

Review Article

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Black Soldier Fly: A New Vista for Waste Management and Animal Feed

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ABSTRACT

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The newest waste management technology is bioconversion using fly larvae converting organic waste to insect larval biomass and organic residue. Bioconversion is a practice of recovering resources while simultaneously limiting the amount of organic material affecting landfill behaviour. Several organisms have been used in this treatment process. Several studies have been done using the black soldier fly larvae to degrade organic material. Most of these studies focused on the degradation of cow, chicken or pig manure by *Hermetia illucens* larvae in cost- and maintenance-intensive systems of developed countries. Undoubtedly, organic waste continues to cause several problems in developing countries, as no valid solution has yet been identified. Development from experimental to full-scale waste treatment facilities, using the larvae of the black soldier fly, offers several advantages. Since such facilities can be developed and operated at low cost (low building and maintenance costs; independent from power supply), they are more adapted to the economic potential of developing countries. This paper presents future areas of research and collected information is expected to open new avenues for a large scale use of insect for management of waste.

Introduction

Urban solid waste management is considered one of the most immediate and serious environmental problems confronting urban governments in low- and middle-income countries. The severity of this challenge will increase in the future onus to the trends of rapid urbanisation and growth of urban population. Due to growing public pressure and environment concerns, waste experts worldwide are formulating to develop efficient and sustainable methods of utilization of

municipal waste that embrace the concept of a circular economy. Recycling organic waste material (bio-waste) is still fairly limited, especially in low- and middle-income settings, although this is by far the largest fraction of all generated municipal waste. The present paper describes the fairly novel approach of bio-waste conversion by insect larvae, using the example of the Black Soldier Fly (BSF), *Hermetia illucens*. However, academic publications on BSF are limited might be due to the business interest and perceived need to maintain a competitive edge Hence, the

practical day-to-day working steps required to operate such a facility is still lacking. The popularity of this competitive low-cost technology is on the rise. Therefore, this publication aims to introduce the technology to Indian farmers and provide the practical benefits over and above the existing waste utilization methods. Further, the author describes the nutritional benefits of the BSF larvae feeding to animals and birds. Filling this gap is the main objective of this publication. Upscaling or transferring this information to a larger facility might require some adaptation or adjustment of equipment. It is, however, our opinion that the standard procedures described are valid for a large range of scaling-up. It has drawn attention of scientist for its dual effect of waste utilization and use of BSF larvae as protein source in feed especially poultry. The small farmers especially in Thailand, Malaysia backyard poultry growers are using this low-cost technology, efficiently. India is producing more than 10 MT of organic waste including fruits, vegetables and meat industry. However, not more than 15-25 % total agro-processing waste is being utilized.

The black soldier fly

The black soldier fly (*Hermetia illucens* Linnaeus) is a member of the Stratiomyidae family. The adult fly is wasp-like and 15-20 mm long (Hardouin *et al.*, 2003). Primarily black, the female's abdomen is reddish at the apex and has two translucent spots on the second abdominal segment.

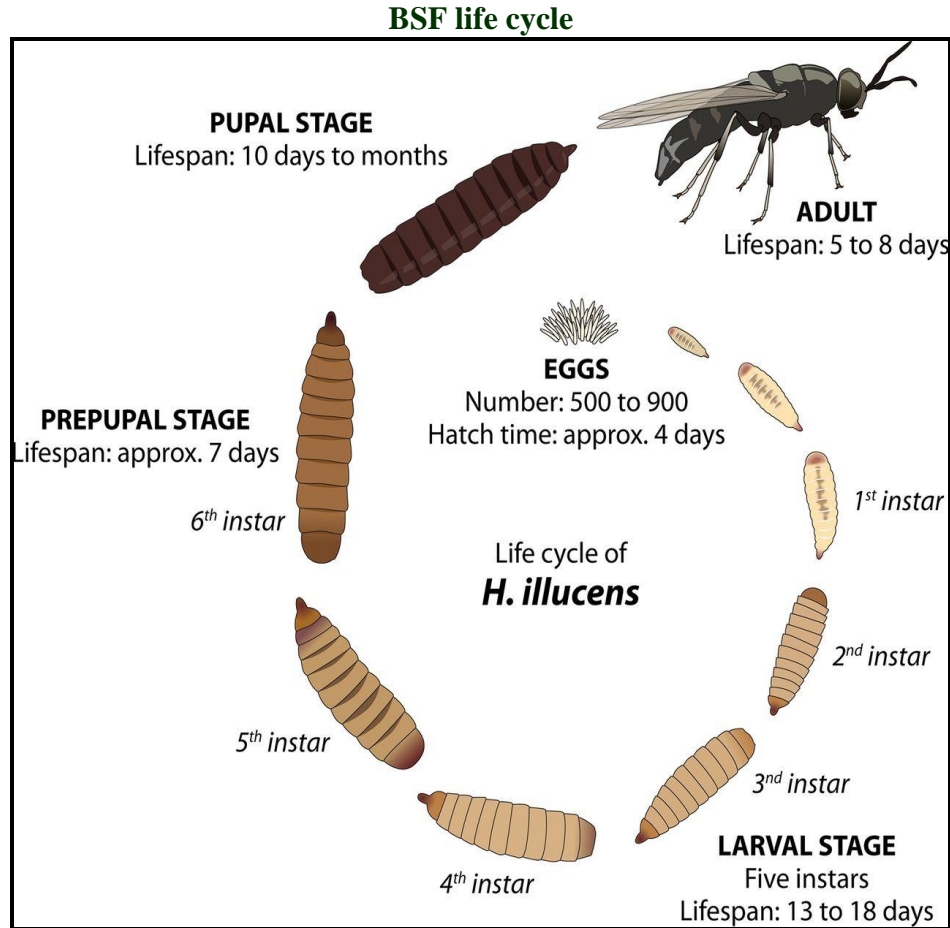
The male's abdomen is somewhat bronze in color. *H. illucens* is native to the tropical, subtropical and warm temperate zones of America, but during World War II they spread into Europe, Asia, including India, and even to Australia. The development of international transportation since the 1940s has resulted in its naturalisation in many regions of the world (Leclercq, 1997). It is now widespread in

tropical and warmer temperate regions (Diener *et al.*, 2011), breeding in compost, manure and outdoor toilets. The flies can be seen in bright sunlit areas, resting on nearby structures or vegetation.

They are generally considered a beneficial insect and non pest. The adult fly does not have mouthparts and doesn't even feed during its short lifespan. They do not bite or sting, feed only as larvae, and are not associated with disease transmission. Black soldier flies make breeding areas of houseflies less desirable. The fly is often associated with the outdoors and livestock, usually being found around decaying organic matter such as animal waste or plant material. Adult flies are easily distinguished by their long antennae (Gennard, 2012). Black soldier flies are an extremely resistant species capable of dealing with demanding environmental conditions, such as drought, food shortage or oxygen deficiency (Diener *et al.*, 2011) (Table 1-3).

Larva as bio-converter

Rearing *H. illucens* has been proposed as an efficient way to dispose of organic waste, by converting them into a protein and fat-rich biomass suitable for various purposes, including animal feeding for all livestock species, biodiesel and chitin production (Van Huis *et al.*, 2013; Diener *et al.*, 2011; Li *et al.*, 2011). These have been used to reduce animal manure in commercial swine and poultry facilities in western countries, but in India the practice is not common. BSFL can convert around 58% of the dry matter within an organic source into high quality animal feedstuff (Sheppard *et al.*, 1994). There is a good opportunity to utilise these flies for bioconversion considering the fact that approximately 1.3 billion tonnes of food is wasted from the food produced each year in world (Gustavsson *et al.*, 2011) (Table 4, 5 and 6).



The larvae convert organic waste material faster than worms used in vermicomposting. A colony of 2,000 larvae can consume about a kg of house hold food waste per day. They have large and powerful chewing mouthparts and hence are able to consume organic compounds before they have time to decompose, thereby immediately eliminating odor. Additionally, the larvae modify the microflora of manure, potentially reducing harmful bacteria such as *Escherichia coli* 0157:H7 and *Salmonella enterica* (Van Huis *et al.*, 2013). It has been reported that the larvae contain natural antibiotics which act on growth promoter in the animal feed (Newton *et al.*, 2008). In addition to the larvae, the residue or castings which are obtained during larval rearing under controlled conditions can be used for soil amendment.

Salient features

Waste biomass is converted into larvae and residue. The larvae consist of $\pm 35\%$ protein and $\pm 30\%$ crude fat. This insect protein is of high quality and is an important feed resource for chicken and fish farmers. Feed trials have confirmed it as being a suitable alternative to fish meal.

Feeding waste to larvae has been shown to inactivate disease transmitting bacteria, such as *Salmonella* spp. This implies that the risk of disease transmission between animals and between animals and humans is reduced when using this technology at farm level or when treating waste of animal origin in general (e.g. chicken manure or slaughterhouse waste). However, risk reduction is achieved mainly

through material reduction ($\pm 80\%$) rather than through pathogen inactivation.

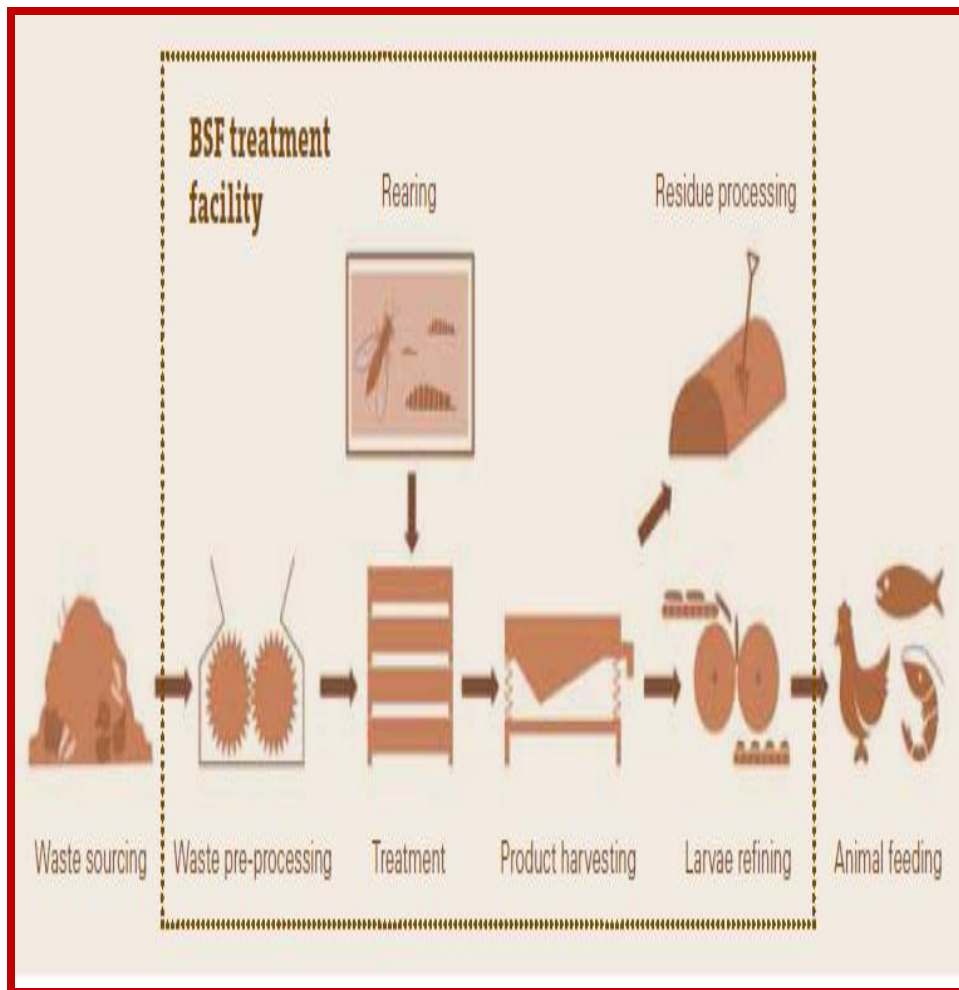
Waste reduction of up to 80% on wet weight basis has been demonstrated. If treatment is applied at the source of bio-waste generation, the costs for waste transport and space requirements for landfills can, thus, be reduced drastically. Such organic waste treatment could furthermore reduce open dumping, which is still an unfortunate reality in low- and middle-income settings.

The residue, a substance similar to compost, contains nutrients and organic matter and, when used in agriculture, helps to reduce soil depletion.

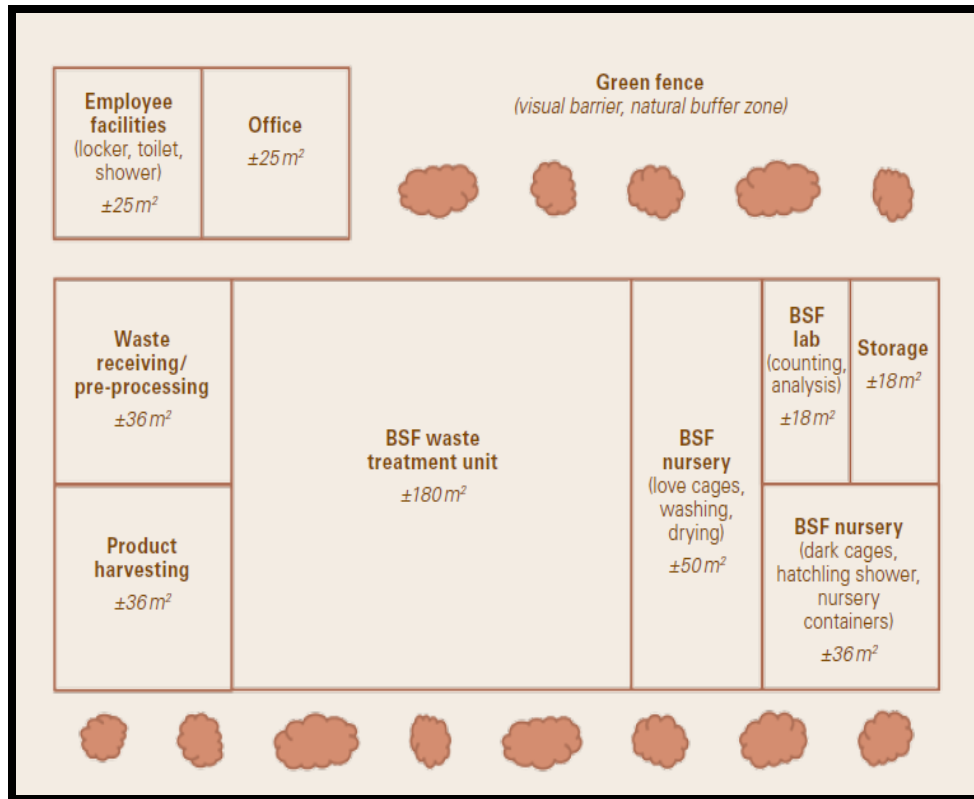
A high waste-to-biomass conversion rate of up to 25% on wet weight basis.

There is no need for sophisticated high-end technology to operate, so it is suitable for low-income groups without skill labours.

Layout of a BSF treatment facility (Two tons of Bio-waste per day)



(Source: St-Hilaire *et al.*, 2007)



(Source: St-Hilaire *et al.*, 2007)

The economic viability of a BSF processing facility will depend on following local conditions

- Scale and respective capital and operating costs of the facility
- Climate (temperature, humidity)
- Potential revenue from waste processing (tipping fees)
- Sales revenue from larvae derived products (e.g. whole larvae, protein meal, larval oil, etc.)
- Sales of the waste residue as soil amendment or its use in a biogas plant.

General benefits

The potential financial benefits of this program are many, and can be locally or widely distributed. Primarily there are environmental benefits to valorizing the large volume of organics currently underutilized. In addition, the aquaculture and livestock

industries can benefit by locally sourced cost competitive alternate protein meals. Greenhouse and vegetable production industries can achieve a double benefit, through an outlet for organics waste and return of high quality growing medium to enhance plant growth and health. The high value market products both lend themselves to pelleting, which enables economic delivery to a wider market, should production exceed local market demand, which is unlikely within India. Additionally, potential health benefits may be derived from what would be a natural feed ingredient for free range poultry and fish, from the ideal nature of the amino acids, possible antimicrobial peptides and natural chitins. In terms of further sustainability of the agriculture industry, vegetable wastes left in fields represent leachate and contamination of the environment and so must be hauled away to disposal sites, and it has proved very difficult to find alternative methods of nutrient management. Similarly to composting this

leaves large problematic volumes of liquid waste for disposal post digestion. The larval growth model provides for many of these issues providing nutrient recycling, reduction, and value add, all significant contributions to the economic viability, competitiveness and strategic development of the horticulture and greenhouse industries. An over-riding benefit of this project to the Province would be the potential development of a new “value add” industry to service existing bio-product markets, allowing enhanced competitiveness and potential expansion of other primary industries. All these benefits revolve around the core benefit of removing organic wastes from the landfill and disposal systems, freeing up space, potentially saving large amounts of costs on transportation, while providing much higher value add end products.

Environmental benefits

Black soldier flies are also known to reduce the mass and nutrient content of swine manure at efficiencies similar to poultry manure, with benefits for improved farm hygiene, reduced pest fly populations, and reduced nutrient pollution in runoff. Although the flies would not be produced in sufficient volumes to feed the swine, they can be redirected to other uses such as fish feed, and the remaining manure residue used for horticulture, enabling plants to grow in otherwise low-quality soils or even sand. BSFL can be reared on dairy cow manure, which is often mixed with other materials to improve larval yields and total waste reduction due to the high crude fiber content of pure dairy manure that the flies otherwise cannot fully digest. BSFL can also be reared on slaughterhouse blood and offal, again valorizing wastes from human food production. It is therefore well established that BSFL can be used to feed many vertebrates and can use various vertebrate wastes as a substrate, with no effects on the palatability of the BSFL-fed meats for humans and with significant implications for sustainable and

lower-input agriculture in the developing world. While the potential benefits are greatest in these developing nations, BSFL and other insect feeds are expected to play larger roles over time in advanced economies such as the United States, due to pledges to reduce waste among food conglomerates seeking approval from increasingly environmentally-conscious consumers and regulators, combined with the volatile prices of fish meal and other feed directing producers to seek alternatives (Table 7).

Legal regulations

Closely tied with food safety and issues of supply is food regulation (Maurer *et al.*, 2016). Areas without traditional histories of entomophagy and with food policies that prioritize risk avoidance, namely Europe (Knowles *et al.*, 2007; Siegrist, 2007; Vos, 2000; Laurenza and Carreño, 2015), have more stringent rules about insects as a “novel food” that must be addressed before insects can be marketed as human food (European Parliament and the Council of the European Union (Regulation, 2015). A search of FAOLEX, the United Nations’ Food and Agriculture Organization’s publically available database on food regulations worldwide, has at this point a single entry that specifically mentions black soldier fly. Dating to May 2017, the regulation (European Commission. Regulation, 2017) identifies seven insect species “currently reared in the Union”, including *Hermetia illucens* that fulfill the safety conditions for insect production for farmed and pet animal feed. Namely: “these should not be pathogenic or have other adverse effects on plant, animal or human health; they should not be recognized as vectors of human, animal or plant pathogens and they should not be protected or defined as invasive alien species.” They also place restrictions on the substrates fed to BSFL or these other species.

Table.1 Comparison of nutritional value of black soldier fly larvae meals vis-à-vis conventional meal

Constituents (% in DM)	BSF Larvae	Fish meal	Soy meal
Crudeprotein	56.9	70.6	51.8
Lipid	26.0	9.9	2.0
Calcium	7.56	4.34	0.39
Phosphorus	0.90	2.79	0.69
Ca:P ratio	8.4	1.56	0.57

(Source: Makkar *et al.*, 2014)

Table.2 Amino acid composition (g/16 g nitrogen) of Black Soldier Fly larvae meals vis-à-vis conventional meal

Amino acids	BSF Larvae	Fishmeal	Soymeal
Essential			
Methionine	2.1	2.7	1.32
Cystine	0.1	0.8	1.38
Valine	8.2	4.9	4.50
Isoleucine	5.1	4.2	4.16
Leucine	7.9	7.2	7.58
Phenylalanine	5.2	3.9	5.16
Tyrosine	6.9	3.1	3.35
Histidine	3.0	2.4	3.06
Lysine	6.6	7.5	6.18
Threonine	3.7	4.1	3.78
Tryptophan	0.5	1.0	1.36
Non-essential			
Serine	3.1	3.9	5.18
Arginine	5.6	6.2	7.64
Glutamicacid	10.9	12.6	19.92
Aspartic acid	11.0	9.1	14.14
Proline	6.6	4.2	5.99
Glycine	5.7	6.4	4.52
Alanine	7.7	6.3	4.54

(Source: Makkar *et al.*, 2014)

Table.3 Mineral composition of BSF larvae

Mineral	Mean value
Calcium	75.6 g/kg
Phosphorus	9.0 g/kg
Potassium	6.9 g/kg
Sodium	1.3 g/kg
Magnesium	3.9 g/kg
Iron	1.37 g/kg
Manganese	246 mg/kg
Zinc	108 mg/kg
Copper	6 mg/kg

(Source: Newton *et al.*, 1977)

Table.4 Facility required for BSF processing

BSF rearing unit	This ensures that a reliable and consistent amount of small larvae (called 5-DOL) is always available to inoculate the daily amount of bio-waste that is received for processing at the treatment facility. A certain number of larvae hatchlings are, however, kept in the rearing unit to ensure a stable breeding population.
Waste receiving and pre-processing unit	It is critical that the waste received at the facility is suitable for feeding to the larvae. A first step involves a control of the waste to ensure it contains no hazardous materials and no inorganic substances. Further steps then involve a reduction of the waste particle size, a dewatering of the waste if it has too high moisture and/or a blending of different organic waste types to create a suitable balanced diet and moisture (70-80%) for the larvae.
BSF waste treatment unit	This is where the rearing unit are fed with bio-waste in containers called “larveros”. Here, the young larvae feed on the bio-waste, grow into large larvae and, thus, process and reduce the waste.
Product harvesting unit	Shortly before turning into prepupae, the larvae are harvested from the larva. The waste residue itself is also a product of value.
Post-treatment unit (larvae refining and residue processing)	Both products, larvae and residue, can be further processed if required by the local market demand. We call this “product refining”. Typically, a first step will be to kill the larvae. Other steps of larvae refinement can be to freeze or dry the larvae, or to separate larvae oil from larvae protein. A typical step for residue refinement is composting or feeding the residue into a biogas digester for fuel production.

Table.5 Optimal environmental conditions and food sources

Warm climate:	The ideal temperature is between 24 and 30°C. If too hot, the larvae will crawl away from the food in search of a cooler location. If too cold, the larvae will slow down their metabolism, eat less and develop slower.
Shaded environment:	Larvae avoid light and will always search for a shaded environment, away from sunlight. If their food source is exposed to light, they will move deeper into the layer of food to escape the light.
Water content of the food:	The food source has to be quite moist with a water content between 60% and 90% so that the larvae can ingest the substance.
Nutrient requirements of the food:	Substrates rich in protein and easily available carbohydrates result in good larval growth. Ongoing research indicates that waste may be more easily consumed by the larvae if it has already undergone some bacterial or fungal decomposition process.
Particle size of the food:	As the larvae have no chewing mouthparts, access to nutrients is easier if the substrate comes in small pieces or even in a liquid or pasty form.

Table.6 Steps in Production

Step-1	Hang a clean love cage onto its hanger using the loops.
Step-2	Measure weight of the love cage with hanger
Step-3	Attach the hanger onto the mobile frame using the long stick and fasten it at the bottom
Step-4	Move the mobile frame with the attached love cage to the first dark cage and connect the two tunnels of the cages, using four binder clips. Turn on the light which is attached to the mobile frame as soon as the love cage is connected to the dark cage. Gently shake the cage to rouse the flies.
Step-5	After 30 minutes, disconnect and close the tunnel, measure weight of love cage and hanger and move the same love cage to the next dark cage. Repeat the same process of connecting, disconnecting and weighing after 30 minutes. Repeat this for all dark cages with emerged flies
Step-6	Disconnect the love cage from the last dark cage and turn off the light. Close the tunnels with a rope
Step-7	Now, the love cage contains all the freshly emerged flies from the dark cages. Measure the weight of the love cage with hanger again. The difference to the empty love cage measured at the beginning will correspond to the mass (grams) of flies in the love cage. If you collect 20 flies and measure their total weight and divide by 20, you will have an average weight of one fly. You can use the mass of flies and divide by the average weight of one fly to obtain the number of flies in the love cage
Step-8	Move the love cage with its hanger to the love cage table using the long stick with a hook and hang it into the love cage table
Step-9	Prepare attractant container: fill an empty attractant container with 100 grams of dead flies from an old love cage, 200 grams of residue from the nursery containers, 200 grams of residue from the old attractant container and one litre of fermenting fruit water (if no fermenting fruit water is available, use regular water). Mix thoroughly
Step-10	Prepare 10 clean eggies: Take clean wooden sheets and separate those between the sheets with pushpins and sheets without pushpins (see also Step 5). The pushpins will create a small gap (1-2mm) between the wooden sheets. Build up the egg media alternating between a sheet with and without pushpins. The sheets are held together by two rubber bands on both ends of the bundle. Prepare 10 of these bundles (eggies) for each love cage
Step-11	Prepare water bowl: Fill a clean container with tap water until it is almost full. Take the lid and a clean cotton cloth and push the cloth on both side through the incision slits made into the lid. The towel should lie flat on top of the lid, while its ends pass through the incision slits and are immersed in the water in the container below the lid. Sprinkle the towel with water
Step-12	Open the love cage with the zipper. Pay attention to avoid flies escaping from the love cage. Place the attractant containers into the love cage and then place the 10 clean eggies over the attractant container. Cover the attractant container and the eggies with the shading basket placed upside down onto four small pedestals (e.g. binder clips which keep the shading basket away from the surface to avoid egg laying underneath). Finally, place the water bowl with towel onto the shading basket and close the love cage
Step-13	After closing the love cage, add a sticker on the table next to the cage labelling the date of placement

Table.7 Difference between BSF and worm composting

Sr. No	Characteristics/Parameter	BSF	Worm composting
1	Raw material	Any organic matter (bio-waste/slaughter house waste/Egg shells/any manure etc.) High moisture products even more than 80 % moisture content	Consume only the bacteria generated by the decaying plant materials
2	Temperature	Best results 25-35 ⁰ C (tolerate even upto 40 ⁰ C) more suitable in Indian conditions	Best results 10-15 ⁰ C, dampness
3	Humidity	Low/even dry	High humidity 65-85 ⁰ C
4	Process efficiency	Fat 20% digestion requires only 24 hr also known as Accelerator	Slow process Initially you have to decay the plant material for 20 days by adding cow dung etc.
5	Nutritive value as feed	BSF larvae have 35% protein, Good source of energy and can fulfil the requirement of Essential amino acids for poultry feed, easily digestible, Further these kill salmonella, so problem of Salmonellosis in poultry can reduced	No such benefit
6	Quality of product	Free from bad odour, smell	Free from smell and odour
7	Biogas	Residues can be utilized in biogas plant	Cannot utilized
8	Nutritive value of compost	Depend on the type of raw material. It provide much higher assimilated nitrogen the vermicompost	Av. Organic carbon: 9.5-17.98% Nitrogen: 0.5-1.5% Phosphorous 0.1-0.3%
9	Economics/Cost of production	Cost effective lower period, initially availability is a problem however no sophisticated machinery nor skilled labour, process can be completed in 3-5 days.	Cost effective, Commonly used in India so availability of worms is not a problem, but process takes 45-60 days.

Equipments required

One love cage made of sturdy mosquito netting with loops at each corners, a long

zipper opening and a central round tunnel opening. This is suitable for 6,000-10,000 flies
One hanger per love cage

- Two attractant containers per love cage
- One shading basket (slightly larger basket than attractant container) with four small pedestals.
- One water bowl with lid per love cage. Make two incision slits into the lid at both sides. The slits should be long and wide enough for a cotton cloth to pass through.
- One cotton cloth (towel) per love cage
- Ten egg media units (eggies) per love cage.
- One mobile frame (with attached electrical light) (see Blue print 2). One can be used to serve several love cages
- A stick (approx. 2m) with a hook at the end
- Four ant traps per love cage table. The containers should always contain water. The love cage table legs are placed into these containers.
- One love cage table with a frame which is large enough for three love cages. The frame should be as high as the love cage so that the bottom of the cage rests on the table (see Blue print 3).
- Eight binder clips to attach the dark cage's transfer tunnel to the love cage and to form the pedestals of the shading basket.

The substrates must contain “products of non-animal origin” or a limited set of animal products that includes fishmeal, rendered fats, blood and gelatin from non-ruminants, milk, eggs, honey, etc. Flesh is not listed, and manure, “catering waste” (human food waste), and “other waste” are explicitly excluded (European Commission. Regulation, 2017). These restrictions eliminate the risk of prion contamination of the BSFL, but greatly limit its usage to close nutrient loops.

In the United States of America, animal feed is considered a “food” and should be regulated by the Food and Drug Administration (FDA); however, the FDA has an official Memorandum of Understanding with the Association of American Feed

Control Officers (AAFCO) for all regulations regarding animal feed (Klonick, 2017). The FDA and AAFCO would regulate BSFL production, packaging, Labeling, distribution, sale, import, and export for direct human and animal consumption respectively.

In August 2016, AAFCO approved the dried larvae of *Hermetia illucens* “that has been raised on a feedstock composted exclusively of feed grade materials (and which) must contain not less than 34% crude protein and 32% fat on an as-fed basis” for use in feeding salmonid fishes (Association of American Feed Control Officials Reports, 2016). At this time, therefore, BSFL cannot be reared on non-feed grade substrates or fed to non-salmonids. Rearing BSFL on chicken manure and feeding them to fish or chickens or humans is thus not allowed in the USA at this time. Requiring feed-grade substrates for BSFL greatly reduces their environmental benefit; and the protein and fat floors, which were stipulated to ensure consistent product, further limit the types of feed suitable for the larvae and, therefore, their environmental benefit (Klonick, 2017). The authors regrettably cannot include information on food regulations, whether they reference *H. illuscens* or not, for all other nations.

Regarding international bodies, insects are not listed in the Codex Alimentarius, a United Nations document on what is considered “food” that informs much global food regulatory policy, except as impurities that contaminate food (Van Huis, 2013). This is a problem in the USA as well, where insects are described as a “defect” that can only be found in foods up to a certain point, but not explicitly stated as food (FDA Handbook, 2010). Note that insects are currently sold in the USA and other nations as novelty foods for humans, with the unstated understanding that if the food is supposed to contain insects, then the insects are not a defect. Still, the

legal perception of insects as a contaminant and not a food and the general human perception of insects as unwanted in the food are both barriers to BSFL or any other insect being normalized as food (Shelomi, 2015).

In conclusion, the ability of black soldier fly larvae to convert low value organic waste products into a high value feedstuff accessible not only to carps, but also to carnivorous fish may limit the need for fish meal and fish oil in the aquaculture industry.

BSFL are edible, nutritious (especially when defatted), and can theoretically be reared more sustainably than extant farmed insects (and, therefore, extant farmed animals) pending further development of large-scale bio refineries. This makes them a potential protein source for humans both in the future and in the developing world. BSF Larvae they are commonly used in household and manure composting in western countries since long time. The rearing of BSF is easier in India as larvae flourish more in tropical environment than in colder one, hence composting using BSFL should be recommended in India as well.

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