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UTILIZATION OF BLACK SOLDIER FLY'S LARVAE FOR INTEGRATED WASTE MANAGEMENT AT FARMER HOUSEHOLD

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ABSTRACT
In 2021, Indonesia mass-produces as much as 28,649,763.30 million tons of different groups of organic waste. This abundance of waste contributed to releasing methane, a very strong greenhouse gas linked to climate change and directly affects the ecosystems. Degrading waste is crucial so that the landfill does not bear too heavy a burden on waste problems. Some biological agents have been studied as a potential bioconversion of any waste produced by household, industrial, and agricultural fields. This research aims to provide information on the utilization of *Hermetia illucens* (*Black Soldier Fly*) as a bioconversion force to diminish waste, particularly in the agricultural field. The larvae known for their high source of protein initiated an integrated-sustainable agricultural system. A conceptual design was performed in this study and the method used was a literature study of secondary data research. The discussion consists of several topics, including the morphology of BSF fly, larval growth media, larval nutritional content based on age, use of larvae for livestock feed, and the concept of integrated waste management that utilizes larva, livestock, fish, and plant cultivation. This study demonstrates that larvae not only serve as a protein source in feed but also as a constituent in the zero-waste agriculture system.

KEY WORDS
Black soldier fly, fish, protein, organic waste.

Alterations in consumption patterns, lifestyles, and population growth have led to an increase in waste quantity, especially in urban areas. Indonesia will generate 28.649.763 million tons of waste by 2021. Unmanaged waste from this garbage has a value of 10.218.347 (tons/year) or 35,67% of total existing waste. Based on the type of waste, 41% is food waste, 17,1% is plastic waste, and the remaining comprises wood, paper, rubber, cloth, glass, metal, and other materials. The provinces of Java Island with the highest proportion of waste are Central Java (5,223,906 tons/year), West Java (4,559,600 tons/year), East Java (3,752,894 tons/year), and DKI Jakarta (3,083,437 tons/year)*.

Waste is a severe problem that requires serious attention since its management is frequently not conducted using environmental practices (Gold et al., 2018; Lopes et al., 2022; Mertenat et al., 2019; Pahmeyer et al., 2022; Salam et al., 2022). Waste management is concentrated in Final Processing Sites (through landfilling (69%), burial (10%), composting and recycling (7%), burning (5%), and the remaining is not managed (7%). This method of waste storage increases the burden on landfills and shortens their economic life (Mertenat et al., 2019; Salam et al., 2022; Suyanto et al., 2015)

Numerous wastes are generated from various community activities. According to the Ministry of Environment and Forestry (2022)*, household activities contribute the most considerable waste, with a proportion of 40,9% of destruction; on the other hand, industrial waste accounts for 18,4%, and traditional market waste contribute 17,1%. The waste

*Official website of the Ministry of Environment and Forestry (2022) https://sipsn.menlhk.go.id/sipsn/ accessed 09 August 2022].

generated by conventional markets comprises organic waste such as leftovers of greens, fruit, meat, and inorganic waste including plastic, cardboard, *et cetera*. Untreated organic waste produces leachate waste which contaminates groundwater, and methane which pollutes the air (Mertenat et al., 2019). Aside from the negative effects, organic waste has potential since it delivers good nutrition and is beneficial after the further process. Through a fermentation process involving living organisms, organic waste can be converted into simple compounds, proteins, and fat (Gold et al., 2018; Pahmeyer et al., 2022; Salam et al., 2022). The most prevalent decomposer organisms are insect larvae from the family: *Stratiomydae*, genus: *Hermetia*, and species: *Hermetia illucens* species (Gold et al., 2018; Lopes et al., 2022; Mertenat et al., 2019).

Hermetia illucens, otherwise called the Black Soldier Fly (BSF), produces larvae that contribute significantly to reducing living waste. Utilizing BSF larvae in the management of organic waste is an innovative and sustainable strategy for reducing landfill loads (Lopes et al., 2022; Pahmeyer et al., 2022; Salam et al., 2022). BSF larvae have a life phase in which they primarily function as decomposers who can convert substantial amounts of living waste into protein-rich biomass (Fahmi, 2018). The use of BSF larvae has been studied to reduce urban organic waste by up to 70% (Diener et al., 2011). Bioconversion using BSF larvae has numerous advantages rather to other conversion ways (Hakim et al., 2017; Kim et al., 2021). BSF larvae have higher *amylase, lipase, and protease* activity contrasted to other insect species (Fonseca et al., 2017). BSF larvae have the highest nutritional content of any insect that can be developed as feed, with 45-50% protein and 24-30% fat (Bosch et al., 2014; Lourenço et al., 2022).

The nutritional component of BSF larvae is frequently utilized as a substitute product for animal or fish feed. Even though it is only used as a mixture, BSF larvae feed is less expensive than other types of animal feed. The protein matter of BSF larvae is nearly identical to the protein matter of fish flour, as the primary component in poultry and fish feed. The high protein content in BSF larvae can enhance livestock growth, performance, and productivity. Since the protein found in BSF larvae is straightforward to digest, it is highly appropriate to use as a substitute for fish feed. The coefficient of digestibility of crude protein, dry matter, and energy in the BSF larvae diet was studied to be remarkably higher than those in the fish fluor (Muin & Taufek, 2022). A combination of BSF larvae flour and fish meal has been demonstrated to significantly affect the increase of weight in laying quail rations (Mawaddah et al., 2018; Pandra, 2021). BSF larvae are helpful as a fish feed mixture in addition to being used as animal feed (pellets). A study found that using BSF larvae as pellets can fulfill the nutritional requirements of *Rainbow Kurumoi fish* and can maintain the ammonia levels; thus, water quality can be preserved (Irfan & Manan, 2013).

BSF larvae produce compost during their life phase, the final residue of the BSF larval metabolic processes (excretion and secretion) (Fahmi, 2018). The nutrient content of BSF larvae compost (locally called '*kasgot*') has good nutrients for plant growth. Using BSF larvae compost as an organic fertilizer is a part of maintaining eco-friendly sustainable agriculture (Lopes et al., 2022; Pahmeyer et al., 2022; Salam et al., 2022). According to the literature, the macro and micronutrients contained in larvae compost can promote *Cabbage* growth and add biomass. The bioconversion value of BSF larvae waste is approximately 33,3% of the organic waste provided per day. It implies that if 30 tons of organic waste are provided per day, the by-product organic material that can be used as BSF larvae compost is as much as 9.990 kg (Salomone et al., 2017).

The magnitude of BSF larvae benefits has the potential to form an integrated and sustainable system known as zero-waste farming. This system combines interrelated components such as agriculture, animal husbandry, fisheries, and waste management. This study objects to discuss the characteristics of BSF larvae, their potential use as organic waste decomposers, and product differentiation as fish feed, which is subsequently connected to an integrated system for zero-waste BSF larvae utilization.

Morphology and living phase of the Black Soldier Fly. The larvae of the BSF differ from those of other Diptera larvae that come from the housefly group, such as the genera *Musca* and *Chrysomya* (Fonseca et al., 2017). The larvae of houseflies have an elliptical body with a smooth surface, black veins, and a black hook on the head. BSF larvae have an orange head surface, no hooks, and a flat, round, or boat-shaped body. Hair and pores can also be found on the larvae's bodies. The pupae have the same shape as the larva; the body's surface is wrinkled, and this fly has a different life cycle than the green fly. The BSF living phase is illustrated in Figure 1.

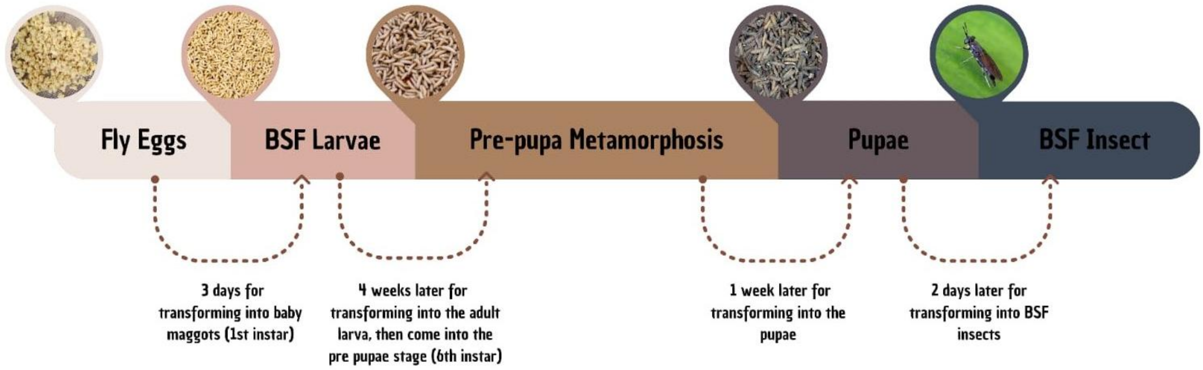

Figure 1 – The Life Cycle of a BSF

Adult flies do not possess functional mouth parts since they move only to mate and reproduce (Wardhana, 2016). The BSF undergoes metamorphosis during its life cycle. The BSF has a shorter fly phase than its larval phase; on the other hand, the green fly has a more extended life phase. Environmental element such as humidity, temperature, light intensity, and food quality and quantity can all impact the BSF's living phase. The life cycle of flies is also essential to understand since the protein content of flies varies with each phase.

Adult BSF can lay around 320-1.000 eggs in this life cycle, which are placed on dry substrates and between dirty gaps; thus, when the larvae hatch, they can easily find their food source and are protected from the threats of predators or sunlight (Dortmans et al., 2017). BSF eggs are oval, about 1 mm long, and yellowish cream in color which becomes darker as hatching time approaches. With higher temperatures, BSF eggs will hatch on day 4 or day 3. The BSF eggs will hatch with a size of 0,66 mm and move toward the food source after 3 days.

BSF larvae will migrate to a dark site away from light and enter cracks in the maintenance media. When these larvae are 4-5 weeks old, their bodies will adapt to the ambient temperature. The larvae will leave the feeding activity and enter the pre-pupae phase. On the 19th day, the pre-pupae phase begins. The characteristic of body color turns black or darker during the pre-pupae phase. After entering the pre-pupae phase, larvae do not molt (change in size). As they approach the pre-pupa phase, BSF larvae will stop eating and begin to migrate from the food sources to drier and more protected places (Gold et al., 2018).

The following stage is the pupal phase, which begins on the 24th day after hatching. The pupal phase lasts 8 days before the insect metamorphoses into an adult. Characteristics of the pupal phase include the changing of color and activity (stiff) until finally, the end of the pupae's body is bent. The larvae begin to metamorphose into insects eight days afterward or on the 32nd day (imago).

Male BSF insects are smaller than female BSF insects, and male BSF insects appear 1-2 days before female BSF insects. BSF male and female insects mate in the morning, beginning at 08.30 and peaking at 10.00 Indonesia time, with a light intensity of approximately 110 *lux*. BSF are territorial insects, in which the male flies will chase away other male flies to enter their mating area. Adult insects mate and lay eggs at fine temperatures ranging from 24-40º C and relative humidity levels ranging from 30-90%. Female insects live only for approximately 5-7 days, while male insects live a little longer for 9-10 days (Palma et al., 2018).

The number of eggs produced by adult BSF insects is affected by the quality and mass of food and culture media consumed during the larval phase. The shape and texture of larval growth media vary depending on the material used. The selection of a suitable growing media is necessary; thus, the larvae can develop and reach the optimal weight for production. This species of BSF prefers organic media with a distinct aroma; thus, not all media can be used for the egg-laying phase (Hopkins et al., 2021; Malawey et al., 2021).

Media for growing black soldier fly larvae. The quality of the media to grow BSF larvae conclusively correlates with the larval length and adult fly survival percentage (De Haas et al., 2006). BSF larvae are polyphagia (high feeding rhythm), allowing them to process various food sources (Fahmi, 2018). These larvae consume everything humans consume, including food scraps, garbage, fermented foods, fruits, meat or bones, animal carcasses, and vegetables. BSF fly larvae prefer waste containing salt and amino acids, despite being able to live at a reasonably high PH (Wardhana, 2016). Acceptable content of amino acids will increase the pupa's weight, allowing it to develop into an adult (Hopkins et al., 2021; Nguyen et al., 2015).

BSF larvae can be flourished in various media, including chicken bran, coconut waste, fish waste, and manure. The mixture of bran and chicken contains a reasonable amount of protein (Wahyuni et al., 2021). The larvae creates biomass by converting protein and various nutrients with a 50-70% of reduction. High biomass can also be produced by combining bran media with tofu waste. The mixture of bran media and tofu waste can also produce a high level of biomass. It is because the larvae can optimally absorb the nutrients from tofu (Cicilia & Susila, 2012). In addition to its benefits, the mixture derives from tofu waste media is relatively weak since it has a high water content which inhibits BSF larvae to grow normally.

High water content can trap ammonia (NH_3) and methane (CH_4), causing the growing larval media to become hot and oxygen-low (Rofi et al., 2021). The same case occurred in any media containing coconut waste (Amran & Pane, 2020), fish waste, and fruit-vegetables waste (Hopkins et al., 2021). Vegetables have a higher water content (approximately 72,29%); however, they produce 7,45% more protein and 10.58% less fat. In contrast to tofu and coconut waste, vegetable and fruit waste have a positive effect as a media for larvae growth. Other references stated that adding water derived from plant extracts can extend the life of BSF larvae by up to two weeks (Fahmi, 2018), and using almond hulls as larvae feedstock is beneficial for larvae cultivation by increasing the aeration up to 0.36mL min^{-1} g dry $weight^{-1}$, calcium content to 18%, and moisture content to 680 g kg^{-1} (Palma et al., 2018).

Meat and fish waste have a high potential for the growth of BSF larvae. Meat waste has a lower water content of approximately 65.67%, a higher protein content of 10,40%, and a 15,14% higher fat content. Tuna fish waste contains high levels of protein and fat, each at 25,38% and 8,77%, respectively. Fish waste can also attract BSF flies, causing them to lay more eggs. Using the combination of waste from fish, tofu, fruit, and vegetables as an attractant media (a media for stimulating the sense of smell) resulted in the highest egg production compared to a single medium using only tofu waste, fruit, or vegetables. BSF larvae have the potential to be agents for decomposing fishery processing industrial waste, with the larvae absorbing 99,2% of the nutrients in tuna waste feed (Hakim et al., 2017).

According to these studies, combining growing media from vegetables and fish or meat is preferable. The organic waste feed combination that significantly contributes to the growth of BSF larvae is a 3:1 ratio of meat and vegetables. The survival rate of the larvae can reach 100% with a reasonably high nutrient content of 12,95% protein, 7,65% fat, and 73,06% water content (Amri, 2021). The nutrient absorption of this growing media will be affected by the larvae's age, whilst the larvae cultivator prefers more heavyweight larvae since it yields a higher selling value.

Black Soldier Fly larvae as an alternative feed. BSF larvae have both direct and indirect benefits when it is used as animal feed. Since BSF larvae are detritivores (organisms that eat plants and decomposed animals), they can effectively decompose organic waste, including manure (livestock waste). Unlike *Muscidae* and *Calliphoridae*, fly larvae do not emit a pungent odor when decomposing organic waste, allowing them to be produced in homes or settlements (Fonseca et al., 2017; Lourenço et al., 2022).

The advantage of the larvae is having antimicrobial and antifungal properties, thereby increasing the body's resistance to animals it feeds. BSF larvae have the potential to be a substitute product for fish flour that is commonly used as raw material for fish feed, as the price of fish flour increases (Fauzi et al., 2022). Since the raw materials do not compete with human food ingredients, using feed from insect groups is eco-friendly and cost-effective. Hence, larvae are an alternative protein source for fish feed.

Making pellets from BSF larvae begins with preparation, which includes harvesting and sorting, cleaning the wet larvae, and freezing them for 24 hours. BSF larvae are dried with a heater for 12-15 hours at 60°C before being floured by grinding them in a blender and then sifting and molding them with a pellet instrument. Larval flour and larval pellets are physically similar since their color is dark, smell fishy, and are slightly oily. However, larval pellets are crushed easily with a 25-minute shelf life in water (Irfan & Manan, 2013).

The nutritional value of high protein in feed accelerates growth, reproduction, and the immune system. According to research, the protein requirement for tilapia for optimal growth ranges between 28 and 35% (Zulkhasyni et al., 2017). BSF larvae have storage organs called *trophocytes* that store nutrient content so that the protein that enters the fish's body causes the fish to grow fast; even though the content of the essential amino acids is lower in amount.

Using BSF larvae in feed ingredients is one strategy to accomplish more sustainable food production. The nutritional content produced by alternative feeds derived from larvae is nearly identical to conventional fish feeds. The content of *eicosapentaenoic acid, alpha-linolenic acid,* and *docosahexaenoic acid* in larval fish feed provides nutrients for the fish to move and grow. Feed derived from larvae has flaws due to its low calcium, potassium, and sodium content; however, this is to be expected because fish obtain these nutrients from the water they live in. Too much calcium and potassium absorption are poor because it prevents the absorption of other minerals (namely Zn, Fe, and Mn) (Oteri et al., 2021).

Feeding BSF larvae have been studied to increase the body weight of tilapia by as much as 43.28 g fish^{-1}(Muin & Taufek, 2022), However, using larvae as a pellet’s raw material for tilapia is preferable to be used in a different dose combination than the total dose (Hopkins et al., 2021). Fish digestion of the larvae is reduced since the larvae contain *chitin*, which resembles a crystal-shaped shell on its body and does not dissolve in acidic solutions (Jayanegara et al., 2017); therefore, it is difficult for fish to digest in excess quantities.

Integrated waste management– larvae – livestock – fish – plant. Waste management is ruled by Waste Management Law No. 18 of 2008. The essence of the law is 1) prohibiting waste elimination by open dumping (disposing of waste without covering the ground), 2) emphasize waste as a resource, not burning waste without compliance with waste management technical requirements, and 3) implementing ‘the three R’ principles, namely reducing waste, reusing waste, and recycling waste. The source of waste is the foundation for waste management, as mandated by Law No. 18 of 2008, articles 11, paragraphs 1 and 13.

Sources of waste derive from organic and non-organic materials. Typically, the inorganic waste group is processed through recycling. Organic waste groups that are difficult to decompose are partly recycled, used as fuel, or used as raw materials for handicrafts. Generally, easily decomposable taste groups are anaerobically decomposed into organic fertilizers or left to decompose in landfills. If waste is left to decompose, it risks releasing greenhouse gases; methane (CH_4) which is 25 times more powerful in trapping heat in the atmosphere than CO_2. Thus, waste management through recycling is recommended (Hopkins et al., 2021; Lopes et al., 2022; Mertenat et al., 2019).

The waste treatment system can be integrated with waste for agricultural, fishing, and animal husbandry purposes (Figure 2). BSF larvae are produced by waste utilization and can be processed into larvae flour as a mixture or concentrated in ruminant feed. The amino acid, fat, and calcium content of BSF larvae flour are highly necessary for ruminant growth. Ruminant livestock, such as cows and goats, were studied to prefer feed containing protein from BSF larvae over feed containing soy flour (Andrianto et al., 2020; Mulianda et al., 2021). Animal manure, a byproduct of the livestock industry, can be used as organic fertilizer in farming or as part of larvae feed mixture.

In fishing businesses, larvae flour can also be used as fish feed. BSF larvae can be produced in large quantities quickly and continuously. BSF larvae are less expensive than fish meal, making them a viable option for lowering production costs in fish farming. This larvae-based feed is suitable for ornamental fish such as bettas. According to research, giving larvae pellets positively affects betta fish (Irfan & Manan, 2013) and tilapia (Muin & Taufek, 2022) to gain in weight and length.

Several fish species, including catfish and tilapia, can consume larvae in fresh conditions. Fresh BSF larvae contain more protein than flour; however, its too-large size must be adjusted to fit the mouth of the cultivated fish. Supplemental larvae feeding was able to generate a profit of IDR 4 million and save costs for procuring pellets by 29,72% in a case study of a catfish-rearing business with a stocking size of 6.000 heads and a volume of 32 m^3 of water (Waluyo & Nugraha, 2020).

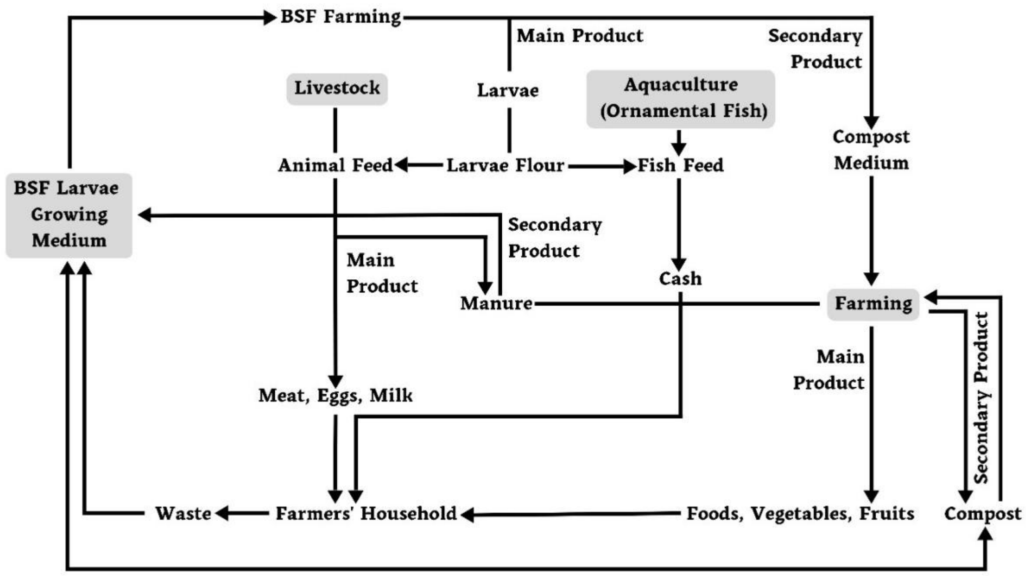

Figure 2 – Integrated Waste Management at Farmer's Household

Aside from the larvae body, the growth media also can be utilized. BSF larvae grow well in household waste such as vegetable and fish waste. Frequently, waste is only processed after it has been transferred to the Final Processing Site. Waste is processed by sorting and grinding until it achieves a suitable texture to be used as a culture media for BSF larvae. Household scale larvae cultivators prefer the growing media derived from vegetables and fruits rather than the growing media derived from meat waste. It is because those media produces an odor that pollutes the air and potentially brings rats or diseases. The business of cultivating larvae from organic waste should be conducted in an integrated manner to avoid socially undesirable negative effects (Lourenço et al., 2022).

The BSF larvae will decompose the waste media and eventually develop into flies. Flies will breed and lay eggs in cages. The frass in BSF cultivation produces a pure, clean, and unsmelling compost called larvae compost or *kasgot* (local name). The larvae compost is made by microorganisms such as bacteria, fungi, and yeast decomposing organic matter. It provides and balances the essential elements (macro/micro) for plant growth. The larvae compost has an advantage since it contains high nitrogen together with porous and moist media (Lopes et al., 2022).

The larvae compost is the most straightforward approach to producing organic fertilizer. BSF larvae contain numerous symbiotic bacteria, including *Bacillus sp.,* which are helpful as pathogen control agents and growth-promoting *rhizobacteria* (Kusumawati et al., 2018;

Lopes et al., 2022). This activity causes the compost produced by the larvae's decomposition to be cleaner and devoid of dangerous microbes that can impair the health of humans, cattle, and plants. The waste can be utilized as the larvae's living medium for 30 to 40 days. After 40 days, cultivators will replace it with a new medium. However, the leftover contains both macro and micro components required by other living thing, such as plants. The current content is 3,27% Nitrogen, 3,38% Phosphor, 9,74% Kalium, 40,95% Organic Calcium, a C/N ratio of 12,50%, and 11,04% water content (Nuryana et al., 2022).

The larvae compost is advantageous to agriculture since it is quickly processed (Fauzi et al., 2022; Lopes et al., 2022; Nuryana et al., 2022). The process of composting only takes 4 weeks, much faster than composting leaf litter, which takes 14 weeks. The larvae compost still needs to be fermented before they can be used as organic fertilizer. Without the ripening process, microbial activity in the larvae compost is still very high, which possibly reduces the oxygen and nitrogen content in the soil and inhibits plant growth (Dortmans et al., 2017).

The larvae compost can be used as a liquid fertilizer, as well as a solid fertilizer, particularly those from vegetables. After one week of decomposition, the BSF fly larvae media can produce up to 1,5 liters of liquid waste from 2 kg of vegetable and fruit waste. This liquid is utilized to make liquid fertilizer after it is separated from the larvae and solid residue in the manufacturing of solid compost (Kusumawati et al., 2018). Due to its pungent odor and high carbon dioxide levels, liquid fertilizer is less preferred than solid fertilizer.

The larvae compost can be utilized in monoculture, multicultural, or integrated farming activities such as mina-rice (rice and fish), duck-rice, or cow-corn. There are numerous alternatives to integrated farming patterns, such as crop-livestock-fish combinations. Integrated agriculture has grown in popularity since combining plants, livestock, and fish can improve soil quality, increase diverse food yields, and encourage the efficiency of land use. Farming yields will be distributed to the retail industry or traditional markets. The waste of farmer households can be collected and reused as growing media for larvae. The process is sustainable to create a zero waste (0%) concept.

CONCLUSION

BSF larvae are waste-reducing agents that could be developed through integrated waste management involving fisheries, livestock, and agriculture. The larval bioconversion process potentially reduces organic waste by up to 50%-70% in nearly all organic waste types, including vegetables, fruits, meat, and fish. BSF larvae growing media residues can be utilized as fertilizer in monocultures or multicultural agriculture, such as agriculture fisheries or livestock. Agricultural, livestock, and fishery products will be distributed to retail or traditional markets, generating waste that will be reused as a medium for larvae growth. An integrated agricultural analysis of waste management, larval cultivation, agriculture, and fisheries/livestock must be performed to determine the number of advantages and cost efficiency. Integrated waste management requires a lot of financial budgeting and must be conducted in an integrated manner to reduce the negative environmental impact.

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