Promoting sustainable aquaculture of freshwater species: the continuous quest for alternative feeds and adoption of feeding strategies

JTF 6-2 Pillar II.
Promotion of sustainable aquaculture and resources enhancement in Southeast Asia

Frolan A. Aya, Sayaka Ito, Leobert D. de la Peña, and *Richelle T. Bautista*

Keywords: alternative protein source, aquafeeds, freshwater aquaculture, skip feeding

The potential of black soldier fly larvae (BSFL) is being explored in developing alternative feeds for freshwater fish species in the Philippines (scale bar = 1 cm)

Among farm inputs, feeds are the highest recurring cost in aquaculture. Indeed, feeds have become even more expensive after the COVID-19 pandemic, undeniably affecting the aquaculture economics. The pressing need to alleviate feed costs has to be prioritized, considering its implications for sustained aquaculture production to support the ever-increasing global population. Substantially, the rising costs of manufactured feeds have driven the continuous quest for new alternative feed ingredients in aquafeeds and the adoption of feed management strategies to improve the profitability of aquaculture operations. These two strategies addressed in this study are imperative in promoting freshwater aquaculture among the ASEAN Member States. This article highlights the exploration of feeding trials using alternative protein sources and feeding strategies. Because of their economic relevance to the freshwater aquaculture industry in the Philippines, Nile tilapia, giant freshwater prawn, and tropical anguillid eel, particularly the Pacific shortfin eel, were chosen in this study.

From 2020 to 2024, the Aquaculture Department of the Southeast Asian Fisheries Development Center (SEAFDEC/AQD) has been implementing the project "Sustainable Aquaculture through Cost-effective Culture Systems, and Prompt and Effective Aquatic Animal Health Management" with support from the Japanese Trust Fund (JTF). The Project supports the ASEAN-SEAFDEC Resolution and Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030 (RES&POA-2030), specifically POA No. 64 *Improve the efficient use of aquafeeds by regulating the quality of manufactured feed and feed ingredients, and support continued/applied research for developing suitable alternative protein sources that will reduce the cost and dependence on fish meal and other fish-based products, and subsequently promote regional sharing of information on feed ingredients; encourage the culture of species requiring no or low fish meal content in their feed and application of effective feeding management practices, taking into account the need for cultural and social acceptance of feed ingredients.* Under this Project, one of the underscored

activities centers on a cost-effective culture system that promotes alternative feeds to reduce feed costs.

In aquaculture, strategies to address the high feed cost include the continuous prospects for alternative sources of protein or additives and the feeding strategy. Due to limited resources, high-quality and sustainable protein sources such as agricultural by-products (ABPs), mangrove yeasts, insects, and invasive fish and plant species are being used in aquafeeds formulation (Abarra *et al*., 2017; Øverland *et al*., 2018; Aya *et al*., 2021; Agpoon *et al*., 2024). Suitable feeding management techniques may also improve feed utilization efficiency by reducing feed losses without affecting fish performance. The alternate-day feeding strategy, which helped lower production costs, has been successfully demonstrated in tropical fish species such as Nile tilapia (Bolivar *et al*., 2006; Cuvin-Aralar *et al*., 2012) and milkfish (de Jesus-Ayson & Borski, 2010).

In light of the above considerations, the Japanese Trust Fund has supported the 5-year study to promote sustainable feed technologies for freshwater aquaculture species. The highlights of the feeding trials exploring the use of alternative protein sources and feeding strategies are presented.

Alternative feed ingredients in aquafeeds

Insect meal

In a quest for viable alternative protein sources, insects have increasingly been promoted as high-quality, cost-effective, and sustainable sources of alternative proteins in other countries. Black soldier fly (BSF, *Hermetia illucens*) larvae is a suitable candidate for mass production due, in part, to its simple rearing system, high capacity to convert biowastes into protein-rich biomass, and being as non-pathogenic (St-Hilaire *et al*., 2007; Siddiqui *et al*., 2022). Due to its high levels of protein (40–60 %) and lipids (up to 35 %) and balanced amino acid profile similar to that of fishmeal (Barragan-Fonseca *et al*., 2017; Shumo *et al*., 2019; Mouithys-Mickala *et al*., 2020), BSF has been successfully utilized in Nile tilapia (Devic *et al*., 2017; Nairuti *et al*., 2021) and African catfish (Adeoye *et al*., 2020) diets.

In the Philippines, there is a good prospect of utilizing insect meal due to several private farms producing insect larvae, albeit in a limited capacity or quantity. Initially, these private farms were used as livestock facilities extremely affected by the Asian swine flu (ASF) outbreak. These facilities were converted into insect-rearing facilities to produce BSF larvae. Anecdotal reports showed the efficacy of insect meal in promoting fish performance. However, studies on suitable rearing substrates and their application in aquafeeds in the Philippine setting have yet to be determined.

The biological effects of supplementing full-fat BSF larvae and adult meals in Nile tilapia diets were studied in biofloc-based conditions to improve current aquafeed formulations. Dietary BSF larvae and adult meals ranging from 0 % to 12 % to substitute fishmeal and soybean meal proteins were used to reveal differences in growth and feed utilization. Nile tilapia fingerlings fed 6 % BSF larvae attained a higher weight gain and feed utilization efficiency. In a cage experiment where the fish were fed identical diets, the weight gain and feed efficiency of Nile tilapia were improved even in diets with 12 % BSF larvae. An explanation for this might be that natural food enhances the utilization of BSF larvae in the diet.

Agricultural by-products

Similarly, by-products from major crop industries are also used to develop alternative feed formulations. In combination with insect meal, soybean curd residue or okara meal (**Figure 1**), has been incorporated in giant freshwater prawn diets due to its lower price, high nutritional qualities, and positive effects on fish performance. Okara meal has 25.31 % crude protein, 12.8 5% crude fat, and 3.72 % ash, suggesting its potential use as a protein source in aquafeed formulations (Aya *et al*., 2021).

Figure 1. Soybean residue or okara meal is regarded as a low-cost and high-quality alternative protein source in aquafeeds

The effect of the gradual substitution of dietary fishmeal and soybean meal by BSF larvae and okara meal on growth and feed utilization was studied using three replacement levels in clear and biofloc-based conditions. Weight gain and feed utilization efficiency were higher in biofloc-based conditions, confirming the benefits of biofloc in promoting better fish performance. The inclusion of BSF larvae meal up to 25 % in giant freshwater prawn diets increased growth and feed efficiency in biofloc-based conditions. An outdoor cage experiment confirmed a positive relation between dietary level and growth parameters (**Figure 2)**. In contrast, growth and feed efficiency slightly decreased with the dietary BSF larvae and okara meals in clear water condition.

Figure 2. Outdoor cage setup for the growth trial of giant freshwater prawn

Invasive aquatic plants

Invasive aquatic plant species such as water hyacinth (*Eichhornia crassipes*) and water cabbage (*Pistia stratiotes*) (**Figure 3**) pose some problems in fishing and boat navigation because they proliferate very fast in the waters of Laguna de Bay and elsewhere in the Philippines. In efforts to find cheaper dietary protein sources due to their large biomass or volume, utilization of these invasive aquatic plants in aquafeed formulation is imperative. This is also based on the fact that both aquatic plants contain acceptable nutritional levels, with water hyacinth leaf meal containing 23.29 % crude protein, 0.42 % crude fat, and 13.67 % ash. Meanwhile, water cabbage leaf meal has 17.15 % crude protein, 1.00 % crude fat, and 21.08 % ash. A preliminary trial examined the potential of a mixture of water hyacinth and water cabbage (60:40 ratio) leaf meals to replace soybean meal at varying replacement levels (0.0 %, 3.3 %, 6.6 %, and 10.8 %) in Nile tilapia diets. Under biofloc-based conditions, the high growth rates at the highest inclusion level suggest that Nile tilapia can grow equally on soya meal and aquatic leaf meal protein.

Figure 3. Raw and dried pulverized leaves of water hyacinth *Eichhornia crassipes* (top row) and water cabbage *Pistia stratiotes* (bottom row)

Adopting feed management strategies to reduce feed cost

Feeding management strategies have been evaluated to decrease feed inputs and address aspects of water quality (Cuvin-Aralar *et al*., 2012). Skip or alternate-day feeding has been suggested as an economically and environment-friendly practice in the cage culture of Nile tilapia (Cuvin-Aralar *et al*., 2012). Using this feeding strategy, the stocks are fed on alternate days. However, a land-based cage experiment modified the feeding strategy used by Aralar *et al*. (2012) with a daily feed ration of 5–2 % (**Figure 4**) by reducing the daily feed ration and alternating them from one-day low at 1.75 % followed by one-day high at 3.75 %. While results suggest no compensatory growth in Nile tilapia subjected to alternate-day feeding, reduced feed rations still support better growth and feed utilization. Similar results were reported by Hezron *et al*. (2019) using a feeding cycle of one-day low (2.5 %) and one-day high (5.0 %). Therefore, a one-day low (1.75 %) feeding cycle followed by a one-day high (3.75 %) feed ration could be an alternative feeding strategy to optimize Nile tilapia production in cages.

Figure 4. Testing the skip-feeding strategy with reduced rations in land-based cage-cultured Nile tilapia

Meanwhile, tropical anguillid eels, such as the Pacific shortfin eel (*Anguilla bicolor pacifica*), are regarded as an alternative to the Japanese eel (*A. japonica*) for culture (Cuvin-Aralar *et al*., 2019). However, the prohibitive cost of feeds in eel nursery production remains one of the biggest problems confronting the eel industry. The skip or alternate day feeding strategy was tested in an outdoor tank trial in an attempt to reduce production costs in eel production while maintaining fish performance. Indeed, feeding on alternate days effectively promoted compensatory growth and a lower feed conversion ratio (FCR), translating to a 40 % decrease in feed consumption and better water quality (Aya *et al*., 2023). Partial economic analysis also showed that alternate-day feeding provided higher net profit and profit index. Therefore, this feeding strategy should be promoted in the tank culture of tropical anguillid eels.

In the case of giant freshwater prawn culture, studies on the performance and welfare of this prawn species subjected to feed restriction are limited (Marques & Lombardi, 2011; Ghosh *et al*., 2018; Rahman *et al*., 2019; Pontes *et al*., 2020). In addition, most of these studies were conducted under laboratory conditions. Examining the growth response of giant freshwater prawns in cage conditions will provide a better understanding of how temporary feed restriction followed by refeeding affects the production parameters of this aggressive and territorial species. Feeding schedules, consisting of daily feeding, alternate day feeding, two days feeding followed by two days non-feeding, four days feeding followed by three days non-feeding, and five days feeding followed by two days non-feeding, were evaluated in cage culture conditions. Preliminary results showed that short-term fasting and re-feeding promote compensatory growth in giant freshwater prawn. Based on FCR values, feed costs may be reduced through feeding on alternate days and two days of feeding followed by two days of non-feeding.

Way Forward

Developing innovative methods and searching for novel feed ingredients are vital in promoting sustainable freshwater aquaculture. The findings from this study present the potential use of insect meal, agricultural wastes, and invasive aquatic plants as alternative feed ingredients in Nile tilapia and giant freshwater prawn diets. The application of alternate day feeding in tropical anguillid eels and giant freshwater prawn farming leads to compensatory growth and reduced feed costs. It is hoped that after the successful evaluation and verification trials, small-scale farmers in the ASEAN region will adopt the alternative feeds and feeding strategies developed from this study.

Furthermore, as warranted by the results of the different feeding trials on Nile tilapia and giant freshwater prawn, leveraging insect meal in aquafeed production offers excellent potential in the aquaculture industry of the Philippines and an environment-friendly solution for managing biological wastes. However, producing insect meal on an industrial scale is needed to maximize the full potential of this viable alternative feed ingredient. Future studies on using insect meal as an emerging protein source in aquafeed should address the integration of alternative feed development and sound feeding management practices for other farmed fish and prawn species.

Acknowledgments

This study was supported by the Government of Japan-Trust Fund (8300-B-RD-FD0120 and 5210-B-RD-FD0122) and the Japan ASEAN Integration Fund (Br-02-Y2018B). The technical assistance of *Mr. John Carlo Unida, Mr. Mark Joseph Reyes, Mr. Nemencio Olorvida,* and *Mr. Ricardo Celebre* is acknowledged.

This article is under the project "Sustainable Aquaculture through Cost-effective Culture Systems, and Prompt and Effective Aquatic Animal Health Management" implemented by the SEAFDEC Aquaculture Department (AQD) with support from the Japanese Trust Fund. *Dr. Sayaka Ito* is the Lead Technical Officer for this Project.

References

Abarra, S.T., Velasquez, S.F., Guzman, K.D.D.C., Felipe, J.L.F., Tayamen, M.M., & Ragaza, J.A. (2017). Replacement of fishmeal with processed meal from knife fish *Chitala ornata* in diets of juvenile Nile tilapia *Oreochromis niloticus*. *Aquaculture Reports, 5,* 76–83. http://dx.doi.org/10.1016/j.aqrep.2017.01.001

Adeoye, A.A., Akegbejo-Samsons, Y., Fawole, F.J., & Davies, S.J. (2020). Preliminary assessment of black soldier fly (*Hermetia illucens*) larval meal in the diet of African catfish (*Clarias gariepinus*): Impact on growth, body index, and hematological parameters. *Journal of the World Aquaculture Society, 51*, 1024–1033. https://doi.org/10.1111/jwas.12691

Agpoon, I.E., Aya, F.A., Watanabe, K., Bennett, R.M., Aki, T., Dedeles, & G.R. (2024). *Pichia kudriavzevii* as feed additive in Nile tilapia (*Oreochromis niloticus*) diet. *Letters in Applied Microbiology ovae 057*. https://doi.org/10.1093/lambio/ovae057

Aya, F.A., Unida, J.C.L., Romana-Eguia, M.R.R., & Salayo, N.D. (2023). Alternate day feeding as a cost-effective strategy in the tank culture of the Pacific shortfin eel *Anguilla bicolor pacifica*. *The Philippine Agricultural Scientist, 106*, 281-292.

Aya, F.A., Unida, J.C.L., Sayco, M.J.P., Romana-Eguia, M.R.R., Salayo, & N.D. (2021). Potential use of agricultural wastes in aquafeed production. In: Aya F.A., dela Peña L.D., Salayo N.D., Tendencia (Editors). *Proceedings of the International Workshop on Sustainable Aquaculture, Aquatic Animal Health and Resource Enhancement in Southeast Asia (SARSEA)*.

Barragan-Fonseca, K., Dicke, M., van Loon, & J.J.A. (2017). Nutritional value of black soldier fly (*Hermetia illucens*) and its suitability as animal feed: a review. *Journal of Insects as Food and Feed 3*(2), 105–120. https://doi.org/10.3920/JIFF2016.0055

Bolivar, R.B., Jimenez, E.B.T., Brown, & C.L. (2006). Alternate-day feeding strategy for Nile tilapia grow out in the Philippines: marginal cost-revenue analyses. *North American Journal of Aquaculture 68*(2), 192–197. https://doi.org/10.1577/A05-012.1

Cuvin-Aralar, M.L., Aya, F.A., Rowena-Eguia, M.R., & Logronio, D.J. (2019). Nursery culture of tropical anguillid eels in the Philippines. Tigbauan, Iloilo, Philippines: Aquaculture Department, Southeast Asian Fisheries Development Center. 38 p.

Cuvin-Aralar, M.L., Gibbs, P., Palma, A., Andayog, A., & Noblefranca, L. (2012). Skip feeding as an alternative strategy in the production of Nile tilapia *Oreochromis niloticus* (Linn.) in cages in selected lakes in the Philippines. *Philippine Agricultural Scientist, 95*(4), 378–385. http://hdl.handle.net/10862/1424

de Jesus-Ayson, E.G.T. & Borski, R.J. (2010). Alternative feeding strategies to improve milkfish production efficiency in the Philippines. *In Technical reports: investigations 2007-2009, 1,* 79–96. Corvallis, Oregon, USA: AquaFish Collaborative Research Support Program, Oregon State University.

Devic, E., Leschen, W., Murray, F., & Little, D.C. (2017). Growth performance, feed utilization and body composition of advanced nursing Nile tilapia (*Oreochromis niloticus*) fed diets containing Black Soldier Fly (*Hermetia illucens*) larvae meal. *Aquaculture Nutrition, 24,* 416–423. https://doi.org/10.1111/anu.12573

Ghosh, A.K., Biswas, M., Azad, M.A.K., Islam, S.S., Huq, K.A., & Shah, M.S. (2018). Effect of restricted feeding on growth performance and feed utilization of freshwater prawn (*Macrobrachium rosenbergii*) in pond aquaculture system. *Khulna University Studies, 15,* 13–22.

Hezron, L., Madalla, N., & Chenyambuga, S.W. (2019). Alternate daily ration as a feeding strategy for optimum growth, nutrient utilization and reducing cost in Nile tilapia production. *Livestock Research for Rural Development, 31,* 113. http://www.lrrd.org/lrrd31/7/lhlut31113.html

Nairuti, R.N., Munguti, J.M., Waidbacher, H., & Zollitsch, W. (2021). Growth performance and survival rates of Nile tilapia (*Oreochromis niloticus* L.) reared on diets containing Black soldier fly (*Hermetia illucens* L.) larvae meal. *Journal of Land Management, Food and Environment, 72*(1), 9-19. https://doi.org/10.2478/boku-2021-0002

Øverland, M., Vuoristo, K.S., Horn, & S.J. (2018). Microbial protein produced from brown seaweed and spruce wood as a feed ingredient. *Journal of Agriculture and Food Chemistry, 66* (31), 8328–8335. https://doi.org/10.1021/acs.jafc.8b01835

Rahman, F., Ghosh, A.K., & Islam, S.S. (2019). Effect of time-restricted feeding and refeeding regimes on compensatory growth, body composition, and feed utilization in prawn (*Macrobrachium rosenbergii*) culture system. *Journal of Applied Aquaculture, 32*(3), 236–249. https://doi.org/10.1080/10454438.2019.1661328

Pontes, C.S., Arruda, M.F., Santana, V.G.S., & Santos, D.B. (2020). Animal performance and welfare of giant freshwater prawn (*Macrobrachium rosenbergii*) subjected to feed restriction. *Revista Brasileira de Zootecnia, 49*, e20190128. https://doi.org/10.37496/rbz4920190128

Shumo, M., Osuga, I.M., Khamis, F.M., Tanga, C.M., Fiaboe, K.K.M., Subramanian, S., Ekesi, S., van Huis, A., & Borgemeister, C. (2019). The nutritive value of black soldier fly larvae reared on common organic waste streams in Kenya. *Scientific Reports, 9*, 10110. https://doi.org/10.1038/s41598-019-46603-z

Siddiqui, S.A., Ristow, B., Rahayu, T., Putra, N.S., Yuwono, N.W., Nisa, K., Mategeko, B., Smetana, S., Saki, M., Nawaz, A., & Nagdalian, A. (2022). Black soldier fly larvae (BSFL) and their affinity for organic waste processing. *Waste Management, 140*, 1–13. https://doi.org/10.1016/j.wasman.2021.12.044

St-Hilaire, S., Sheppared, C., Irving, S., Newton, L., McGuire, M.A., Mosley, E.E., Hardy, R.W., Sealey, & W. (2007). Fly pre-pupae as a feedstuff for rainbow trout, *Oncorhynchus mykiss. Journal of the World Aquaculture Society, 38*(1), 59–67. https://doi.org/10.1111/j.1749-7345.2006.00073.x

About the Authors

Dr. Frolan A. Aya is a Senior Scientist at the Binangonan Freshwater Station and the Program Leader of the Quality Seeds and Sustainable Aquaculture Program (QSSAP) of SEAFDEC Aquaculture Department in Iloilo, Philippines (Email: faya@seafdec.org.ph)

Dr. Sayaka Ito is a Scientist and the Deputy Chief and the Government of Japan Trust Fund Co-manager of SEAFDEC Aquaculture Department in Iloilo, Philippines (Email: akasaya@seafdec.org.ph)

Dr. Leobert de la Peña is a Senior Scientist and Research Division Head of the SEAFDEC Aquaculture Department in Iloilo, Philippines (Email: leobertd@seafdec.org.ph)

Ms. Richelle Tupas-Bautista is the Special Departmental Coordinator and Training Officer of SEAFDEC Aquaculture Department in Iloilo, Philippines (Email: rbautista@seafdec.org.ph)