

EGG POWDER AS AN ALTERNATIVE PROTEIN SOURCE AND HEALTH MODULATOR IN SHRIMP *PENAEUS VANNAMEI*

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Introduction

Shrimp farming, particularly of the species *Penaeus vannamei*, is a rapidly expanding sector within aquaculture, driven by the global demand for seafood. However, the sustainability and efficiency of shrimp feed remain critical challenges, particularly concerning the reliance on traditional marine protein sources such as fish meal and squid meal. These sources, while nutritionally effective, are subject to supply constraints and environmental concerns.

This study investigates the potential of egg powder nutrition products as a sustainable and nutritionally viable alternative protein source for shrimp feeds. Egg powder is rich in essential amino acids, cholesterol, and phospholipids, which are crucial for the growth, health, and disease resistance of shrimp. By comparing the nutritional composition and health benefits of egg powder with conventional marine protein sources, we aim to assess its feasibility and advantages in shrimp nutrition. Additionally, the incorporation of egg powder could potentially reduce feed costs and enhance shrimp health through its bioactive compounds, thus offering an innovative solution to improve the sustainability and productivity of shrimp aquaculture.

General composition and amino acid profile of high-quality marine protein sources compared to egg powder

When comparing the proximate composition of the marine ingredients with egg powder, the values for moisture, crude protein, and crude fibre appear to be within the same range. However, the respective values for crude fat/lipid and ash are notably higher and lower.

Typical cholesterol content in shrimp feeds and potential contribution of egg powder

Crustaceans cannot synthesise cholesterol *de novo* (Teshima & Kanazawa, 1971; Goad, 1981; Su et al., 2023). The optimum content of cholesterol (and the potential contribution of egg powder for that content) in shrimp feed, depends on species, feed rate, and the presence of other nutrients (Castille et al., 2004).

All studies that have investigated cholesterol requirements of shrimp have demonstrated a true requirement that has been generally established through observation of a reduced growth response or comparatively higher mortality (National Research Council, 2011). The reported dietary requirement, expressed as percentage of diet, commonly ranges from 0.2% to 1.0%.

Evidence suggests that higher levels of dietary cholesterol may exert an adverse effect on growth (Thongrod & Boonyaratpalin, 1998; National Research Council, 2011).

Low fish meal diets are usually accompanied by low dietary cholesterol (Li et al., 2022), and therefore supplementation with purified cholesterol or other cholesterol containing ingredients is often needed to obtain optimum growth (Coutteau et al., 2002; Castille et al., 2004). Purified cholesterol is a relatively expensive ingredient for use in shrimp feeds, and the costs of supplementing feeds with purified cholesterol may be significant and even prohibitive. However, the usage of other cholesterol containing ingredients has been investigated as an alternative for fish meal (Castille et al., 2004). Chicken egg powder was reported to be one of the cheapest and most easily available protein sources to replace fish meal (Tuna Keleştemur et al., 2022).

Whole egg powder when carefully processed has a high feeding value for aquaculture feeds. It provides protein, fat, cholesterol, and phospholipids. Thus, whole egg powder is used in commercial aquaculture feed for fish and shrimp, particularly in larvae feed. An inclusion rate of 1.0 to 3.0% is reportedly practised (Hertrampf & Piedad-Pascual, 2000a).

Health benefits of including phospholipids in shrimp feeds and cross analysis with phospholipids contents in egg powder product.

Phospholipids are a group of lipids typically comprising a hydrophilic "head" containing a phosphate group and two hydrophobic "tails" derived from fatty acids, joined by an alcohol residue (usually a glycerol molecule). Marine phospholipids typically have omega-3 fatty acids EPA and DHA integrated as part of the phospholipid molecule. The phospholipid provided in different dietary forms has been demonstrated to be required for growth and survival of juvenile and larval forms of shrimp. The apparent absence of such a requirement in adult forms suggests that the requirement is age-specific and is founded on an insufficient rate of synthesis to meet the demands of the comparatively rapid growth rates characteristic of early life stages (National Research Council, 2011). Moreover, not all phospholipids have equivalent effect. For species of juvenile penaeid shrimp, reported dietary phospholipid requirements, commonly fall within the range of 1.2 to 1.5% (Chen & Jenn, 1991; Chen, 1993; Coutteau et al., 1996; National Research Council, 2011). Some of these estimates are based on investigations in which highly purified sources of phospholipids have been added to diets. Addition of 1.5% phosphatidylcholine (PC) (95% pure) from either a soybean source or 6.5% deoiled soybean lecithin (23% PC) significantly increased growth of *P. vannamei* relative to a PC-deficient diet. Addition of 1.5% PC (94% pure) derived from chicken egg yielded growth similar to that observed with the 95% pure PC from the soybean source (Coutteau et al., 1996; National Research Council, 2011). Nevertheless, a relatively confident and conservative estimate based upon the collective results of all studies is the provision of PC at a level between 0.5 to 1.5%.

Information on health modulating compounds present in egg powder and its potential role on shrimp health improvement and protection against disease.

Bioactive components in egg products, include the antioxidants lutein and zeaxanthin, bioactive egg yolk lipids, antimicrobial proteins, such as ovotransferrin, and ovomucin.

The colour of shrimp flesh is an important criterion of quality and affects consumer choice in the marketplace (Ju et al., 2011). Astaxanthin (Ax) is a pigment producing a red colour for many aquatic animals, including shrimp. Although some carotenoids (e.g., lutein, zeaxanthin, and β -carotene) can be bioconverted by shrimp to Ax (Hertrampf & Piedad-Pascual, 2000b), shrimp are unable to biochemically synthesize Ax de novo, and therefore depend on dietary sources for these pigments. In addition to flesh pigmentation, Ax has been reported to provide many positive biological effects for shrimp, such as enhancing maturation, increasing immune response, and reducing stress associated with ammonia levels (Merchie et al., 1998; Pan et al., 2001; Chien et al., 2003; Ju et al., 2011). In addition, research showed that increasing levels of carotenoid pigments in the diet, improved growth performance in shrimp (Zhang et al., 2013; Ettefaghdoost & Haghighi, 2021; Fang et al., 2021).

Some studies have shown that egg yolk lipids promote shrimp growth, improve lipid utilization, and reduce shrimp mortality (Kiosseoglou, 2003; Zorriezhahra et al., 2016; Jaroensaensuai et al., 2022).

Conclusion

This study demonstrates the potential of egg powder as a sustainable and nutritionally viable alternative to traditional marine protein sources in shrimp feeds. Egg powder provides essential nutrients like amino acids, cholesterol, and phospholipids, crucial for the growth, health, and disease resistance of *Penaeus vannamei*. It can reduce reliance on fish and squid meals, which face supply and environmental issues.

Egg powder matches traditional marine ingredients in moisture, crude protein, and fiber, with benefits in fat/lipid and ash content. It meets shrimp's dietary cholesterol needs, lowering the need for costly supplements. Phospholipids in egg powder support juvenile shrimp growth and survival, while bioactive compounds enhance health, immune response, and flesh pigmentation.

Incorporating egg powder into shrimp feeds offers a cost-effective, nutritionally rich alternative, promoting sustainability and productivity in shrimp aquaculture.

REFERENCES- Bibliografy

- Anger, K. (2003). Salinity as a key parameter in the larval biology of decapod crustaceans. *Invertebrate Reproduction & Development*, 43(1), 29–45.
<https://doi.org/10.1080/07924259.2003.9652520>
- Bórquez, A. S., & Hernández, A. J. (2009). *Status of and trends in the use of small pelagic fish species for reduction fisheries and for human consumption in Chile*.
- Briggs, M. R. P., Jauncey, K., & Brown, J. H. (1988). The cholesterol and lecithin requirements of juvenile prawn (*Macrobrachium rosenbergii*) fed semi-purified diets. *Aquaculture*, 70(1–2), 121–129. [https://doi.org/10.1016/0044-8486\(88\)90011-7](https://doi.org/10.1016/0044-8486(88)90011-7)
- Brinker, A., & Reiter, R. (2011). Fish meal replacement by plant protein substitution and guar gum addition in trout feed, Part I: Effects on feed utilization and fish quality. *Aquaculture*, 310(3–4), 350–360. <https://doi.org/10.1016/J.AQUACULTURE.2010.09.041>
- Castell, J. D., & Covey, J. F. (1976). Dietary lipid requirements of adult lobsters, *Homarus americanus* (M.E.). *The Journal of Nutrition*, 106(8), 1159–1165.
<https://doi.org/10.1093/JN/106.8.1159>
- Castille, F., Lawrence, A., Buisman, P., Drost, R., Cruz Suárez, L. E., Ricque Marie, D., Nieto López, M. G., Villarreal, D., Scholz, U., & González, M. (2004). *Effects of Sterol Supplements (Cholesterol FG, Cholesterol SF, and Sterols M1M) on Growth and Survival of the Shrimp, Litopenaeus vannamei Boone*.
- Chen, H. Y. (1993). Requirements of marine shrimp, *Penaeus monodon*, juveniles for phosphatidylcholine and cholesterol. *Aquaculture*, 109(2), 165–176.
[https://doi.org/10.1016/0044-8486\(93\)90213-I](https://doi.org/10.1016/0044-8486(93)90213-I)
- Chen, H. Y., & Jenn, J. S. (1991). Combined effects of dietary phosphatidylcholine and cholesterol on the growth, survival and body lipid composition of marine shrimp, *Penaeus penicillatus*. *Aquaculture*, 96(2), 167–178. [https://doi.org/10.1016/0044-8486\(91\)90147-Y](https://doi.org/10.1016/0044-8486(91)90147-Y)
- Chien, Y. H., Pan, C. H., & Hunter, B. (2003). The resistance to physical stresses by *Penaeus monodon* juveniles fed diets supplemented with astaxanthin. *Aquaculture*, 216(1–4), 177–191.
[https://doi.org/10.1016/S0044-8486\(02\)00056-X](https://doi.org/10.1016/S0044-8486(02)00056-X)
- Codabaccus, B. M., Carter, C. G., Fitzgibbon, Q. P., Trotter, A. J., & Smith, G. G. (2020). Growth and biochemical composition of hatchery reared Scyllaridae lobster (*Thenus australiensis*) larval stages, nisto and juvenile first stage. *Aquaculture*, 524, 735262.
<https://doi.org/10.1016/J.AQUACULTURE.2020.735262>
- Coutteau, P., Camara, M. R., & Sorgeloos, P. (1996). The effect of different levels and sources of dietary phosphatidylcholine on the growth, survival, stress resistance, and fatty acid composition of postlarval *Penaeus vannamei*. *Aquaculture*, 147(3–4), 261–273.
[https://doi.org/10.1016/S0044-8486\(96\)01387-7](https://doi.org/10.1016/S0044-8486(96)01387-7)
- Coutteau, P., Peeters, J., Nur, A., & Kontara, E. (2002). *Cholesterol: Indispensable but not irreplaceable in shrimp feeds - Responsible Seafood Advocate*. Global Seafood Alliance.
<https://www.globalseafood.org/advocate/cholesterol-indispensable-but-not-irreplaceable-inshrimp-feeds/>
- Cruz-Suárez, L. E., Tapia-Salazar, M., Villarreal-Cavazos, D., Beltran-Rocha, J., Nieto-López, M. G., Lemme, A., & Ricque-Marie, D. (2009). Apparent dry matter, energy, protein and amino acid digestibility of four soybean ingredients in white shrimp *Litopenaeus vannamei* juveniles. *Aquaculture*, 292(1–2), 87–94. <https://doi.org/10.1016/J.AQUACULTURE.2009.03.026>
- Davis, D. A., & Robinson, E. H. (1986). Estimation of the Dietary Lipid Requirement Level of the White Crayfish *Procambarus acutus acutus*. *Journal of the World Aquaculture Society*, 17(1–4), 37–43. <https://doi.org/10.1111/J.1749-7345.1986.TB00552.X>
- Derby, C. D., Elsayed, F. H., Williams, S. A., González, C., Choe, M. N., Bharadwaj, A. S., & Chamberlain, G. W. (2016). Krill meal enhances performance of feed pellets through concentration-dependent prolongation of consumption by Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 458, 13–20. <https://doi.org/10.1016/J.AQUACULTURE.2016.02.028>
- Deshimaru, O., & Kuroki, K. (1974). Studies on a purified diet for prawn. 2. Optimum contents of cholesterol and glucosamine in the diet. *Bulletin of the Japanese Society of Scientific Fisheries*, 40(4), 421–424.
- Duerr, E. O., & Walsh, W. A. (1996). Evaluation of cholesterol additions to a soyabean meal-based diet for juvenile Pacific white shrimp, *Penaeus vannamei* (Boone), in an outdoor growth trial. *Aquaculture Nutrition*, 2(2), 111–116. <https://doi.org/10.1111/J.1365-2095.1996.TB00017.X>

Emery, A. E. (1987). *The cholesterol and lecithin requirement of the marine shrimp, Penaeus vannamei* Boone. <https://oaktrust.library.tamu.edu/handle/1969.1/ETD-TAMU-1987-THESIS53>

Ettefaghdoost, M., & Haghighi, H. (2021). Impact of different dietary lutein levels on growth performance, biochemical and immuno-physiological parameters of oriental river prawn (*Macrobrachium nipponense*). *Fish & Shellfish Immunology*, 115, 86–94. <https://doi.org/10.1016/J.FSI.2021.05.024>

Fang, H. H., He, X. S., Zeng, H. L., Liu, Y. J., Tian, L. X., & Niu, J. (2021). Replacement of Astaxanthin With Lutein in Diets of Juvenile *Litopenaeus vannamei*: Effects on Growth Performance, Antioxidant Capacity, and Immune Response. *Frontiers in Marine Science*, 8, 803748. <https://doi.org/10.3389/FMARS.2021.803748/BIBTEX>

Goad, L. J. (1981). Sterol biosynthesis and metabolism in marine invertebrates. *Pure and Applied Chemistry*, 53(4), 837–852. <https://doi.org/10.1351/PAC198153040837/MACHINEREADABLECITATION/RIS>

Gong, H., Lawrence, A. L., Jiang, D. H., Castille, F. L., & Gatlin, D. M. (2000). Lipid nutrition of juvenile *Litopenaeus vannamei*: I. Dietary cholesterol and de-oiled soy lecithin requirements and their interaction. *Aquaculture*, 190(3–4), 305–324. [https://doi.org/10.1016/S0044-8486\(00\)00414-2](https://doi.org/10.1016/S0044-8486(00)00414-2)

González-Félix, M. L., Gatlin, D. M., Lawrence, A. L., & 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. <https://doi.org/10.1111/J.1749-7345.2002.TB00509.X>

Hasler, C. M. (2000). The changing face of functional foods. *Journal of the American College of Nutrition*, 19(5 Suppl), 499S–506S. <https://doi.org/10.1080/07315724.2000.10718972>

Hertrampf, J. W., & Piedad-Pascual, F. (2000a). Egg Powder. *Handbook on Ingredients for Aquaculture Feeds*, 125–130. https://doi.org/10.1007/978-94-011-4018-8_14

Hertrampf, J. W., & Piedad-Pascual, F. (2000b). Feed Carotenoids. *Handbook on Ingredients for Aquaculture Feeds*, 142–156. https://doi.org/10.1007/978-94-011-4018-8_16

Ju, Z. Y., Deng, D. F., Dominy, W. G., & Forster, I. P. (2011). Pigmentation of Pacific White Shrimp, *Litopenaeus vannamei*, by Dietary Astaxanthin Extracted from *Haematococcus pluvialis*. *Journal of the World Aquaculture Society*, 42(5), 633–644. <https://doi.org/10.1111/J.1749-7345.2011.00511.X>

Kanazawa, A., Teshima, S., & Tokiwa, S. (1977). Nutritional requirements of prawn. VII. Effect of dietary lipids on growth. *Nippon Suisan Gakkaishi*, 43(7), 849–856. <https://doi.org/10.2331/SUISAN.43.849>

KÖSE, Ö., KARABULUT, H. A., KURTOĞLU, İ. Z., & ER, A. (2021). Effects of feed rations containing egg powder in different proportions on growth performance, feed utilization, body composition, and survival rate of rainbow trout (*Oncorhynchus mykiss* Walbaum, 1792) fry. *Ege Journal of Fisheries and Aquatic Sciences*, 38(1), 69–78. <https://doi.org/10.12714/EGEJFAS.38.1.08>

Kumar, V., Bels, L. De, Couck, L., Baruah, K., Bossier, P., & Broeck, W. Van den. (2019). PirABVP Toxin Binds to Epithelial Cells of the Digestive Tract and Produce Pathognomonic AHPND Lesions in Germ-Free Brine Shrimp. *Toxins*, 11(12), 717. <https://doi.org/10.3390/toxins11120717>

Lemos, D., & Phan, V. N. (2001). Ontogenetic variation in metabolism, biochemical composition and energy content during the early life stages of *Farfantepenaeus paulensis* (Crustacea: Decapoda: Penaeidae). *Marine Biology*, 138(5), 985–997. <https://doi.org/10.1007/S002270000516/METRCS>

Li, X., Chen, Y., Chen, X., Zhang, S., Dong, X., Chi, S., Deng, J., Tan, B., & Xie, S. (2022). Cholesterol supplementation improved growth performance, cholesterol metabolism, and intestinal health of Pacific white shrimp (*Litopenaeus vannamei*) fed a low fishmeal diet. *Aquaculture Reports*, 27, 101351. <https://doi.org/10.1016/J.AQREP.2022.101351>

Liu, X. H., Ye, J. D., Kong, J. H., Wang, K., & Wang, A. li. (2012). Apparent digestibility of 12 proteinorigin ingredients for pacific white shrimp *Litopenaeus vannamei*. *North American Journal of Aquaculture*, 75(1), 90–98. <https://doi.org/10.1080/15222055.2012.716019>

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* (Fabricius). *Aquaculture Research*, 29(8), 579–585. <https://doi.org/10.1046/J.1365->

2109.1998.00245.X

- National Research Council. (2011). Nutrient Requirements of Fish and Shrimp. In *Nutrient Requirements of Fish and Shrimp*. National Academies Press. <https://doi.org/10.17226/13039>
- Nunes, A. J. P., Dalen, L. L., Leonardi, G., & Burri, L. (2022). Developing sustainable, cost-effective and high-performance shrimp feed formulations containing low fish meal levels. In *Aquaculture Reports* (Vol. 27). Elsevier B.V. <https://doi.org/10.1016/j.aqrep.2022.101422>
- Nunes, A. J. P., Sá, M. V. C., Andriola-Neto, F. F., & Lemos, D. (2006). Behavioral response to selected feed attractants and stimulants in Pacific white shrimp, *Litopenaeus vannamei*. *Aquaculture*, 260(1–4), 244–254. <https://doi.org/10.1016/J.AQUACULTURE.2006.06.027>
- Paibulkichakul, C., Piyatiratitivorakul, S., Kittakoo, P., Viyakarn, V., Fast, A. W., & Menasveta, P. (1998). Optimal dietary levels of lecithin and cholesterol for black tiger prawn *Penaeus monodon* larvae and postlarvae. *Aquaculture*, 167(3–4), 273–281. [https://doi.org/10.1016/S0044-8486\(98\)00327-5](https://doi.org/10.1016/S0044-8486(98)00327-5)
- Pan, C.-H., Chien, Y.-H., & Cheng, J.-H. (2001). Effects of Light Regime, Algae in the Water, and Dietary Astaxanthin on Pigmentation, Growth, and Survival of Black Tiger Prawn *Penaeus monodon* Post-larvae. *Zoological Studies*, 40(4), 371–382. <http://www.sinica.edu.tw/zool/zoolstud/40.4/371.pdf>
- Ponat, A., & Adelung, D. (1983). Studies to establish an optimal diet for *Carcinus maenas* - 3. Vitamin and quantitative lipid requirements. *Marine Biology*, 74(3), 275–279. <https://doi.org/10.1007/BF00403451/METRICS>
- Prajanban, B. on, Jangpromma, N., Araki, T., & Klaynongsruang, S. (2017). Antimicrobial effects of novel peptides COT2 and sOT2 derived from *Crocodylus siamensis* and *Pelodiscus sinensis* ovotransferrins. *Biochimica et Biophysica Acta (BBA) - Biomembranes*, 1859(5), 860–869. <https://doi.org/10.1016/J.BBAMEM.2017.01.035>
- Pratoomyot, J., Bendiksen, E. Å., Bell, J. G., & Tocher, D. R. (2010). Effects of increasing replacement of dietary fishmeal with plant protein sources on growth performance and body lipid composition of Atlantic salmon (*Salmo salar* L.). *Aquaculture*, 305(1–4), 124–132. <https://doi.org/10.1016/J.AQUACULTURE.2010.04.019>
- Sheen, S. S., & D'Abramo, L. R. (1991). Response of juvenile freshwater prawn, *Macrobrachium rosenbergii*, to different levels of a cod liver oil/corn oil mixture in a semi-purified diet. *Aquaculture*, 93(2), 121–134. [https://doi.org/10.1016/0044-8486\(91\)90211-O](https://doi.org/10.1016/0044-8486(91)90211-O)
- Sheen, S. S., Liu, P. C., Chen, S. N., & Chen, J. C. (1994). Cholesterol requirement of juvenile tiger shrimp (*Penaeus monodon*). *Aquaculture*, 125(1–2), 131–137. [https://doi.org/10.1016/0044-8486\(94\)90289-5](https://doi.org/10.1016/0044-8486(94)90289-5)
- Su, C., Li, J., Zhang, M., Pan, L., Wang, Y., Ding, Y., Chen, Z., & Lu, M. (2023). Dietary cholesterol enhances osmoregulation, antioxidant defenses and immune response of *Litopenaeus vannamei* to alleviate the macromolecular damage induced by salinity stress. *Aquaculture*, 563, 738861. <https://doi.org/10.1016/J.AQUACULTURE.2022.738861>
- Suresh, A. V., Kumaraguru vasagam, K. P., & Nates, S. (2011). Attractability and palatability of protein ingredients of aquatic and terrestrial animal origin, and their practical value for blue shrimp, *Litopenaeus stylirostris* fed diets formulated with high levels of poultry byproduct meal. *Aquaculture*, 319(1–2), 132–140. <https://doi.org/10.1016/J.AQUACULTURE.2011.06.039>
- Tacon, A. G. J., & Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: Trends and future prospects. *Aquaculture*, 285(1–4), 146–158. <https://doi.org/10.1016/J.AQUACULTURE.2008.08.015>
- Teshima, S. I., & Kanazawa, A. (1971). Biosynthesis of sterols in the lobster, *Panulirus japonica*, the prawn, *Penaeus japonicus*, and the crab, *Portunus trituberculatus*. *Comparative Biochemistry and Physiology Part B: Comparative Biochemistry*, 38(3), 597–602. [https://doi.org/10.1016/0305-0491\(71\)90314-2](https://doi.org/10.1016/0305-0491(71)90314-2)
- Thongrod, S., & Boonyaratpalin, M. (1998). Cholesterol and lecithin requirement of juvenile banana shrimp, *Penaeus merguensis*. *Aquaculture*, 161(1–4), 315–321. [https://doi.org/10.1016/S0044-8486\(97\)00278-0](https://doi.org/10.1016/S0044-8486(97)00278-0)
- Truong, H. H., Hines, B. M., Emerenciano, M. G., Blyth, D., Berry, S., Noble, T. H., Bourne, N. A., Wade, N., Rombenso, A. N., & Simon, C. J. (2022). Mineral nutrition in penaeid shrimp. *Reviews in Aquaculture*. <https://doi.org/10.1111/RAQ.12780>
- Tuna Keleştemur, G., Keleştemur, N., & Uslu, A. A. (2022). Application of egg powder in diets and

its effect on serum parameters of juvenile rainbow trout. *Araştırma Makalesi BAUN Fen Bil. Enst. Dergisi*, 24(1), 172–181. <https://doi.org/10.25092/baunfbed>

Venkateswarlu, V., & Vardi Venkateswarlu, C. (2019). Growth performance effect of dietary fish meal quality in shrimp *Litopenaeus vannamei*. 400 ~ *International Journal of Fisheries and Aquatic Studies*, 7(5), 400–402. <https://doi.org/10.1111/j.1365-2109.2007.01704.x>

Vieira, C. C. F., Pinto, R. C. C., Diogenes, A. F., & Nunes, A. J. P. (2022). Apparent digestibility of protein and essential aminoacids from commonly used feed ingredients in Brazil for juvenile shrimp *Litopenaeus vannamei*. *Brazilian Journal of Animal Science*. <https://doi.org/10.37496/rbz5120210177>

Yang, Q., Zhou, X., Zhou, Q., Tan, B., Chi, S., & Dong, X. (2009). Apparent digestibility of selected feed ingredients for white shrimp *Litopenaeus vannamei*, Boone. *Aquaculture Research*, 41(1), 78–86. <https://doi.org/10.1111/j.1365-2109.2009.02307.x>

Zhang, J., Liu, Y. J., Tian, L. X., Yang, H. J., Liang, G. Y., Yue, Y. R., & Xu, D. H. (2013). Effects of dietary astaxanthin on growth, antioxidant capacity and gene expression in Pacific white shrimp *Litopenaeus vannamei*. *Aquaculture Nutrition*, 19(6), 917–927. <https://doi.org/10.1111/ANU.12037>