Environment and Ecology 40 (4A) : 2156—2162, October–December 2022
ISSN 0970-0420

Insects as Alternative Protein Sources for Aquaculture : A Review

P. Bera, H. Dhara, S. K. Sau

Received 2 July 2022, Accepted 11 August 2022, Published 4 November 2022

ABSTRACT

Culture of fish is increasing day by day to fulfill the demand of growing population as good protein source. For constant and excess capturing, global fish stock is depleting continuously. So, implementation of new techniques has been started to increase production in aquaculture sector. Fish meal contains a high nutritional profile making it one of the most important components in fish diet. Due to economical and availability issues, alternative protein source is needed as a replacement of fish meal protein. Some experimental feeding trials have been made with insect based meal as substitution, making it a desirable candidate. Insect such as black soldier fly, silkworm, housefly, locust, meal worm have been used as they are rich in protein, lipids, vitamins, minerals and poor in anti-nutritional factors. They have easy rearing facilities and better biomass production with a satisfactory nutritional profile than any other animal protein source. Low level of inclusion of insect meal (25-30%) in fish diet has improve growth rate, survivability, feed conversion ratio and immunity of the target species. Research work must be carried out for large scale farming, production and processing of insect meal by keeping in mind their impact on food safety and environment.

Keywords Insects meal, Alternative protein source, Nutritional profile, Black soldier fly.

P. Bera, H. Dhara, S. K. Sau*
Department of Aquaculture, Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Sciences, 5, Budherhat Road, Chakgaria, Panchasayar, Kolkata 700094, India
Email : sksauffs@gmail.com
*Corresponding author

INTRODUCTION

Due to rapidly growing human population, demand of fish is increasing day by day as a cheap source of protein. So research works are being done for better commercial production by maintaining sustainable environment. To increase fish productivity, fish feed is the most important factor. Plant protein sources are difficult to use as feed ingredients due to presence of anti-nutritional factors, non-starch polysaccharides, as well as the amino acid and fatty acid profiles, which are less suitable for fish (Daniel 2018). Among all the animal protein sources, fish meal has become a good substitution as it has a better nutritional profile and is easily digestible. In current condition due to scarcity of fish meal, the price is increasing day by day. So a suitable, economical and environmental friendly alternative protein source is necessary to find out as major group of commercial fish species are either carnivorous or omnivorous.

Recently, the insect-based protein sources have come to limelight as they can easily generate food from organic waste. Need of feed is 6 times less for them as they produce less greenhouse gases emission than cattle (Frangoul 2016). Reproduction of insects need smaller surface on waste stream and short period of time making their yield higher per hectare than other crops (Verbeke *et al*. 2015). They have a good nutritional profile comprising of different essential and non-essential amino acids, saturated and unsaturated fatty acids, vitamins, minerals, polysaccharide polymers, bioactive compounds, antioxidants, antimicrobial and immune-stimulatory factors with high FCR (Harikrishnan *et al.* 2012).

Thus insects can be used as fish feed ingredient and alternative source of protein, which can partly or completely substitute fish meal. Among all insects' larvae and pupae of black soldier fly, larvae of housefly, mealworm, silkworm pupae, adult crickets, grasshoppers have shown better result. The nutritional composition of important insects generally used in aquaculture are shown in Table 1.

Use of insects as fish feed

Black soldier fly (*Hermetia illucens*)

Black soldier fly (BSF) is a common insect in tropical and subtropical regions and now it is spreading worldwide. Before becoming pupae, larvae nourished themselves from decomposed organic matter with help of enzymes like amylase, lipase, protease and intestinal flora combining proteobacteria, bacteroides.

Culture of BSF is a easy process as during the time of harvest they fly to clear substrate leaving the decaying substrate. Now-a-days several experiments have been done to replace different protein meals (fish meal, soyabean meal) with BSF larvae meal. Chopped BSF larvae (BSFL) and whole larvae were mixed with commercial feed of channel catfish. Chopped meal showed more acceptance of rather than whole BSF. Though BSF fed fish aroma is acceptable to fish, there was a reduction in feed efficiency ratio but their growth rate showed better result. For yellow catfish,

Table 1. Nutritional composition of important insects generally used in aquaculture.

Nutritional component	Black soldier fly	Housefly	Silkworm	Yellow mealworm	Locust (Cricket)
Crude protein	42-56%	50-62.4%	60.7-81%	52.8-82.6%	63-76.5%
Methionine	2.1*	2.2	3.5	1.5	1.4
Valine	8.2	4	5.5	6	5.1
Isoleucine	5.1	3.2	5.1	4.6	4.4
Leucine	7.9	5.4	7.5	8.6	9.8
Phenylalanine	5.2	4.6	5.2	4	3
Tyrosine	6.9	4.7	5.9	7.4	5.2
Histidine	3	2.4	2.6	3.4	2.3
Lysine	6.6	6.1	7	5.4	5.4
Arginine	5.6	4.6	5.6	4.8	6.1
Glutamic acid	10.9	11.7	13.9	11.3	10.4
Aspartic acid	11	7.5	10.4	7.5	7.7
Proline	6.6	3.3	5.2	6.8	5.6
Glycine	5.7	4.2	4.8	4.9	5.2
Alanine	7.7	5.8	5.8	7.3	8.8
Lipid	26%	18.9%	25.7%	36.1%	17.3%
Palmitic acid	16.1%	31.1%	24.9%	21.1%	23.4%
Stearic acid	5.7%	3.4%	5.4%	2.7%	9.8%
Oleic acid	32.1%	24.8%	24.3%	37.7%	23.8%
Linoleic acid	4.5%	19.8%	6.3%	27.4%	38%
Linolenic acid	0.19%	2%	36%	1.2%	1.2%
EPA	0.03%	-	0.2%	-	-
DHA	0.006%	-	-	-	-
Ca:P ratio	8.4	0.29	0.63	0.35	1.28

*Amino acid composition value is as per g/16 g nitrogen. Data is collected from the published paper of Alfiko *et al.* (2022).

when 25% of fishmeal protein was replaced with BSF larvae meal, it showed good growth (Zhang *et al.* 2014). Manure reared chopped BSF larvae meal increased 28% feed efficiency and 140% weight gain in blue tilapia. When 50% of fishmeal protein was substituted with BSF prepupae meal reared in cattle manure, it showed a slight difference in growth of rainbow trout. There was no change in growth, feed efficiency by using BSFL meal for Atlantic salmon. It did not affect the volatile organic composition and fillet quality but it slightly increased the n-3 PUFA in this fish (Lock *et al.* 2014). The growth, fillet sensory parameters, nutritional utilization, apparent digestibility coefficients of protein, lipid, amino acid, fatty acids, digestive enzyme activities were not affected when fishmeal was substituted with BSFLM in Atlantic salmon (Weththasinghe *et al.* 2021). All the experiments showed that there was reduction in feed intake rate when inclusion rate of BSF was more. The larval extract of BSF showed inhibitory affect to gram negative bacteria, thermo-tolerant coliforms (Lalander *et al.* 2015). Better assimilation of BSF protein has been observed for climbing perch (*Anabas testudineus*) than fish meal protein (Vongvichith *et al.*2020). Jahan *et al.* (2021) also observed that common carp fry showed better protein efficiency ratio for BSF meal than fish meal. Defatted BSFM showed increased catalase activity and anti-oxidant status in Jian carp juveniles after 60 days feeding trial when 50% fishmeal protein was substituted with BSFM (Li *et al*. 2017).

Housefly (*Musca domestica*)

The application of housefly as a fish food supplement has primarily been explored in freshwater fishes. Limited edition 25-30% of HFMM in fish diet had a better growth rate for African catfish. More than 30% inclusion rate of HFM in catfish diet showed lower growth performance in catfish (Saleh 2020). When feed was mixed with wheat bran and maggots @4:1 ratio nile tilapia showed good FCR, SGR and survival rate. 15-68% substitution of fish meal with HFM showed higher growth performance, better survival rate and good fatty acid profile in tilapia. Wang *et al.* (2017) experienced that HFMM @18 gm/kg feed increased flesh quality in tilapia. When 20% of fishmeal protein was substituted with HFMM, no adverse effect was found in nile tilapia (Alofa *et al*. 2020). But complete substitution of fish meal with HFMM showed adverse effect like reduction in growth rate, decrease of phagocytosis. According to Li *et al.* (2019), incorporation of HFMM in fish diet increased the serum activity in common carp and black carp. It also enhanced hepatic index, C_3, C_4, CAT level at 4.2 % inclusion rate. Phagocytic activity and inert immunity system were improved in red sea bream with low level inclusion of HFMM. Multiple trial have shown that inclusion of HFM in diets increased growth rate, FCR, feeding efficiency and reduced physiological stress in fishes.

Silkworm (*Bombyx mori*)

90% of silk production in India happens from mulbery silkworm (*Bombyx mori*). Silkworm makes a raw silk coccon for its self-protection purpose. After releasing silk fibers, the remaining silkworm pupae (SWP) are used as feed ingredient.

Fermented SWP incorporated feed showed better feed conversion ratio (FCR) and specific growth rate (SGR) than untreated SWP in IMC. Non defatted and defatted silkworm pupae meal (SPM) showed no adverse effect on FCR and growth rate, organoleptic quality of common carp when replaced with 50% FM protein (Karthick Raja *et al.* 2019). Fermented SWP silage resulted better growth than using FM incorporated diet with fresh silkworm pupae meal in the polyculture system of catla, mrigal, rohu and silver carp. Silver carp showed better growth in pellet feed prepared with SWP, clam meat and shrimp wastes. SWP also improve whole body protein deposition in minor carp (Ji *et al.* 2015). Different marine fishes like chum salmon, ayu, rainbow trout, flounder, sea bass resulted better effects when FM in their diets were substituted with SWP at different levels (Dheke and Gubhaju 2013). When fish meal was replaced partially with deoiled SWP, mahseer showed better growth rate. It showed better growth rate also in *Clarius batrachusas.* In ornamental fish industry SWP substitution showed satisfactory result for silver barbs, gourami, zebra fish, rainbow shark. Positive results were observed when 30-50% defatted or non-defatted SWPM were given to rohu, common carp, mahseer and rainbow trout (Astuti and Komalasari 2020). In freshwater prawn, SWP incorporation at 8.6% by weight to replace 100% FM protein showed good growth performance. 16.9% inclusion rate of SWP at dry matter basis also resulted better feed efficiency for abalone juveniles. Now a days, high value proteins and bio active peptides are prepared using SWP in industry level which gives more profit than using SWP in fish feeds (Altomare *et al.* 2020).

Yellow meal worm (*Tenebrio molitor*)

Yellow mealworm (YMW) is the larval stage of beetle of Tenebrionidae family. Fresh and dried YMW have been used in aquaculture as fish feed for several years. In African catfish, YMWM increased growth and feed utilization efficiency by substituting 40% fish meal protein. In common catfish and yellow catfish it increased immunological responses and bacterial resistance at 18% inclusion rate. Sea breams showed better growth performance and good FCR when 25% fishmeal protein was substituted with YMW but 50% substitution showed negative impact on growth rate (Piccolo *et al.*2014). The mealworm diet at 25% by weight showed no difference in growth performance of rainbow trout (Gasco *et al.* 2014). Full fat mealworm diet increased fatty acids, including C16:0, C18:1n9, and C18:2n6 but EPA and DHA gradually decreased in fillets. Dietary mealworm ingredient in the diet of rainbow trout up to 14% increased growth traits (Jeong *et al.* 2020). There was reduction in FCR, SGR value in European sea bass when more than 50% YMW was incorporated in fish diet. Su *et al.* (2017) observed that YMW based diet increased non specific immunity in fish. YMW diets also increased the level of different immunological parameters like serum MDA, SOD, glutathione peroxidase, myeloperoxidase activity in fishes (Sankian *et al.* 2018). Immune response in *Litopenaeus vannamei* improved when 50% fish meal protein was replaced with mealworm (Choi *et al.* 2018). The chitin content of mealworm helped to activate immune cells in fishes. It also acted as prebiotic by increasing gut microflora. YMW supplements also improved protein digestibility in fish (Ana *et al.* 2020).

Locust

Locust is a group of edible insects including grasshoppers, crickets. Locust/cricket meals are always formulated with other ingredients. In African catfish, grasshopper meal and desert locust meal showed better result after substitution of 25% fish meal protein (Alegbeleye *et al.* 2012). In walking catfish, grasshopper meal increased histological and physiological parameters along with hematological parameters. Locust meal increased nutrient digestibility when it was replaced with 25% fish meal protein in fingerlings of nile tilapia (Abanikannda 2012). There was a reduction in FCR and feed intake rate causing lower growth when locust meal was incorporated at more than 30% rate. In perch, a 12 week feeding trial was done by replacing 25% fish meal protein with house cricket meal which increased growth rate, survivability and FCR. 60% cricket meal with 40% rice bran showed best growth and survival rate in hybrid tilapia (Lee *et al.* 2017). 20% inclusion of house cricket meal improved linoleic fatty acid and a total level of n-6 fatty acids fillets, increased survival rate and FCR but reduced growth rate in perch (Tilami *et al.* 2020). More feeding trials are required to ensure safe use of locust meal in aquaculture.

Others

Some feeding trials have been done with others insects and used as alternative protein sources apart from above mentioned five insects.

Termite belongs to group of insects of order Isoptera. It is closely related to ants. Mendi termite (*Macrotermes subhyalinus*) was used in diets of African catfish with soyabean meal resulting an increase in protein and lipid level in fish body (Sogbesan and Ugwumba 2018). Subterranean termite (*Macrotermes* sp.) with soyabean meal at 75:25 ratio also resulted good growth performance and survival rate of this species. Rhinocerous beetles (*Oryctes* sp.) powder used in pellet diets showed no adverse effects on health of gold fish, common carp, climbing perch and oscar. Fakayode and Ugwumba (2013) observed negative impact on growth rate after complete replacement of fish meal protein with *Oryctes* sp. powder in mud catfish. 25% replacement showed better result in terms of nutrients utilization, FCR, ADC, feed intake rate, growth performance. House crickets in dried form showed lowest specific growth rate in walking catfish. Diet of *Acheta* sp. and fish meal @ 1:3 showed best growth and nutritional indicts with 100% survival rate in fishes. Jamaican field cricket (*Gryllus assimilis*) also improved growth rate in nile tilapia fingerlings (Fontes *et al.* 2019).

Processing of insects

To make insects available throughout the year, technical knowledge is necessary to make ambient rearing management and consistent larval production. Some insect rearing start-up enterprises have been made all over the world mainly in Europe, China, and Thailand. Critical factors such as appropriate rearing conditions and feeding formulations are necessary for large-scale manufacturing of insect-based feed. Details of the different steps required for processing was established by Rumpold *et al.* (2017). To produce insect meals the following steps are followed generally –

1. We have to first ensure the availability of the particular insect biomass in that area
2. Decontamination is then carried out with the help of thermal or radiation processes.
3. Third step is drying the whole insect or pupae or maggot by convection or radiation.
4. Then insects are broken into small pieces by grinding. During this time some insects (Eg- yel low mealworm) need extraction of fat by defatting process.
5. Then, chitin must be removed from the insect meal by fermentation process with the help of micro-organisms.

For insect mass raising and breeding environmental conditions must be controlled to optimize their growth.

CONCLUSION

Insect meal must have good nutritional profile, price, quality and year round availability to compete with traditional protein resources for aquaculture. After numerous experimental trials, it can be told that insect can be a good replacement for fish meal protein in diets of carnivore and omnivore fishes. Though, complete substitution of insect meal with fish meal protein is controversial as it reduces growth rate, feed intake rate, phagocytic activity but 25-30% replacement has given the best result. In future, research work must be done on – increase the nutritional value of insects through standard feeding, effect of insect meal on immunology and physiology of fish, study on insect meals on molecular basis, development of cost-effective mass scale rearing facilities of insects, life cycle assessments and impact of feeding insect meal on quality and social acceptance of the fishery product. Sanitation measures like safe use of culture substrate must be ensured as insect can convert bio-waste into valuable protein resource. Overall, a proper framework is needed for this. Besides experiments on feeding trials, the economically viable production of insects into mass scale is necessary. In the near future, insect farming to produce them as a fish feed ingredient will affect aquaculture substantially making it more profitable.

REFERENCES

Abanikannda MF (2012) Nutrient digestibility and hematology of Nile tilapia (*Oreochromis niloticus*) fed with varying levels of locust (*Locusta migratoria*) meal. Bachelor of Aquaculture and Fisheries Management. Federal University of Agriculture, Abeokuta, Ogun State.

Alegbeleye WO, Obasa SO, Olude OO, Otubu K, Jimoh W (2012) Preliminary evaluation of the nutritive value of the variegated grasshopper (*Zonocerus variegatus* L.) for African catfish *Clarias gariepinus* (Burchell. 1822) fingerlings. *Aquaculture Res.*43:412–420.

Alfiko Y, Xie D, Astuti RT, Wong J, Wang L (2022) Insects as a feed ingredient for fish culture: Status and trends. *Aquaculture Fish* 7:166-178. https://doi.org/10.1016/j.aaf.2021.10.004

Alofa CS, Adite A, Abou Y (2020) Evaluation of spirulina (*Spirulina platensis*) wastes and live housefly (*Musca domestica*) larvae as dietary protein sources in diets of Oreochromis niloticus (Linnaeus 1758) fingerlings. *Aquaculture Rese* 3 (1): 24-35.

Altomare AA, Baron G, Aldini G, Carini M, D'Amato A (2020) Silkworm pupae as source of high value edible proteins and of bioactive peptides. *Food Sci Nutr* 8: 2652–2661.

Ana B, Elisabete M, Luisa MPV (2020) Nutritional value of different insect larvae meals as protein sources for European sea bass (*Dicentrarchus labrax*) juveniles. *Aquaculture* 521: 735085. https://doi.org/10.1016/j.aquaculture.2020.735085

Astuti DA , Komalasari K (2020) Feed and animal nutrition: Insect as animal feed. IOP Conference Series: Earth and Environmental Science, 465.Article 012002.

Choi IH, Kim JM, Kim NJ, Kim JD, Park C, Park JH, Chung TH (2018) Replacing fish meal by mealworm (*Tenebrio molitor*) on the growth performance and immunologic responses of white shrimp (*Litopenaeus vannamei*). Acta Scientiarum. Animal Science 40. https://doi. org/10.4025/ actascianimsci. v40i1.39077

Daniel N (2018) A review on replacing fish meal in aqua feeds using plant protein sources. *Int J Fish Aquatic Studies* 6:164–179.

Dheke S, Gubhaju RS (2013) Growth response of rainbow trout (*Oncorhynchus mykiss*) on substitution of shrimp meal by different protein sources. *Nepalese J Zool* 1(1):24-9.

Fakayode O, Ugwumba A (2013) Effects of replacement of fishmeal with palm grub (*Oryctes rhinoceros* Linnaeus 1758) meal on the growth of *Clarias gariepinus* (Burchell 1822) and *Heterobranchus longifilis* (Valenciennes 1840) fingerlings. J Fish Aqua Sci .8: 101-107

Fontes TV, De Oliveira KRB, Gomes Almeida IL, Maria Orlando T, Rodrigues PB, Costa DVd (2019) Digestibility of insect meals for Nile tilapia fingerlings. *Animals* 9 :181.

Frangoul A (2016) Insects: Food of The Future? (US: CNBC LLC)

Gasco L, Belforti M, Rotolo L, Lussiana C, Parisi G, Terova G, Roncarati A, Gai F (2014a) Mealworm (*Tenebrio molitor*) as a potential ingredient in practical diets for rainbow trout (*Oncorhynchus mykiss*). In: Insects to Feed The World, The Netherlands, 14–17 May pp 78.

Harikrishnan R, Kim JS, Balasundaram C, Heo MS (2012) Dietary supplementation with chitin and chitosan on haematology and innate immune response in *Epinephelus bruneus* against *Philasterides dicentrarchi*. Experim Parasitol 131: 116-124.

Jahan R, Hasan MM, Haque MM, Md. Salam A (2021) Black soldier fly (*Hermetiail lucens*) larvae meal as a fish meal replacement in diets for nursing common carp (*Cypri nus carpio*) fry. Bangladesh Agriculture University. https://doi:10.31220/agriRxiv.2021.00030.

Jeong SM, Khosravi S, Mauliasari IR, Lee SM (2020) Dietary inclusion of mealworm (*Tenebrio molitor*) meal as an alternative protein source in practical diets for rainbow trout (*Oncorhynchus mykiss*) fry. *Fish Aqua Sci* 23 : 1–8.

Ji H, Zhang JL, Huang JQ, Cheng XF, Liu C (2015) Effect of replacement of dietary fish meal with silkworm pupae meal on growth performance, body composition, intestinal protease activity and health status in juvenile Jian carp (*Cyprinus carpio* var Jian). *Aquaculture Res* 46 (5):1209-21.

Karthick Raja P, Aanand S, Stephen Sampathkumar J, Padmavathy P (2019) Silkworm pupae meal as alternative source of protein in fish feed. J Entomol Zool Studies 7: 78–85.

Lalander CH, Fidjeland J, Diener S, Eriksson S, Vinneras B (2015) High waste-to-biomass conversion and efficient *Salmonella* spp. reduction using black soldier fly for waste recycling. *Agron Sustain Devlop* 35(1): 261-271.

Lee SW, Tey HC, Wendy W and Wan Zahari M (2017) The effect of house cricket (*Acheta domesticus*) meal on growth per formance of red hybrid tilapia (*Oreochromis* sp.). *Int J Aquatic Sci* 8:78–82.

Li SL, Ji H, Zhang BX, Zhou JS, Yu HB (2017) Defatted black soldier fly (*Hermetiail lucens*) larvae meal in diets for juvenile Jian carp (*Cyprinus carpio* var Jian): Growth performance, antioxidant enzyme activities, digestive enzyme activities, intestine and hepatopancreas histological structure. *Aquaculture* 477 :62–70.

Li X, Rahimnejad S, Wang L, Lu K, Song K, Zhang C (2019) Substituting fish meal with housefly (*Musca domestica*) maggot meal in diets for bullfrog Rana (Lithobates) catesbeiana: Effects on growth, digestive enzymes activity, antioxidant capacity and gut health. *Aquaculture* 499: 295-305.

Lock EJ, Arsiwalla T, Waagbo R (2014) Insect meal: A promising source of nutrients in the diet of Atlantic salmon (*Salmo salar*). In: Insects to Feed the World, The Netherlands, 14–17 May, pp 74.

Piccolo G, Marono S, Gasco L, Iannaccone F, Bovera F, Nizza A (2014) Use of *Tenebrio molitor* larvae meal in diets for gilthead sea bream *Sparus aurata* juveniles. In: Insects to Feed the World, The Netherlands, 14–17 May, pp 7

Rumpold BA, Klocke M, Schluter O (2017) Insect biodiversity: underutilized bioresource for sustainable applications in life sciences. *Regional Environm Change* 17 : 1445–1454.

Saleh HH (2020) Effect of feeding on fresh (wet) housefly maggots (*Musca domestica*) with or without artificial diet on water quality and growth rates of African catfish (*Clarias gariepinus* Burchell 1822) fry under laboratory conditions. *J Zool Res* 2: 2053.

Sankian Z, Khosravi S, Kim YO, Lee SM (2018) Effects of dietary inclusion of yellow mealworm (*Tenebrio molitor*) meal on growth performance, feed utilization, body composition, plasma biochemical indices, selected immune parameters and antioxidant enzyme activities of mandarin fish (*Sinipercas cherzeri*) juveniles. *Aquaculture* 496: 79-87

Sogbesan AO, Ugwumba AAA (2018) Nutritional evaluation of termite (*Macrotermes subhyalinus*) meal as animal protein supplements in the diets of *Heterobranchus longifilis* (Valenciennes 1840) fingerlings. *Turkish J Fish Aqua Sci* 8(1): 149-157.

Su J, Gong Y, Cao S, Lu F, Han D, Liu H, Xie S (2017) Effects of dietary *Tenebrio molitor* meal on the growth performance, immune response and disease resistance of yellow catfish (*Pelteobagrus fulvidraco*). *Fish Shellfish Immunol* 69: 59-66.

Tilami SK, Turek J, Cerveny D, Lepic P, Kozak P, Burkina V (2020) Insect meal as a partial replacement for fish meal in a formulated diet for perch *Perca fluviatilis. Turkish J Fish Aquat Sci* 20: 867–878.

Verbeke W, Spranghers T, De Clercq P, De Smet S, Sas B, Eeckhout M (2015) Insects in animal feed: Acceptance and its determinants among farmers, agriculture sector stakeholders and citizens. *Animal Feed SciTechnol* 20:72–87.

Vongvichith B, Morioka S, Sugita T, Phousavanh N, Chanthasone P, Pommachan P, Nakamura S (2020) Evaluation of the efficacy of aquaculture feeds for the climbing perch *Anabas testudineus*: replacement of fish meal by black soldier fly *Hermetia illucens* prepupae. *Fish Sci* 86(1):145-151.

Wang L, Li J, Jin JN, Zhu F, Roffeis M, Zhang XZ (2017) A comprehensive evaluation of replacing fishmeal with housefly (*Musca domestica*) maggot meal in the diet of Nile tilapia (*Oreochromis niloticus)*: Growth performance, flesh quality, innate immunity and water environment. *Aquaculture Nutr* 23(5): 983-993.

Weththasinghe P, Hansen JO, Nokland D, Lagos L, Rawski M, Overland M (2021) Full-fat black soldier fly larvae (*Hermetia illucens*) meal and paste in extruded diets for Atlantic salmon (*Salmo salar)*: Effect on physical pellet quality, nutrient digestibility, nutrient utilization and growth performances. *Aquaculture* 530 :735-785.
Zhang JB, Zheng LY, Jin P, Zhang DN, Yu ZN (2014) Fishmeal substituted by production of chicken manure conversion with microorganisms and black soldier fly. In: Insects to Feed the World, The Netherlands, 14–17 May, pp 153.