Pelleted Diets for Farmed Decapods

Subjects: Zoology

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The current practice of decapod aquaculture involves the provision of juveniles with food such as natural diet, live feed, and formulated feed. Knowledge of nutrient requirements enables diets to be better formulated. By manipulating the levels of proteins and lipids, a formulated feed can be expected to lead to optimal growth in decapods. The use of formulated feed for decapods at a commercial scale is still in the early stages. This is probably because of the unique feeding behavior that decapods possess: being robust, slow feeders and bottom dwellers, their feeding preferences change during the transition from pelagic larvae to benthic juveniles as their digestive systems develop and become more complex.

Keywords: feed ; feeding diets ; macro-micronutrients ; feeding behavior ; pellet–decapod performances

1. Historical Developments in Cultivation

Decapods are valuable sources of aquatic food protein, and their fisheries and aquaculture support the economic growth of many coastal countries [1]. The increasing demand for seafood products has led to considerable interest in cultivating decapod species at a larger scale. The cultivation of decapods in various countries began during the 1980s with raising juveniles from the wild. In 2018, aquaculture reported a strong growth in decapod production, primarily of penaeid shrimp, crabs, and spiny lobsters (9.4 million tons), as compared with the previous year [2].

The success of decapod farming is dependent on the variety of diets [3][4][5]. Current practices of commercially decapod farming involve the provision of juveniles with food such as natural diet, live feed, and formulated feed [6]. The developments of a formulated feed for decapods begins with the use of fish oil (FO) and fishmeal (FM) as the main sources of lipids and proteins, with other ingredients such as wheat flour being the main source of carbohydrates (CHO). The inclusion of vitamins and minerals, probiotics, and other feed additives, when combined, satisfy the growth demand.

Current research into the development of decapod formulated feeds is geared towards the juvenile stage, but limited information is available on decapod groups in the adult stage. This is probably because of the unique feeding behavior that decapods possess: being robust [7], slow feeders [8] and bottom dwellers [9]. In addition, most published studies on commercially farmed decapod nutrition lack data on the physical characteristics of the feeds, such as water stability, palatability, and digestibility. Due to these issues, it is difficult to establish a standard feed formulation that focuses on physical pellet properties.

2. Decapod Feeding Biology

Decapods typically have two pairs of appendages (antennules and antennae) in front of the mouth and paired appendages near the mouth that function as jaws, which affects their feeding selection. Many decapod crustaceans are described as bottom feeders and scavengers that feed on dead animals that reside on the seafloor [10].

In addition, several species are restricted to certain environments that affect the feeding selection between species and between life stages [11][12][13][14].

Moreover, feeding preferences also change at different growth stages, for example, the pelagic larvae of many decapod groups such as shrimp and crabs are generally opportunistic, preying on anything suspended in the water, such as plankton (phyto- and zooplankton) [15].

2.1. Factors That Affect Feeding of Decapods

2.1.1. Biotic Factors

Biotic factors that affect feeding selection in decapods involve the sensory basis, which includes vision, chemoreception, mechanoreception, and electrosensory systems. In adult decapods such as prawns, shrimps, and crabs, vision is not as important as the other sensory systems since they are nocturnal [10][16][17]. At the same time, other decapods such as the tropical spiny lobster use chemoreception to locate food from the beginning of the juvenile stage since this species resides on the seafloor [18].

On the other hand, mechanoreception is defined as the ability of a decapod to detect and respond to mechanical stimuli such as touch, sound, and changes in pressure or posture in their surrounding environment. In decapods, mechanoreception is used to avoid predators or detect prey.

2.1.2. Abiotic Factors

Abiotic factors such as light and day length, temperature, water quality, and the physical properties of the food greatly affect decapod feeding responses. The presence of light is especially important in the decapod during larval stages because, compared with adult decapods, they are primarily nocturnal during the mature stage [19].

Meanwhile, water quality directly affects feeding responses in decapods. Decapod species depend on their chemical senses for foraging and social interactions, so a low water quality may result in a low feeding rate.

3. Nutritional Requirements of Juvenile Stages

In decapod feedings, protein, lipid, and carbohydrate (CHO) are described as the most important components of the nutrient classes, acting as the main sources of nutrients for embryonic development and growth [20]. Table 1 shows the macro- and micronutrients of different decapod groups during the juvenile stages.

Table 1. Macro and micronutrients in feed formulation of decapods during juvenile stages.

Decapod Group	Macronutrients						Micronutrients		
	Protein	Carbohydrates	Lipid Derivatives				Vitamin	Mineral	Feed Additives
			Lipid	Cholesterol	Fatty Acids	Carotenoid			
Prawn	47.3%	N/A	7.5%	0.5%	3.0% EFA	Carophyll pink: 0.15%	1.6%	2.0%	Ethoxyquin, squid mantle muscle, L-a-phosphatidylcholine crystalline amino acids, sodium alginate, tetra-sodium-pyrophosphatem, α cholestane, α-cellulose
	Isonitrogenous feed 39%	30.8–32.50%	10.15–10.48%	N/A	n-3/n-6: 0.54–0.65	N/A	1.0%	1.0%	Shrimp shell meal, corn grain
	39.18%	35.47%	6.91%	N/A	n-3/n-6: 0.69 EPA/DHA: 0.81	N/A	1.0%	2.5%	Soybean lecithin, choline chloride, cellulose, squid paste, calcium phosphate, beer yeast cell, spray dried blood powder

Decapod Group	Macronutrients						Micronutrients		Feed Additives
	Protein	Carbohydrates	Lipid Derivatives				Vitamin	Mineral	
			Lipid	Cholesterol	Fatty Acids	Carotenoid			
Shrimp	Isonitrogenous feed 21% dry weight	N/A	77.1–85.9%	3%	N/A	N/A	2.5%	2.0%	Soy lecithin, antifungic, antioxidant (ethoxyquin), Vitamin E
	30%	42.1%	6%	0.5%	N/A	N/A	1.0%	4.7%	Lecithin, alpha cellulose, alginate, sodium hexametaphosphate
	35%	N/A	8%	0.2%	DHA: 0.5% ARA: 0.13%	N/A	2.0%	0.5%	Calcium phosphate dibasic, lecithin, StayC
	32.1%	48.1%	5.84%	N/A	N/A	N/A	8.53%	8.53%	Soybean lecithin, alginic acid
	40.08–42.93%	33.09–36.4%	7.37–8.39%	0.1%	N/A	N/A	0.5%	0.2%	Lecithin, alginate
	34.2% to 36.3% dry weight	40.5% to 44.3%	3.9% to 6.0% dry weight	N/A	N/A	N/A	1.8%	0.5%	Choline chloride, Stay-C 35% active
	36%	N/A	8%	0.1%	N/A	N/A	1.8%	0.5%	Choline chloride, Stay-C250 mg/kg, CaP-diebasic, lecithin, chromium oxide
	42.2%	N/A	9.1%	0.5%	N/A	N/A	2.0%	2.0%	Calcium phosphate soya lecithin
	39.7%	30.7%	9.45%	0.16%	N/A	N/A	0.28%	0.28%	Krill meal, monocalcium phosphate, lecithin
	34.8% protein in feed with soy meal and 29.3% protein in feeds with FM	38.76% in feed with soy meal and 22.45% in feed with FM	6.65% in feed with soy meal and 5.84% in feeds with FM	N/A	N/A	N/A	0.93% in feed with soy meal and 0.85% in feed with FM	0.93% in feed with soy meal and 0.85% in feed with FM	Soy lecithin, alginic acid, cellulose, antioxidant
	35.8% to 36.6% dry weight	34.7% to 38.9%	7.9% to 8.1%	0.2%	N/A	N/A	0.5%	0.5%	Lecithin-soy, methionine, lysine, titanium dioxide
	Isonitrogenous feed 40% dry weight	N/A	Isolipidic feed 9.00% dry weight	0.02%	N/A	N/A	1.2%	1.0%	Lecithin powder 97%, amygluten
	Isonitrogenous feed 35% dry weight	31.93–32.78%	8.18–8.63% lipid	N/A	ARA:1.68%; EPA: 2.87%; DHA: 4.66%	N/A	15%	25%	Dicalcium phosphate, antifungal, antioxidant, lysine, methionine, garlic powder
	Isonitrogenous feed 36% crude protein	N/A	7.9–9.00% lipid	0.11%	N/A	N/A	0.25%	0.25%	Antioxidant, antifungic agent, Vitamin C, choline chloride,
	37%	38.32 to 38.88%	10%	0.5%	N/A	1.46% (5% from 29.23% carotenoid extracted)	1.0%	1.0%	Monocalcium phosphate, cellulose

Decapod Group	Macronutrients						Micronutrients		Feed Additives
	Protein	Carbohydrates	Lipid Derivatives				Vitamin	Mineral	
			Lipid	Cholesterol	Fatty Acids	Carotenoid			
Crayfish	Isonitrogenous with 39.02% to 39.74% dry weight	41.38% to 44.00% dry weight	Isolipidic 7.03% to 7.53% dry weight	12.6% to 12.9% dry weight	Saturated with 2.52% to 2.72% dry weight and unsaturated with 4.51% to 4.81% dry weight	N/A	N/A	Sodium (1.4% to 1.5%), Calcium (3.3%) & Iron (0.7% to 1.3%)	N/A
	Isonitrogenous (40% protein as-fed basis)	28.33%	7.03%	0%	ARA: 1.09% EPA: 3.58% DHA: 7.94%	N/A	2.0%	0.5%	Lecithin, dicalcium phosphate, Vitamin C, choline chloride
Crab	44.85% to 46.73% dry matter	N/A	7% and 12% lipid	0.50%	DHA/EPA ratio between 2.2 and 1.2 at 7% and 12% lipid, respectively	N/A	1.00%	1.50%	Monocalcium phosphate, choline chloride, cellulose
	Isonitrogenous with 43.64 to 46.08% dry weight	17.2 kJ g^{-1}	Dietary lipid level of 8.52–11.63% (op timum 9.5%)	0.8%	ARA: 0.5%; EPA: 6.9%; DHA: 6.1%	N/A	3.00%	2.00%	Lecithin, sodium alga acid, squid paste, cellulose
	Isonitrogenous feed with 45% crude protein	N/A	Isolipidic diets containing 9.5% oil (FO, lard, safflower oil, perilla seed oil or mixture oil	0.8%	ARA: 0.5%; EPA: 14.1%; DHA: 11.7%	N/A	3.00%	2.00%	Lecithin, sodium alga acid, squid paste, cellulose
	46.9% to 47.03% dry weight	N/A	Isolipidic feed ~8% dry weight	0.50%	N/A	0.009% β-carotene	1.50%	5.00%	Cellulose, dextrin, lecithin
	Isonitrogenous with 45% dry weight	N/A	Isolipidic with 10.8% dry weight	0.50%	0.13% ARA; 0.64–0.66% EPA & 0.37–0.38% DHA	0.009% β-carotene	1.50%	5.00%	Cellulose, dextrin, lecithin
	32 to 40% dry weight	17.2 MJ kg^{-1}	6% or 12% dry weight	0.1%	N/A	N/A	1.50%	0.50%	Seaweed, soy lecithin, dicalphos
	Isonitrogenous 48.5%	N/A	5.3 to 13.8% lipid dry weight	1.0%	0.36–0.4% ARA; 6.54–7.03% EPA; 2.29–2.81%	0.01% Astaxanthin	4.00%	4.00%	Taurine, choline chloride, vitamin A, Vitamin D3, Vitamin E
	46.6% protein dry weight	N/A	8.6% lipid dry weight	0.51%	N/A	0.01% Astaxanthin	4.00%	4.00%	Taurine, choline chloride, vitamin A, Vitamin D3, Vitamin E
	44.0–45.7% dry weight	N/A	1.1% to 1.08% lipid dry weight	0.5% dry weight	0.2% ALA, 0.2% ARA, 0.2% DHA dry weight	0.01% Astaxanthin	4.00%	4.00%	Taurine, choline chloride, vitamin A, Vitamin D3, Vitamin E
Lobster	Isonitrogenous 53% dry weight	N/A	10.04%	2%	N/A	1% Carophyll pin (8% astaxanthin)	1.1%	0.6%	Lecithin, Stay-C
	25% and 35% protein	23.75–24.73%	6.2–7%	N/A	N/A	N/A	5%	5%	Vitamin C, Vitamin E Calcium carbonate, dicalcium phosphat

N/A: Not available. EFA: Essential Fatty Acid.

4. Development of Formulated Feed for Juvenile Decapod

4.1. Type of Formulated Feed

There are two main types of feed processing technology that have been introduced in aquaculture: the extruded (pressured) pellet and the steam pellet. The extrusion technique involves the use of a feed extruder, whereby pellets are forced through a die using higher pressure and steam heat before being left to cool and having a vitamin and mineral premix added. The extrusion method is different from the steam pellet in that the extruder does not use any pellet binder to add adhesion to the particles [50], where they only expand through gelatinization of starch [51]. The gelatinization of starch helps to improve feed digestibility in decapods [52]. For this reason, the use of extruder feed is better than a steam pellet as it offers high stability and functional properties [53].

4.1.1. Dry Pellet

Dry pellets can be used in a variety of forms: dry-sinking pellet, extruded sinking pellet, and extruded floating pellet. Suitable feed ingredient selection, together with proper manufacturing procedures such as an extrusion or steaming process, ensures high-water stability pellets, which is the main criterion for producing high-quality feeds. Overall, dry-sinking pellets are more practical for bottom feeders [54] such as shrimp [55], prawns [50], lobsters [56], crayfish [8][39], and mud crabs [57]. Necessary for the creation of water-stable dry pellets are good binding agents and finely ground ingredients to ensure the maximum adhesion of the binder molecules.

4.1.2. Moist Pellet

Moist, or wet, pellets are soft pellets consisting of a combination of high-moisture ingredients and dry pulverized ingredients. The use of moist pellets led to high growth performance in juvenile rock lobsters (Jasus edwardsii) [58], freshwater crayfish [59], and green mud crabs [48]. Although the use of moist pellets is widely accepted among decapods, it is highly desirable to have the advantage of storage without the need for a refrigerator in order to prevent fungal growth and mold problems. This has led to the innovation of semi-moist pellets, which have been successfully developed at a laboratory scale. Compared to moist pellets, the moisture content of semi-moist pellets is lower, and under the permissible level to avoid yeast and mold growth, with the addition of chemical agents [60].

4.2. Pellet Characteristics Requirement

The success of decapod farming has highlighted the importance of physical pellet characteristics, which directly emphasizes the significance of artificial or formulated diets to replace live and fresh foods. The success of formulated feed may be controlled by the moisture content in the diet, which directly affects the physical forms. The high moisture content in the pellets is often associated with nutrient leaching since it dissociates easily upon entering the water. Apparently, the low pellet stability and durability resulting from high moisture content may not be suitable for decapods, partly because some species are aggressive in handling food [61]. In addition, the proper storage and handling of feed products may be difficult to achieve, as is the case with wet pellets. Since wet pellets have a high moisture content, rapid spoilage, such as from mold problems, is unavoidable during long storage periods [62]. Other physical pellet attributes, such as the palatability, type of binder, water stability, and durability, as well as buoyancy, are important to avoid pellet disintegration from decapods' strong mastication and from long exposure to water.

4.3. Current Status of Nutritional Research and Developments

Many studies have evaluated adjustments to decapod crustacean feeding formulations by reducing the dependency on FM (protein source) and FO (lipid source). Recent research has explored the use of protein and lipid sources from various sources: terrestrial animal-based materials, plant-based materials, insect meal, food waste, and fishery and aquaculture byproducts [63]. The use of these alternative sources is often evaluated through several reliable indicators such as the voluntary feed intake, feed conversion ratio (FCR), and protein efficiency ratio (PER) in determining the effectiveness of the feed. Feed that uses both FO and FM ingredients has confirmed efficiency in decapod performance in terms of FCR (1.8) and PER (2.8) [33], and, thus, they have been used as a baseline to develop a new feed formulation that uses other protein and lipid sources.

5. Conclusions

The importance of good pellet physical characteristics in decapod feeding cannot be overemphasized in order to ensure that decapods meet their nutrient needs. The current development of decapod formulated feeds is focused on the juvenile stage. However, the unique feeding behaviors of adult decapods (slow feeding, bottom dwelling, and aggression when handling feed) are major challenges to developing a high-quality pellet for adult decapods. A high-quality pellet not only depends on the binding agent, but also on the attractants that enhance palatability, as well as the correct proportion of nutrients to boost decapod performance. However, most studies published on decapod nutrition lack data on the physical qualities of the feed. Thus, it is difficult to establish a standard feed formulation that focuses on the physical pellet properties.

References

1. Waiho, K.; Glenner, H.; Miroliubov, A.; Noever, C.; Hassan, M.; Ikhwanuddin, M.; Fazhan, H. Rhizocephalans and Their Potential Impact on Crustacean Aquaculture. Aquaculture 2021, 531, 735876.
2. FAO. The State of World Fisheries and Aquaculture (SOFIA): Sustainability in Action; Food and Agriculture Organization of the United Nations: Rome, Italy, 2020.
3. Azra, M.N.; Ikhwanuddin, M. A review of maturation diets for mud crab genus Scylla broodstock: Present research, problems and future perspective. Saudi J. Biol. Sci. 2016, 23, 257–267.
4. Wouters, R.; Lavens, P.; Nieto, J.; Sorgeloos, P. Penaeid shrimp broodstock nutrition: An updated review on research and development. Aquaculture 2001, 202, 1–21.
5. Chimsung, N. Maturation diets for black tiger shrimp (Penaeus monodon) broodstock: A review. Songklanakarin J. Sci. Technol. 2014, 36, 265–273.
6. Djunaidah, I.S.; Wille, M.; Kontara, E.K.; Sorgeloos, P. Reproductive performance and offspring quality in mud crab (Scylla paramamosain) broodstock fed different diets. Aquac. Int. 2003, 11, 3–15.
7. Hidir, A.; Aaqillah-Amr, M.A.; Noordiyana, M.N.; Ikhwanuddin, M. Diet and internal physiological changes of female orange mud crabs, Scylla olivacea (Herbst, 1796) in different ovarian maturation stages. Anim. Rep. Sci. 2018, 195, 216–229.
8. Thompson, K.R.; Muzinic, L.A.; Christian, T.D.; Webster, C.D. Effect on growth, survival, and fatty acid composition of Australian red claw crayfish Cherax quadricarinatus fed practical diets with and without supplemental lecithin and/or cholesterol. J. World Aquac. Soc. 2003, 34, 1–10.
9. Saleela, K.N.; Somanath, B.; Palavesam, A. Effects of binders on stability and palatability of formulated dry compounded diets for spiny lobster Panulirus homarus (Linnaeus, 1758). Indian J. Fish. 2015, 62, 95–100.
10. Alberts-Hubatsch, H.; Lee, S.Y.; Meynecke, J.O.; Diele, K.; Nordhaus, I.; Wolff, M. Life-history, movement, and habitat use of Scylla serrata (Decapoda, Portunidae): Current knowledge and future challenges. Hydrobiologia 2016, 763, 5–21.
11. Redzuari, A.; Azra, M.N.; Abol-Munafi, A.B.; Aizam, Z.A.; Hii, Y.S.; Ikhwanuddin, M. Effects of feeding regimes on survival, development and growth of blue swimming crab, Portunus pelagicus (Linnaeus, 1758) larvae. World Appl. Sci. J. 2012, 18, 472–478.
12. Abol-Munafi, A.B.; Mukrim, M.S.; Amin, R.M.; Azra, M.N.; Azmie, G.; Ikhwanuddin, M. Histological profile and fatty acid composition in hepatopancreas of blue swimming crab, Portunus pelagicus (Linnaeus, 1758) at different ovarian maturation stages. Turk. J. Fish. Aquat. Sci. 2016, 16, 251–258.
13. Taufik, M.; Bachok, Z.; Azra, M.N.; Ikhwanuddin, M. Effects of various microalgae on fatty acid composition and survival rate of the blue swimming crab Portunus pelagicus larvae. Indian J. Mar. Sci. 2016, 45, 1512–1521.
14. Ikhwanuddin, M.; Azmie, G.; Nahar, S.F.; Wee, W.; Azra, M.N.; Abol-Munafi, A.B. Testis maturation stages of mud crab (Scylla olivacea) broodstock on different diets. Sains Malays. 2018, 47, 427–432.
15. Anger, K.; Harzsch, S.; Thiel, M. Developmental Biology and Larval Ecology: The Natural History of the Crustacean; Oxford University Press: Oxford, UK, 2020; Volume 7, Available online: https://books.google.com.my/books?id=surkDwAAQBAJ&printsec=frontcover#v=onepage&q&f=false (accessed on 3 February 2021).
16. Mane, S.; Deshmukh, V.D.; Sundaram, S. Fishery and behaviour of banana prawn, Fenneropenaeus merguiensis (de Man, 1888) around Mumbai waters. Int. J. Life Sci. 2018, 6, 549–556.
17. Zhang, X.; Yuan, J.; Sun, Y.; Li, S.; Gao, Y.; Yu, Y.; Liu, C.; Wang, Q.; Lv, X.; Zhang, X.; et al. Penaeid shrimp genome provides insights into benthic adaptation and frequent molting. Nat. Commun. 2019, 10, 356.
18. Marchese, G.; Fitzgibbon, Q.P.; Trotter, A.J.; Carter, C.G.; Jones, C.M.; Smith, G.G. The influence of flesh ingredients format and krill meal on growth and feeding behaviour of juvenile tropical spiny lobster Panulirus ornatus. Aquaculture 2019, 499, 128–139.
19. Parra-Flores, A.M.; Ponce-Palafox, J.T.; Spanopoulos-Hernández, M.; Martinez-Cardenas, L. Feeding behavior and ingestion rate of juvenile shrimp of the genus Penaeus (Crustacea: Decapoda). J. Sci. 2019, 3, 111–113.
20. Ayisi, C.L.; Hua, X.; Apraku, A.; Afriyie, G.; Kyei, B.A. Recent studies toward the development of practical diets for shrimp and their nutritional requirements. HAYATI J. Biosci. 2017, 24, 109–117.
21. Glencross, B.D.; Smith, D.M.; Thomas, M.R.; Williams, K.C. Optimising the essential fatty acids in the diet for weight gain of the prawn, Penaeus monodon. Aquaculture 2002, 204, 85–99.
22. Kangpanich, C.; Pratoomyot, J.; Senanan, W. Effects of alternative oil sources in feed on growth and fatty acid composition of juvenile giant river prawn (Macrobrachium rosenbergii). Agric. Nat. Resour. 2017, 51, 103–108.
23. Li, L.; Wang, W.; Yusuf, A.; Zhu, Y.; Zhou, Y.; Ji, P.; Huang, X. Effects of dietary lipid levels on the growth, fatty acid profile and fecundity in the oriental river prawn, Macrobrachium nipponense. Aquac. Res. 2020, 51, 1893–1902.
24. Martínez-Rocha, L.; Gamboa-Delgado, J.; Nieto-López, M.; Ricque-Marie, D.; Cruz-Suárez, L.E. Incorporation of dietary nitrogen from fish meal and pea meal (Pisum sativum) in muscle tissue of Pacific white shrimp (Litopenaeus vannamei) fed low protein compound diets. Aquac. Res. 2012, 44, 1–13.

25. Velasco, M.; Lawrence, A.L.; Neill, W.H. Development of a static-water ecoassay with microcosm tanks for postlarval P enaeus vannamei. Aquaculture 1998, 161, 79–87.

26. Samocha, T.M.; Patnaik, S.; Davis, D.A.; Bullis, R.A.; Browdy, C.L. Use of commercial fermentation products as a highl y unsaturated fatty acid source in practical diets for the Pacific white shrimp Litopenaeus vannamei. Aquac. Res. 2010, 41, 961–967.

27. Gonzalez-Galaviz, J.R.; Casillas-Hernández, R.; Flores-Perez, M.B.; Lares-Villa, F.; Bórquez-López, R.A.; Gil-Núñez, J. C. Effect of genotype and protein source on performance of Pacific white shrimp (Litopenaeus vannamei). Ital. J. Anim. Sci. 2020, 19, 289–294.

28. Suresh, A.V.; Kumaraguru-vasagam, K.P.; Nates, S. Attractability and palatability of protein ingredients of aquatic and t errestrial animal origin, and their practical value for blue shrimp, Litopenaeus stylirostris fed diets formulated with high l evels of poultry byproduct meal. Aquaculture 2011, 319, 132–140.

29. Galkanda-Arachchige, H.S.C.; Guo, J.; Stein, H.H.; Davis, D.A. Apparent energy, dry matter and amino acid digestibility of differently sourced soybean meal fed to Pacific white shrimp Litopenaeus vannamei. Aquac. Res. 2019, 51, 326–34 0.

30. Fang, X.; Yu, D.; Buentello, A.; Zeng, P.; Davis, D.A. Evaluation of new non-genetically modified soybean varieties as in gredients in practical diets for Litopenaeus vannamei. Aquaculture 2016, 451, 178–185.

31. Palma, J.; Bureau, D.P.; Andrade, J.P. Effects of binder type and binder addition on the growth of juvenile Palaemonete s varians and Palaemon elegans (Crustacea: Palaemonidae). Aquac. Int. 2008, 16, 427–436.

32. Derby, C.D.; Elsayed, F.H.; Williams, S.A.; González, C.; Choe, M.; Bharadwaj, A.S.; Chamberlain, G.W. Krill meal enh ances performance of feed pellets through concentration-dependent prolongation of consumption by Pacific white shri mp, Litopenaeus vannamei. Aquaculture 2016, 458, 13–20.

33. Gil-Núñez, J.C.; Martínez-Córdova, L.R.; Servín-Villegas, R.S.; Magallon-Barajas, F.J.; Bórques-López, R.A.; Gonzalez -Galaviz, J.R.; Casillas-Hernández, R. Production of Penaeus vannamei in low salinity, using diets formulated with diffe rent protein sources and percentages. Lat. Am. J. Aquat. Res. 2020, 48, 396–405.

34. Weiss, M.; Rebelein, A.; Slater, M.J. Lupin kernel meal as fishmeal replacement in formulated feeds for the whiteleg shr imp (Litopenaeus vannamei). Aquac. Nutr. 2019, 26, 752–762.

35. Moniruzzaman, M.; Damusaru, J.H.; Won, S.; Cho, S.J.; Chang, K.H.; Bai, S.C. Effects of partial replacement of dietary fish meal by bioprocessed plant protein concentrates on growth performance, hematology, nutrient digestibility and dige stive enzyme activities in juvenile Pacific white shrimp, Litopenaeus vannamei. J. Sci. Food Agric. 2019, 100, 1285–129 3.

36. Tazikeh, T.; Kenari, A.A.; Esmaeili, M. Effects of fish meal replacement by meat and bone meal supplemented with garli c (Allium sativum) powder on biological indices, feeding, muscle composition, fatty acid and amino acid profiles of white leg shrimp (Litopenaeus vannamei). Aquac. Res. 2019, 51, 674–686.

37. Gamboa-Delgado, J.G.; Morales-Navarro, Y.I.; Nieto-López, M.G.; Villarreal-Cavazos, D.A.; Cruz- Suárez, L.E. Assimila tion of dietary nitrogen supplied by fish meal and microalgal biomass from Spirulina (Arthrospira platensis) and Nannoc hloropsis oculata in shrimp Litopenaeus vannamei fed compound diets. J. Appl. Phycol. 2019, 31, 2379–2389.

38. Simião, C.D.S.; Colombo, G.M.; Schmitz, M.J.; Ramos, P.B.; Tesser, M.B.; Wasielesky, W., Jr.; Monserrat, J.M. Inclusio n of Amazonian Mauritia flexuosa fruit pulp as functional feed in the diet for the juvenile Pacific white shrimp Litopenaeu s vannamei. Aquac. Res. 2019, 51, 1731–1742.

39. Volpe, M.G.; Varricchio, E.; Coccia, E.; Santagata, G.; Di-Stasio, M.; Malinconico, M.; Paolucci, M. Manufacturing pellet s with different binders: Effect on water stability and feeding response in juvenile Cherax albidus. Aquaculture 2012, 32 4–325, 104–110.

40. Wang, X.; Jin, M.; Cheng, X.; Hu, X.; Zhao, M.; Yuan, Y.; Sun, P.; Jiao, L.; Betancor, M.B.; Tocher, D.R.; et al. Dietary D HA/EPA ratio affects growth, tissue fatty acid profiles and expression of genes involved in lipid metabolism in mud crab Scylla paramamosain supplied with appropriate n-3 LC-PUFA at two lipid levels. Aquaculture 2021, 532, 736028.

41. Zhao, J.; Wen, X.; Li, S.; Zhu, D.; Li, Y. Effects of dietary lipid levels on growth, feed utilization, body composition and a ntioxidants of juvenile mud crab Scylla paramamosain (Estampador). Aquaculture 2015, 435, 200–206.

42. Zhao, J.; Wen, X.; Li, S.; Zhu, D.; Li, Y. Effects of different dietary lipid sources on tissue fatty acid composition, serum biochemical parameters and fatty acid synthase of juvenile mud crab Scylla paramamosain (Estampador 1949). Aquac. Res. 2016, 47, 887–899.

43. Unnikrishnan, U.; Paulraj, R. Dietary protein requirement of giant mud crab Scylla serrata juveniles fed iso-energetic for mulated diets having graded protein levels. Aquac. Res. 2010, 41, 278–294.

44. Unnikrishnan, U.; Chakraborty, K.; Paulraj, R. Efficacy of various lipid supplements in formulated pellet diets for juvenile Scylla serrata. Aquac. Res. 2010, 41, 1498–1513.

45. Catacutan, M.R. Growth and body composition of juvenile mud crab, Scylla serrata, fed different dietary protein and lipi d levels and protein to energy ratios. Aquaculture 2002, 208, 113–123.

46. Sheen, S.S.; Wu, S.W. The effects of dietary lipid levels on the growth response of juvenile mud crab Scylla serrata. Aq uaculture 1999, 175, 143–153.

47. Sheen, S.S. Dietary cholesterol requirement of juvenile mud crab Scylla serrata. Aquaculture 2000, 189, 277–285.
48. Sheen, S.S.; Wu, S.W. Essential fatty acid requirements of juvenile mud crab, Scylla serrata (Forskål, 1775) (Decapod a, Scyllaridae). Crustaceana 2002, 75, 1387–1401.
49. Perera, E.; Fraga, I.; Carillo, O.; Díaz-Iglesias, E.; Cruz, R.; Báez, M.; Galich, G.S. Evaluation of practical diets for the Caribbean spiny lobster Panulirus argus (Latreille, 1804): Effects of protein sources on substrate metabolism and diges tive proteases. Aquaculture 2005, 244, 251–262.
50. Misra, C.K.; Sahu, N.P.; Jain, K.K. Effect of extrusion processing and steam pelleting diets on pellet durability, water ab sorbtion and physical response on Macrobrachium rosenbergii. Asian Australas J. Anim. 2002, 15, 1354–1358.
51. Bandyopadhyay, S.; Rout, R.K. Aquafeed extrudate flow rate and pellet characteristics from low-cost single-screw extru der. J. Aquat. Food Prod. Technol. 2001, 10, 3–15.
52. Simon, C.J. Advancing the Nutrition of Juvenile Spiny Lobster, Jasus ewardsii, in Aquaculture. Ph.D. Thesis, University of Auckland, Auckland, New Zealand, 2009. Available online: https://researchspace.auckland.ac.nz/docs/uoa-docs/right s.htm (accessed on 5 March 2021).
53. Mohamad-Yazid, N.S.; Abdullah, N.; Muhammad, N.; Matias-Peralta, H.M. Application of starch and starch-based prod ucts in food industry. J. Sci. Tech. 2018, 10, 144–174.
54. Lim, C.; Cuzon, G. Water stability of shrimp pellet: A review. Asian Fish. Sci. 1994, 7, 115–127.
55. Obaldo, L.G.; Divakaran, S.; Tacon, A.G. Method for determining the physical stability of shrimp feeds in water. Aquac. Res. 2002, 33, 369–377.
56. Kurnia, A.; Yusnaini, M.W.H.; Astuti, O.; Hamzah, M. Replacement of fish meal with fish head meal in the diet on the gr owth and feed efficiency of spiny lobster, Panulirus Ornatus under reared in sea net cage. Int. J. Eng. Sci. 2017, 6, 34–38.
57. Ahamad-Ali, S.; Syama-Dayal, J.; Ambasankar, K. Presentation and evaluation of formulated feed for mud crab Scylla s errata. Ind. J. Fish. 2011, 58, 67–73.
58. Crear, B.J.; Thomas, C.W.; Hart, P.R.; Carter, C.G. Growth of juvenile southern rock lobsters, Jasus edwardsii, is influe nced by diet and temperature, whilst survival is influenced by diet and tank environment. Aquaculture 2000, 190, 169–182.
59. Ruscoe, I.M.; Jones, C.M.; Jones, P.L.; Caley, P. The effects of various binders and moisture content on pellet stability of research diets for freshwater crayfish. Aquac. Nutr. 2005, 11, 87–93.
60. Paulraj, R. Handbook on Aquafarming: Aquaculture Feed. Manual; MPEDA: Cochin, India, 1993.
61. D’Abramo, L.R. Challenges in Developing Successful Formulated Feed for Culture of Larval Fish and Crustaceans. In Proceedings of the Memorias del VI Simposium Internacional de Nutricion Acuicila, Mississippi, MS, USA, 3–6 Septem ber 2002; pp. 143–149.
62. Cuzon, G.; Guillaume, J.; Cahu, C. Review: Composition, preparation and utilization of feeds for Crustacea. Aquacultur e 1994, 124, 253–267.
63. Hua, K.; Cobcroft, J.M.; Cole, A.; Condon, K.; Jerry, D.R.; Mangott, A.; Praeger, C.; Vucko, M.J.; Zeng, C.; Zenger, K.; e t al. The future of aquatic protein: Implications for protein sources in aquaculture diets. One Earth 2019, 1, 316–329.