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Research Article

Optimizing Nutritional Requirements for Sustainable Shrimp and Prawn Aquaculture

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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: Vitamin; Mineral; Essential Fatty Acid; Aminoacid

Introduction

Aquaculture has emerged as one of the most rapidly expanding global food industries [1]. 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 [1]. 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. 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.

Global Seafood Alliance

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

- 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 [2].

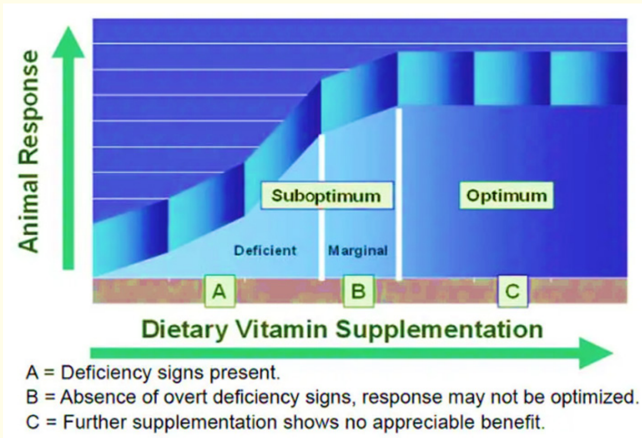

Figure a

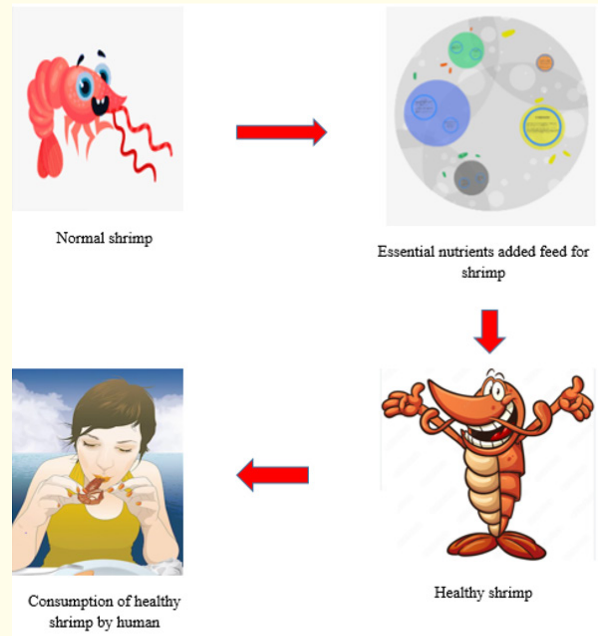

Figure b

- 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.
- 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.
- 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 [3]. 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 [4-8].

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 [9].

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 [10]. 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	11
	L. vannamei	Ammonia-N.	150 mg	12
	Macrobrachiurn nipponense	Ammonia	4000 mg	13
	P. monodon	*Vibrio anguillarum*	0.25%	14

Table a

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 [15]. 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 [16]. 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. 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 [17-19].

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 [20-22].

Growing evidence suggests that vitamins C and E play crucial roles as antioxidants, safeguarding lipids within the tissues of aquatic animals [21].

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 [22]. In animal feeds, synthetic antioxidants like butylated hydroxytoluene (BHT), butylated hydroxyanisole (BHA), and ethoxyquin are employed to minimize oxidative rancidity. 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	23
	Penaeus monodon		200 mg	24
	L. vannamei		620mg	25
	Fenneropenaeus indicus		300 mg	16
	Macrobrachium nipponense	*Aeromonas hydrophila*	160 mg	26

Table b

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 [27]. 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*) [28], tiger shrimp (*Penaeus monodon*) [29], and Indian white prawn (*Fenneropenaeus indicus*) [30]. 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
1	*Litopenaeus vannamei*	106.95mg B_6	31
2	*P. monodon*	89 mg B_6	32
3	*Penaeus monodon*	0.2 mg B_6	33
4	*Litopenaeus vannamei*	54.2 mg B_1	34

Table c

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 [35]. 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*. [35], 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.

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
1	*Macrobrachium rosenbergii*	3g calcium	35
2	*Litopenaeus vannamei*	22g phosphorous	36
3	*Penaeus vannamei*	2g calcium and 1g phosphorous	37
4	*Macrobrachium amazonicum*	18% phosphorous	38
5	*(Colossoma macropomum)*		
6	*Litopenaeus vannamei*	2% calcium	39

Table 4

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 researchers. 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 [34]. Additionally, significant growth enhancement in *L. vannamei* with diets containing 35 to 45% protein at salinity levels of 30 and 50 were reported.

As conserving dietary protein is imperative, identifying cost-effective non-protein energy sources becomes crucial. Wang., *et al.* [13] 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 [40].

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.

Chen., *et al*. [41] 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% [42]. 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 previously. 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.

Sl no	Species	Essential Fatty Acid	References
	Litopenaeus vannamei	12 g	40
	Litopenaeus vannamei	60 g	42
	Penaeus chinensis	1%	43
	Litopenaeus vannamei	0.5%	44
	Penaeus monodon	105 g	45
	Macrobrachium nipponense	6.91%	31

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

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.

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

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 [42].

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. 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.

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 [46]. Optimal methionine levels have been recognized to decrease the oxidation of other amino acids, fostering an increased growth rate according to the NRC of [47].

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.

Sl nos	Species	Amino acid	References
1	*Litopenaeus vannamei*	2.32% Arginine	43
2	*Penaeus monodon*	Histidine, 0.80%;	42
3	*Penaeus monodon*	Isoleucine, 1.01%	42
4	*Penaeus monodon*	Leucine, 1.7%	42
5	*Penaeus monodon*	Phenylalanine, 1.4%	42
6	*Penaeus monodon*	Tryptophan, 0.2%	42
7	*Litopenaeus vannamei*	1.51% threonine	43
8	*Litopenaeus vannamei*	0.8%, 0.029 g-methionine	44
9	*Litopenaeus vannamei*	1.64% lysin	45

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

Conclusion

The findings from numerous spotlighting, highlighting the diverse nutritional needs of different shrimp species and presenting strategies to address nutritional challenges in shrimp farming.

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