Songklanakarin J. Sci. Technol.
45 (5), 605–612, Sep. – Oct. 2023

http://www.sjst.psu.ac.th

Review Article

Nutrition requirements for giant freshwater prawn, *Macrobrachium rosenbergii* (De Man, 1879) broodstock: A review

Saadiah Ibrahim[1, 2*]

[1] *Pulau Sayak Fisheries Research Institute, Department of Fisheries Malaysia, Ministry of Agriculture and Food Security, Kota Kuala Muda, Kedah, 08500 Malaysia*

[2] *Fish Nutrition Laboratory, School of Biological Sciences, Universiti Sains Malaysia, Penang, 11800 Malaysia*

Received: 2 December 2022; Revised: 15 October 2023; Accepted: 25 October 2023

Abstract

The giant freshwater prawn (GFP), *Macrobrachium rosenbergii* (De Man, 1879) farming industry consistently maintains a high production volume, ranging from 233 to 238 thousand metric tons worldwide annually from 2014 to 2018. Improvements in the quality and quantity of fry are necessary to further boost production. Maturation feed stands as a critical factor in enhancing the quality of broodstock. The nutrient requirements for GFP, (*M. rosenbergii*) broodstock consist of essential nutrients such as protein (40-45%), lipids (8-10%), and carbohydrates (25-35%). In addition to these major nutrients, minor nutrients like essential fatty acids, cholesterol, phospholipids, vitamins, and minerals play a crucial role in developing a high-quality maturation feed. Research focused on determining optimal levels of essential amino acids and essential fatty acids is essential to enhancing reproductive performance. High-quality maturation diet significantly contributes to the broodstock's reproductive performance and high-quality fry, both of which are paramount in the GFP farming industry. This review paper on maturation diets for GFP serves as a valuable reference for hatchery managers, aiding in the production of high-quality maturation feeds to enhance production efficiency.

Keywords: maturation diets, *Macrobrachium rosenbergii*, giant freshwater prawn, broodstock, high - quality fry

1. Introduction

In the past, fish consumption heavily relied on capture fisheries. However, aquaculture now plays a pivotal role, providing nearly 50% of the global fish consumption. Freshwater aquaculture production has shown a significant increase, rising from 38.6 million tonnes in 2011 to 51.6 million tonnes in 2018, and it increased to a level of 54.4 million tonnes in 2020 (Food and Agriculture Organization of the United Nations [FAO], 2018, 2022).

The giant freshwater prawn (GFP), *Macrobrachium rosenbergii* (De Man, 1879), stands as one of the most extensively cultured species in Asia and other parts of the world. Global production of this species increased from 193.5 thousand tonnes in 2010 to 202.5 thousand tonnes in 2015, further to 245,170 thousand tonnes in 2016, and reached 294.0 thousand tonnes in 2020 (FAO, 2022). GFP farming has been expanding for more than 40 years since the 1970s, and it is one of the promising candidates for growth, being a commercially essential and popular freshwater prawn species in the aquaculture industry.

One of the critical challenges in GFP farming is the inconsistency in seed supply. The quality of broodstock plays a critical role in producing high-quality seed or fry. Strategies to improve seed supply involve enhancing the quality of broodstock through domestication, genetic improvement, maturation diet, larval feed, stocking density, feeding regime, and effective general larval management (Cavalli, Batista, Lavens, Sorgeloos, Nelis, & De Leenheer, 2003; Chand, Trivedi, Dubey, Rout, Beg, & Das, 2015; Habashy, 2013; Kitcharoen, Koonawootrittiron, & Na-Nakorn, 2010; Nhan, Wille, De Schryver, Defoirdt, Bossier, & Sorgeloos, 2010).

*Corresponding author
Email address: sadiahibrahim7@gmail.com

Therefore, a high-quality maturation diet is vital for improving broodstock and producing good-quality seeds. Broodstock feeds are categorised into fresh food and complete or formulated feed.

2. Fresh Food

Maturation feeds typically used for GFP include fresh foods such as fresh squid, bivalves, fish fillets, and marine worms (polychaetes). Previous studies have consistently demonstrated that fresh food positively impacts growth, reproductive performance, and larval development (Coman, Arnold, Barclay, & Smith, 2011; Hoa, Wouters, Wille, Thanh, Dong, Van Hao, & Sorgeloos, 2009; Shanju & Geraldine, 2011).

Many hatchery managers believe that fresh food yields superior performance for prawn broodstock compared to formulated pellet. However, some hatchery operators opt for commercially formulated pellets, often of the "grower stage" type, which have not been specifically designed for broodstock. Consequently, these pellets may not entirely meet the nutritional requirements for optimal reproductive development of the broodstock.

Despite its positive effects on GFP broodstock performance, the quality of fresh food can vary between batches and may pose a risk as a potential disease carrier. Additionally, proper storage and freezing conditions are crucial for managing fresh food. Failure to store it properly can result in spoilage and deterioration, leading to harmful bacterial growth that can be fatal to GFP broodstock.

Moreover, Thanh Hien, Hai, Yen, Bich Hang, Phuong, Ogata, and Wilder (2003) reported that a formulated feed containing 43% crude protein and 9% lipid yielded reproductive performance in GFP broodstock comparable to that with fresh food. Therefore, utilising a well-balanced formulated feed with optimal nutrient requirements for broodstock performance can significantly enhance production efficiency.

3. Complete Feed

A complete feed is a formulated diet that contains all the necessary nutrients for maximising the reproductive performance of *M. rosenbergii* broodstock. The formulation of a complete feed includes optimal levels of vital nutrients, such as protein, lipid, carbohydrate, vitamins, minerals, and other additives that enhance the feed's quality.

Complete feeds offer numerous advantages over fresh or frozen diets, including a consistent supply, quick and convenient preparation, known nutrient content, uniform quality, and the flexibility to add specific additives to enhance the overall feed quality. While there are commercial maturation feeds available in the market, they are currently considered relatively expensive and primarily cater to marine shrimp broodstock.

Various researchers have conducted studies on the nutritional requirements essential for the development of maturation feeds, including studies on protein, amino acids, lipids, fatty acids, carbohydrates, vitamins, and minerals (Cavalli, Lavens, & Sorgeloos, 1999; Cavalli, Tamtin, Lavens, & Sorgeloos, 2001; Cavalli *et al*., 2003; Cavalli, Menschaert, Lavens, & Sorgeloos, 2000; Murmu, Sahu, Malik, Reddy, & Kohli, 2007; Shanju & Geraldine, 2011). Detailed investigations into the specific nutrient requirements for each of these components are necessary. The subsequent sections will elucidate the fundamental nutrient requirements for broodstock, commencing with protein and amino acids.

4. Protein and Amino Acids

Protein is an essential nutrient required for various biological functions, including growth, tissue repair, maintenance, and regeneration. Additionally, proteins play a crucial role in the production of hormones, enzymes, and other biologically important substances such as antibodies and hemoglobin (Tacon, 1987). According to numerous studies, the optimal dietary protein level for GFP broodstock falls within the range of 40 – 45% (Balamurugan, 2006; Bhavani, Sujay Kumar, Hareesh, & Srinivasulu Reddy, 2014; Cavalli *et al*., 1999, 2001; Das, Saad, Ang, Law, & Harmin, 1996; Mitra, Mukhopadhyay, & Chattopadhyay, 2005; Nik Sin, Seok Kian, & Shapawi, 2016; Thanh Hien *et al*., 2003). Table 1 below summarises reported studies on protein requirements for *Macrobrachium* species broodstock.

The amino acid profile in *M. rosenbergii* eggs comprises seventeen amino acids, including nine essential amino acids (EAAs) and eight nonessential amino acids (NEAAs), and is crucial for understanding broodstock requirements (Bhavan, Radhakrishnan, Seenivasan, Shanthi, Poongodi, & Kannan, 2010; Das *et al*., 1996; Yao, Zhao, Wang, Zhou, Hu, Duan, & An, 2006). The contents of amino acids vary across different embryonic stages, with the highest recorded at the zoea stage (Yao *et al*., 2006). Essential amino acids, like leucine, methionine, and arginine have shown significant differences between early and late embryonic stages (Yao *et al*., 2006). In GFP eggs, the highest levels of free amino acids were observed for specific amino acids as reported by Nguyen, Chen, Shiau, Cheng, and Chang (2019).

Proline, derived from glutamic acid, is crucial for embryonic development. It dominates the amino acid composition, especially at stage VII. Among essential amino acids (EAAs), leucine content is notably high and EAAs increase proportionally as development progresses (Yao *et al*., 2006). Table 2 offers essential amino acid data for *Macrobrachium rosenbergii* eggs, serving as a valuable reference for determining EAA requirements, particularly for maturation diets.

5. Lipid and Fatty Acids

Lipids in diets provide high-density energy and essential fatty acids (EFAs). Indulkar & Belsare (2003) estimated the dietary lipid requirement for *M. rosenbergii* juveniles (average weight of 6.26 ± 0.23 mg) to be between 7.5% and 10.0% based on growth parameters, and 3% of a combination marine algae oil and soybean oil has been suggested (Kangpanich, Pratoomyot, & Senanan, 2017). Dietary lipid requirements for prawn broodstock range from 3% to 7% (Mitra *et al*., 2005), extendable up to 10% without affecting reproduction (Murmu *et al*., 2007). A diet with lipids supplement, comprising two parts squid oil and one part corn oil, is recommended for GFP broodstock (Thanh Hien, Hai, Phuong, Hang, Yen, Ogata, & Wilder, 2001). Dietary lipid requirements for *M. rosenbergii* are summarised in Table 3.

Table 1. Dietary protein requirements of *Macrobrachium rosenbergii* broodstock

% Protein used in diet	Sources of protein	Suggested level	Reference
44-45	Fisheries sources (Lobster meal, soy protein isolate, squid meal, shrimp meal, crab meal)	44-45	Cavalli, Lavens, & Sorgeloos, (1999)
44-45	Fisheries sources (Lobster meal, soy protein isolate, squid meal, shrimp meal, crab meal)	44-45	Cavalli, Menschaert, Lavens, & Sorgeloos, (2000).
45	Combination of fisheries sources and plant protein (Fish meal, shrimp meal, soybean meal)	45	Thanh Hien, *et al.* (2001)
44-45	Fisheries sources (Lobster meal, soy protein isolate, squid meal, shrimp meal, crab meal)	44-45	Cavalli *et al*. (2003)
45	Fish meal, shrimp meal, soybean meal	45	Thanh Hien *et al*. (2003)
46	Fish meal, shrimp head meal and acetes meal	44	Murmu *et al*., (2007)
40	Fishery resources	40	Nik Sin, Seok Kian, & Shapawi, (2016)

Table 2. Quantitative essential amino acid profile (% of total amino acids) in the composition of *Macrobrachium rosenbergii* prawn eggs

EAA	Egg (Das *et al*. 1996)	Egg (Stage VII, (Yao *et al*., 2006))	Egg (Nguyen *et al*., 2019)
Histidine	2.34±0.02	2.73	2.69
Isoleucine	2.65±0.03	5.35	1.58
Leucine	2.40±0.03	8.33	3.74
Lysine	2.28±0.05	7.29	5.66
Methionine	1.57±0.04	2.56	0.46
Phenylalanine	1.76±0.04	4.32	2.41
Threonine	n.a.	3.92	1.93
Tryptophan	1.93±0.01	n.a.	0.97
Valine	2.21±0.04	6.72	2.47

Table 3. Dietary lipid requirements of *Macrobrachium rosenbergii*

Species	% Lipid	Sources of lipid	Suggested level (%)	Reference
M. rosenbergii (Adult, broodstock)	9	Corn oil Fish oil E50 Hydrogenated plant oil	9	Cavalli, Lavens, & Sorgeloos, (1999)
M. rosenbergii (Adult, broodstock)	9	De-oiled soy lecithin, Soybean oil, Hydrogenated plant oil & fish oil E50	9	Cavalli *et al*. (2000)
M. rosenbergii (Adult, broodstock)	9	corn oil and squid oil	9	Thanh Hien *et al*. (2001)
M. rosenbergii (adult)	9	Squid and corn oil (2:1)	9	Thanh Hien *et al*. (2003)
M. rosenbergii (adult)	10	Fish oil	10	Nik Sin *et al*. (2016)
M. rosenbergii (juvenile)	12	Sardine oil	12	Naik & Murthy (2012)
M. rosenbergii (juvenile)	7	Cod liver oil, Sunflower oil, Coconut oil and Castor oil	7	Muralisankar *et al*. (2014)
M. rosenbergii (juvenile)	3	Marine algae oil & soybean oil	3	Kangpanich *et al*. (2017)

Yao *et al*. (2006) reported varying quantities of primary fatty acids during *M. rosenbergii's* different embryonic stages. Arachidonic acid (ARA, 20: 4n-6) is a crucial fatty acid for gonad development (Kangpanich, Pratoomyot, Siranonthana, & Senanan, 2016), and its content varies throughout embryogenesis (Yao *et al*., 2006). ARA at 0.8% in maturation feed improves the reproductive performance (Kangpanich *et al*., 2016).

Newly hatched larvae of various crustaceans typically have docosahexaenoic acid (DHA, C22:6n-3) (Figueiredo, Lin, Anto, & Narciso, 2012). DHA and eicosapentaenoic acid (EPA, C20:5n-3) contents in GFP eggs decrease from early to late embryogenesis stages (Yao *et al*., 2006). Table 4 compiles DHA, EPA, and ARA compositions, while Table 5 shows recommended levels for GFP broodstock performance.

5.1 Cholesterol and phospholipids

Cholesterol plays a vital role in freshwater prawns, serving as a crucial component of cell membranes, a precursor to essential steroids, brain and moulting hormones, and a source of vitamin D (Mukhopadhyay, Rangacharyulu, Mitra, & Jana, 2003). Studies suggest adding around 0.3% to 1.0% cholesterol in maturation feed for *Macrobrachium* sp. (Cavalli, Lavens, & Sorgeloos, 2001; D`Abramo, 1989; Harikrishnan, Balasundaram, Devi, & Balamurugan, 2019; Meunpol, Meejing, & Piyatiratitivorakul, 2005; Ruiz, Ribeiro,

Table 4. Fatty acids from ovary and eggs of wild and farmed adult female *Macrobrachium rosenbergii*

Ovarian stage	Sample	Fatty acid (mg/g dry weight)					n-6/n-3	Reference
		LOA (18:2n-6)	LNA (18:3n-3)	ARA (20:4n6)	EPA (20:5n3)	DHA (22:6n-3)		
IV	Ovary	30.57±3.36 (Wild)	4.53±0.45 (Wild)	4.95±0.44 (Wild)	6.59±0.59 (Wild)	6.77±0.61 (Wild)	2.05 (Wild)	Balamurugan, Mariappan, & Balasundaram, (2015)
		14.45±1.58 (F1)	6.26±0.55 (F1)	1.98±0.39 (F1)	6.98±0.62 (F1)	5.28±0.61 (F1)	0.85 (Farm 1)	
		13.03±1.43 (F2)	5.59±0.63 (F2)	2.43±0.52 (F2)	7.78±0.70 (F2)	6.05±0.54 (F2)	0.80 (Farm 2)	
IV	Eggs	36.33±3.99 (Wild)	3.91±0.35 (Wild)	3.83±0.66 (Wild)	5.36±0.63 (Wild)	4.66±0.73 (Wild)	3.05 (Wild	Balamurugan *et al*. (2015)
		13.09±1.57 (F1)	4.41±0.62 (F1)	1.57±0.63 (F1)	4.71±0.53 (F1)	4.83±0.53 (F 1)	1.08 (F 1)	
		9.79±0.87 (F2)	5.16±0.46 (F2)	2.03±0.24 (F2)	6.06±0.54 (F2)	5.11±0.45 (F 2)	0.72 (F 2)	
I	Ovary (Wild)	17.4 ± 2.5	1.2±0.3	12.8±3.7	7.9±2.1	3.9±1.3	2.55	Cavalli, Tamtin, Lavens, & Sorgeloos (2001)
II	Ovary (Wild)	41.5±6.1	2.6±1.0	9.6±1.1	11.2±3.3	7.9± 2.2	2.61	Cavalli *et al*. (2001)
III	Ovary (Wild)	50.1±26.2	4.1±2.2	7.3±0.6	9.0±2.1	6.5±3.3	3.45	Cavalli *et al*. (2001)
IV	Ovary (Wild)	47.7±15.6	3.8±1.1	6.6±1.6	9.0±3.2	7.7±3.1	3.11	Cavalli *et al*. (2001)
V	Ovary (Wild)	43.0±6.8	3.7±1.2	6.4±1.1	9.0±3.0	6.6±2.5	3.01	Cavalli *et al*. (2001)

Note: LOA = linoleic acid, LNA = Linolenic acid, ARA = Arachidonic acid, EPA = Eicosapentaenoic acid, DHA = Docosahexaenoic acid, n-6 = Omega 6, n-3 = Omega 3

Table 5. A compilation of studies on dietary fatty acid requirements and composition in *Macrobrachium rosenbergii* broodstock

Type of fatty acids	Sources of lipid	Suggested level	Reference
n-3		0.08	D'Abramo and Sheen (1993)
n-3 PUFA		15	Cavalli *et al*. (1999)
DHA (22:6n-3)		3.9-7.9 mg/g dry weight	Cavalli *et al*. (2001)
EPA (20:5n-3) in ovary at different maturation stages (From Stage I-V)		7.9 - 11.2 mg/g dry weight 5.02±0.40 (wild) 5.82±0.75 (Farm 1) 6.96±0.90 (Farm 2)	Cavalli *et al*. (2001)
ARA (20:4n-6) in ovary at different maturation stages (From Stage I – V)	Natural sources Wild sample	12.8 - 6.4 mg/g dry weight	Cavalli *et al*. (2001)
ARA (20:4n-6)		5.51±0.44 (wild) 2.04±0.76 (Farm 1) 3.29±0.46(Farm 2)	Balamurugan, Mariappan, & Balasundaram (2015).
ARA	*Mortierella alpine*	2% (8.33±0.04% of TFA)	Kangpanich, Pratoomyot, Siranonthana, & Senanan (2016)

Note: ARA = Arachidonic acid, EPA = Eicosapentaenoic acid, DHA= Docosahexaenoic acid, PUFA = polyunsaturated fatty acids, n-3 = Omega 3

Vicentini C, Vicentini I, & Papa, 2019; Teshima, Ishikawa, Koshio, & Kanazawa, 1997). On considering the cost implications, the suggested cholesterol level in prawn feeds is around 0.5% of the dry weight (Smith, Tabrett, & Barclay, 2001).

Vitamin E (tocopherol), is an essential vitamin for GFP, aiding immune and reproductive functions (Mcdowell, 1989). Diets with 80 – 160 mg/kg of vitamin E benefit reproductive performance and antioxidant capacity in *Macrobrachium nipponense* female prawns (Li, Fan, Huang, Wu, Zhang, & Zhao, 2018). Research on *Procambarus clarkii* demonstrated that feeding Vitamin E at 200 mg/kg increases spawning rates in high numbers of females (Li, Dong, Xu, & Wang, 2007). For GFP female maturation diets, the suggested vitamin E range is 80-200 mg/kg.

Freshwater prawns lack the ability to produce phospholipids (PL) internally. For broodstock needs, a base of 0.8% dietary PLs is essential (Sarman, Vishal, Mahavadiya, & Sapra, 2018). Lecithin, crucial for its growth-promoting effect in shrimp, is commonly derived from soybean lecithin, available in standard fluid (63% phospholipid) or powder forms (Gong, Lawrence, Jiang, & Gatlin III, 2000; González-

Félix, Gatlin, Lawrence, & Perez-Velazquez, 2002; Kontara, Coutteau, & Sorgeloos, 1997). The optimal lecithin level in maturation feed is suggested to be 0.8% dietary PL.

5.2 Role of essential fatty acids in reproduction

Fatty acid requirements of freshwater crustaceans like GFP are less researched than those of marine species like *P. monodon*. Therefore, marine species findings often serve as a reference for nutrient requirements of freshwater crustaceans, especially of broodstock. Essential fatty acids (EFA), such as ARA, EPA and DHA are vital for reproductive performance of aquatic animals.

Crustaceans have a limited ability to synthesize these long-chain polyunsaturated fatty acids (LC-PUFA) and research has explored modifying their levels in diets to enhance reproductive performance (Coman, Arnold, Callaghan, & Preston, 2007; Forster, Divakaran, Conquest, Decamp, & Tacon, 2006; Glencross, 2009; Glencross & Smith, 2001; Hoa *et al*., 2009; Izquierdo, Kanazawa, Teshima, Tokiwa, & Ceccaldi, 1979; Huang, Jiang, Lin, Zhou, & Ye, 2008; Meunpol *et al*., 2005; Racotta, Palacios, & Ibarra, 2003; Wouters, Piguave, Bastidas, Calderon, & Sorgeloos, 2001).

Both wild and farmed GFP *M. rosenbergii* exhibit deficiencies in linolenic acid (LNA) and arachidonic acid (ARA) (Balamurugan, Mariappan, & Balasundaram, 2015). Fatty acid composition varies across ovarian stages (Cavalli *et al*., 1999, 2001), and supplementation levels for broodstock are detailed in Tables 4 and 5.

6. Carbohydrate

GFP, *M. rosenbergii* efficiently utilises carbohydrates as the primary source of energy. During fasting, the prawn's energy metabolism is primarily fuelled by carbohydrates, followed by lipids and proteins (Sarman *et al*., 2018). The recommended carbohydrate level for GFP broodstock ranges from 25 to 35% (Mitra *et al*., 2005).

7. Vitamins and Minerals

Vitamins are essential micronutrients required in small amounts for growth and bodily maintenance. A fundamental premix of vitamins for GFP broodstock should include vitamins B1, B2, B3, B5, B6, B7 (Biotin), B9 (Folic acid), B12, Choline, Inositol and K, at respective levels of 30, 30, 150, 75, 30, 0.25, 6.0, 0.04, 1600, 700 and 12 mg/kg. Additionally, vitamins A and D should be included at levels of 6,750,000 IU and 1,450,000 IU per kg of feed, respectively (Plaipetch, 2015; Tacon, 1987).

The requirement of ascorbic acid (vitamin C) for *M rosenbergii* used in maturation diets is reported variously as 0.5% (Harikrishnan *et al*., 2019), 0.27% (Cavalli *et al*., 2000; Cavalli *et al*., 2001) and 0.029% (Cavalli *et al*., 2003). The suggested amounts for successful reproduction and larval viability are 60 mg of ascorbic acid and 300 mg of tocopherol per kg of diet (Cavalli *et al*., 2003; Mitra *et al*. (2005).

Asaikkutti, Bhavan, & Vimala (2016) recommended a diet with 2.0 mg/kg of folic acid for improved *M. rosenbergii* survival, growth, antioxidant defense and production. Increased vitamin A intake was found to accelerate ovarian development in crayfish, *C. quadricarinatus* (Liñán-Cabello, Medina-Zendejas, Sánchez-Barajas, & Herrera, 2004; Pangantihon-Kühlmann, Millamena, & Chern, 1998).

Mineral requirements, particularly magnesium, potassium, and calcium, are crucial for prawn broodstock. A recommended dietary zinc range is 50 – 90 mg/kg for GFP (El-Saidy and Habashy, 2012; Mitra *et al*., 2005). Prawn broodstock diets are suggested to contain Ca, P, K and Mg at levels of 2.5%, 1.4%, 0.9% and 0.13%, respectively (Plaipetch, 2015). Furthermore, the addition of Fe, Mn, Cu, Co, I, Cr and Se at levels of 100, 60, 12, 1.2, 6.0, 1.0 and 0.25 mg/kg feed, respectively, is recommended (Plaipetch, 2015).

8. Additives

Various dietary additives, including polysaccharides, hormones, vitamins, microorganisms, and biologically active materials, possess antioxidant and immune-stimulant properties, promoting a strong defense response in the host (Kumar, Pillai, Sahoo, Mohanty, & Mohanty, 2009; Mohapatra, Chakraborty, Kumar, Deboeck, & Mohanta, 2013; Wang, Sun, Liu, & Xue, 2017).

Astaxanthin (3,3-dihydroxy-4,4-diketo-β, β-carotene) is a red carotenoid pigment found in a diverse range of living organisms, and it acts as a pigment enhancer and as an antioxidant. Kumar *et al*. (2009), indicated that including astaxanthin at a level of 50 mg/kg was sufficient for sub-adults of *M. rosenbergii*. Incorporating *Ganoderma lucidum* at 1.5 g/kg in the diet can enhance the development and innate immune system of *M. rosenbergii,* increasing resistance to bacterial infections, particularly that by *A. hydrophila* (Mohan, Muralisankar, Uthayakumar, Chandirasekar & Karthick Rajan, 2019).

9. Conclusions

Maturation pellet feed enriched with essential nutrients and fortified with key additives, exhibiting strong water stability, has shown potential in enhancing the reproductive performance of *M. rosenbergii* broodstock. As a result, these refined maturation feeds can be effectively shared with local hatchery managers, contributing to improvements in domesticated broodstock quality and the production of high-quality fry. Consequently, this approach may aid in diminishing the reliance on wild broodstock sourced from rivers.

Acknowledgements

The author would like to thank the Director General, Department of Fisheries Malaysia for his permission to publish this article. The author would like to acknowledge the contributions of colleagues and staffs at the Institut Penyelidikan Perikanan (IPP) (*Fisheries Research Institute*), Department of Fisheries Malaysia, particularly IPP Pulau Sayak and IPP Glami Lemi.

References

Asaikkutti, A., Bhavan, P. S., & Vimala, K. (2016). Effects of different levels of dietary folic acid on the growth performance, muscle composition, immune response and antioxidant capacity of freshwater prawn. *Macrobrachium Rosenbergii*. *Aquaculture*, *464*, 136–144. Retrieved from https://doi.org/10.1016/j.aquaculture.2016.06.014

Balamurugan, P. (2006). *Biochemical analysis of brooders for the formulation of broodstock diet to augment production of freshwater prawn, Macrobrachium rosenbergii* [Bharathidasan University, Tamil Nadu, Thailand]. Retrieved from http://hdl.handle.net/10603/113284

Balamurugan, P., Mariappan, P., & Balasundaram, C. (2015). Comparison of fatty acid profile of wild and farm reared freshwater prawn *Macrobrachium rosenbergii* (De Man) brooders for broodstock diet formulation. *African Journal of Biotechnology*, *14*(1), 10–16. Retrieved from https://doi.org/10.5897/AJB09.30

Bhavan, P. S., Radhakrishnan, S., Seenivasan, C., Shanthi, R., Poongodi, R., & Kannan, S. (2010). Proximate composition and profiles of amino acids and fatty acids in the muscle of adult males and females of commercially viable prawn species *Macrobrachium rosenbergii* collected from natural culture environments. *International Journal of Biology*, *2*(2), 107–119. Retrieved from https://doi.org/10.5539/ijb.v2n2p107

Bhavani, M., Sujay Kumar, G., Hareesh, & Srinivasulu Reddy, M. (2014). Monitoring of growth potentials in fresh water prawn *Macrobrachium rosenbergii* feeding with experimental diets with different nutrients. *Discovery*, *26*(95), 79–83.

Cavalli, R. O., Lavens, P., & Sorgeloos, P. (1999). Performance of *Macrobrachium rosenbergii* broodstock fed diets with different fatty acid composition. *Aquaculture*, *179*(1–4), 387–402. Retrieved from https://doi.org/10.1016/S0044-8486(99)00173-8

Cavalli, R.O., Menschaert, G., Lavens, P., & Sorgeloos, P. (2000). Maturation performance, offspring quality and lipid composition of *Macrobrachium rosenbergii* females fed increasing levels of dietary phospholipids. *Aquaculture International*, *8*(1), 41–58. Retrieved from https://doi.org/10.1023/A:1009220932268

Cavalli, R. O., Batista, F. M. M., Lavens, P., Sorgeloos, P., Nelis, H. J., & De Leenheer, A. P. (2003). Effect of dietary supplementation of vitamins C and E on maternal performance and larval quality of the prawn *Macrobrachium rosenbergii*. *Aquaculture*, *227*(1–4), 131–146. Retrieved from https://doi.org/10.1016/S0044-8486(03)00499-X

Cavalli, R. O., Tamtin, M., Lavens, P., & Sorgeloos, P. (2001). Variations in lipid classes and fatty acid content in tissues of wild *Macrobrachium rosenbergii* (de Man) females during maturation. *Aquaculture*, *193*(3–4), 311–324. Retrieved from https://doi.org/10.1016/S0044-8486(00)00497-X

Cavalli, R. O., Lavens, P., & Sorgeloos, P. (2001). Reproductive performance of *Macrobrachium rosenbergii* females in captivity. *Journal Of The World Aquaculture Society*, *32*(1), 60–66. Retrieved from https://doi.org/10.1111/j.1749-7345.2001.tb00922.x

Chand, B. K., Trivedi, R. K., Dubey, S. K., Rout, S. K., Beg, M. M., & Das, U. K. (2015). Effect of salinity on survival and growth of giant freshwater prawn *Macrobrachium rosenbergii* (de Man). *Aquaculture Reports*, *2*, 26–33. Retrieved from https://doi.org/10.1016/j.aqrep.2015.05.002

Coman, G. J., Arnold, S. J., Barclay, M., & Smith, D. M. (2011). Effect of arachidonic acid supplementation on reproductive performance of tank-domesticated *Penaeus monodon*. *Aquaculture Nutrition*, *17*(2), 141–151. Retrieved from https://doi.org/10.1111/j.1365-2095.2009.00716.x

Coman, G. J., Arnold, S. J., Callaghan, T. R., & Preston, N. P. (2007). Effect of two maturation diet combinations on reproductive performance of domesticated *Penaeus monodon*. *Aquaculture*, *263*(1–4), 75–83. Retrieved from https://doi.org/10.1016/j.aquaculture.2006.10.016

D`Abramo, L. R. (1989). Lipid requirements of shrimp. *Advances in Tropical Aquaculture*, *9*, 277–285. Retrieved from https://doi.org/10.1046/j.1365-2095.2002.00221.x

Das, N. N., Saad, C. R., Ang, K. J., Law, A. T., & Harmin, S. A. (1996). Diet formulation of *Macrobrachium rosenbergii* (de Man) broodstock based on essential amino acid profile of its eggs. *Aquaculture Research*, *27*(7), 543–555. Retrieved from https://doi.org/10.1111/j.1365-2109.1996.tb01285.x

EL-Saidy, D. M. S. D., & Habashy, M. M. (2012). Growth performance of the giant freshwater prawn, *Macrobrachium rosenbergii* juvenile fed on a basal diet containing different zinc concentrations. *The Egyptian Society of Animal Production*, *47*(Nov), 193–201.

Food and Agriculture Organization of the United Nations [FAO]. (2018). The state of world fisheries and aquaculture 2018. Rome, Italy: Author. Retrieved from https://doi.org/10.1093/japr/3.1.101

Food and Agriculture Organization of the United Nations [FAO]. (2022). The state of world fisheries and aquaculture 2022. Towards blue transformation. Rome, Italy: Author. Retrieved from https://doi.org/10.4060/cc0461en

Figueiredo, J., Lin, J., Anto, J., & Narciso, L. (2012). The consumption of DHA during embryogenesis as an indicative of the need to supply DHA during early larval development: A review. *Journal of Aquaculture Research and Development*, *3*(5), 1–7. Retrieved from https://doi.org/10.4172/2155-9546.1000140

Glencross, B. D., & Smith, D. M. (2001). A study of the arachidonic acid requirements of the giant tiger prawn, *Penaues monodon*. *Aquaculture Nutrition*, *7*, 59–69.

Glencross, B. D. (2009). Exploring the nutritional demand for essential fatty acids by aquaculture species. *Reviews in Aquaculture*, *1*(2), 71–124. Retrieved from https://doi.org/10.1111/j.1753-5131.2009.01006.x

Gong, H., Lawrence, A. L., Jiang, D-H., & Gatlin III, D. M. (2000). Lipid nutrition of juvenile *Litopenaeus vannamei* II. Active components of soybean lecithin.

Aquaculture, *190*(3–4), 325–342. Retrieved from https://doi.org/10.1016/S0044-8486(00)00415-4

González-Félix, M. L., Gatlin, D. M., Lawrence, A. L., & Perez-Velazquez, M. (2002). Effect of dietary on essential fatty acid requirements and tissue lipid composition of *Litopenaeus vannamei* juveniles. *Aquaculture*, *207*(1–2), 151–167. Retrieved from https://doi.org/10.1016/S0044-8486(01)00797-9

Habashy, M. M. (2013). On the breeding behaviour and reproduction of the freshwater prawn, *Macro brachium rosenbergii* (de Man 1879) (Decapoda-Crustacea) under laboratory conditions. *Aquaculture Research*, *44*(3), 395–403. Retrieved from https://doi.org/10.1111/j.1365-2109.2011.030 44.x

Harikrishnan, R., Balasundaram, C., Devi, G., & Balamurugan, P. (2019). Evaluation of marine algal fatty acids supplementation broodstock diets on *Macrobrachium rosenbergii* (De Man). *Inter national Journal of Nutritional Sciences*, *4*(2), 1–7.

Hoa, N. D., Wouters, R., Wille, M., Thanh, V., Dong, T. K., Van Hao, N., & Sorgeloos, P. (2009). A fresh-food maturation diet with an adequate HUFA composition for broodstock nutrition studies in black tiger shrimp *Penaeus monodon* (Fabricius, 1798). *Aquaculture*, *297*(1–4), 116–121. Retrieved from https://doi.org/10.1016/j.aquaculture.2009.09. 005

Huang, J., Jiang, S., Lin, H., Zhou, F., & Ye, L. (2008). Effects of dietary highly unsaturated fatty acids and astaxanthin on the fecundity and lipid content of pond-reared *Penaeus monodon* (Fabricius) broodstock. *Aquaculture Research*, *39*, 240–251. Retrieved from https://doi.org/10.1111/j.1365-2109. 2007.01868.x

Indulkar, S. T., & Belsare, S. G. (2003). Evaluation of some formulated diets for rearing the post-larvae of *Macrobrachium rosenbergii*. *Journal of the Indian Fisheries Association*, *30*, 113–119.

Izquierdo, M., Forster, I., Divakaran, S., Conquest, L., Decamp, O., & Tacon, A. (2006). Effect of green and clear water and lipid source on survival, growth and biochemical composition of Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition*, *12*(3), 192–202. Retrieved from https://doi.org/10.1111/j.1365-2095.2006.00385.x

Kanazawa, A., Teshima, S., Tokiwa, S., & Ceccaldi, H. J. (1979). Effects of dietary linoleic and linolenic acids on growth of prawn. *Oceanologica Acta*, *2*(1), 41–48.

Kangpanich, C., Pratoomyot, J., Siranonthana, N., & Senanan, W. (2016). Effects of arachidonic acid supple mentation in maturation diet on female reproductive performance and larval quality of giant river prawn (*Macrobrachium rosenbergii*). *PeerJ*, *4*, e2735. Retrieved from https://doi.org/10.7717/peerj. 2735

Kangpanich, C., Pratoomyot, J., & Senanan, W. (2017). Effects of alternative oil sources in feed on growth and fatty acid composition of juvenile giant river prawn (*Macrobrachium rosenbergii*). *Agriculture and Natural Resources, 51*(2), 103–108. Retrieved from https://doi.org/10.1016/j.anres.2016.12.004

Kitcharoen, N., Koonawootrittiron, S., & Na-Nakorn, U. (2010). Selection of brooders from early maturing freshwater prawns (*Macrobrachium rosenbergii*) results in faster growth rates of offspring than in those selected from late maturing prawns. *Aquaculture*, *306*(1–4), 362–364. Retrieved from https://doi.org/10.1016/j.aquaculture.2010.06.015

Kontara, E. K. M., Coutteau, P., & Sorgeloos, P. (1997). Effect of dietary phospholipid on requirement and incorporation of n-3 highly unsaturated fatty acids in postlarval *Penaeus japonicus* Bate. *Aquaculture*, *158*, 305–320.

Kumar, V., Pillai, B. R., Sahoo, P. K., Mohanty, J., & Mohanty, S. (2009). Effect of dietary astaxanthin on growth and immune response of giant freshwater prawn *Macrobrachium rosenbergii* (de man). *Asian Fisheries Science*, *22*(1), 61–69.

Li, M., Dong, W.J., Xu, J.Y. & Wang, Y.F. (2007). The effect of vitamin E in diet on spawning of red swamp crayfish *Procambarus clarkii* Girard. *Journal of Fisheries of China S1*. Retrieved from http://en. cnki.com.cn/Article_en/CJFDTOTAL-SCKX2007S 1012.htm

Li, Y., Fan, B., Huang, Y., Wu, D., Zhang, M., & Zhao, Y. (2018). Effects of dietary vitamin E on reproductive performance and antioxidant capacity of *Macro brachium nipponense* female shrimp. *Aquaculture Nutrition*, *24*(6), 1-11.

Liñán-Cabello, Marco Agustín, Medina-Zendejas, R., Sánchez-Barajas, M., & Herrera, A. M. (2004). Effects of carotenoids and retinol in oocyte maturation of crayfish *Cherax quadrucarinatus*. *Aquaculture Research*, *35*(9), 905–911. Retrieved from https://doi.org/10.1111/j.1365-2109.2004.010 83.x

McDowell, L. R. (1989). *Vitamins in animal nutrition*. San Diego, CA: Academic Press.

Meunpol, O., Meejing, P., & Piyatiratitivorakul, S. (2005). Maturation diet based on fatty acid content for male *Penaeus monodon* (Fabricius) broodstock. *Aquaculture Research*, *36*(12), 1216–1225. Retrieved from https://doi.org/10.1111/j.1365-2109. 2005.01342.x

Mitra, G., Mukhopadhyay, P. K., & Chattopadhyay, D. N. (2005). The farming of the giant freshwater prawn. *Aqua Feeds*: *Formulation and Beyond*, *2*(1), 17–19.

Mohan, K., Muralisankar, T., Uthayakumar, V., Chan dirasekar, R., & Karthick Rajan, D. (2019). Dietary *Ganoderma lucidum* polysaccharides to enhance the growth, immune response and disease resistance of freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture Reports*, *14*, 100203. Retrieved from https://doi.org/10.1016/j.aqrep.2019.100203

Mohapatra, S., Chakraborty, T., Kumar, V., Deboeck, G., & Mohanta, K. N. (2013). Aquaculture and stress management: A review of probiotic intervention. *Journal of Animal Physiology and Animal Nutrition*, *97*(3), 405–430. Retrieved from https://doi.org/ 10.1111/j.1439-0396.2012.01301.x

Mukhopadhyay, P. K., Rangacharyulu, P. V., Mitra, G., & Jana, B. B. (2003). Applied nutrition in freshwater prawn, *Macrobrachium rosenbergii*, culture. *Journal of Applied Aquaculture*, *13*(3–4), 317–340. Retrieved from https://doi.org/10.1300/J028v13n03_06

Murmu, K., Sahu, N. P., Mallik, S. K., Reddy, A. K., & Kohli, M. P. S. (2007). Rematuration of spent *Macro brachium rosenbergii* female broodstock through dietary manipulation and eyestalk ablation. *Israeli Journal of Aquaculture - Bamidgeh*, *59*(2), 104–110.

Nguyen, T. M. T., Chen, T. Y., Shiau, C. Y., Cheng, Y. T., & Chang, Y. W. (2019). Study on biochemical divergences of the meat and egg of freshwater prawns (*Macrobrachium rosenbergii*). *Food Science and Nutrition*, *7*, 2017–2023. Retrieved from https://doi.org/10.1002/fsn3.1031

Nhan, D. T., Wille, M., De Schryver, P., Defoirdt, T., Bossier, P., & Sorgeloos, P. (2010). The effect of poly β-hydroxybutyrate on larviculture of the giant freshwater prawn *Macrobrachium rosenbergii*. *Aquaculture*, *302*(1–2), 76–81. Retrieved from https://doi.org/10.1016/j.aquaculture.2010.02.011

Nik Sin, N. H., Seok Kian, A. Y., & Shapawi, R. (2016). Effects of different protein sources in the broodstock diet on reproductive performance of giant freshwater prawn (*Macrobrachium rosenbergii*). *International Journal of Aquatic Science*, *7*(2), 87–94.

Pangantihon-Kühlmann, M. P., Millamena, O., & Chern, Y. (1998). Effect of dietary astaxanthin and vitamin A on the reproductive performance of *Penaeus monodon* broodstock. *Aquatic Living Resources*, *11*(6), 403–409. Retrieved from https://doi.org/10.1016/S0990-7440(99)80006-0

Plaipetch, P. (2015). Reproductive Biology and Nutrient Requirements of Giant Freshwater Prawn (*Macro brachium rosenbergii*) Broodstock. *Burapha Science Journal* (*in Thai*), *20*(2), 232–248.

Racotta, I. S., Palacios, E., & Ibarra, A. M. (2003). Shrimp larval quality in relation to broodstock condition. *Aquaculture*, *227*(1–4), 107–130. Retrieved from https://doi.org/10.1016/S0044-8486(03)00498-8

Ruiz, T. F. R., Ribeiro, K., Vicentini, C. A., Vicentini, I. B. F., & Papa, L. P. (2019). Effects of dietary cholesterol on hepatopancreas associated with morphotypic differentiation in male Amazon River Prawns, *Macrobrachium amazonicum* (Heller, 1862). *Aquaculture Research*, *50*(3), 862–870. Retrieved from https://doi.org/10.1111/are.13958

Sarman, V., Vishal, R., Mahavadiya, D., & Sapra, D. (2018). Nutritional aspect for freshwater prawn (*Macro brachium rosenbergii*) farming. *International Journal of Fauna and Biological Studies*, *5*(2), 172–175.

Shanju, S., & Geraldine, P. (2011). Quantitative protein profile of three *Macrobrachium* species during reproductive cycle. *Asian Journal of Animal and Veterinary Advances*, *6*(7), 731–737. Retrieved from https://doi.org/10.3923/ajava.2011.731.737

Smith, D. M., Tabrett, S. J., & Barclay, M. C. (2001). Cholesterol requirement of subadult black tiger shrimp *Penaeus monodon* (Fabricius). *Aquaculture Research*, *32*(*Supplemental Issue*), 399–405. Retrieved from https://doi.org/10.1046/j.1355-557x.2001.00030.x

Tacon, A. G. J. (1987). The nutrition and feeding of farmed fish and shrimp - a training manual. *FAO Field Document*, 208. Retrieved from http://www.fao.org/3/ab470e/AB470E00.htm#TOC

Teshima, S.-I., Ishikawa, M., Koshio, S., & Kanazawa, A. (1997). Necessity of dietary cholesterol for the freshwater prawn. *Fisheries Science*, *63*(4), 596–599. Retrieved from https://doi.org/10.2331/fishsci.63.596

Thanh Hien, T. T., Hai, T. N., Phuong, N. T., Hang, B. T. B., Yen, D. T. T., Ogata, H., & Wilder, M. N. (2001). The effects of feeding diets containing various sources of lipid on the performance of freshwater prawn (*Macrobrachium rosenbergii*) broodstock. *The Proceeding of 2001 Annual Workshorp of JIRCAS Mekong Delta Project*, *September*, 173–182.

Thanh Hien, T. T., Hai, T. N., Yen, D. T., Bich Hang, B. T., Phuong, N. T., Ogata, H. Y., & Wilder, M. N. (2003). Study on feeds and feeding of larvae and broodstock of giant freshwater prawn (*Macro brachium rosenbergii*): A review. *Freshwater Prawn International Symposium 2003*, 1–8.

Wang, W., Sun, J., Liu, C., & Xue, Z. (2017). Application of immunostimulants in aquaculture: current knowledge and future perspectives. *Aquaculture Research*, *48*(1), 1–23. Retrieved from https://doi.org/10.1111/are.13161

Wouters, R., Piguave, X., Bastidas, L., Calderon, J., & Sorgeloos, P. (2001). Ovarian maturation and haemolymphatic vitellogenin concentration of Pacifc white shrimp *Litopenaeus vannamei* (Boone) fed increasing levels of total dietary lipids and HUFA. *Aquaculture Research*, *32*, 573–582.

Yao, J. J., Zhao, Y., Wang, Q., Zhou, Z. L., Hu, X., Duan, X., & An, C. (2006). Biochemical compositions and digestive enzyme activities during the embryonic development of prawn, *Macrobrachium rosenbergii*. *Aquaculture*, *253*(1–4), 573–582. Retrieved from https://doi.org/10.1016/j.aquaculture.2005.08.01