high level of salinity and temperature and protect young against cannibalism and predators, which is why these species thrive in these areas (Baylon, 2010; Alberts-Hurbatsch et al., 2014). In addition to its undeniable importance to society, it is an integral part of the mangrove ecosystem since it is critical in nutrient cycling and energy transfer (Mirera, 2011). Thus, wild mangrove crabs are increasingly being collected, leading to increased concern that a decrease in their abundance might negatively affect their ecosystems (Alberts-Hubatsch et al., 2016). Furthermore, habitat destruction has been a serious concern resulting from the hunting of these wild species (Shelley, 2008). Due to high demand in the market, even juveniles of mangrove crabs (crab farming's main source of crab seeds) are still extracted despite rising concerns (Lindner, 2005). Due to its higher survival rate and resistance to disease than shrimps, the mangrove crabs trade is a reliable source of income and is also a good alternative for shrimp farmers (Marichamy and Rajapackiam, 2001). As a result, commercial mangrove crab culture initiatives are being developed (Williams and Field, 1999). Different techniques have been developed to achieve the best possible method for fattened crabs to survive and grow (Shelley, 2008; Agbayani, 2011; Petersen et al., 2011; Quinitio, 2017). In addition, there is an ongoing effort to develop alternative feeds that would produce better quality mangrove crabs, both in size and consistency (Alber, 2003).

Mangrove crabs consume fish, mollusks, crustaceans, sand, and detritus (Viswanathan and Raffi, 2015). However, as the culture of this product has grown, the supply of feeds has become a major problem (Alber, 2003). Particularly, trash fish, one of the fishmeal feeds to mangrove crabs, have competing demands with the growing human food consumption (Gasco et al., 2018). Therefore, mangrove crab culture may not be worthwhile due to the high prices of trash fish in response to the competing demand over the years. As a result of this problem, researchers have worked on formulating alternative feeds to fatten mangrove crabs, such as plant-based, algae, animal-based, insects, and crustacean feeds (Alber, 2003; Krogdahl, 2016; Gasco et al., 2018). Crab shellmeal has been used as a replacement for fishmeal in poultry and livestock (Vijayalingam and Rajesh, 2020). Due to the high chitin content of crustacean by-products such as shrimp heads and shells and crab shells, the use of these products in feed has gained an increasing amount of attention in recent years (Gasco et al., 2018). In food and pharmaceutical manufacturing, chitin is a biopolymer with various uses (Kato et al., 2003). Toppe et al. (2006) stated that crab by-products could be used as a feed in diets for the fish Atlantic cod, *Gadus morhua*. In crustaceans, such as prawn *Macrobrachium rosenbergii,* chitin diets are shown to advance growth (Kumar et al., 2006). In addition, increasing survival with chitin diets has been linked to removing potentially pathogenic bacteria from adult male shore crab *Carcinus maenas* (Powell and Rowley, 2007). However, researchers are still investigating whether crab shells can be used as a feed ingredient in aquaculture (Ringo et al., 2012). Considering this, the study examined the effectiveness of formulated feed incorporated with crab shells as a meal for mangrove crab *S. serrata* on survival, growth, proximate composition, feed utilization, and carcass composition.

2. Material and Methods

2.1. Study site and duration

This study was conducted at the Multi-Species Hatchery of the College of Fisheries, Mindanao State University Tawi-Tawi College of Technology and Oceanography (MSU-TCTO), Sanga-Sanga, Bongao Tawi-Tawi, Philippines (Figure 1) for a duration of 30 days.

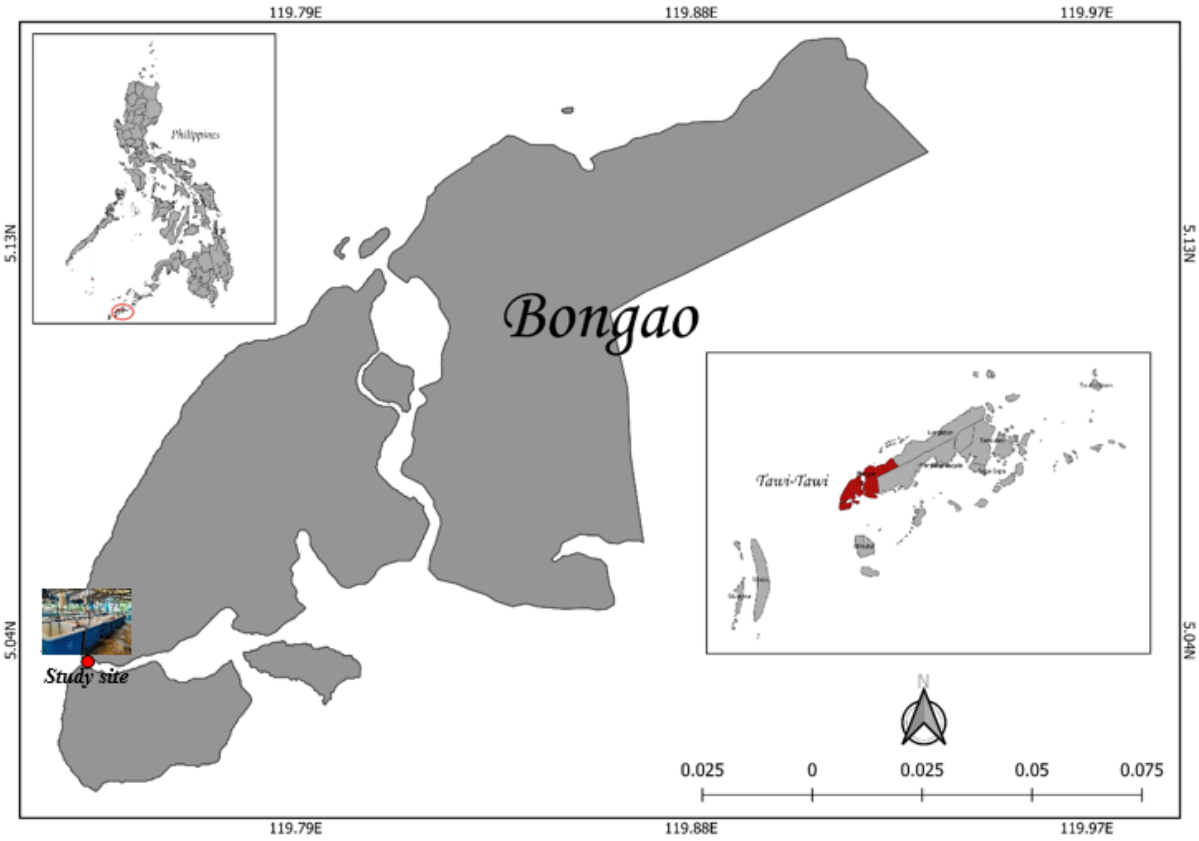

Figure 1. Map of the study site.

2.2. Source of crab shells and feed ingredients

Blue swimming crab (*Portunus pelagicus*) shells were used as the source of powdered crab shells from the carapace and pincers only because these parts of crab shells could be cleaned and powdered easily. These were collected from Crab Meat Processing Plant in Tubig Boh, Bongao, Tawi-Tawi, Philippines. Roughly 1.4 tons (wet weight) of crab shells (Figure 2) were discarded monthly by this processing plant (Pers. Com.). In addition, the feed ingredients used in the experiment were purchased from Bongao Public Market, as well as the fresh *Sardinella* sp. that was used for the positive control diet.

Figure 2. Discarded crab shell in Crab Meat Processing Plant, Bongao, Tawi-Tawi, Philippines.

2.3. Experimental Species

Mangrove crab *S. serrata* was used as an experimental animal, purchased from fisherfolk in Panglima Sugala, Tawi-Tawi, which was previously collected from mangrove areas. The crabs were transported by pump boat to Bongao, Tawi-Tawi, and landed at the MSU-TCTO Multi-purpose Hatchery.

Figure 3. Experimental animals.

2.4. Preparation of powdered crab shells

Blue swimming crab (*P. pelagicus*) shells were cleaned thoroughly and air-dried within five days until they could be crushed easily and ground using a grinder. The ground crab shells were sieved, packed in ziplock plastic, and stored at room temperature to be used to formulate experimental diets.

2.5. Preparation of treatment diets

Table 1 presents the ingredients of the experimental diet. Using locally available ingredients, crab shells were gradually substituted for fishmeal in a feed formulation. They were dried and processed, along with other ingredients for animal feed. The ingredients were powdered in an osteorizer and sieved through a 0.5 mm mesh siever. In an electric blender, with the binder dissolved in 500 mL of purified water, the ingredients were mixed according to the formula. The mixture was kneaded into a dough and formed into a spherical ball approximately 2.0 cm in diameter by hand (Ali et al., 2011). The spherical balls were steamed at atmospheric pressure for five minutes and dried in an electric oven at 60 ˚C for 12 hours to remove excess water. The dried feeds were stored in sealed plastic containers until used. There were five diets prepared, four experimental diets incorporated with 0% (negative control), 10%, 20%, and 30% powdered crab shells $kg^{-1,}$ respectively, and positive control (chopped *Sardinella* sp.). All treatment diets were evaluated using proximate analysis, which was done at Davao Analytical Laboratories Inc. (DALI) in Davao City and the Department of Science and Technology (DOST) in Region IX, Zamboanga City, Philippines.

Table 1. Composition of the treatment diets in crab shellmeal as replacement of fishmeal (g kg^{-1})

Ingredients	**Inclusion level**			
	0% Crab shell	10% Crab shell	20% Crab shell	30% Crab shell
Crab shell meal (g)	0	100	200	300
Fishmeal (g)	300	200	100	0
Copra meal (g)	300	300	300	300
Rice Bran (g)	300	300	300	300
Corn starch (g)	40	40	40	40
Palm Oil (mL)	40	40	40	40
NaCl (g)	19.5	19.5	19.5	19.5
Vitamin Premix (g)	0.5	0.5	0.5	0.5
Total	1 000	1 000	1 000	1 000

2.6. Stocking of crabs

Experimental animals to be considered were a young adult male and female mangrove crabs that have already reached sexual maturity (approximately 150 – 350 grams in weight). Prior to stocking, 50 crabs were used and acclimatized for one week with salinity ranging from 30 to 33 ppt and temperature from 26 to 30 °C. The crabs were subjected to an intensive environment where feeds were provided, the water was replenished, and waste was removed regularly. During the experiments, the crabs were randomly weighed (207.24 ± 7.66g), assigned, and stocked in 30-L plastic containers (one crab per container). Each treatment had ten replicates.

2.7. Water maintenance

The temperature and salinity of the water were monitored using a thermometer and refractometer. Prior to feeding each day, both parameters were checked before and after changing the water in the plastic containers. Every week, approximately 80% of the water was changed. Siphoning the container every early in the morning was done before changing the water to remove uneaten feeds.

2.8. Feeding

There were five dietary treatments used in the experiment: Diet 1 (30% FM and 0% CSM) as the negative control, Diet 2 (20% FM and 10% CSM), Diet 3 (10% FM and 20% CSM), Diet 4 (0% FM and 30% CSM crab), and Diet 5 (chopped *Sardinella* sp.) as the positive control. The experimental feeds and chopped *Sardenella* sp. were weighed and supplemented based on the weight of each crab per plastic container. Feeding was done once a day in the afternoon with 5% of the average body weight.

2.9. Experimental design

This study used a Completely Randomized Design (CRD) with five experimental diets and ten replicates for each diet (Figure 4). The experiment was conducted using a 50 rectangular clear plastic container (30 L volume capacity) half-filled with seawater with holes on its cover to enable air passage and another hole on its side that serve as excess water passage from the container.

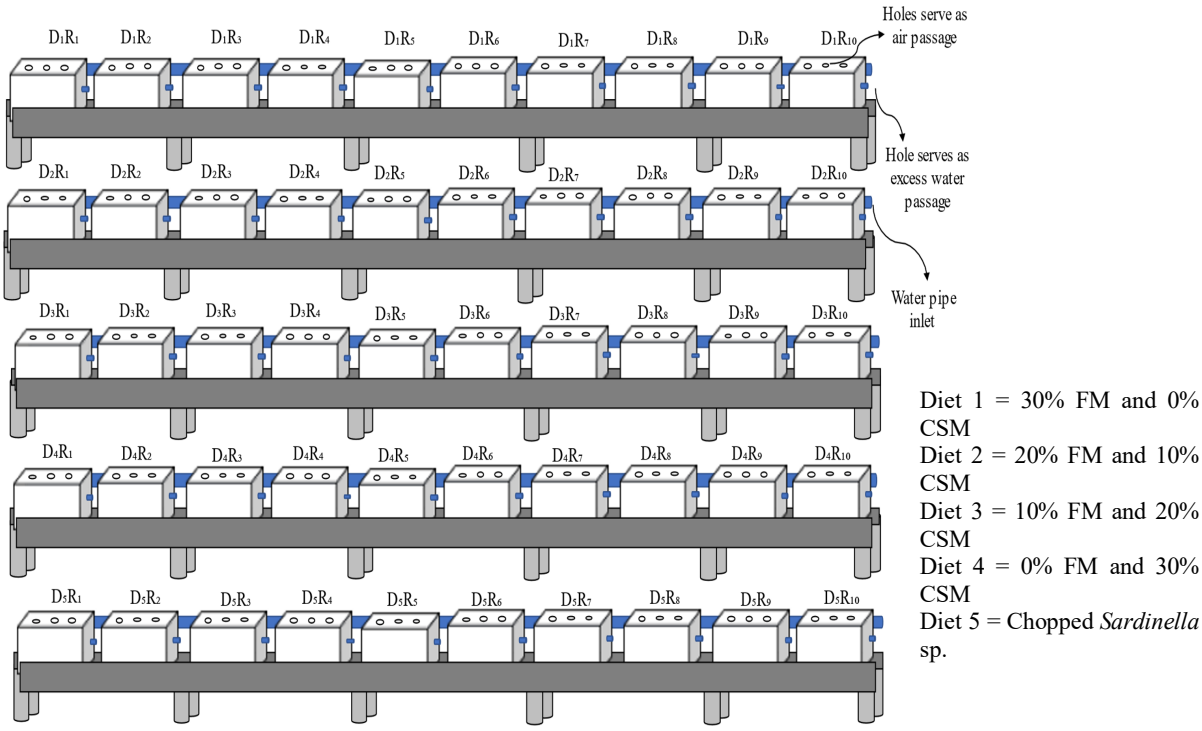

Figure 4. Experimental set-up of the study.

2.9. Sampling

Sampling was done every 15 days to determine the survival and growth rates. Analysis of the body composition was done at the end of the culture period. In order to avoid scaping the crab, a plastic bowl was used, which was weighed using a weighing scale, then tared to zero weight before placing the crab inside. Samples of treatment diets and body composition of experimental animals were sent to DOST, Zamboanga City, and DALI, Davao City, for proximate and carcass analysis such as ash, moisture, carbohydrates, crude fat, crude protein, crude fiber, and calorie. Proximate and carcass analysis was conducted after 30 days of the culture period. The survival rate, specific growth rate (SGR), and feed utilization were computed using the following formula (Kader et al., 2017):

A. Survival rate

$$Survival\ rate = \frac{Final\ number\ of\ stocks}{Initial\ number\ of\ stocks} \times 100 \quad (1)$$

B. Growth rate

$$WG\ (g) = ABWf - ABWi \quad (2)$$

$$SGR\ (\%\ Day) = \frac{\ln(ABWf) - \ln(ABWi)}{DOC} \times 100 \quad (3)$$

Where: WG = weight gain
ABWf = average body weight final
ABWi = average body weight initial
DOC = days of culture

C. Feed utilization

$$FCR = \frac{FI}{WG} \quad (4)$$

$$PER = \frac{WG}{FI} \times Diet\ CP \quad (5)$$

Where: FCR = feed conversion ratio
FI = feed intake
WG = weight gain
PER = protein efficiency ratio

2.10. Statistical analysis

The collected data were presented as mean ± standard error of the mean (SEM) and subjected to a one-way analysis of variance (ANOVA) using IBM SPSS 20.0 software package to identify significant differences in the different treatments in terms of growth, survival rate, and feed utilization at $\alpha = 0.05$. Levene's Test was used to test for homogeneity of variance, and Duncan's Post-Hoc Test was used to rank the mean.

3. Results

3.1. Proximate composition treatment diets

The proximate composition of treatment diets is shown in Table 2. Levels of ash content and carbohydrates varied from 5.57 ± 0.12 % – 15.23 ± 0.13 % and 1.16 ± 0.87 % – 38.23 ± 0.27 %,

respectively, indicating that Diet 4, which contains 30 % crab shellmeal inclusion significantly higher ($p<0.05$) among all diets. Moisture content ranged from 15.09 ± 0.04 % – 20.38 ± 0.18 %, where Diet 2, Diet 3, and Diet 4 were significantly lower ($p<0.05$) than Diet 1 and Diet 5. Crude fat levels varied from 9.60 ± 0.06 % – 28.47 ± 0.23 %. Diet 1 was significantly greater ($p<0.05$) in all diets in terms of crude fat. Levels of crude protein in all experimental diets ranged from 8.93 ± 0.22 % – 57.60 ± 0.70 %, where Diet 5 was significantly higher ($p<0.05$) among all diets. Crude fiber levels varied from 0.46 ± 0.04 % – 9.79 ± 0.41 %, and Diets 3 and 4 were significantly higher ($p<0.05$) in all diets.

Table 2. Proximate composition of experimental diets (%)

[1]Diet	Ash	Moisture	Carbohydrates	Crude fat	Crude protein	Crude fiber
Diet 1	5.57 ± 0.12^{e}	17.30 ± 0.10^{b}	28.63 ± 0.58^{d}	28.47 ± 0.23^{a}	20.03 ± 0.18^{b}	3.91 ± 0.27^{d}
Diet 2	9.33 ± 0.03^{d}	15.25 ± 0.05^{d}	31.73 ± 0.26^{c}	25.90 ± 0.17^{b}	17.77 ± 0.09^{c}	6.62 ± 0.44^{c}
Diet 3	11.67 ± 0.03^{b}	16.90 ± 0.08^{c}	35.80 ± 0.44^{b}	24.27 ± 0.43^{c}	11.30 ± 0.06^{d}	9.50 ± 0.59^{ba}
Diet 4	15.23 ± 0.13^{a}	15.09 ± 0.04^{d}	38.23 ± 0.27^{a}	22.53 ± 0.12^{d}	8.93 ± 0.22^{e}	9.79 ± 0.41^{a}
Diet 5	11.27 ± 0.12^{c}	20.38 ± 0.18^{a}	1.16 ± 0.87^{e}	9.60 ± 0.06^{e}	57.60 ± 0.70^{a}	0.46 ± 0.04^{e}

[1]Values are measures of triplicates. Means with the same letters within a row do not differ significantly (P> 0.05), n = 15.

3.2. Growth and survival performance and feed utilization

The gain weight and specific growth rate (SGR, % day^{-1}) of *S. serrata* are shown in Figures 4 and 5. The gain weight of Diet 1, Diet 2, Diet 3, Diet 4, and Diet 5 groups were 19.08 ± 7.48 g, 16.04 ± 2.93 g, 15.96 ± 1.91 g, 21.75 ± 7.91 g, and 23.87 ± 8.99 g, respectively. All experimental diets were not significantly different ($p>0.05$) in terms of weight gain after 30 days of the culture period. However, mangrove crab fed with Diet 4 was higher than Diet 2, Diet 3, and the negative control diet. Moreover, Diet 1, Diet 2, Diet 3, Diet 4, and Diet 5 achieved SGR of 0.26 ± 0.09 % day^{-1}, 0.26 ± 0.07 % day^{-1}, 0.26 ± 0.05 % day^{-1}, 0.35 ± 0.11 % day^{-1}, and 0.42 ± 0.18 % day^{-1}, respectively. All experimental diets were not significantly different ($p>0.05$). Nevertheless, Diet 4, which contains a 30 % diet of crab shellmeal inclusion fed on mangrove crab *S. serrata* obtained higher SGR, although there was no significant difference.

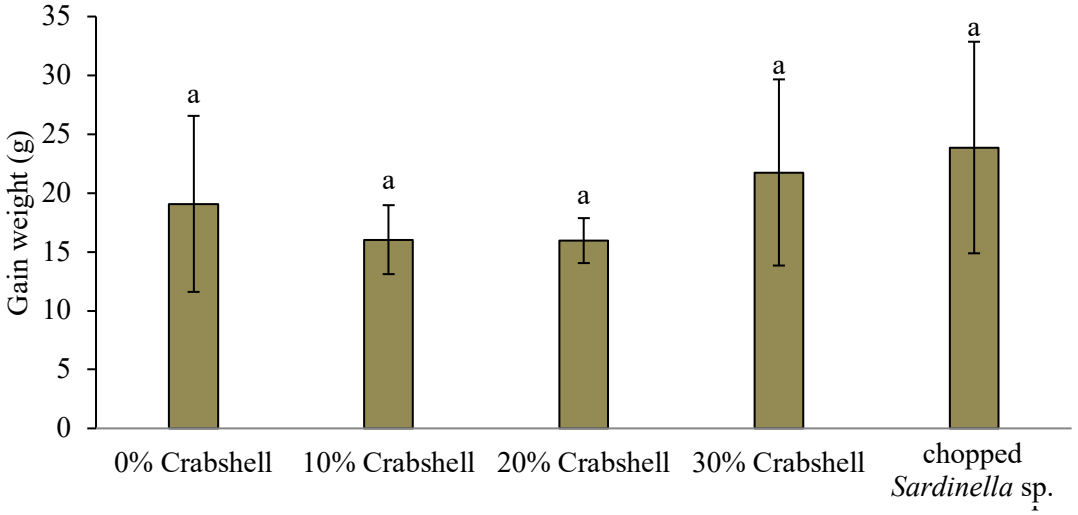

Figure 4. Gain weight performance of mangrove crab *S. serrata* fed with different diets after 30 days of culture. Diet 1 = 0% Crabshell, Diet 2 = 10% Crabshell, Diet 3 = 20% Crabshell, Diet 4 = 30% Crabshell, Diet 5 = Copped *Sardinella* sp. Bars with the same letters do not differ significantly (P> 0.05). Values are means ± S.E.M (standard error mean), n= 6 – 40.

The survival rate (SR, %) of Diet 1, Diet 2, Diet 3, Diet 4, and Diet 5 groups were 80.00 ± 13.33 %, 80.00 ± 13.33 %, 60.00 ± 16.33 %, 80 ± 13.33 %, and 100.00 ± 0.00 % (Figure 6). Inclusions of all levels of crab shellmeal fed on mangrove crab *S. serrata* were not significantly different among experimental diets in terms of SR. Moreover, Table 3 shows the feed intake (FI), feed conversion ratio

(FCR), and protein efficiency ratio (PER) values of mangrove crab *S. serrata.* The combination of fishmeal and crab shellmeal had no significant effects in terms of FI, FCR, and PER. However, the FI and FCR of all experimental diets were significantly higher ($p<0.05$) than those of trash fish (chopped *Sardinella* sp.), whereas the PER of trash fish was significantly higher ($p<0.05$) than that of all experimental diets.

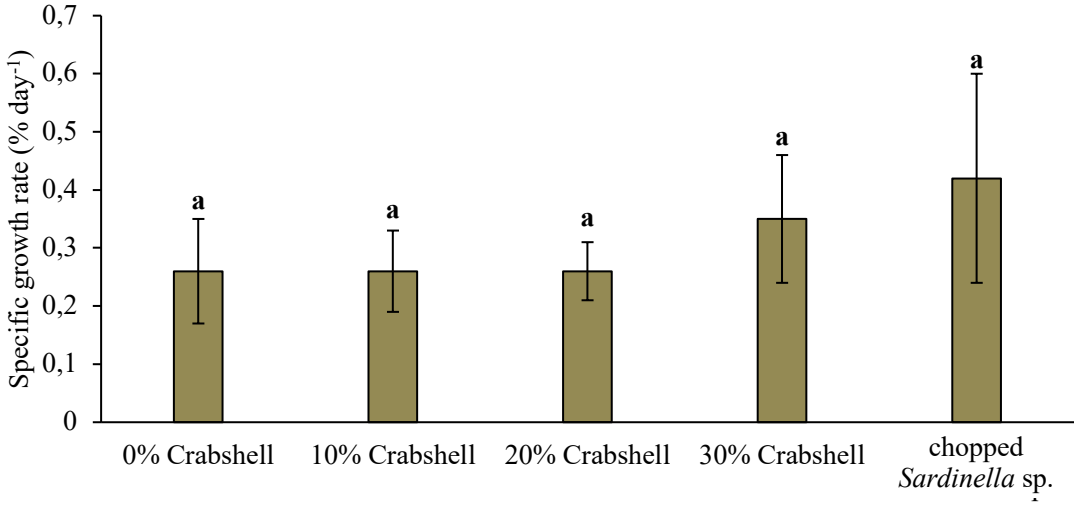

Figure 5. Growth performance (SGR) of mangrove crab S. serrata fed with different diets after 30 days of culture. Diet 1 = 0% Crabshell, Diet 2 = 10% Crabshell, Diet 3 = 20% Crabshell, Diet 4 = 30% Crabshell, Diet 5 = Copped Sardinella sp. Bars with the same letters do not differ significantly (P> 0.05). Values are means ± S.E.M (standard error mean), n= 6 – 40.

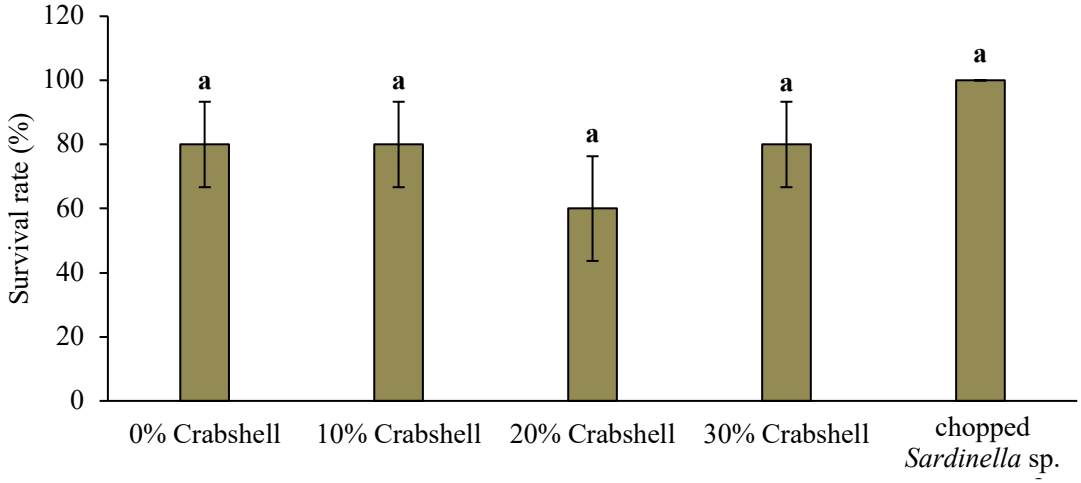

Figure 6. Survival rate of mangrove crab *S. serrata* fed with different diets after 30 days of culture. Diet 1 = 0% Crab shellmeal, Diet 2 = 10% Crab shellmeal, Diet 3 = 20% Crab shellmeal, Diet 4 = 30% Crab shellmeal, Diet 5 = Copped *Sardinella* sp. Bars with the same letters do not differ significantly (P> 0.05). Values are means ± S.E.M. (standard error mean), n = 10 – 50.

Table 3. Feed utilization of mangrove crab *S. serrata*

[1]Diets	FI	FCR	PER
Diet 1	261.94 ± 34.19^{a}	22.17 ± 3.73^{a}	1.41 ± 0.49^{b}
Diet 2	285.12 ± 27.81^{a}	22.23 ± 4.12^{a}	1.15 ± 0.33^{b}
Diet 3	265.43 ± 29.13^{a}	18.31 ± 3.40^{a}	0.75 ± 0.16^{b}
Diet 4	253.45 ± 14.17^{a}	21.30 ± 6.43^{a}	0.75 ± 0.25^{b}
Diet 5	115.71 ± 21.75^{b}	7.71 ± 1.99^{b}	161.81 ± 140.44^{a}

[1]Values are means ± S.E.M. (standard error mean). Means with the same letters within a row do not differ significantly (P> 0.05), n = 40.

3.3. Whole body proximate composition of mangrove crab

Proximate compositions of mangrove crabs are shown in Table 4. Ash content and moisture content varied from 21.53 ± 0.22 % – 31.60 ± 0.20 % and 7.69 ± 0.04 % – 21.48 ± 0.05 %, respectively, where crab fed with Diet 3 was significantly (P<0.05) greater among all diets. Carbohydrates ranged from 13.00 ± 0.10 % – 34.07 ± 0.87 %, indicating that crab fed with Diet 4 was significantly higher (P<0.05) in all experimental diets. Levels of crude fat ranged from 1.73 ± 0.18 % – 5.03 ± 0.07 %, where crab fed with Diet 2 and Diet 4 were significantly lower (P<0.05) than crab fed with Diet 1, Diet 3, and Diet 5. In addition, crude protein varied from 21.83 ± 0.73 % – 37.70 ± 0.12 %, where crab fed with Diet 2 was significantly greater (P<0.05) among all diets. Levels of calories ranged from 218.33 ± 1.45 % – 275.00 ± 1.15 %, indicating that crab fed with Diet 5 was significantly higher (P<0.05) among all experimental diets.

Table 4. Whole body composition of mangrove crab *S. serrata* (%)

[1]Diet	Ash	Moisture	Carbohydrates	Crude Fat	Crude Protein	Calorie
Diet 1	26.67 ± 0.20^{c}	16.33 ± 0.09^{b}	26.57 ± 0.35^{c}	3.00 ± 0.15^{b}	27.43 ± 0.24^{d}	243.00 ± 0.58^{c}
Diet 2	26.10 ± 0.15^{d}	21.48 ± 0.05^{a}	13.00 ± 0.10^{e}	1.73 ± 0.18^{d}	37.70 ± 0.12^{a}	218.33 ± 1.45^{e}
Diet 3	31.60 ± 0.20^{a}	7.69 ± 0.04^{e}	28.77 ± 0.20^{b}	2.47 ± 0.09^{c}	29.47 ± 0.19^{c}	255.33 ± 0.33^{b}
Diet 4	29.40 ± 0.23^{b}	12.79 ± 0.13^{d}	34.07 ± 0.87^{a}	1.90 ± 0.26^{d}	21.83 ± 0.73^{e}	241.00 ± 2.52^{d}
Diet 5	21.53 ± 0.22^{e}	16.09 ± 0.07^{cb}	25.07 ± 0.78^{d}	5.03 ± 0.07^{a}	32.30 ± 0.60^{b}	275.00 ± 1.15^{a}

[1]Values are means ± S.E.M. (standard error mean). Means with the same letters within a row do not differ significantly (P> 0.05), n = 15.

4. Discussion

CSM supplementation can enhance the proximate composition of experimental diets, thereby improving mangrove crab's whole body composition. However, CSM supplementation had no significant effect on feed utilization, as well as the growth and survival rates of mangrove crabs. In mangrove crab farming, shrimp diet and trash fish are commonly used. Therefore, developing an appropriate mangrove crab feed formulation is a priority area of research (Say and Ikhwanuddin, 1999; Zhao et al., 2016; Dayal et al., 2019; Aaqillah-Amr et al., 2022). A farmer can further enhance the quality of the feed by understanding the composition and reformulating the feed if the nutrients are not adequate to sustain the crabs. The crab's body is made of claws and legs, and its back shell is made of hard, opaque tissue called chitin (Cornwall, 2014). Chitin is a polymer that is found in arthropods' exoskeletons, such as crabs (Guerrero, 2000; Brock et al., 2003). Among the most abundant organic compounds in nature, chitin is made up of sugar molecules arranged in a network with a variety of uses, such as agriculture, aquaculture, and biotechnology (Beundia, 1999; Shamshina et al., 2020). About 10% of the shell of the mangrove crab *S. tranquebarica* contains chitin (Thirunavukkarasu and Shanmugam, 2009). Using underutilized by-products in the seafood industry as a substitute for costly FM in mangrove crab diets, the present study aims to develop a more cost-effective diet. By substituting FM with 30% CSM, it is evident that the survival and growth of mangrove crab *S. serrata* can be boosted, although not significantly different. In aquaculture nutrition, the replacement of FM with alternative protein sources has long been well-established for many crustacean and fish species, and research on crab species is meager. Species of crabs such as *Eriocheir sinensis* (Luo et al., 2011; Jiang et al., 2013), *S. serrata* (Nguyen et al., 2014), and *S. paramamosain* (Suwirya et al., 2009) have been studied to replace FM with different vegetable sources of protein. In addition, the fish bone meal (FBM) is regarded as a significantly improved source of dietary protein that can be used to replace 45% of FM in Atlantic cod diets. Luo et al. (2011) stated that it is possible to replace 40% of FM with rapeseed meal and soybean meal in the diet of *E. sinensis*. In addition, *S. paramamosain*, soybean meal, and corn gluten meal could replace 20 – 40% of FM (Suwirya et al*.,* 2009). In our study, 10 – 20% FM could be replaced with CSM for *S. serrata.* The higher level of FM could be replaced by animal protein sources, possibly

due to higher protein content, fatty acids, balanced amino acids, palatability, and less toxin or antinutrients (Kader et al., 2017).

FBM tended to increase dietary phosphorus, calcium, and ash contents, which helped to enhance Atlantic cod growth and feed consumption (Toppe et al., 2006). A crabstick (farm-made feed) developed for crab fattening increased moisture, crude protein, crude lipids, crude fiber, and total ash, thereby enhancing FI and FCR in blue swimming crab *P. pelagicus* (Kalidas et al., 2020). In the present study, increasing supplementation of CSM significantly affects dietary ash, moisture content, carbohydrates, crude fat, crude protein, and crude fiber. The nutrient composition of feed, such as ash, moisture content, carbohydrates, fat, protein, and fiber, can control the metabolism of crustaceans, shrimps, and other fishes, provide energy, and contribute to a living cell's functioning (Krogdahl et al., 2005; Ndome et al., 2010). For aquafeed ingredients, the PER is an effective parameter for measuring protein quality (Goytortua-Bores et al., 2006; Luo et al., 2011). In the present study, the FCR, PER, and FI showed no effect with different levels of CSM supplementation; hence, the feed utilization, growth, and survival of the mangrove crab *S. serrata* were not affected. In other studies, different levels of phospholipids enhanced feed utilization for kuruma shrimp (Michael et al., 2008), blue swimming crab (Li et al., 2014), and blant snout bream (Li et al., 2015), and black tiger shrimp (Kumaraguruvasagam et al., 2005).

CSM replacement changed the body composition of the *S. serrata*, such that ash, carbohydrates, moisture, crude fat, crude protein, and calories were significantly different ($p<0.05$). Kader et al. (2017) stated that there were no significant effects of replacing FM with FBM on the composition of whole bodies of *S. paramamosain.* However*,* the inclusion of phospholipids significantly improved crude lipids and crude protein content. Moreover, researchers have observed that dietary phospholipids positively affect protein retention in *Megalobrama amblycephala* (Li et al., 2015) and *Seriolla dumerilli* (Uyan et al., 2009). As shown in the body composition analysis, diets based on CSM (Diet 2, Diet 3, and Diet 4) contain higher levels of ash. Conversely, dietary FBM did not influence the whole body ash composition of *S. paramamosain* (Kader et al., 2017)**,** *Megalobrama amblycephala* (Li et al., 2015), *Penaeus monodon (*Kumaraguruvasagam et al., 2005), *Litopenaeus vannamei* (Gonzalez-Felix et al., 2002) and *Gadus morhua* (Toppe et al., 2006).

Conclusion

The results of this study suggest that fishmeal may be replaced with crab shellmeal from mangrove crab diet formulations. Supplementing crab shellmeal to the diets of mangrove crabs can enhance their whole body composition; however, it did not affect feed utilization, growth performance, and survival rate of the mangrove crab. By utilizing the by-products and waste products of crab meat processing plants, crab shellmeal can be the most cost-effective and efficient option for aquatic animal feed as it contains chitin and protein.

Acknowledgments

The authors are grateful to MSU-TCTO for the support given during the conduct of the study. The authors are also indebted to Maria Liza B. Toring-Farquerabao for the map. Finally, the authors greatly appreciate the insightful comments and suggestions from anonymous reviewers, which helped improve the manuscript.

References

Aaqillah-Amr, M. A., Hidir, A., David, M., Ahmad-Ideris, A. R., Muhammad-Zulhilmi, R., Julius, Y. F. S., Noordiyana, M. N., Abualreesh, M. H., Peng, T. H., Ma, H., & Ikhwanuddin, M. (2022). Development of semi-moist formulated feed for female orange mud crabs, Scylla olivacea (Herbst, 1796) broodstocks with graded lipid levels. *Animal Feed Science and Technology*, *290*, 115365. https://doi.org/10.1016/j.aqrep.2022.101209

Agbayani, R. F. (2001). Production economics and marketing of mud crabs in the Philippines. *Asian Fisheries Science*, *14*(2), 201-210. http://hdl.handle.net/10862/1886

Alber, R. 2003. Growth and Survival of Mud crab (*Scylla serrata*) Fed with Bagungon Meat (Telescopium telescopium) as Alternative Feed Ingredient in Mud crab Fattening. Presented during the National Research Symposium held at the BSWM Convention Hall

Alberts-Hubatsch, H., Lee, S. Y., Meynecke, J. O., Diele, K., Nordhaus, I., & Wolff, M. (2016). Life-history, movement, and habitat use of *Scylla serrata* (Decapoda, Portunidae): current knowledge and future challenges. *Hydrobiologia*, *763*(1), 5-21.

Alberts-Hubatsch, H., Yip Lee, S., Diele, K., Wolff, M., Nordhaus, I. (2014). Microhabitat use of Early Benthic Stage Mud Crabs, *Scylla serrata*, in Eastern Australia. *Journal of Crustacean Biology*, *34*(5), 604-610.

Ali, S. A., Dayal, J. S., & Ambasankar, K. (2011). Presentation and evaluation of formulated feed for mud crab *Scylla serrata*. *Indian Journal for Fisheries* 58(2): 67-73

Barnes, D. K. A., Dulvy, N. K., Priestley, S. H., Darwall, W. R. T., Choisel, V., & Whittington, M. (2002). Fishery characteristics and abundance estimates of the mangrove *crab Scylla serrata* in southern Tanzania and northern Moçambique. *African Journal of Marine Science*, *24*, 19-25.

Basu, S., & Roy, A. (2018). Economic assessment of mud crab (*Scylla Serrata*) culture as an adaptation strategy to salinity intrusion in south-west region of Bangladesh. *International Journal of Environmental Studies*, *75*(6), 891-902. https://doi.org/10.1080/00207233.2018.1470402

Baylon, J. C. (2010). Effects of salinity and temperature on survival and development of larvae and juveniles of the mud crab, *Scylla serrata* (Crustacea: Decapoda: Portunidae). *Journal of the World Aquaculture Society*, *41*(6), 858-873. https://doi.org/10.1111/j.1749-7345.2010.00429.x

Brock, T. D., Madigan, M. T., Martinko, J. M., & Parker, J. (2003). *Brock biology of microorganisms*. Upper Saddle River (NJ): Prentice-Hall, 2003.

Cornwall, J. (2014). Edible Crab Measuring Guide". *Retrieved on September*, *26*.

Dayal, J. S., Balasubramanian, C. P., Ambasankar, K., Jannathulla, R., & Claret, E. A. (2019). Effect of dietary protein level on fattening and mineral profiles of mud crab, *Scylla serrata*, in individual cages under mangrove ecosystem. *Aquaculture Research*, *50*(7), 1993-2003. https://doi.org/10.1111/are.14094

FAO. (2022). The State of World Fisheries and Aquaculture 2022. Towards Blue Transformation. Rome, FAO. https://doi.org/10.4060/cc0461en

Gasco, L., Gai, F., Maricchiolo, G., Genovese, L., Ragonese, S., Bottari, T., & Caruso, G. (2018). Fishmeal alternative protein sources for aquaculture feeds. In *Feeds for the aquaculture sector* (pp. 1-28). Springer, Cham.

Gonzalez-Felix, M. L., Lawrence, A. L., Gatlin III, D. M., & Perez-Velazquez, M. (2002). Growth, survival and fatty acid composition of juvenile *Litopenaeus vannamei* fed different oils in the presence and absence of phospholipids. *Aquaculture,* 205: 325–343. https://doi.org/10.1016/S0044-8486(01)00684-6

Goytortua-Bores, E., Civera-Cerecedo, R., Rocha-Meza, S., & Green-Yee, A. (2006). Partial replacement of red crab (*Pleuroncodes planipes*) meal for fish meal in practical diets for the white shrimp *Litopenaeus vannamei*: Effect on growth and in vivo digestibility. *Aquaculture,* 256: 414–422.

Guerrero, R. (2000). Brock biology of microorganisms.

Hasanuzzaman, A. F. M., Arafat, S. T., & Huq, K. A. (2014). Mud Crab (*Scylla spp.*) Aquaculture in the south-west Sundarbans region of Bangladesh. *Iraqi Journal of Aquaculture*, *11*(1), 57-83. https://doi.org/10.1111/j.1439-0426.2006.00757.x

Jiang, H. B., Chen, L. Q., Qin, J. G., Gao, L. J., Li, E. C., Yu, N., Sun, S. M., & Jiang, X. Q. (2013). Partial or complete substitution of fish meal with soybean meal and cottonseed meal in Chinese mitten crab *Eriocheir sinensis* diets. *Aquaculture International,* 21: 617–628.

Kader, M. A., Bulbul, M., Asaduzzaman, M., Abol-Munafi, A. B., Noordin, N. M., Ikhwanuddin, M., ... & Ali, M. E. (2017). Effect of phospholipid supplements to fishmeal replacements on growth performance, feed utilization and fatty acid composition of mud crab, *Scylla paramamosain* (Estampador 1949). *J Sustain Sci Manag*, *2017*, 47-61.

Kader, M. A., Koshio, S., Ishikawa, M., Yokoyama, S., Bulbul, M., Nguyen, B. T., Gao, J., & Laining, A. (2012). Can fermented soybean meal and squid by-product blend be used as fishmeal replacements for Japanese flounder (*Paralichthys olivaceus*). *Aquaculture Research,* 43: 1427–1438. https://doi.org/10.1111/j.1365-2109.2011.029455.x

Kalidas, C., Prabu, D. L., Ranjith, L., Kavitha, M., & Vimalkumaran, S. (2020). Portunid crab fattening in indigenous re-circulatory cellular units: a sensitivity analysis. *Journal of Experimental Zoology, India*, *23*(2), 1771-1781.

Kato, Y., Onishi, H., & Machida, Y. (2003). Application of chitin and chitosan derivatives in the pharmaceutical field. *Current Pharmaceutical Biotechnology*, *4*(5), 303-309. https://doi.org/10.2174/13892010334897448

Krogdahl, A. 2016. The Fishmeal Meal Dilemma – what are the alternatives?. Proceedings of the aquaculture breakout session at the 2016 World Nutrition Forum in Vancouver, Canada

Krogdahl, Å., Hemre, G. I., & Mommsen, T. P. (2005). Carbohydrates in fish nutrition: digestion and absorption in postlarval stages. *Aquaculture nutrition*, *11*(2), 103-122. https://doi.org/10.1111/j.1365-2095.2004.00327.x

Kumar, P., Sahu, N. P., Saharan, N., Reddy, A. K., & Kumar, S. (2006). Effect of dietary source and level of chitin on growth and survival of post-larvae *Macrobrachium rosenbergii*. *Journal of Applied Ichthyology*, *22*(5), 363-368.

Kumaraguruvasagam, K. P., Ramesh, S., & Balasubramanian, T. (2005). Dietary value of different vegetable oil in black tiger shrimp *Penaeus monodon* in the presence and absence of soy lecithin supplementation: effect on growth, nutrient digestibility and body composition. *Aquaculture,* 250: 317–327. https://doi.org/10.1016/j.aquaculture.2005.02.035

Le Vay, L., Ut, V. N., & Walton, M. (2007). Population ecology of the mud crab *Scylla paramamosain* (Estampador) in an estuarine mangrove system; a mark-recapture study. *Marine Biology*, *151*(3), 1127-1135.

Li, X., Wang, J., Han, T., Hu, S., Jiang, Y., & Wang, C. (2014). Effect of dietary phospholipids levels and sources on growth performance, fatty acid composition of the juvenile swimming crab, *Portunus trituberculatus*. *Aquaculture,* 430: 166– 172. https://doi.org/10.1016/j.aquaculture.2014.03.037

Li, Y., Gao, J., & Huang, S. (2015). Effects of different dietary phospholipid levels on growth performance, fatty acid composition, PPAR gene expressions and antioxidant responses of blunt snout bream *Megalobrama amblycephala* fingerlings. *Fish Physiology and Biochemistry,* 41: 423–436.

Lindner, R. K. (2005). *Impacts of mud crab hatchery technology in Vietnam* (No. 434-2016-33653). Australian Centre for International Agricultural Research, pp. 66

Luo, Z., Li, X. D., Wang, W. M., Tan, X. Y., & Liu, X. (2011). Partial replacement of fish meal by a mixture of soybean meal and rapeseed meal in practical diets for juvenile Chinese mitten crab *Eriocheir sinensis*: effects on growth performance and in vivo digestibility. *Aquaculture Research,* 42: 1616–1622. https://doi.org/10.1111/j.1365-2109.2010.02751.x

Marichamy, R., & Rajapackiam, S. (2001). The aquaculture of *Scylla* species in India. *Asian Fisheries Science*, *14*, 231-238. Michael, F. R., & Koshio, S. (2008). Biochemical studies on the interactive effects of dietary choline and inositol in juvenile Kuruma shrimp, *Marsupenaeus japonicus*. *Aquaculture,* 285: 179–183. https://doi.org/10.1016/j.aquaculture.2008.08.006

Mirera, O. D. (2011). Trends in exploitation, development and management of artisanal mud crab (*Scylla serrata*-Forsskal-1775) fishery and small-scale culture in Kenya: An overview. *Ocean & coastal management*, *54*(11), 844-855. https://doi.org/10.1016/j.ocecoaman.2011.08.001

Ndome, C., Oriakpono, O., & Ogar, A. (2010). Proximate composition and nutritional values of some commonly consumed fishes from the Cross River Estuary. *Tropical Freshwater Biology*, *19*(1), 11.

Nguyen, N. T. B., Chim, L., Lemaire, P., & Wantiez, L. (2014). Feed intake, molt frequency, tissue growth, feed efficiency and energy budget during a molt cycle of mud crab juveniles, *Scylla serrata* (Forskal, 1775), fed on different practical diets with graded levels of soy protein concentrate as main source of protein. *Aquaculture,* 434: 499–509. https://doi.org/10.1016/j.aquaculture.2014.09.014

Petersen, E. H., Suc, N. X., Thanh, D. V., & Hien, T. T. (2011). Bioeconomic analysis of extensive mud crab farming in Vietnam and analysis of improved diets. *Aquaculture Economics & Management*, *15*(2), 83-102. https://doi.org/10.1080/13657305.2010.549164

Powell, A., & Rowley, A. F. (2007). The effect of dietary chitin supplementation on the survival and immune reactivity of the shore crab, *Carcinus maenas*. *Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology*, *147*(1), 122-128. https://doi.org/10.1016/j.cbpa.2006.12.027

Quinitio, E. T. (2017). Overview of the mud crab industry in the Philippines. In *Philippines: In the forefront of the mud crab industry development: proceedings of the 1st National Mud Crab Congress, 16-18 November 2015, Iloilo City, Philippines* (pp. 1-12). Aquaculture Department, Southeast Asian Fisheries Development Center. http://hdl.handle.net/10862/3159

Ringo, E., Zhou, Z., Olsen, R. E., & Song, S. K. (2012). Use of chitin and krill in aquaculture–the effect on gut microbiota and the immune system: a review. *Aquaculture Nutrition*, *18*(2), 117-131. https://doi.org/10.1111/j.1365-2095.2011.00919.x

Sathiadhas, R., & Najmudeen, T. M. (2004). Economic evaluation of mud crab farming under different production systems in India. *Aquaculture Economics & Management*, *8*(1-2), 99-110. https://doi.org/10.1080/13657300409380355

Say, W. C., & Ikhwanuddin, A. M. (1999). Pen culture of mud crabs, genus *Scylla*, in the mangrove ecosystems of Sarawak, East Malaysia. In *ACIAR Proceedings* (pp. 83-88). *Australian Centre for International Agricultural*

Shamshina, J. L., Kelly, A., Oldham, T., & Rogers, R. D. (2020). Agricultural uses of chitin polymers. *Environmental Chemistry Letters*, *18*(1), 53-60.

Shelley, C. (2008). Capture-based aquaculture of mud crabs (*Scylla spp*.). *Capture-based aquaculture. Global overview. FAO Fisheries Technical Paper*, *508*, 255-269.

Shelley, C., & Lovatelli, A. (2011). Mud crab aquaculture: a practical manual. *FAO Fisheries and aquaculture technical paper*, (567). Food and Agriculture Organization of the United Nations. Rome, 80p

Suwirya, K., Giri, N. A., & Marzuqi, M. (2009). Replacement of fish meal protein by soybean and corn gluten meal proteins in the diet of mud crab, *Scylla paramamosain*. *Indonesian Aquaculture Journal,* 4: 75–78. http://dx.doi.org/10.15578/iaj.4.1.2009.75-78

Thirunavukkarasu, N., & Shanmugam, A. (2009). Extraction of chitin and chitosan from mud crab Scylla tranquebarica (Fabricius, 1798). *International Journal on Applied Bioengineering*, *4*(2), 31-33.

Toppe, J., Aksnes, A., Hope, B., & Albrektsen, S. (2006). Inclusion of fish bone and crab by-products in diets for Atlantic cod, *Gadus morhua*. *Aquaculture,* 253: 636– 645. https://doi.org/10.1016/j.aquaculture.2005.09.015

Uyan, O., Koshio, S., Ishikawa, M., Yokoyama, S., Uyan, S., Ren, T., & Hernandez, L. H. H. (2009). The influence of dietary phospholipid level on the performances of juvenile amberjack, *Seriola dumerili*, fed non-fishmeal diets. *Aquaculture Nutrition,* 15: 550–557. https://doi.org/10.1111/j.1365-2095.2008.00621.x

Vijayalingam, T. A. & Rajesh, N. V. (2020). Analysis of Nutritional Value of crab meal as feed supplement for Livestock and Poultry. *Chemical Science Review and Letters*, *9* (35), 773-776. https://doi.org/10.37273/chesci.CS205107195

Viswanathan, C., & Raffi, S. M. (2015). The natural diet of the mud crab *Scylla olivacea* (Herbst, 1896) in Pichavaram mangroves, India. *Saudi Journal of Biological Sciences*, *22*(6), 698-705. https://doi.org/10.1016/j.sjbs.2015.08.005

Williams, G., & Field, D. (1999). Development of hatchery practices for the culture of mud crabs in Northern Australia. *World Aquaculture-Baton Rouge*, *30*(4), 56-58.

Zhao, J., Wen, X., Li, S., Zhu, D., & Li, Y. (2016). Effects of different dietary lipid sources on tissue fatty acid composition, serum biochemical parameters and fatty acid synthase of juvenile mud crab *Scylla paramamosain* (E stampador 1949). *Aquaculture Research*, *47*(3), 887-899. https://doi.org/10.1111/are.12547