White Paper

OPTIMUM OMEGA NUTRITION ™ FOR SHRIMP

By Dr. Ester Santigosa, Ian Carr, and Prof. Brett Glencross

veramaris®
A JOINT VENTURE OF DSM AND EVONIK

MEETING DIETARY EPA AND DHA REQUIREMENTS OF SHRIMP: IMPROVING HEALTH, WELFARE, AND PERFORMANCE

SUMMARY:

Eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) are Omega-3 essential fatty acids (EFA) vital for the survival, health, performance, and, eventually, product quality of farmed shrimp species. Traditionally, EFA dietary requirements have been met with fish oil (FO) and fish meal (FM). Yet, supply limitations and environmental considerations are driving the use of more sustainable ingredients such as vegetable or marine algal oils. The former, however, are low in Omega-3 fatty acids, which negatively affect shrimp welfare, growth performance, and fatty acid profile, and thus hinder the quality of the product. In contrast, marine algal oil is high in EPA & DHA Omega-3, making it a consistent and favourable alternative to FM and FO.

Veramaris® natural marine algal oil is a sustainable source of EPA and DHA that meets shrimp optimum dietary requirements which is at least 1% of EPA & DHA in the diet and improves its health, robustness, and growth performance throughout production in challenging farming conditions. Nevertheless, EFA requirements throughout the life cycle of farmed shrimp remain still unresolved. In order to develop nutritionally complete diets and fully exploit shrimp production potential, a thorough understanding of the nutritional requirements at all development stages is necessary.

THE ESSENTIALITY OF ESSENTIAL FATTY ACIDS

Lipids are considered to be the most important dietary nutrients for shrimp owing to their role as chemical messengers, key components of cell membranes, and source of energy and essential fatty acids (EFA) (1). EFA are polyunsaturated fatty acids (PUFAs) that cannot be sufficiently synthesized by animals, and therefore must be acquired through the diet (2). EFA are divided into two main families. The first, Omega-3 (n-3) PUFA, includes alpha-linolenic acid (LNA; 18:3n-3), eicosapentaenoic acid (EPA; 20:5n-3), and docosahexaenoic acid (DHA; 22:6n-3). The second, Omega-6 (n-6) PUFA, includes linoleic acid (LOA; 18:2n-6) and arachidonic acid (ARA; 20:4n-6).

Amongst many other functions, EFA are required for normal metabolic and endocrine functions, reproduction, cellular synthesis and ionic regulation, development and function of the nervous system, and for the process of moulting in shrimp (3–6). EPA and DHA in particular are recognized as the most indispensable EFA (1,7,8). These are vital for potentiating shrimp growth, feed efficiency, and survival (9,10), and thus have higher nutritional value. Aside from performance and welfare, dietary EFA also shape the nutritional profile of the shrimp – hence affecting product quality (4).

EFA are also of special interest for their role on the immune system of shrimp. They are precursors of eicosanoids, which act as mediators of the immune response (11,12). More specifically, ARA-derived eicosanoids are pro-inflammatory. Dietary ARA has been reported to modulate the immune responses of shrimp induced by microcystin-LR (MC-LR) stress, which causes great harm to shrimp (6). On the other hand, eicosanoids derived from EPA and DHA are anti-inflammatory (13). Although both n-3 and n-6 fatty acids (FAs) are essential components, a ratio skewed in favour of n-3 FAs is, however, favourable: research in mammals, fish, and invertebrates has established that a high n-3:n-6 ratio promotes the synthesis of anti-inflammatory molecules that may impact the immune response and increase resistance to disease and stress (7,14–16). Higher n-3 FAs levels also avoid negative effects on FA composition, thus ensuring a high quality of the products (5,17,18). However, more research in shrimp species is still needed to determine the optimum levels of EFA as well as their ratios to meet shrimp demands and also deliver a high-quality product for end-consumers (19).

THE CHALLENGING ROAD TOWARDS SUSTAINABILITY IN AQUAFEEDS

Pacific white shrimp *(Litopenaeus vannamei)* is the leading cultured shrimp species worldwide (20). As the demand for shrimp continues to grow, so does the demand for feed. For years, the primary source of lipids for aquaculture feeds has been fish oil (FO) and fishmeal (FM) (7,18). Indeed, approximately 70% of the annual FO supply goes towards aquaculture (21). However, feed sustainability has become a critical issue for the shrimp farming supply chain. The global availability of FO and FM is limited by the capacity of fisheries, many of which are already fished at or above sustainable limits (14), leading to unpredictable availability, higher costs, and variation in the quality of these sources of EFA. Apart from the commercial considerations, increasing environmental and social concerns regarding the exploitation of wild fisheries and the use of FO and FM in aquafeeds catalysed changes in feed formulations.

Finding more sustainable alternative ingredients with consistent EPA and DHA levels addressing shrimp Omega-3 demands has become an urgent issue. Vegetable oils (VOs) have been used as an alternative to FO and FM in aquafeeds for decades (4). Indeed, the substitution of FO and FM by VOs has reduced the use of FM in shrimp feeds from 20% in the late 90s to less than 10% nowadays (22). Additionally, replacing expensive ingredients such as FO in aquafeeds substantially curbs the costs of shrimp feed, which represents a significant fraction of production costs. While this could spur growth and economic sustainability of the industry (18), the use of VOs entails negative consequences for shrimp and the final consumer. Importantly, shrimp nutrition and health are not optimal when VOs are used due to their high content in Omega-6 and low content in Omega-3 (4). This disrupts the n-3:n-6 ratio and promotes the synthesis of pro-inflammatory molecules, thus affecting the shrimp's immune response and decreasing its stress and disease resistance capacity (11). Nevertheless, recent research efforts have focused on modifying VOs, particularly canola oil, to enhance the Omega-3 levels and validate its use as an alternative ingredient to FO (23). However, and despite their potential in supporting shrimp growth without negatively affecting their fatty acid profile (24), genetically modified (GM) VOs are neither rich in EPA or DHA, have levels below that of FO and do not contain both EPA & DHA. Moreover, the introduction of these products entails challenging issues associated with consumer perception and acceptance of GM organisms (25) in the food chain.

VERAMARIS® ALGAL OIL: FROM THE NATURAL SOURCE TO SHRIMP FARMS

Marine algal oil has recently become a promising source of EFA: algal oil is a rich source of Omega-3, with high levels of EPA and DHA. The interest in marine algae originates from a better understanding of marine food webs: marine algae are the principal primary producer in our oceans and the food source of zooplankton, which are consumed by shrimp or fish that are caught and turned into FO for aquafeeds. Based on this, Veramaris® turned to marine algae as the original source of EFA to produce a sustainable alternative that naturally supports shrimp growth, health, and development.

Veramaris® algal oil is the world's first natural oil from marine algae high in EPA & DHA Omega-3 (65%). The high concentration in Omega-3 ensures a naturally balanced n-3:n-6 ratio. Moreover, only a small concentration of algal oil (< 2%), is needed to reach shrimp's nutritional requirements (EPA & DHA levels of 1% of diet). These qualities make algal oil a better lipid source than other ingredients, and with a more stable production. Indeed, one tonne of Veramaris® algal oil yields as much EPA and DHA as up to 66 tonnes of forage fish. This breakthrough innovation can supplement and even replace marine ingredients, hence reducing the marine footprint of shrimp farmers and allowing the aquaculture industry to grow more sustainably. Moreover, due to its stable production, supply and price variability are minimized, thus offering increased market security. Veramaris® algal oil can be used in conjunction with the Optimum Omega NutritionTM (OON) guidelines. OON guidelines are based on an expert review of current science to help farmers meet shrimp Omega-3 and Omega-6 requirements, thereby supporting shrimp welfare and performance in challenging conditions.

Multiple scientific trials have demonstrated that Veramaris® algal oil supports shrimp performance and survival equally well as FO and FM (internal data). Moreover, shrimp fed with Veramaris® algal oil were reported to be at least three times richer in EPA & DHA Omega-3 than those fed with a conventional FO-based diet (internal data). Additional trials also demonstrated an increased resistance to pathogens: the replacement of FM and FO by Veramaris® algal oil, together with a soy-based commercial product (MrFeed® Pro50), in the diet of Pacific white shrimp significantly ($p < 0.01$) improved survival after challenge with *Vibrio parahaemolyticus*,

veramaris®
A JOINT VENTURE OF DSM AND EVONIK

the causative agent of early mortality syndrome (26). These results support the use of Veramaris® algal oil in shrimp feeds and show how they improve aquaculture productivity without compromising the conservation of natural resources.

UNFINISHED BUSINESS: DEFINING EFA REQUIREMENTS FOR FARMED SHRIMP

Meeting dietary omega requirements, specifically EPA and DHA, is crucial in farming conditions that constantly challenge shrimp with, for instance, changes in salinity and temperature, and with disease outbreaks. The current optimum considerations for EPA and DHA inclusion in shrimp feeds are at least 1% in the diet to better support shrimp robustness by counteracting the negative effects of biological and environmental stressors (27–29). More specifically, expert opinion suggests EPA & DHA Omega-3 inclusion of not less than 0.4 – 0.6% of the diet in *L. vannamei*, and up to 1.1% in giant tiger prawn *(Penaeus monodon)* (Table 1, Figure 1).

Despite all the research efforts in EFA requirements, they remain obscure (3,4). So far, the nutritional requirements of *L. vannamei* remain incomplete, and mostly focus on a single life stage. The differences in requirements observed in studies of post-larvae and juvenile stages of Pacific white shrimp, see for instance Mayra L. González-Felix *et al.* (30) and Wang *et al.* (31), evidence the need for better knowledge on the PUFA requirements for this species at different life stages (32). A precise definition of the requirements for larval, juvenile, and adult stages will aid to fully exploit the grow-out potential of shrimp.

Besides, the industry needs to better integrate scientific findings and research into shrimp feed formulations. A downward trend has been noted in the levels of EPA and DHA in commercial shrimp feeds, with a reduction of a 16% between 2014 and 2016. This is likely associated with the replacement of FM and FO by vegetable ingredients and its compensation with phospholipids and protein (27). This highlights how the disregard of scientific research regarding shrimp EFA requirement levels can be widely detrimental for the industry. Undeniably, research shows that the reduction in essential lipids such as EPA and DHA significantly impacts shrimp growth, feed conversion, and protein efficiency (27). Addressing the dietary EFA shrimp requirements, both in terms of research and its implementation in aquafeeds, will be an essential step forward and enable the sustainable growth of the industry in the long run.

Overall, it is evident that further research efforts are required to comprehensively define quantitative nutritional requirements for EFA throughout the life cycle of farmed shrimp, and the optimum ratio of n-3:n-6 in particular. This information must eventually be used to develop nutritionally complete, sustainable, and cost-effective diets that are specific to the needs of different development stages of farmed shrimp, from nurseries to grow-out farms. This is not only required to meet shrimp nutritional demands, but also the changing retailer sourcing values and consumer sentiment. Ultimately, these advances will promote the future expansion and sustainable development of the shrimp aquaculture industry.

TABLE 1

Shrimp weight	ARA	EPA	DHA	EPA + DHA	n-3 : n-6	EPA : DHA
0.1 – 1 g	0 – 0,1	0,2 – 0,5	0,2 – 0,5	0,5 – 1,1	>2 : 1	1 – 1.5 : 1 – 2
1 – 10 g	0 – 0,1	0,1 – 0,5	0,2 – 0,5	0,4 - 1	>2 : 1	1 – 1.5 : 1 – 3
10 – 40 g	0 – 0,1	0,1 – 0,4	0,2 – 0,4	0,4 – 0,8	>2 : 1	1 : 1 – 3

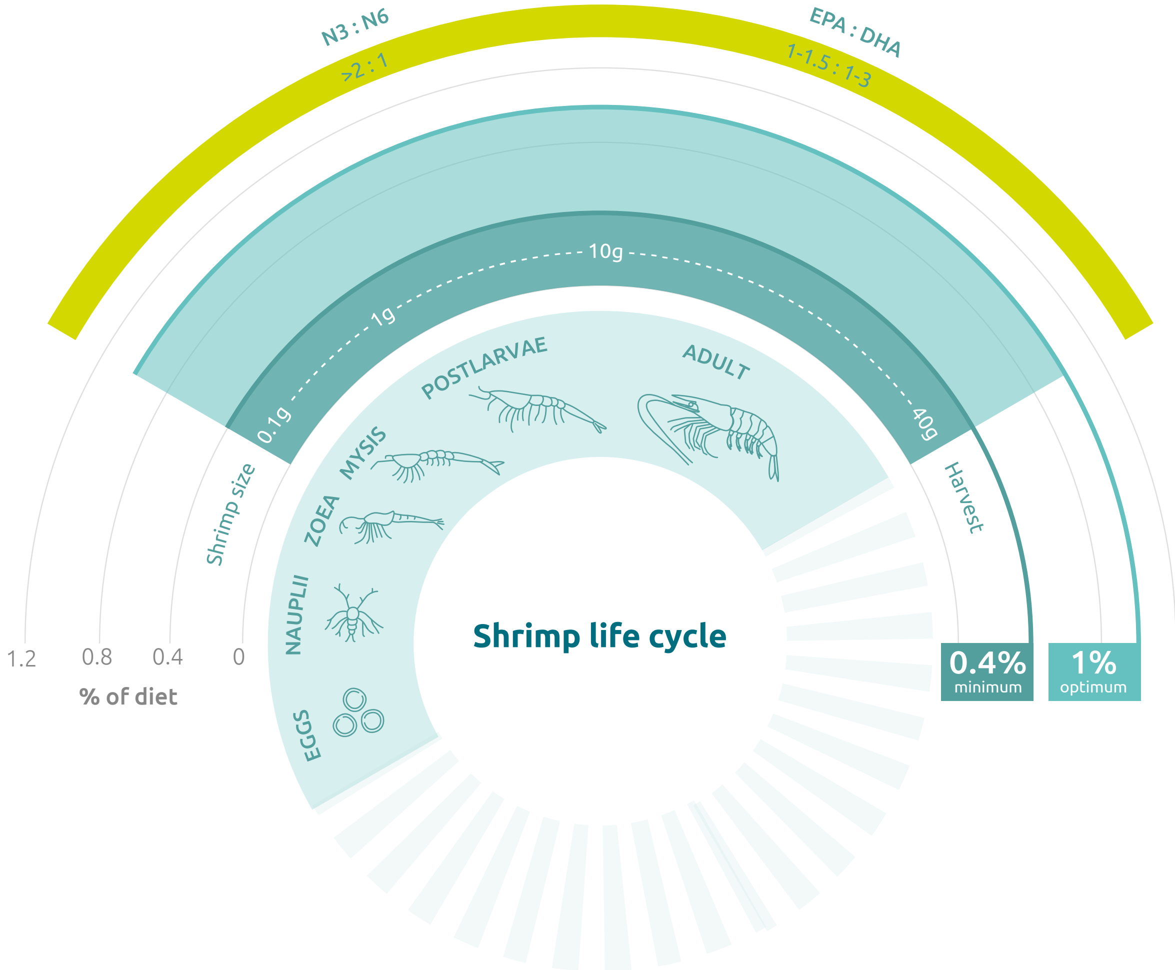
Expert opinion on requirements of essential fatty acids in Pacific white shrimp and Giant tiger prawn under laboratory and farm conditions to support adequate growth, survival, and health. Values expressed in % of diet.

OPTIMUM OMEGA NUTRITION™
FOR SHRIMP

Veramaris analysis supported by
Prof. Brett Glencross based on latest
available information and science

TOTAL EPA & DHA REQUIREMENT

Data from lab and farm conditions



OPTIMUM OMEGA NUTRITION™

Supported with Veramaris natural marine algae oil rich in EPA, DHA & ARA essential fatty acids

Figure 1. Expert opinion on shrimp EPA & DHA Omega-3 requirements throughout the production cycle. Further research is required to comprehensively define EPA & DHA nutritional requirements throughout the life cycle of shrimp and their optimum ratios.

veramaris®
A JOINT VENTURE OF DSM AND EVONIK

REFERENCES

1. Zhou Q-C, Li C-C, Liu C-W, Chi S-Y, Yang Q-H. Effects of dietary lipid sources on growth and fatty acid composition of juvenile shrimp, Litopenaeus vannamei. Aquacult Nutr. 2007 Jun;13(3):222–9.
2. National Research Council, Division on Earth and Life Studies, Board on Agriculture and Natural Resources, Committee on the Nutrient Requirements of Fish and Shrimp. Nutrient Requirements of Fish and Shrimp. National Academies Press; 2011. 392 p.
3. González-Félix, Perez-Velazquez M. Current Status of Lipid Nutrition of Pacific White Shrimp, Litopenaeus vannamei. ACU [Internet]. 2002 [cited 2022 Jan 9]; Available from: https://nutricionacuicola.uanl.mx/index.php/acu/article/view/226
4. Glencross BD. Exploring the nutritional demand for essential fatty acids by aquaculture species. Rev Aquac. 2009 Jun;1(2):71–124.
5. Nesara KM, Paturi AP. Nutritional requirement of fresh water prawn and shrimps: A review. J Entom and Zoo Stud. 2018;6(4):1526–32.
6. Duan Y, Lu Z, Zeng S, Dan X, Zhang J, Li Y. Effects of dietary arachidonic acid on growth, immunity and intestinal microbiota of Litopenaeus vannamei under microcystin-LR stress. Aquaculture. 2022 Feb 25;549:737780.
7. Zhang W, Wang F, Tan B, Yang Q, Chi S, Dong X, et al. Effects of dietary n3HUFA on different growth stages of the white shrimp, Litopenaeus vannamei : Growth, haematological characteristics, enzyme activities and fatty acid profiles. Aquacult Nutr. 2019 Oct;25(5):1098–114.
8. Kanazawa A, Teshima S-I, Tokiwa S, Kayama M, Hirata M. Essential fatty acids in the diet of prawn. II. Effect of docosahexaenoic acid on growth. Nippon Suisan Gakkai Shi. 1979;45(9):1151–3.
9. González-Félix, Lawrence AL, Gatlin DM III, Perez-Velazquez M. Nutritional evaluation of fatty acids for the open thelycum shrimp, Litopenaeus vannamei : I. Effect of dietary linoleic and linolenic acids at different concentrations and ratios on juvenile shrimp growth, survival and fatty acid composition. Aquacult Nutr. 2003 Apr;9(2):105–13.
10. González-Félix, Gatlin DM III, Lawrence AL, Perez-Velazquez M. Nutritional evaluation of fatty acids for the open thelycum shrimp, Litopenaeus vannamei : II. Effect of dietary n-3 and n-6 polyunsaturated and highly unsaturated fatty acids on juvenile shrimp growth, survival, and fatty acid composition. Aquacult Nutr. 2003 Apr;9(2):115–22.
11. Nonwachai T, Purivirojkul W, Limsuwan C, Chuchird N, Velasco M, Dhar AK. Growth, nonspecific immune characteristics, and survival upon challenge with Vibrio harveyi in Pacific white shrimp (Litopenaeus vannamei) raised on diets containing algal meal. Fish Shellfish Immunol. 2010 Aug;29(2):298–304.
12. Mercier L, Racotta IS, Yepiz-Plascencia G, Muhlia-Almazán A, Civera R, Quiñones-Arreola MF, et al. Effect of diets containing different levels of highly unsaturated fatty acids on physiological and immune responses in Pacific whiteleg shrimpLitopenaeus vannamei(Boone) exposed to handling stress. Aquac Res. 2009 Nov;40(16):1849–63.
13. Calder PC. n-3 fatty acids, inflammation and immunity: new mechanisms to explain old actions. Proc Nutr Soc. 2013 Aug;72(3):326–36.
14. Patterson E, Wall R, Fitzgerald GF, Ross RP, Stanton C. Health implications of high dietary omega-6 polyunsaturated Fatty acids. J Nutr Metab. 2012 Apr 5;2012:539426.
15. Gogus U, Smith C. n-3 Omega fatty acids: a review of current knowledge. Int J Food Sci Technol. 2010 Mar;45(3):417–36.
16. Bell JG, McVicar AH, Park MT, Sargent JR. High dietary linoleic acid affects the fatty acid compositions of individual phospholipids from tissues of Atlantic salmon (Salmo salar): association with stress susceptibility and cardiac lesion. J Nutr. 1991 Aug;121(8):1163–72.
17. Yang Q, Zhang W, Tan B, Wang F, Chi S, Dong X, et al. Effects of dietary n-3HUFA on juvenile white shrimp, Litopenaeus vannamei: Growth, feed utilization, antioxidant enzymes activities and fatty acid compositions. Aquac Res. 2019 Mar;50(3):882–94.
18. Xu Z, Wang A, Wang H. The effect of replacement of fish oil by soybean oil in practical diets, on tissue fatty acid and expression of related genes in Pacific white shrimp Litopenaeus vannamei. Israeli Journal of … [Internet]. 2016; Available from: https://evols.library.manoa.hawaii.edu/handle/10524/54929
19. González-Félix, Perez-Velazquez M, Quintero-Alvarez JM, Davis DA. Effect of various dietary levels of docosahexaenoic and arachidonic acids and different n-3/n-6 ratios on biological performance of pacific white shrimp,Litopenaeus vannamei, raised in low salinity. J World Aquac Soc. 2009 Apr;40(2):194–206.
20. FAO. The State of World Fisheries and Aquaculture 2020: Sustainability in action. Food and Agriculture Organization of the United Nations; 2020. 244 p.
21. Case study - fish meal and fish oil. European Market Observatory for Fisheries and Aquaculture Products; 2019. Report No.: 4.
22. OECD/FAO. OECD-FAO Agricultural Outlook 2019-2028. Paris/Food and Agriculture Organization of the United Nations, Rome: OECD Publishing; 2019.
23. Napier JA, Usher S, Haslam RP, Ruiz-Lopez N, Sayanova O. Transgenic plants as a sustainable, terrestrial source of fish oils. Eur J Lipid Sci Technol. 2015 Sep;117(9):1317–24.

24. Gia Vo LL, Galkanda‐Arachchige HSC, Iassonova DR, Davis DA. Efficacy of modified canola oil to replace fish oil in practical diets of Pacific white shrimp Litopenaeus vannamei. Aquac Res. 2021 Jun;52(6):2446–59.

25. Lucht JM. Public Acceptance of Plant Biotechnology and GM Crops. Viruses. 2015 Jul 30;7(8):4254–81.

26. McLean E, Barrows FT, Alfrey K, Tran L, Mével JY. Study replaces dietary fish oil with microalgal oil. Global Aquaculture Advocate [Internet]. 2020 Apr 20 [cited 2022 Jan 10];
Available from: https://www.globalseafood.org/advocate/study-replaces-dietary-fish-oil-with-microalgal-oil/

27. van Halteren A, Coutteau P. Survey of nutrient levels in commercial shrimp feeds in India. 2017.

28. Kanazawa A, Teshima S, Endo M. Requirement of prawn, Penaeus japonicus, for essential fatty acids. Mem Fac Fish Kagoshima Univ. 1979;28:27–33.

29. Shiau S-Y. Nutrient requirements of penaeid shrimps. Aquaculture. 1998;164(1–4):77–93.

30. González-Félix, Gatlin DM, Lawrence AL, Perez-Velazquez M. Effect of dietary phospholipid on essential fatty acid requirements and tissue lipid composition of Litopenaeus vannamei juveniles. Aquaculture. 2002 Apr 30;207(1):151–67.

31. Wang Y, Li M, Filer K, Xue Y, Ai Q, Mai K. Replacement of fish oil with a DHA-richSchizochytriummeal on growth performance, activities of digestive enzyme and fatty acid profile of Pacific white shrimp (Litopenaeus vannamei) larvae. Aquacult Nutr. 2017 Oct;23(5):1113–20.

32. Araújo BC, Mata-Sotres JA, Viana MT, Tinajero A, Braga A. Fish oil-free diets for Pacific white shrimp Litopenaeus vannamei: The effects of DHA-EPA supplementation on juvenile growth performance and muscle fatty acid profile. Aquaculture. 2019 Sep 15;511:734276.