**NUTRITIONAL REQUIREMENTS OF SHRIMP AND PRAWN**

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**Abstract**

Aquaculture, particularly shrimp farming, has gained immense significance as a global food production sector. Despite its growth, shrimp aquaculture confronts challenges, notably the high cost of feed and nutritional deficiencies leading to diseases. This comprehensive overview delves into the critical nutritional requirements of shrimp, covering vitamins (C, E and B), minerals (calcium and phosphorus), essential fatty acids, and amino acids. Deficiencies or imbalances in these nutrients can result in various developmental abnormalities, weakened immune responses, and reduced growth rates in shrimp populations. Understanding and managing the specific dietary needs of shrimp species is vital for maintaining their health, improving growth, and ensuring sustainable aquaculture practices. The article synthesizes findings from numerous spotlighting, highlighting the diverse nutritional needs of different shrimp species and presenting strategies to address nutritional challenges in shrimp farming.

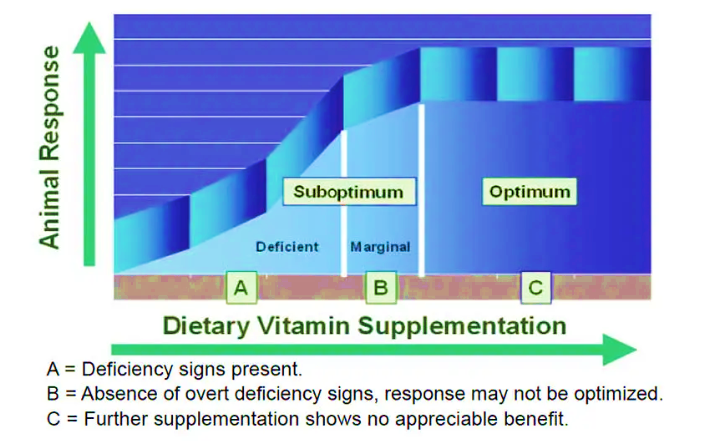
**Keywords Aquaculture**

Shrimp farming, Nutritional requirements, Vitamins (C, E, B), Minerals (calcium, phosphorus), Essential fatty acids, Amino acids, Nutritional challenges, Strategies

**Introduction**

Aquaculture has emerged as one of the most rapidly expanding global food industries (Rahman et al., 2015). Shrimp farming, an aquaculture endeavour focused on cultivating marine shrimps or prawns for human consumption, has evolved into a significant economic and food production sector. It's increasingly acknowledged as a crucial source of protein for human consumption and stands as a pivotal component in food production, closely trailing agriculture. The expansion of shrimp aquaculture has paralleled the growth of overall aquaculture for many years. Among the diverse sectors within aquaculture, shrimp cultivation has witnessed significant global growth due to the rapid maturation rate of shrimps, shorter culture periods, their high export value, and increasing market demand (Rahman et al., 2015). While shrimp aquaculture holds considerable importance within global aquaculture production, it faces numerous challenges, with the high cost of feed being particularly noteworthy. The nutritional aspect of shrimp is crucial for ensuring profitability in shrimp farming, as diet expenses alone often 50% of the variable production cost within a commercial enterprise (Jatoba et al., 2014). Given the extensive variety of shrimp species being cultivated, there is limited available information regarding the specific nutritional needs of shrimp. Despite decades of extensive research by scientists focusing on both qualitative and quantitative nutrient requirements for shrimps, there persist a lack of comprehensive data. In the last two decades, the global shrimp industry has encountered significant economic setbacks attributed to nutritional deficiencies and the prevalence of viral, bacterial, and fungal diseases. Understanding shrimp immunology is of crucial significance in devising disease control strategies and fostering the growth of sustainable aquaculture practices. Moreover, distinct age groups of shrimps may exhibit varying nutritional needs. This section aims to explore the observed nutrient requirements across various shrimp species, contributing valuable insights to address gaps in our understanding and promote the development of effective nutritional strategies for sustainable shrimp aquaculture.

**Keywords :** Vitamin, Mineral, Essential fatty acid, Aminoacid



(Global Seafood Alliance)

Nutritional diseases in shrimp can arise due to deficiencies or imbalances in essential nutrients. Some of these conditions include:

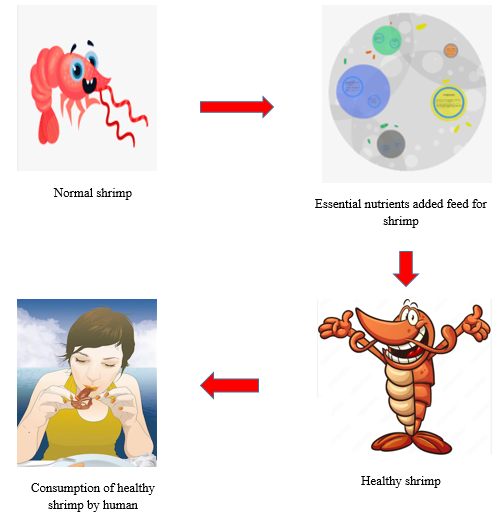
1.Vitamin Deficiencies: Insufficient intake of vitamins like Vitamin C, Vitamin E, or Vitamin B-complex can lead to various issues. For instance, Vitamin C deficiency might result in poor growth, deformities, or weakened immune function. Vitamin E deficiency can cause muscle degeneration or reduced reproductive performance (Shefat and Karim, 2018)

2.Mineral Imbalances: Inadequate levels or imbalances of minerals such as calcium, phosphorus, magnesium, or selenium can lead to shell deformities, weakened exoskeletons, or impaired growth.

3.Essential Fatty Acid Deficiency: Omega-3 and Omega-6 fatty acids are crucial for shrimp growth and health. Deficiencies in these fatty acids might result in poor growth, reduced survival rates, or impaired reproductive performance.

4.Amino Acid Imbalances: Inadequate levels of specific amino acids can hinder protein synthesis, impacting growth and overall health. Methionine and lysine, for example, are essential amino acids for shrimp growth.

These nutritional disorders can manifest as developmental abnormalities, weakened immune responses, reduced growth rates, increased susceptibility to diseases, and overall poor health in shrimp populations. Proper nutrition management and assurance of a balanced diet are crucial in preventing these conditions in shrimp farming (Tacon and Tran, 2022). Maintaining optimal nutritional conditions not only mitigates the risk of these disorders but also plays a pivotal role in enhancing the overall health, vitality, and productivity of shrimp populations within aquaculture systems



**Vitamin C**

Vitamin C, also known as l-ascorbic acid (AsA), plays a pivotal role as a critical nutrient for numerous aquatic animal species, including penaeid shrimp. Fish and crustaceans are typically unable to produce their own AsA due to the absence of enzyme gluconolactone oxidase necessary for converting glucose into ascorbic acid. Consequently, many aquatic creatures depends on a consistent dietary intake of vitamin C. Several studies have explored the significance of AsA in promoting growth, survival rates, feed efficiency, molting, stress resilience, and immune responses in penaeid shrimp (Merchie et al., 1998; He and Lawrence, 1993; Shiau and Hsu, 1994; Lee and Shiau, 2002; Lightner et al., 1979).

Research indicated that elevating dietary vitamin C levels through live food significantly improved the typical growth, survival rates, and stress resilience of white shrimp (Penaeus vannamei) and freshwater prawn (*Macrobrachium rosenbergii*) larvae (Merchie et al., 1997).

However, vitamin C is notably unstable, and its efficacy diminishes in formulated diets due to exposure to high temperatures, oxygen, moisture, and light during processing and storage.

This instability could potentially hinder the advancement of larval shrimp development. Nonetheless, efforts have been made to enhance the stability and bioactivity of AsA by employing stabilized derivatives. Consequently, various trials involving the incorporation of these stable AsA forms into shrimp feeds have been carried out (Hsu and Shiau, 1997, 1998; Chen and Chang, 1994). Among the derivatives of AsA, ascorbyl monophosphate stands out for its purported high stability and multiple advantages. Table 1 shows the requirement of dietary vitamin C levels in shrimp and prawns.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl no | Species | Challenge | Vitamin C level | References |
|  | *M. japonicus* | Formalin stress test | 71 mg | Moe et al.2004 |
|  | *L. vannamei* | Ammonia-N. | 150 mg | Asaikkutti et al. 2018 |
|  | *Macrobrachiurn nipponense* | Ammonia | 4000 mg | Wang et al. 2005 |
|  | *P. monodon* | *Vibrio anguillarum* | 0.25% | Felix et al. 2014 |

**Vitamin E**

Vitamin E stands as a vital nutrient across animal species. As a fat-soluble vitamin, it function as a powerful antioxidant within biological membranes, acting as an effective chain-breaking, a lipid-soluble component that contributes significantly to membrane stability (McDowell, 1989). Numerous research investigations have underscored the essential nature of fat-soluble vitamins A, D, E, and K in the diets of most animals. These vitamins play crucial roles in supporting normal health and various life functions, including growth, development, maintenance, and reproduction. Vitamin E serves to shield crucial cellular structures from harm caused by oxygen free radicals and reactive byproducts resulting from lipid peroxidation. Existing in various natural forms, a-tocopherol exhibits the highest vitamin E activity. DL-a-Tocopheryl acetate (DL-a-TOA), known for its stability, stands out as the most prevalent vitamin E supplement utilized in animal feeds. When a hydrogen atom is removed from the central carbon of a fatty acid chain, it generates a lipid radical (L) that rapidly interacts with oxygen in the atmosphere, forming a proxy radical (LOO). This newly formed radical (LOO) can then extract hydrogen from another acyl chain, leading to the formation of a lipid hydroperoxide (LOOH) and generating another radical, denoted as L. This series of reactions, known as propagation, persists until it is disrupted by the presence of an antioxidant like tocopherol (vitamin E). Tocopherol serves as a hydrogen atom donor, transforming into a less reactive radical, thereby interrupting the chain reaction (Ouraji et al. 2011). Aquatic animals maintain high levels of unsaturated fatty acids to preserve cell membrane fluidity, particularly in colder environments. Vitamin E is believed to play a significant role in this process (Blazer, 1992). Researchers have explored the function of vitamin E in numerous immunological responses in mammals and teleosts. Studies indicate its enhancement of both humoral and cellular defences, while diets lacking in vitamin E have been associated with diminished immune responses (Panush and Delafuente, 1985; Moriguchi et al. 1990; Beharka et al. 1997)

Initial research on vitamin nutrition in crustaceans indicated the necessity of dietary vitamin E for *Daphnia magna* and *Moina macrocopa*. Since then, numerous studies have since been carried out to assess the dietary importance of vitamin E for penaeids (Viehoever and Cohen 1938; Conklin and Provasoli 1977; Cahu et al.1991; He et al. 1992)

Growing evidence suggests that vitamins C and E play crucial roles as antioxidants, safeguarding lipids within the tissues of aquatic animals (Conklin 1997)

In shrimp nutrition, Vitamin E potentially holds a significant role as an antioxidant, effectively preventing the oxidation of polyunsaturated fatty acids both within feeds and within shrimp tissues (Kanazawa 1977). In animal feeds, synthetic antioxidants like butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), and ethoxyquin are employed to minimize oxidative rancidity (He and Lawrence 1993). In 1985, Kanazawa observed that incorporating vitamin E into diets led to enhanced survival rates among larval *Marsupenaeus japonicas*. Table 2 shows the requirement of dietary vitamin E level in shrimp and prawn.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Sl no | Species | Challenge | Vitamin E level | References |
|  | *Eriocheir sinensis* | *Aeromonas hydrophila* | 100 mg | Wang et al. 2015 |
|  | *Penaeus monodon* |  | 200 mg | Jiang et al. 2020 |
|  | *L. vannamei* |  | 620mg | Montalvo et al. 2022 |
|  | *Fenneropenaeus indicus* |  | 300 mg | Ouraji et al. 2011 |
|  | *Macrobrachium nipponense* | *Aeromonas hydrophila* | 160 mg | Li et al. 2019 |

**Vitamin B**

Thiamin, also known as vitamin B1, holds the distinction of being the inaugural vitamin to be discovered. It serves as a crucial nutrient for a diverse range of animal species, including aquatic crustaceans (Catcutan et al. 1979). Thiamin is mainly found in animal tissue in the form of thiamin pyrophosphate (TPP) and functions as a coenzyme in significant enzymatic processes involved in energy production. These processes encompass decarboxylation and transketolase reactions (National Research Council 2011). Within the crustacean species, evaluations of the dietary thiamin needs have been conducted for various shrimp types, including the kuruma shrimp (*Marsupenaeus japonicus*) (Deshimaru & Kuroki 1979), tiger shrimp (*Penaeus monodon*) (Chen et al. 1991), and Indian white prawn (*Fenneropenaeus indicus*) (Boonyaratpalin, 1998). Vitamin B6 encompasses the 2-methylpyridine derivatives with the biological efficacy of pyridoxine. It's a vital nutrient necessary for upholding the regular physiological functions of animals. Pyridoxal phosphate, a type of Vitamin B6, plays a crucial role as a prosthetic group within numerous metabolic reactions. Its primary involvement lies in supporting enzymes, especially in processes linked to protein and amino acid metabolism. Most land-dwelling animals have established their dietary need for this vitamin.

Vitamin B12, or cobalamin, belongs to the category of water-soluble vitamins and is part of a compound group featuring a corrin ring. Within B12, the lower ligand connects to the cobalt-coordinated corrin ring through a nucleotide loop, with 5,6-dimethylbenzimidazole serving as a base.

Functioning as the precursor to the coenzyme pyridoxal phosphate, it plays a pivotal role in numerous metabolic reactions, especially those linked to the breakdown of proteins and amino acids. Being the precursor to the coenzyme pyridoxal phosphate, it actively participates in numerous metabolic reactions, especially those closely tied to the metabolism of proteins and amino acids. Table 3 shows the requirement of dietary vitamin B level in shrimp and prawn.

|  |  |  |  |
| --- | --- | --- | --- |
| Sl no | Species | Vitamin B level | References |
|  | *Litopenaeus vannamei* | 106.95mg B6 | Li et al.2010 |
|  | *P. monodon* | 89 mg B6 | Shiau and Wu, 2003 |
|  | *Penaeus monodon* | 0.2 mg B6 | Shiau and Lung,1993 |
|  | *Litopenaeus vannamei* | 54.2 mg B1 | Huang et al. 2015 |

**Calcium and Phosphorus**

Calcium plays a vital role in supporting hard tissue formation, blood clotting, muscle contractions, nerve signals, osmoregulation, and assisting enzymes in their functions (Lall and Prasad, 1989). Many aquatic species can directly absorb calcium from their surrounding environment to fulfill their calcium needs. The essential intake of calcium through diet could be influenced by variations in water chemistry, differences between species, and the levels of phosphorus in the diet. In the case of marine shrimp calcium deficiencies are often resolved through absorption from seawater. However, for organism residing in freshwater environments, accessing sufficient calcium is not always straightforward due to the diverse concentrations of calcium found in various freshwater sources.

According to Zimmertnann et al. (1994), incorporating dietary calcium becomes crucial, especially in instances of low mineral concentration, such as in soft water conditions. Shrimp species like *L. vannamei* and *Penaeus monodon* in seawater, as well as *Metapenaeus macleayi* in brackish water, did not exhibit a specific dietary need for calcium. An excess of dietary calcium was observed to hinder the growth of these shrimp

Phosphorus, a significant nutrient found in shrimp culture effluent, has been recognized as a major factor impacting the coastal environment due to its scarcity in natural water sources. Selecting the right phosphorus source can enhance its availability to the cultured species, leading to reduced investment in excess nutrients and lowering the nutrient load in both the culture system and effluent waters. The effectiveness of phosphorus sources can vary significantly among species, and even within the same species, the suitability of phosphorus sources can differ based on changing environmental conditions, such as variations in water salinity (Niu et al.2008).

Penaeid shrimp significantly rely on phosphorus (P) as one of the essential minerals due to its limited accessibility in rearing conditions. Phosphorus actively participates in energy-releasing processes and plays a fundamental role in cellular operations, serving as a vital component in nucleic acids, phospholipids, phosphoproteins, ATP, and numerous crucial enzymes. Furthermore phosphorus (P) is intricately linked with calcium in the formation of the exoskeleton and is associated with alkaline phosphatase (AP), an enzyme that adjusts according to changes in salinity during acclimation and plays a role in osmoregulation among crustaceans.

Given to its numerous roles, disruptions in phosphorus (P) balance can have significant impacts on various metabolic levels and organ systems potentialy leading to a phosphorus deficiency with consequential effects across most species.

The dietary phosphorus (P) requirement for many marine shrimp, including *L. vannamei, M. japonicus, P. monodon, F. merguiensis, Fenneropenaeus chinensis,* and *Farfantepenaeus aztecus,* falls within the range of 0.35% to 2.0%.

Considering the potential phosphorus (P) pollution originating from practical feeds, there is a significant focus on understanding P requirements and availability. Some research also recommends considering not just individual dietary mineral levels but also the dietary Ca/P ratio. Table 4 shows the requirement of dietary Calcium and Phosphorus levels in shrimp and prawn.

|  |  |  |  |
| --- | --- | --- | --- |
| Sl no | Species | Calcium and Phosphorous level | References |
|  | *Macrobrachium rosenbergii* | 3g calcium | Zimmertnann et al. (I994 |
|  | *Litopenaeus vannamei* | 22g phosphorous | Niu et al. 2008 |
|  | *Penaeus vannamei* | 2g calcium and 1g phosphorous | Davis et al. 1993 |
|  | *Macrobrachium amazonicum* | 18% phosphorous | Flickinger et al. 2020 |
|  | *(Colossoma macropomum)* |
|  | *Litopenaeus vannamei* | 2% calcium | Cheng et al.2006 |

**Essential fatty acids**

Osmoregulation in shrimp is a dynamic process that relies on energy, and strategic dietary adjustments can enhance their ability to adapt to varying salt levels in the environment. When faced with substantial deviations from their usual salinity conditions, shrimps tap into their internal energy reserves, leading to a rapid decline in their growth rate as evidenced by studies (Chen et al. 2014; Wang et al. 2015). The role of protein as an energy source during salinity changes has been extensively explored, with findings indicating that the protein requirements of L. vannamei increase in high salinity conditions (Huang et al., 2003). Additionally, Sui et al. (2015) observed significant growth enhancement in *L. vannamei* with diets containing 35 to 45% protein at salinity levels of 30 and 50.

As conserving dietary protein is imperative, identifying cost-effective non-protein energy sources becomes crucial. Wang et al. (2015) assessed the protein-saving impact of carbohydrates in *L. vannamei*, proposing a specific protein-to-carbohydrate ratio to meet the energy and protein needs of shrimp in low salinity conditions. Additionally, lipids play a pivotal role in elevating non-protein energy levels, preserving cellular integrity, and contributing essential fatty acids and vitamins for the proper physiological functioning of the shrimp (Tseng and Hwang, 2008).

In crustaceans, mirroring the pattern observed in other animals, the lipogenesis of fattyacids unfolds through a sequence of stages. Initiated by the synthesis of saturated fatty acids from acetate, these precursors undergo subsequent transformations into monounsaturated products, specifically within the palmitoleic (n-7) and oleic (n-9) acid series. Unlike saturated fatty acids, many aquatic species, including crustaceans, do not synthesize polyunsaturated fatty acids such as linoleic (n-6) and linolenic (n-3) de novo, deeming them essential components of their dietary intake. Nonetheless, numerous species exhibit the capacity to elongate and desaturate dietary n-6 and n-3 fatty acids within their bodies, albeit often insufficiently to fully meet their growth and metabolic requirements.

During salinity adjustments, a cascade of energy-demanding processes is initiated to uphold hemolymph osmotic and ionic balance in crustaceans. In this context, lipids emerge as active contributors to protein function within cell membranes, exerting a profound influence on enzymatic activity and assuming a pivotal role in the intricate mechanism of osmoregulation (Nordgarden et al. 2002).

Chen et al. (2014) conducted a study on *L. vannamei* revealing heightened activity of key enzymes associated with lipid mobilization— specifically adipose triglycerol lipase, lipoprotein lipase, and hormone-sensitive lipase—under both hypo (3‰) and hyper (30‰) saline conditions, in comparison to their activity at the optimal salinity of 17‰. Moreover, the study revealed an increase in the enzymes responsible for lipogenesis, namely fatty acid synthase and diacylglycerol acyltransferase, at salinities of 3‰ and 30‰. This suggests an augmented capacity for both lipogenesis and lipolysis in *L. vannamei* under conditions of both high and low salinity levels.

In the realms of commercial shrimp feed, lipid content typically falls within the range of 6 to 7%, with a maximum allowable level of 10% (Akiyama et al. 1991). Essential fatty acids crucial for penaeid nutrition and physiology, such as linoleic (18:2c), linolenic (18:3), arachidonic (20:4), eicosapentaenoic (20:5), and docosahexaenoic (22:6) acids, have been identified by Merican and Shim (1996) and Glencross et al. (2002). This underscores the importance of understanding the intricate enzymatic processes and lipid requirements in L. vannamei to optimize commercial shrimp feed formulations and ensure the overall health and nutritional well-being of the species.

Table 5 shows the requirement of dietary essential fatty acid levels in shrimp and prawn.

|  |  |  |  |
| --- | --- | --- | --- |
| Sl no | Species | Essential Fatty Acid | References |
|  | *Litopenaeus vannamei* | 12 g | Jannathulla et al. 2019 |
|  | *Litopenaeus vannamei* | 60 g | Zhou et al. 2007 |
|  | *Penaeus chinensis* | 1% | Xu et al. 1994 |
|  | *Litopenaeus vannamei* | 0.5% | González‐Félix et al. 2002 |
|  | *Penaeus monodon* | 105 g | Glencross et al. 2002 |
|  | *Macrobrachium nipponense* | 6.91% | Li et al. 2020 |

**Amino Acid**

In the realm of shrimp nutrition research, the primary focus centers on precisely determining the quantitative requirements for the 10 essential amino acids. Shrimp, given their distinctive feeding behavior and reliance on diets stable in water, face challenges in efficiently utilizing crystalline amino acids (CAAs). This has made the identification of their essential amino acid needs a complex task (Millamena et al. 1999)

Among these essential amino acids, arginine holds particular significance for shrimp as their urea cycle exhibits limited activity, rendering arginine indispensable for the regular growth and functioning as a crucial phosphagen in crustaceans (Alam et al. 2002).

Within the diets of penaeid shrimp, arginine is often recognized as the most crucial essential amino acid, exerting profound effects. It not only acts as a precursor for the synthesis of creatine and nitric oxide but also serves as a potent stimulant for insulin and growth hormone, potentially playing a significant role in anabolic processes. Moreover. arginine is integral in nitrogen metabolism and functions as a primary substrate for the generation of nitric oxide, highlighting its multifaceted importance in the physiological processes of shrimp (Millamena et al., 1999).

Arginine emerges as a standout amino acid due to its unique contribution to the amidino group necessary for creatine synthesis and its role as a significant reservoir of high-energy phosphate crucial for the restoration of ATP within the muscle. Researchers have undertaken estimations of the required dietary levels of arginine for certain shrimp species, exhibiting a notably high dietary need in comparison to other aquatic species (Dall et al., 1990). Specifically, in Pacific white shrimp (*Litopenaeus vannamei*), those on an arginine-deficient diet showed significantly lower weight gain compared to those on the standard control diet (Fox et al. 1995).

Threonine, is one of the three primary amino acids possessing an alcohol group, undergoes phosphorylation to become phosphothreonine facilitated by threonine kinase. Additionally, threonine, lysine, and methionine are identified as the most frequently deficient indispensable amino acids in plant-based protein sources.

Methionine, is a crucial amino acid for fish and shrimp nutrition, is prominently present in feeds tailored for these aquatic creatures, particularly in formulations that rely heavily on plant proteins (Millamena et al. 1996). Optimal methionine levels have been recognized to decrease the oxidation of other amino acids, fostering an increased growth rate according to the NRC of 2011.

Lysine, another essential amino acid, plays a pivotal role in the normal growth of shrimp, often being the most restricted amino acid in formulations with high levels of plant proteins or those processed under severe conditions (Teshima et al. 2002; NRC, 2011)

Table 6 shows the requirement of dietary amino acid levels in shrimp and prawn.

|  |  |  |  |
| --- | --- | --- | --- |
| Sl nos | Species | Amino acid | References |
|  | *Litopenaeus vannamei* | 2.32% Arginine | Zhou et al. 2012 |
|  | *Penaeus monodon* | Histidine, 0.80%; | Millamena et al. 1999 |
|  | *Penaeus monodon* | Isoleucine, 1.01% | Millamena et al. 1999 |
|  | *Penaeus monodon* | Leucine, 1.7% | Millamena et al. 1999 |
|  | *Penaeus monodon* | Phenylalanine, 1.4% | Millamena et al. 1999 |
|  | *Penaeus monodon* | Tryptophan, 0.2% | Millamena et al. 1999 |
|  | *Litopenaeus vannamei* | 1.51% threonine | Zhou et al. 2013 |
|  | *Litopenaeus vannamei* | 0.8%, 0.029 g-methionine | Lin et al. 2015 |
|  | *Litopenaeus vannamei* | 1.64% lysin | Xie et al. 2012 |

**Reference**

1. Akiyama DM (1991) Penaeid shrimp nutrition for the commercial feed industry: revised. In Proceeding of the aquaculture feed processing and nutrition workshop (pp. 80-98). American Soybean Association.
2. Alam MS, Teshima S, Koshio S, Ishikawa M (2002) Arginine requirement of juvenile Japanese flounder Paralichthys olivaceus estimated by growth and biochemical parameters. Aquaculture 205: 127–140.
3. Asaikkutti A, Bhavan PS, Vimala K, Karthik M (2018) Effect of different levels of dietary vitamin C on growth performance, muscle composition, antioxidant and enzyme activity of *Macrobrachium rosenbergii*. Proceedings of the National Academy of Sciences, India Section B: Biological Sciences, 88:477-486.
4. Beharka A, Redican S, Leka L, Meydani SN (1997) Vitamin E status and immune function. Methods in enzymology: vitamins and coenzymes, Part L. New York: Academic Press; 247e63.
5. Boonyaratpalin M (1998) Nutrition of *Penaeus merguiensis* and *Penaeus indicus*. Rev. Fish. Sci., 6, 69–78.
6. Cahu C, Villete M, Quazuguel P, Guillaume J (1991) The e¡ect of n-3 highly unsaturated fatty acid and vitamin E supplementation in broodstock feed on reproduction of *Penaeus indicus*. In: Fish Nutrition in Practice, Biarritz (France),Vol.61: 589-598. Paris, France
7. Catcutan MR, De La Cruz M (1979) Growth and midgut Cell profile of *Penaeus monodon* juveniles fed water soluble vitamin-deficient diets. Aquaculture, 81: 137–144
8. Chen HY, Chang CF (1994) Quantification of vitamin C requirements for juvenile shrimp, *Penaeus monodon* using polyphosphorylated l-ascorbic acid. J. Nutr. 124: 2033 – 2038.
9. Chen HY, Wu FC, Tang SY (1991) Thiamin requirement of juvenile shrimp (Penaeus monodon). J. Nutr., 121: 1984–1989.
10. Chen K, Li E, Gan L, Wang X, Xu C, Lin H, Qin JG, Chen L (2014) Growth and lipid metabolism of the pacific white shrimp *Litopenaeus vannamei* at different salinities. J. Shellfish Res. 33:825–833. <https://doi.org/10.2983/035.033.0317>.
11. Cheng KM, Hu CQ, Liu YN, Zheng SX, Qi XJ (2006) Effects of dietary calcium, phosphorus and calcium/phosphorus ratio on the growth and tissue mineralization of *Litopenaeus vannamei* reared in low-salinity water. Aquaculture, 251(2-4):472-483.
12. Conklin DE, Provasoli L (1977) Nutritional requirements of the water flea *Moina macrocopa*. Biological Bulletin152:337-350.
13. Dall W, Hill BL, Rothlisburg PC, Staples DJ (1990) The biology of the penaeidae. Advances in Marine Biology 27:167–216.
14. Davis DA, Lawrence AL, Gatlin DM (1993) Response of Penaeus vannamei to dietary calcium, phosphorus and calcium: phosphorus ratio. Journal of the World Aquaculture Society, 24(4):504-515.
15. Deshimaru O, Kuroki K (1979) Requirement of prawn for dietary thiamine, pyridoxine, and choline chloride. Bull. Jpn. Soc. Sci. Fish., 45: 363–367.
16. Felix N, Jeyaseela MP, Kirubakaran CJW, George MR (2014) Dietary administration of stable vitamin C enhances growth and disease resistance of postlarvae of tiger shrimp *Penaeus Monodon* against *Vibrio Anguillarum*. Journal of Aquaculture in the Tropics, 29:(1/2)
17. Flickinger DL, Dantas DP, Proença DC, David FS, Valenti WC (2020) Phosphorus in the culture of the Amazon river prawn (*Macrobrachium amazonicum*) and tambaqui (*Colossoma* *macropomum*) farmed in monoculture and in integrated multitrophic systems. Journal of the World Aquaculture Society, 51(4):1002-1023.
18. Fox JM, Lawrence AL, Li-Chan E (1995). Dietary requirement for lysine by juvenile *Penaeus vannamei* using intact and free amino acid sources. Aquaculture 131: 279–290.
19. Glencross, B.D., Smith, D.M., Thomas, M.R. and Williams, K.C., 2002. Optimising the essential fatty acids in the diet for weight gain of the prawn, Penaeus monodon. *Aquaculture*, *204*(1-2), pp.85-99.
20. Gonzalez‐Felix ML, Gatlin DM, Lawrence AL, Perez‐Velazquez M (2002). Effect of various dietary lipid levels on quantitative essential fatty acid requirements of juvenile Pacific white shrimp *Litopenaeus vannamei*. Journal of the World Aquaculture Society, 33(3):330-340.
21. He H, Lawrence AL (1993) Vitamin C requirements of the shrimp *Penaeus vannamei*. Aquaculture 114:305 – 316.
22. He H, Lawrence AL (1993) Vitamin E requirement of *Penaeus vannamei.* Aquaculture118: 245-255
23. He H, Lawrence AL, Liu R (1992) Evaluation of dietary essentiality of fat-soluble vitamins, A, E, E and K for penaeid shrimp *Penaeus vannamei*. Aquaculture103:177-185.
24. Hsu TS, Shiau SY (1997) Comparison of l-ascorbyl-2-polyphosphate with l-ascorbyl-2-sulphate in meeting vitamin C requirements of juveniles grass shrimp *Penaeus monodon*.
25. Hsu TS, Shiau SY (1998) Comparison of vitamin C requirement for maximum growth of grass shrimp, Penaeus monodon, with l-ascorbyl-2-mono-phosphate-Na and l-ascorbyl-2-monophosphate-Mg. Aquaculture 163: 203 – 213
26. Huang K, Wang W, Lu J (2003) Protein requirements in compounded diets for *Litopenaeus* *vannamei* juveniles. J. Fish. Sci. China 10: 308–321.
27. Huang XL, Xia MH, Wang HL, Jin M, Wang T, Zhou QC (2015). Dietary thiamin could improve growth performance, feed utilization and non‐specific immune response for juvenile Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture Nutrition*, *21*(3):364-372.
28. Jannathulla R, Chitra V, Vasanthakumar D, Nagavel A, Ambasankar K, Muralidhar M. and Dayal JS (2019) Effect of dietary lipid/essential fatty acid level on Pacific whiteleg shrimp, *Litopenaeus vannamei* (Boone, 1931) reared at three different water salinities–Emphasis on growth, hemolymph indices and body composition. Aquaculture, 513:734405.
29. Jatobá A, da Silva BC, da Silva JS, do Nascimento Vieira F, Mouriño JLP, Seiffert WQ, Toledo TM (2014) Protein levels for *Litopenaeus vannamei* in semi-intensive and biofloc systems. Aquaculture, 432:365-371.
30. Jiang S, Liu D, Zhou F, Mo X, Yang Q, Huang J, Yang L, Jiang S (2020) Effect of vitamin E on spermatophore regeneration and quality of pond‐reared, black tiger shrimp (Penaeus monodon). Aquaculture Research, 51(6):2197-2204.
31. Kanazawa A (1985) Nutritional factors in fish reproduction. In Reproductrion and culture of milk fish Proceedings of a workshop held at the Tungkang marine laboratory. Taiwan Lee, Cheng-Sheng and Liao, I-Chiu (eds) (pp. 115-125).
32. Kanazawa A, Tokiwa S, Kayama M, Hirata M (1977) essential fatty acids in the diet of prawn. i. effects of linoleic and linolenic acids on growth.
33. Lall D, Prasad T (1989) Compositional quality of certain unconventional calcium and phosphorus sources in India for use as mineral supplements for livestock. Animal Feed Science and Technology, *23*(4):343-348.
34. Lee MH, Shiau SY (2002) Dietary vitamin C and its derivatives affect immune responses in grass shrimp *Penaeus monodon*. Fish Shellfish Immunol. 12:119 – 129.
35. Li E, Yu N, Chen L, Zeng C, Liu L, Qin JG (2010) Dietary vitamin B6 requirement of the Pacific white shrimp, *Litopenaeus vannamei,* at low salinity. Journal of the World Aquaculture Society, 41(5):756-763.
36. Li L, Wang W, Yusuf A, Zhu Y, Zhou Y, Ji P, Huang X (2020) Effects of dietary lipid levels on the growth, fatty acid profile and fecundity in the oriental river prawn, *Macrobrachium nipponense.* Aquaculture Research, 51(5):1893-1902.
37. Li Y, Huang Y, Zhang M, Chen Q, Fan W, Zhao Y (2019) Effect of dietary vitamin E on growth, immunity and regulation of hepatopancreas nutrition in male oriental river prawn, *Macrobrachium nipponense*. Aquaculture Research, 50(7):1741-1751.
38. Lightner DV, Hunter B, Magarelli Jr, PC, Colvin LB (1979). Ascorbic acid: nutritional requirement and role in wound repair in penaeid shrimp. Proc. World Maric. Soc. 10:513 – 528.
39. Lin H, Chen Y, Niu J, Zhou C, Huang Z, Du Q, Zhang J (2015) Dietary methionine requirements of Pacific white shrimp *Litopenaeus vannamei*, of three different sizes. Israeli Journal of Aquaculture-Bamidgeh, 67.
40. McDowell LR (1989) Vitamin E. In: Vitamins in animal nutrition: comparative aspects to human nutrition. San Diego: Academic Press; 93
41. Merchie G, Kontara E, Lavens P, Robles R, Kurmaly K, Sorgeloos P (1998) Effect of vitamin C and astaxanthin on stress and disease resistance of postlarval tiger shrimp, *Penaeus monodon* Aquac. Res. 29:579 – 585
42. Merchie G, Lavens P, Sorgeloos P (1997) Optimization of dietary vitamin C in fish and crustacean larvae: a review. Aquaculture 155:165 – 181.
43. Millamena OM, Bautista-Teruel MN, Kanazawa A (1996) Methionine requirement of juvenile tiger shrimp *Penaeus monodon* Fabricius. Aquaculture, 143(3-4):403-410.
44. Millamena OM, Teruel MB, Kanazawa A, Teshima S (1999) Quantitative dietary requirements of postlarval tiger shrimp*, Penaeus monodon*, for histidine, isoleucine, leucine, phenylalanine and tryptophan. Aquaculture, 179(1-4):169-179.
45. Moe YY, Koshio S, Teshima SI, Ishikawa M, Matsunaga Y, Panganiban Jr A (2004) Effect of vitamin C derivatives on the performance of larval kuruma shrimp, *Marsupenaeus japonicus*. Aquaculture, 242(1-4):501-512.
46. Montalvo G, Campos S, Arenas M, Barreto A, Escalante K, Cuzon G, Gaxiola, G (2022) Immune gene expression and antioxidant response to vitamin E enriched diets for males *Litopenaeus vannamei* breeder (Boone, 1931). Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 268:111187.
47. Moriguchi S, Kobayshi N, Kishino Y (1990) High dietary intakes of vitamin E and cellular immune function in rats. J Nutr;120:1096e102.
48. Niu J, Liu YJ, Tian LX, Mai KS, Yang HJ, Ye CX, Gao W (2008) Effect of dietary phosphorus sources and varying levels of supplemental phosphorus on survival, growth and body composition of postlarval shrimp (*Litopenaeus vannamei*). Aquaculture Nutrition, 14(5):472-479.
49. Nordgarden U, Hemre GI, Hansen T (2002) Growth and body composition of Atlantic salmon (*Salmo salar* L.) parr and smolt fed diets varying in protein and lipid contents. Aquaculture, 207(1-2):65-78.
50. NRC (National Research Council), 2011. Nutrient Requirements of Fish. National Academy Press, Washington, DC, USA.
51. Ouraji H, Abedian Kenari AM, Shabanpour B, Shabani A, Sodagar M, Jafarpour SA, Ebrahimi GH (2011) Growth, survival, and fatty acid composition of Indian white shrimp *Fenneropenaeus indicus* (Milne Edwards) fed diets containing different levels of vitamin E and lipid. Aquaculture International, 19:903-916.
52. Panush ME, Delafuente JC (1985) Vitamins and immuncompetence. World Rev Nutr Diet;45:97-123
53. Rahman SHA, Razek FAA, Goda AMAS, Ghobashy AFA, Taha SM, Khafagy AR (2010) Partial substitution of dietary fish meal with soybean meal for speckled shrimp, *Metapenaeus monoceros* (Fabricius, 1798) (Decapoda: Penaeidae) juvenile. Aquac Res 41:299-306
54. Shefat SHT, Karim MA (2018) Nutritional diseases of fish in aquaculture and their management: A review. Acta Scientific Pharmaceutical Sciences, 2(12):50-58.
55. Shiau SY, Hsu TS (1994) Vitamin C requirement of grass shrimp, *Penaeus monodon*, as determined with lascorbyl-2-monophosphate. Aquaculture 122: 347 – 357.
56. Shiau SY, Lung CQ (1993) Estimation of the vitamin B12 requirement of the grass shrimp, *Penaeus monodon.* Aquaculture, 117(1-2):157-163.
57. Shiau SY, Wu MH (2003) Dietary vitamin B6 requirement of grass shrimp, *Penaeus monodon*. Aquaculture, 225(1-4):397-404.
58. Smith LL, Lee PL, Lawrence AL, Strawn K (1984) Growth and digestibility by three sizes of Penaeus vannamei Boone: effects of dietary protein level and protein source. Aquaculture 46:85–96. doi: 10.1016/0044-8486(85)90193-0
59. Sui L, Ma G, Deng Y (2015) Effect of dietary protein level and salinity on growth, survival, enzymatic activities and amino-acid composition of the white shrimp *Litopenaeus vannamei* (Boone, 1931) juveniles. Crustaceana 88: 82–95.
60. Tacon A, Tran L (2022) Nutritional Fish and Shrimp Pathology: A Handbook. 5m Books Ltd.
61. Teshima S, Alam MS, Koshio S, Ishikawa M, Kanazawa A (2002) Assessment of requirement values for essential amino acids in the prawn, *Marsupenaeus japonicus* (Bate). Aquaculture Research 33: 395–402
62. Tseng YC, Hwang PP (2008) Some insights into energy metabolism for osmoregulation in fish. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology, 148(4):419-429.
63. Viehoever A, Cohen I (1938) The responses of Daphnia to vitamin E. AmericanJournal of Pharmacology110:297-315
64. Wang L, Chen L, Qin J, Li E, Yu N, Du Z, Kong Y, Qi J (2015) Effect of dietary lipids and vitamin E on growth performance, body composition, anti‐oxidative ability and resistance to *Aeromonas hydrophila* challenge of juvenile Chinese mitten crab *Eriocheir sinensis.* Aquaculture Research, 46(10):2544-2558.
65. Wang WN, Wang AL, Wang Y, Wang J, Sun RY (2005) Effect of dietary vitamin C and ammonia concentration on the cellular defense response of *Macrobrachium nipponense*. Journal of the World Aquaculture Society, 36(1):1-7.
66. Wang XD, Li EC, Wang SF, Qin JG, Chen XF, Lai QM, Chen K, Xu C, Gan L, Yu N, Du ZY (2015). Protein-sparing effect of carbohydrate in the diet of white shrimp *Litopenaeus vannamei* at low salinity. Aquac. Nutr. 21: 904–912. https://doi. org/10.1111/anu.12221.
67. Xie F, Zeng W, Zhou Q, Wang H, Wang T, Zheng C, Wang Y (2012) Dietary lysine requirement of juvenile Pacific white shrimp, *Litopenaeus vannamei*. Aquaculture, 358:116-121.
68. Xu XL, Ji WJ, Castell JD, O'dor RK (1994) Essential fatty acid requirement of the Chinese prawn, *Penaeus chinensis*. Aquaculture, 127(1):29-40.
69. Zhou QC, Li CC, Liu CW, Chi SY, Yang QH (2007) Effects of dietary lipid sources on growth and fatty acid composition of juvenile shrimp, *Litopenaeus vannamei*. Aquaculture Nutrition, 13(3):222-229.
70. Zhou QC, Wang YL, Wang HL, Tan BP (2013) Dietary threonine requirements of juvenile Pacific white shrimp, *Litopenaeus vannamei*. Aquaculture, 392:142-147.
71. Zhou QC, Zeng WP, Wang HL, Wang T, Wang YL, Xie FJ (2012). Dietary arginine requirement of juvenile Pacific white shrimp, *Litopenaeus vannamei*. Aquaculture, 364:252-258.
72. Zimmermann S, Leboute EM, Souza SMG (1994) Effects of two calcium levels in diets and three calcium levels in culture water on the growth of the freshwater prawn, *Macrobrachium rosenbergii* (De Man). In Abstracts of World Aquaculture '94, 14-18 January 1994, New Orleans, 196. World Aquaculture Society Baton Rouge.