Utilization of Food Waste and Sustainable Protein Production from Black Soldier Fly (*Hermetia illucens*) for Fish Feed and Environmental Protection

Hosein Samadieh[1*], Ebrahim Ahmadi[2], Jahangir Khajehali[3]
1, 2, 3. Department of Plant Protection, College of Agriculture, Isfahan University of Technology, Isfahan, Iran

Abstarct
The growing global demand for sustainable protein sources in aquaculture and livestock industries presents significant challenges, particularly concerning the depletion of natural resources such as small fish and soy. The Black Soldier Fly (*Hermetia illucens*), which can efficiently convert food waste into high-quality protein and fat, is a promising solution to these challenges. This paper explores the potential of Black Soldier Fly larvae (BSFL) as an alternative protein source in fish and poultry feed. The nutritional properties of BSFL, including high protein content, essential amino acids, healthy fats, and minerals, make it a viable replacement for conventional feed ingredients like fishmeal and soy. Rearing BSF significantly reduces the pressure on agricultural land, water resources, and marine ecosystems. This paper discusses the environmental and economic benefits of BSFL farming, including its role in food waste reduction, greenhouse gas emission mitigation, and lower resource requirements for protein production. Furthermore, it addresses the challenges and barriers to industrial-scale adoption, including legal issues, scalability concerns, and public perception. Finally, the paper highlights the need for investment in insect farming technologies and the importance of scientific research to establish standards for insect use in animal feed. The findings suggest that incorporating BSF larvae into animal feed could contribute to global food security, environmental sustainability, and economic profitability in the aquaculture and livestock sectors.
Keywords: Black Soldier Fly, Sustainable Protein, Aquaculture Feed, Food Waste Recycling, Environmental Sustainability.

Introduction

In today's world, one of the most significant challenges humanity faces is ensuring the supply of food resources, especially protein, for the growing populations of both humans and animals. This challenge is particularly prominent in the aquaculture and livestock industries, key sectors in providing animal protein (Safdar *et al.,* 2023). As the global population is projected to reach approximately 9.7 billion by 2050, the demand for animal protein, particularly seafood, is increasing (Berthou and Lind, 2012). This has led to rising pressure on natural and agricultural resources, causing significant challenges in providing food for these industries (Schalekamp *et al.,* 2016). Specifically, the aquaculture industry is facing a growing need for protein sources to feed fish, a large portion of which is typically sourced from marine resources such as small fish. This trend not only depletes natural fish stocks but also poses a threat to aquatic ecosystems (Michael and Sogbesan, 2017). Additionally, using plant-based protein sources such as soy in fish feed has become a significant issue due to environmental and economic limitations. Soy, one of the primary plant-based protein sources used in fish feed, contributes to deforestation, loss of biodiversity, and excessive use of water resources. Therefore, there is an urgent need to find new and sustainable protein sources for the aquaculture and livestock industries (Iheanacho *et al.,* 2025).

In this context, using insects, notably the Black Soldier Fly (*Hermetia illucens*), as a novel and sustainable protein source, could be an effective solution to this crisis. The BSF is one of the insects that can naturally convert organic waste and food scraps into high-quality protein sources. In its various life stages, particularly the larval stage, this insect produces large amounts of protein and fat, which can

be used as valuable feed for fish, poultry, and other animals. BSF larvae, being rich in protein, essential amino acids, healthy fats, and minerals, are recognized as a suitable alternative to traditional protein sources such as small fish and soy (Odongo *et al.,* 2024). The use of BSF for animal feed is significant because of its nutritional properties and the insect's ability to convert food waste into high-quality protein. The insect can transform waste materials such as household scraps, agricultural by-products, and inedible organic matter into protein and fat. Therefore, breeding BSF as a sustainable solution to reduce food waste and convert it into a valuable food source can help address the global food production challenge (Chia, 2019). Moreover, the process of rearing BSF has notable environmental benefits. This insect converts food waste into a helpful food source and requires significantly less water and land. For instance, to produce the same amount of protein from plant sources like soy, BSF requires far less water and land. These features make Black Soldier Fly a cost-effective and environmentally friendly option in the aquaculture and livestock industries (Barragán-Fonseca *et al.,* 2023).

This paper examines the importance of rearing BSF as a sustainable food source for protein supply in the aquaculture and livestock industries. This paper will provide scientific information on the nutritional properties of BSF larvae and their benefits, as well as analyze the environmental impacts of this method in reducing food waste and optimizing the use of natural resources. Additionally, the challenges associated with adopting this method at the industrial and economic levels will be discussed, especially the legal barriers, scalability issues, and public acceptance of this method in the aquaculture industry. Ultimately, this paper will answer why we should pay more attention to rearing BSF and how this method can help solve global challenges related to food security, environmental protection, and industrial sustainability.

Main Viewpoint: Why is Rearing Black Soldier Fly a Critical Option for Providing Protein for Fish and Poultry?

One of today's most significant challenges in the aquaculture and livestock industries is providing high-quality and accessible protein. These proteins are primarily sourced from natural resources such as small fish, soy, and other agricultural products. However, these sources are rapidly depleting, and their use has significant environmental and economic consequences (Tincy *et al.,* 2014). Rearing BSF as an alternative and sustainable protein source can effectively solve food crises in this context. BSF larvae not only contain a substantial amount of protein and healthy fats, but their ability to consume food waste and convert it into high-quality nutrients makes this insect one of the prominent options for meeting the nutritional needs of the aquaculture and livestock industries (Sari *et al.,* 2023). This process allows the insect to significantly reduce food waste and enhance the efficiency of natural resource utilization while providing high-quality protein. As an innovative and sustainable solution, this method could help resolve the challenges faced in fish farming and other animal husbandry sectors. BSFL delivers a high-quality, sustainable alternative protein source for animal feed, offering nutritional benefits such as balanced amino acids, essential fatty acids, and minerals. This inclusion enhances animal growth, feed efficiency, and product quality while aligning with sustainability goals by converting organic waste into valuable biomass (Gadzama, 2025).

Creating Sustainable Food Sources: How Can the Use of Black Soldier Fly Larvae Help Solve Food Crises?

One of the most significant challenges of today's world is the food crisis resulting from population growth and the need for sustainable protein sources. The aquaculture and livestock industries increasingly need accessible and affordable protein sources. Currently, a significant portion of the protein used in feeding fish and other animals comes from natural resources, which have limited availability and cost (Nirmal *et al.,* 2025). In this context, using BSF larvae can serve as a sustainable and innovative protein source. The BSF can produce high-quality protein and fats using food waste and

organic by-products. This feature becomes especially important when food resources are limited or subjected to environmental crises. Since these insects can use food waste, they can convert large amounts of waste materials into valuable food sources, thus helping to solve food crises. This is particularly significant in regions facing food shortages or experiencing environmental crises. BSFL is a promising alternative protein source for animal feed, offering critical environmental benefits such as reducing food waste and the need for traditional natural resources. BSFL farming could help address the increasing demand for sustainable protein while minimizing ecological impact (Bessa *et al.*. 2020)

Reducing Dependence on Natural Resources: Using Food Waste for Insect Rearing and Reducing Pressure on Natural Resources

Using natural resources to supply the protein needs of the livestock and aquaculture industries places significant pressure on the environment and natural resources. For example, producing protein from small fish depletes marine fish stocks and threatens marine ecosystems, while producing protein from soy leads to deforestation and loss of biodiversity. Additionally, these processes require high amounts of water and land resources (Horsnell, 2019). In contrast, rearing BSF is an effective and sustainable option, significantly reducing dependence on natural resources. This insect can produce high-quality protein using food waste, without the need for vast agricultural land or excessive water consumption. Producing protein from BSF larvae requires far fewer natural resources than traditional sources like small fish or soy while effectively contributing to reducing food waste. BSF larvae offer a sustainable and efficient protein alternative for fish feed, with a lower environmental impact than yellow mealworm and soybean. The Life Cycle Assessment (LCA) revealed that BSF production requires fewer resources and results in less environmental harm, particularly regarding climate change and water use (Zlaugotne *et al.,* 2023).

Economic and Environmental Benefits: Reducing Costs and Environmental Harm Compared to Traditional Protein Sources

The economic benefits of using BSF larvae for feeding fish and poultry are particularly evident compared to traditional protein sources. The cost of producing protein from insects is significantly lower than from conventional sources. This cost reduction is desirable to fish and poultry producers as it allows them to produce high-quality protein economically (Affedzie-obresi *et al.,* 2020). Moreover, using BSF larvae as animal feed helps reduce the environmental impacts associated with traditional production processes. Producing protein from insects, especially BSF larvae, requires fewer water, land, and fuel resources, reducing greenhouse gas emissions. Additionally, this process helps reduce environmental pollution and prevents the generation of waste that has no value. Ultimately, the use of insects, notably the BSF, can serve as an environmental and economic solution to global crises related to protein supply, helping to reduce the ecological damage caused by the overuse of natural resources (Gadzama, 2025).

Nutritional Properties of Black Soldier Fly Larvae

1. High-Quality Protein and Amino Acids

BSF larvae are naturally rich in high-quality proteins essential for the growth and development of fish and poultry. These proteins include essential amino acids such as leucine, phenylalanine, and isoleucine, which are crucial for improving animal growth and health (Ryvak *et al.,* 2024). The protein quality in BSF larvae is comparable to or even better than traditional proteins, such as those from small fish and soy. Emphasizes the effectiveness of BSF larvae as a potential replacement for fish meal in fish feed. Notably, their high protein content (up to 64% dry matter) and digestibility make them an efficient and sustainable alternative to traditional sources like small fish (Barragan-Fonseca *et al.,* 2017). BSF larvae meal can effectively replace up to 75% of fishmeal in the diet of African catfish without negatively impacting growth performance or nutrient utilization. Including up to 50% BSF in the diet yields optimal results, improving feed conversion and protein efficiency (Fawole *et al.,* 2020).

2. Healthy Fats and Other Beneficial Nutrients

In addition to proteins, BSF larvae contain significant amounts of healthy fats, such as omega-3 and omega-6 fatty acids, which are vital for the health of fish and poultry. These fats help regulate metabolic processes, strengthen the immune system, and improve meat quality and egg production. Furthermore, BSF larvae are rich in essential vitamins and minerals, including vitamins A and D and calcium, strengthening the skeletal system and reducing nutritional deficiencies (Ryvak *et al.,* 2024). BSF larvae meal can fully replace fish meal in the diet of Atlantic salmon without negatively affecting growth performance, feed utilization, or nutrient digestibility. Additionally, it suggests that using insect meal contributes positively to environmental sustainability by reducing reliance on traditional protein sources (Belghit *et al.,* 2019).

Economic Profitability and Sustainability

1. Reducing Feed Production Costs

One of the most significant advantages of using BSF larvae to feed fish and poultry is the substantial reduction in feed production costs (Rana *et al.,* 2015). For example, the cost of producing protein from BSF larvae is much lower than that of traditional protein sources, such as small fish and soy. This cost reduction is especially beneficial for producers seeking more affordable ways to provide animal food (Chia, 2019).

2. Using Food Waste as a Food Source

BSF larvae can effectively consume food waste and organic by-products, converting them into high-quality protein and fat. This feature is incredibly efficient in food waste management, allowing producers to utilize waste materials as valuable food sources (Yunita *et al.,* 2024). As a result, using BSF larvae can significantly reduce feed-production costs while optimizing the use of natural resources. Establishing the efficacy of BSF larvae in converting food waste into high-quality protein for fish helps mitigate food waste issues while providing a sustainable protein source for aquaculture (Newton *et al.,* 2008).

Environmental Benefits

1. Reducing Food Waste and Greenhouse Gas Emissions

One of the most significant environmental challenges today is the accumulation of food waste, which decomposes in landfills and releases greenhouse gases such as methane. The BSF can consume these wastes and convert them into valuable food sources. This process not only helps reduce the volume of food waste but also prevents the release of greenhouse gases, indirectly contributing to the fight against climate change. The ability of BSF larvae to process organic waste, including agricultural by-products, not only provides a valuable food source but also reduces methane emissions from landfills, which confirms the larvae's role in waste reduction and microbial pathogen control (Ferronato *et al.,* 2024).

2. Positive Impacts on Soil, Water, and Other Natural Resources

Compared to traditional protein production methods from agricultural resources, rearing BSF requires less land and water (Maroušek *et al.,* 2023). For instance, producing Black Soldier Fly larvae to generate the same amount of protein as small fish or soy requires significantly fewer water and land resources. These features make Black Soldier Fly rearing a highly sustainable option for reducing pressure on natural resources (Zlaugotne *et al.,* 2023). Additionally, BSF larvae can be used as animal feed at various scales, helping to minimize the need for natural resources such as agricultural land and water (Siva Raman *et al.,* 2022). As a result, using BSF larvae to feed fish and poultry offers significant nutritional benefits. Due to its environmental and economic characteristics, it presents a sustainable and innovative solution to the challenges of the aquaculture and livestock industries. The reduction in feed production costs, the use of food waste as a nutritional resource, and its positive environmental effects

are key advantages of this method. Ultimately, BSF rearing can effectively produce sustainable protein while reducing the negative impacts on natural resources and the environment.

Encouraging Investment in Insect Rearing Technologies

One of the biggest challenges in expanding the insect rearing industry is investing in advanced technologies and appropriate equipment (Veldkamp et al., 2022). Insect farming, notably BSF, requires controlled systems for environmental conditions such as temperature, humidity, and light, which directly impact optimal protein production. Therefore, for the development of this industry, it is essential to focus on financial support and encouraging investment in this field.

Suggestions:

1. Encouraging Governments and Financial Institutions: Creating financial incentives for producers and investment companies involved in this field, especially during the early stages of industry development.

2. Supporting Startups and Innovations: Support active startups in insect-rearing technologies and encourage them to invest in research and development of new equipment.

3. Providing Financial Facilities for Insect Rearing Centers: Provide special facilities for establishing insect-rearing workshops and centers, utilizing low-interest loans and financial support.

Increasing Awareness Among Industry Stakeholders and the Public

One of the main barriers to the acceptance and expansion of the use of insects in animal feeding is the lack of awareness and the negative perceptions about using insects as a food source (Sogari et al. 2019). For success in this field, it is necessary to widely disseminate scientific and practical information about the benefits of using insects in feeding, especially the BSF.

Suggestions

1. Organizing Workshops and Conferences: Organizing training courses and scientific conferences for industry professionals and farmers to familiarize them with the benefits of using insects in animal feeding.

2. Public Awareness and Advertising: Utilizing various media outlets to increase public awareness about the environmental and economic benefits of insect farming and using insects to supply protein for livestock and fish.

3. Creating Online Platforms: Developing online platforms for exchanging experiences and information between producers and researchers in this field, especially for those in the early stages of insect farming.

Supporting Research and Standardization of Insect Use in Animal Feed

Scientific research and process standardization are needed for insect farming to be widely adopted in aquaculture and livestock industries. These studies should specifically focus on the nutritional impacts of insect larvae on the health of fish and poultry, optimal insect rearing methods, and hygiene standards (Morales-Ramos et al. 2024).

Suggestions:

1. Supporting Scientific Research: Allocating funds and resources to researchers and universities to conduct applied research on the use of insects in animal feeding, including investigating the effects of insect protein on the growth and health of fish and other animals.

2. Standardization and Regulation Approval: Collaborating with government and international organizations to develop and approve global standards for insect farming and their use in livestock and fish feed. These standards can cover the methods of rearing, handling, processing, and using insects in feed production.

3. Developing Laboratories and Research Centers: Establishing and strengthening specialized laboratories and research centers that can comprehensively study the effects of feeding insect larvae and develop standard protocols for their use in industry.

Conclusion

The Black Soldier Fly (*Hermetia illucens*) offers a promising and sustainable solution to the growing demand for protein sources in the aquaculture and livestock industries. This insect's ability to convert food waste into high-quality protein and fat makes it an efficient alternative to conventional feed ingredients like fishmeal and soy, which are increasingly scarce and environmentally damaging. The nutritional value of Black Soldier Fly larvae, rich in proteins, essential amino acids, healthy fats, and minerals, positions it as an optimal choice for animal feed, particularly in aquaculture, where the pressure on marine ecosystems is intensifying. Beyond its nutritional benefits, BSF farming also presents significant environmental advantages. It reduces food waste, lowers greenhouse gas emissions, and diminishes the strain on land and water resources, making it a more sustainable and economically viable option than traditional protein production methods. The reduced reliance on agricultural land and water to produce feed from BSF larvae highlights the role of insect farming in mitigating the environmental impact of the food production industry. Despite the clear benefits, the widespread adoption of BSF farming faces challenges, including scalability, legal frameworks, and public perception. Overcoming these barriers requires investment in insect-rearing technologies, scientific research, and the standardization of industry practices. Public awareness campaigns and educational initiatives are essential to shift attitudes toward accepting insect-based feed in animal husbandry. In conclusion, the Black Soldier Fly represents a crucial innovation in pursuing sustainable protein sources. Its integration into animal feed can enhance food security, reduce environmental harm, and promote economic sustainability in the aquaculture and livestock sectors. Moving forward, continued research, technological advancements, and public engagement are vital for realizing the full potential of BSF as a global solution to food production and environmental protection challenges.

Refrensecse

Affedzie-Obresi, S,. Adu-Aboagye, G. and Nkegbe, E.K., 2020. Black Soldier Fly (*Hermetia illucens*) Larvae Meal as Alternative Protein in Broiler Production in Ghana. Ghana Journal of Agriulture Science, 55:1–13, 2020. https://doi.org/10.4314/gjas.v55i1.1

Barragán-Fonseca, K.B., Cortés-Urquijo, J. and Pineda-Mejía, J., 2023. Small-scale Black Soldier Fly-fish farming: a model with socioeconomic benefits. Animal Frontiers, 13:91–101. https://doi.org/10.1093/af/vfad030

Barragan-Fonseca, K.B,. Dicke, M. and van Loon, J.J.A., 2017. Nutritional value of the black soldier fly (*Hermetia illucens* L.) and its suitability as animal feed - a review. Journal of Insects as Food Feed, 3:105–120. https://doi.org/10.3920/jiff2016.0055

Belghit, I., Liland, N.S., Gjesdal P, Biancarosa, I., Menchetti, E., Li, Y. and Waagbø, R., 2019. Black soldier fly larvae meal can replace fish meal in diets of sea-water phase Atlantic salmon (*Salmo salar*). Aquaculture, 503:609–619. https://doi.org/10.1016/j.aquaculture.2018.12.032

Berthou, S. and Lind, K.M., 2012. Global food demand and supply by 2050. (Presented at the 15th Annual Conference on Global Economic Analysis, Geneva, Switzerland). Purdue University, West Lafayette, IN: Global Trade Analysis Project (GTAP).

Bessa, L.W., Pieterse, E., Marais, J. and Hoffman, L.C., 2020. Why for feed and not for human consumption? The black soldier fly larvae. Comprehensive Reviews in Food Science and Food Safety, 19:2747–2763. https://doi.org/10.1111/1541-4337.12609

Chia, S.Y., 2019. Black soldier fly larvae as a sustainable animal feed ingredient in Kenya (Doctoral dissertation, Wageningen University and Research). https://doi.org/10.18174/502357

Fawole, F.J., Adeoye, A.A., Tiamiyu, L.O. and ajala, Kh., 2020. Substituting fishmeal with *Hermetia illucens* in the diets of African catfish (*Clarias gariepinus*): Effects on growth, nutrient utilization,

haemato-physiological response, and oxidative stress biomarker. Aquaculture, 518. https://doi.org/10.1016/j.aquaculture.2019.734849

Ferronato, N., Paoli, R., Romagnoli, F. and Torretta, V., 2024. Life cycle assessment of organic waste treatment by the larvae of Hermetia illucens. Environmental Science and Pollution Research, 31: 17651- 17669.

Gadzama, I.U., 2025. Black soldier fly larvae as animal feed. Bulg J Anim Husbandry/Životnov Dni Nauk, 62.

Horsnell, C., 2019. From Fish to Fish–Evaluating the Socio-Environmental Consequences of the Vietnamese Fishmeal Industry A Life Cycle Assessment and Product Chain Organisation Analysis of the Production of Vietnamese Fishmeal.

Iheanacho, S., Hornburg, S.C., Schulz, C. and Kaiser, F., 2025. Toward Resilient Aquaculture in Africa: Innovative and Sustainable Aquafeeds Through Alternative Protein Sources. Reviews in Aquaculture, 17. https://doi.org/10.1111/raq.13009

Maroušek, J., Strunecký, O. and Maroušková, A., 2023. Insect rearing on biowaste represents a competitive advantage for fish farming. Reviews in Aquaculture, 15:965–975. https://doi.org/10.1111/raq.12772

Michael, K.G. and Sogbesan, O.A., 2017. Alternative protein sources in aquaculture diets: A review. International Journal of Agriculture, Environment and Bioresearch, 2:201–228.

Morales-Ramos, J.A., Tomberlin, J.K., Miranda, C. and Rojas, M.G., 2024. Rearing methods of four insect species intended as feed, food, and food ingredients: a review. Journal of Economic Entomology, 117:1210–1224. https://doi.org/10.1093/jee/toae040

Newton, G.L., Sheppard, D.C. and Burtle, G.J., 2008. Research Briefs: Black Soldier Fly Prepupae—A Compelling Alternative to Fish Meal and Fish Oil. Aquaculture, 24:103–109.

Nirmal, N., Anyimadu, C.F. and Khanashyam, A.C., 2025. Alternative Protein Sources: Addressing Global Food Security and Environmental Sustainability. Sustainable Development. https://doi.org/10.1002/sd.3338

Odongo, E.E., Bbosa, W.K. and Kahunde, P.K., 2024. Black Soldier Fly (BSF): A Sustainable Solution for Protein, Waste Management, and a Circular Bio-Economy. European Journal of Theorertical and Applies Science, 2:822–834. https://doi.org/10.59324/ejtas.2024.2(3).64

Rana, K.S., Salam, M.A., Hashem, S. and Islam, M.A., 2015. Development of black soldier fly larvae production technique as an alternate fish feed. Internatonal Journal of Research in Fisheries and Aquaculture, 5:41–47.

Ryvak, H.P., Levitskyy, T.R. and Boyko, G.I., 2024. Alternative Non-Traditional Sources of Feed Protein and Amino Acids. Scientific and Technical Bulletin of State Scientific Research Control Institute of Veterinary Medical Products and Fodder Additves and Institute of Animal Biology, 25:140–146. https://doi.org/10.36359/scivp.2024-25-1.19

Safdar, L.B., Foulkes, M.J. and Kleiner, F.H., 2023. Challenges facing sustainable protein production: Opportunities for cereals. Plant Community, 4. https://doi.org/10.1016/j.xplc.2023.100716

Sari, D..H, Juniatmoko, R. and Purbowati, D., 2023. Pendampingan Pemanfaatan Maggot Bsf Dan Implementasi Recirculating Aquaculture System Dalam Budidya Lele. Journal of Penelit dan Pengabdi Kpd Masy UNSIQ, 10:123–127. https://doi.org/10.32699/ppkm.v10i2.4538

Schalekamp, D., van den Hill, K. and Huisman, Y., 2016. A horizon scan on aquaculture 2015: Fish feed. Br GSDR-2016.

Siva Raman, S., Stringer, L..C, Bruce, N.C. and Chong, C.S., 2022. Opportunities, challenges and solutions for black soldier fly larvae-based animal feed production. Journal of Cleaner Production, 373. https://doi.org/10.1016/j.jclepro.2022.133802

Sogari, G., Amato, M. and Biasato, I. 2019. The potential role of insects as feed: A multi-perspective review. Animals, 9. https://doi.org/10.3390/ani9040119

Tincy, V., Mishal, P., Akhtar, M.S. and Pal, A.K., 2014. Turning Challenges into Opportunities. World Aquaculture, pp. 67–69.

Veldkamp, T., Meijer, N. and Alleweldt, F., 2022. Overcoming Technical and Market Barriers to Enable Sustainable Large-Scale Production and Consumption of Insect Proteins in Europe: A SUSINCHAIN Perspective. Insects, 1. https://doi.org/10.3390/insects13030281

Yunita, S.M., Siwiendrayanti, A. and Nurjanah, N., 2024. Utilization of Black Soldier Fly Larvae in Processing Expired Food Waste with Various Composition. Jurnal Presipitasi: Media Komunikasi dan Pengembangan Teknik Lingkungan.

Zlaugotne, B., Diaz, Sanchez F.A., Pubule, J. and Blumberga, D., 2023. Life Cycle Assessment of Black Soldier Fly, Yellow Mealworm and Soybean Protein for Use in Fish Feed. CONECT Conference of Environmental and Climate Technologies, pp. 86–87. https://doi.org/10.7250/conect.2023.064