Potential Application of Black Soldier Fly Larvae (BSFL; Hermetia illucens) as Efficient Converters of Under-utilized Organic Farm Wastes in Papua New Guinea | Arthur Roberts, Michael Dom
1 (1) : 68 - 75 | Received: 10/08/2024 | Reviewed: 08/09/2024 | Accepted: 14/09/2024

Potential Application of Black Soldier Fly Larvae (BSFL; *Hermetia illucens*) as Efficient Converters of Under-utilized Organic Farm Wastes in Papua New Guinea

Arthur Roberts*, Michael Dom

National Agricultural Research Institute Livestock Research Program,
Labu, P O Box 1639, Lae, 411 MP, PNG

*Corresponding author: arthur.roberts@nari.gov.pg

Abstract: Food gardens and farms generate a lot of organic waste in the form of crop residues and animal manure, much of which may not be recycled back into reusable forms as compost, mulch or manure fertilizer. There is scant attention paid to the means of regenerating valuable farm inputs from fibrous crop residues and nutrient dense manures which are available as by-products of smallholder farming enterprises. Such options do exist in the form of biowaste management strategies which would enhance the notably low input-output crop-livestock farming systems practiced in Papua New Guinea. The bioconversion of organic material provides a unique opportunity to use animal manure and crop residues in a manner that allows the recycling of essential nutrients, particularly protein and energy, which may otherwise be lost, back into farming systems as processed feed and fertilizer. The larvae of Black Soldier Fly (BSF; *Hermetia illucens*) can digest an array of organic materials, bio-converting nutrients into harvestable insect larval mass, thereby providing a protein feed source for fish, chickens and pigs. In our recent, work Black solider fly larvae (BSFL) was used to reduce household kitchen waste and animal manure and provide a nutritionally valuable protein, fat and energy for small-scale livestock production. The BSFL bioconversion of organic residue was also demonstrated to provide a high nutrient compost which may be used as a soil additive for growing vegetable crops. This paper aims to propose the potential application of BSFL as a bio-converter of organic farm waste and highlights the significant reduction of waste by 48% and the generation of a nutrient-rich compost, emphasizing the dual benefit of waste reduction and resource generation.

Keywords: bioconversion, biowaste, black soldier fly, feed, larvae, wastes

1. Introduction

Insects are particularly rich in protein, fats with a notable array of mineral content for human consumption or a feed source for poultry, fish and pigs [1, 2]. A multitude of insect life also supports the breakdown and decomposition of organic wastes within farming ecosystems. Papua New Guinea's (PNG) mixed livestock-crop farming systems generate wastes in the form of agricultural field wastes (weeding, pruning, harvesting), fibrous crop residue (food gardens), food wastes (pre & post-consumed) and livestock manure which may be generally used for compost mulch, manure fertilizer or animal food [3,4]. While reliable data on the amount, composition and waste streams are unavailable, it is estimated that about one million tons of wastes are produced annually to which 60% may possibly be organic [5, 6].

The mechanisms to reuse, recycle or effectively recover valuable nutrients remain unexplored in PNG [7]. While the commonly used landfills, composting and incineration practices are done in most PNG urban to rural localities [7] these practices are considered unsustainable with serious negative impacts on the environment [8, 9]. The prospect of recovering valuable nutrients from organic wastes through farming of insects has gained attention in developing countries because of their utility to manage organic wastes while using less resources yielding valuable products for food, feed, fertiliser and fuel with lesser impacts on carbon emissions compared to domesticated livestock [9,10].

The common houseflies (*Musca domestica*), Mealworm (Tenebrio molitor) and Black soldier fly (BSF; Hermetia illucens) are the most extensively studied insects for the bioconversions of organic wastes [2]. The most promising is the BSF demonstrating its versatility to dispose a large range of waste streams while accumulating nutrient rich protein-fat larvae [11]. Studies have shown BSF to be an effective waste management tool for human feces, pigs and poultry manure [12, 13, 14] to Municipal solid wastes ideal for under resourced low-income countries [15]. We propose that exploring potential applications of BSFL to recycle organic farm wastes may have greater utility at a smallholder level and be particularly beneficial for village farming of fish and poultry, where valuable protein feeds are less available.

2. Black Soldier Fly Characteristics and Advantages

Hermetia illucens, the Black Soldier Fly (Diptera: Stratiomyidae) is a native to North America with indigenous strains identified to have migratory routes from the Australasian region [16]. The earliest Hermetia specie record dates back to the early 1970's where the H. palmivora was identified in West New Britain [17] while recent emergence of a rare new Hermetia on mainland New Guinea [18]. Widely distributed throughout the sub-tropical and tropical regions tolerating a broad range of environmental conditions [19] BSF may be observed colonizing decomposing fruits, vegetables, agro-industrial wastes (cocoa, coconut wastes, coffee pulp, palm kernel, oil palm) and animal manure or decaying animal tissues. BSF thrives well in temperatures between 24.4 to 34.8 ºC for pupation [19]. Reduced activity is experienced below 20 ºC, causing hibernation and reducing larval activity. Temperatures above 40 ºC reduce larval survivorship dramatically [32]. The optimal humidity levels for mating, hatching and rearing range between 30- 90% with 70% being the most desired for larval development [15]. Our work at the National Agriculture Research Institute (NARI) has reported similar productive conditions for larval rearing and growth [20].

The larvae of BSF are frequently mistaken for the common housefly maggot, Musca domestica. BSF best resembles a wasp-like features and is more differentiated for its larval feeding behaviour and migratory characteristics during pupation [19]. The adult BSF do not occupy human settlements and do not feed as an adult fly; rather digests its own stored fats accumulated during its pre-pupation period [13]. Moreover, BSF does not transmit diseases and is not a disease vector unlike the common housefly [21]. The Black Soldier Fly Larvae (BSFL; Hermetia illucens), is voracious feeder that can eliminate large amounts of organic wastes edible enough in size to feed upon [22]. It is well known to outcompete other filth-inhabiting flies dominating its feed sources reducing biomass by up to 55 – 70% [21, 23]. In addition, BSFL has shown to be effective in reducing concentrations of enteropathogenic and enteric diseases such as Salmonella spp. and E. Coli in human faeces, cattle, chicken and pig manure [23, 24]. The larvae are also less likely to bioaccumulate toxins or drugs [3] and are known to degrade pesticides and pharmaceuticals preventing contaminants re-entering the environment [11].

The BSFL are also tolerant to a wide range of pH [25]. Experimenting with different readily available growth media, fermented household kitchen waste 8.9 and fermented sweet potato (SP) silage 5.8 pH value, it was found that larval mass was greater in the former, while individual larvae weights was higher in the latter [20]. Although, larval proliferation was influenced by several other external factors, it was noted that the kitchen waste provided sufficient loose material for larval movement whereas the SP silage was slightly denser in the packing of wet material. Overall, the application of BSFL significantly reduced the mass of household kitchen waste supplied as larval growth media, bio-converting it into compost. This demonstrates an immediate applicability at household level for producing protein feed from food waste and crop residues.

3. Benefits of Rearing BSFL for Biowaste Conversion

The BSFL is becoming a highly desirable product for food additives, fat extracts [2], fish and livestock feed [26] biodiesel [9] and pharmaceutical derivatives [11] have grown exponentially. Similarly, the rearing of BSFL is increasingly documented elsewhere for managing biowastes in low to middle income countries [11]. Depending on the type of waste mediums used to farm BSFL, the protein content may reach up to 40 to 44% protein, 15 to 25% fatty acid composition [26] generating a comparable amino acid profile rich in lysine with similar compositions to soybean sued in poultry and fish diets. It is also a high value source of vitamins and rich in minerals with an Ash content of 20% [26].

Numerous research using BSFL as protein replacement source in diets for chickens, pigs [13, 27] and several different fish and aquatic species have been well documented as a potential substitution for commonly used protein sources. Pig and chicken manure are the most commonly used waste streams to farm BSFL [26] while other waste mediums like organic household wastes or crop residues have been considered to be useful BSFL mediums [21].

It was reported elsewhere that at smallholder household level, farming BSFL fits well as an integrated waste management system suited for small scale production [26]. Several benefits that may be more beneficial to smallholder farms is the capacity for less space, water and resources to initiate a BSF colony while taking advantage of its higher feed conversion efficiency, high fecundity, omnivorous feeding habits, and BSFL migratory behaviour [9,22].

Moreover, in earlier studies BSFL demonstrated its ability to reduce odorous compounds from poultry, pig and dairy manure to almost 90% [28] providing additional benefit of using BSFL as an environmentally friendly method in managing livestock manure. In addition, the by-products from the rearing process commonly referred to as "frass" (i.e., composition of insect faecal, substrate residue, shed exoskeletons) yields beneficial properties for soil amendments. The decomposed matter, which is odourless and highly fertile is used to germinate seeds, improve biomass for ornamental plants and green leaf vegetable gardens [29, 30]. The frass is an expected by-product of BSFL rearing which can add up to 75% of the feed substate [29]. The same techniques for fertilizer mulch and composting can be applied to food gardens similar to current practices used on manure wastes. BSF may have the potential to create a circular economy for smallholder farms processing decaying organic matter into larval biomass forming a closed loop recycling system (Figure 1). biowaste conversion creates a circular economy by transforming organic waste into valuable resources, such as protein-rich feed and nutrient-rich compost, thereby closing the loop on waste and resource use in farming systems. At NARI's Labu Station the piggery maintains a natural black soldier fly population which is utilized for reducing pig manure in large 80 L buckets. This also provides a means of reducing pest flies and bad odours, apart from reducing organic run-off and a beneficial soil amendment from the frass material supplied to banana plants.

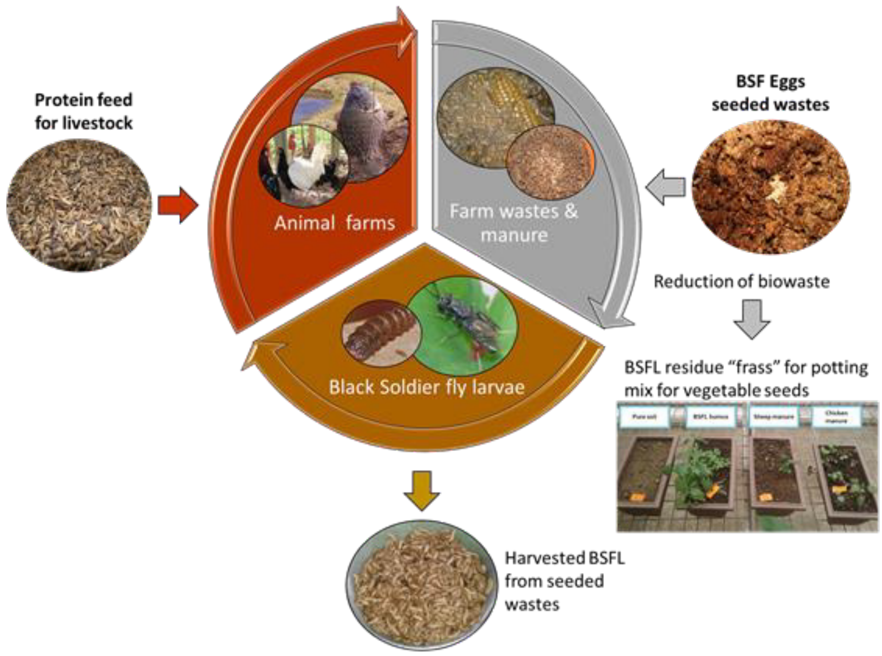

Fig 1: A closed loop recycle diagram using the Black soldier fly to recover farm biowastes from larvae used as feed for livestock.

4. Case study: An Application of BSF as a Biowaste System

PNG estimates its per capita municipal solid waste (MSW) per persons generated to be 0.45 kg daily [6, 7]. This estimate may be undervalued due to drastic population differences and urbanization in cities and townships in PNG in contrast to village households. However, what is clear is that 60% of MSW are arguably organic implicating waste management decisions on a household level. A study collecting weekly kitchen wastes averaged a household collection of 1.9 kg averaging 52.8 kg wet weight per month [20].

The application of BSF as a bioconversion system potentially reduces 29 kg within 14 days (using 48% conversion rate) [20] whilst producing insect larval biomass of 528g wet weight. A third in weight of this, constitutes about 176 g of available crude protein in the form of larval biomass. Three quarters of the 29 kg are rich in N, P and K with potentials for soil amendment application [31]. Our study sample size of 5 to 10 households may perhaps be insufficient; however, provides a decent snapshoot into the potentials of utilizing household wastes to recover nutrients and elements that are occasionally lost through compost dumping. Moreover, the recent work was relatively small in production scale purposely executed for assessing BSFL's bioconversion using natural populations in farming environments. First discovered thriving on ensiled sweet potato root tubers for feeding pigs and occupying pig wastes, BSF was well fitted into cyclic process of a biowaste system. Smallholder farms depend entirely on the low-input system which are based on the farms biological recycling of organic waste products for energy and nutrients. The study demonstrated a 48% reduction in kitchen waste through bioconversion, yielding an average of 200 grams (20%) of Black Soldier Fly Larvae (BSFL) per kilogram of waste consumed [20]. Nutrient proximate analysis from the larvae indicated a crude protein of 34.1% and 30% fat from kitchen waste which compares well with commonly used feed ingredients found in PNG (Table 1). The bioconversion of organic wastes using BSFL potentially addresses low availability of nutrients on farms through bioconversion of organic waste into larval biomass while providing a high value protein source for livestock.

Table 1: A comparison table of feed ingredient resources used as a protein source in comparisons to the Black Soldier Fly larvae

Ingredient	BSFL[3]	Fish meal[1]	Soybean[1]	Copra Meal[1]
Dry Matter	91.3	89.55	89	89.25
Gross Energy ($MJkg^{-1}$)	23.1	19.09	39.89	17.13
Crude Protein (%)	32.1	51.32	48	20.57
Crude Fibre (%)	7	1.56	3	12.46
Ether Extracts (%)	30	10.37	2	-
Phosphorus (%)	1.5	2.44	0.65	0.25
Calcium (%)	5	3.3	0.25	0.66
Ash (%)	20.6	34.97	4.9	7.14
Level of inclusion (Fish)	[2]7.5-30	[1]60	[1]60	[1]20-35
Level of inclusion (Chickens)	[2]12.0	[1]12.0	[1]15.0	[1]20-40
Costs in Kina (PGK)	-	61.90*	70.0*	64.80*

[1]Inclusion rates for Copra meal, Soybean and Fish meal for fish and village chickens taken from E. Thomas (2006).
[2]Inclusion rates for fish are for channel catfish (*Ictalurus punctatu*s) Bondari et al (1981) and chickens taken from Hale [27].
[3]Literature for nutrient specifications on Black Soldier Fly Larvae from kitchen waste [20].
*Current price value for fish meal at Frabelle Limited, Soy bean imported and purchased from Lae Feed Mill and Copra meal from Coconut and Products Limited in Madang.

It should be noted that the study was conducted in an open shed environment using natural populations of Black soldier fly larval biomass. The experiment used seeded larvae stock (3rd and 4th larvae instar stage) from pig manure to initiate the bioconversion process without any artificial breeding process to produce egg clutches for seeding. The average larval mass produced of 528g (200 g dry matter) produced may have not reached its full potential due to disturbances from daily monitoring of the waste mediums (i.e., pH, Moisture, humidity etc.). It has been observed that feeding larvae are best kept under darked conditions for a period of 7 to 14 days to allow feeding to reach maximum yields and allow larvae to migrate from its feeding source [19, 32]. In Addition, the open shed environment lured adult flies to lay egg clutches around biodigesters (Figure 2). These eggs were re-seeded as an additional seed stock into the waste matrix for bioconversion.

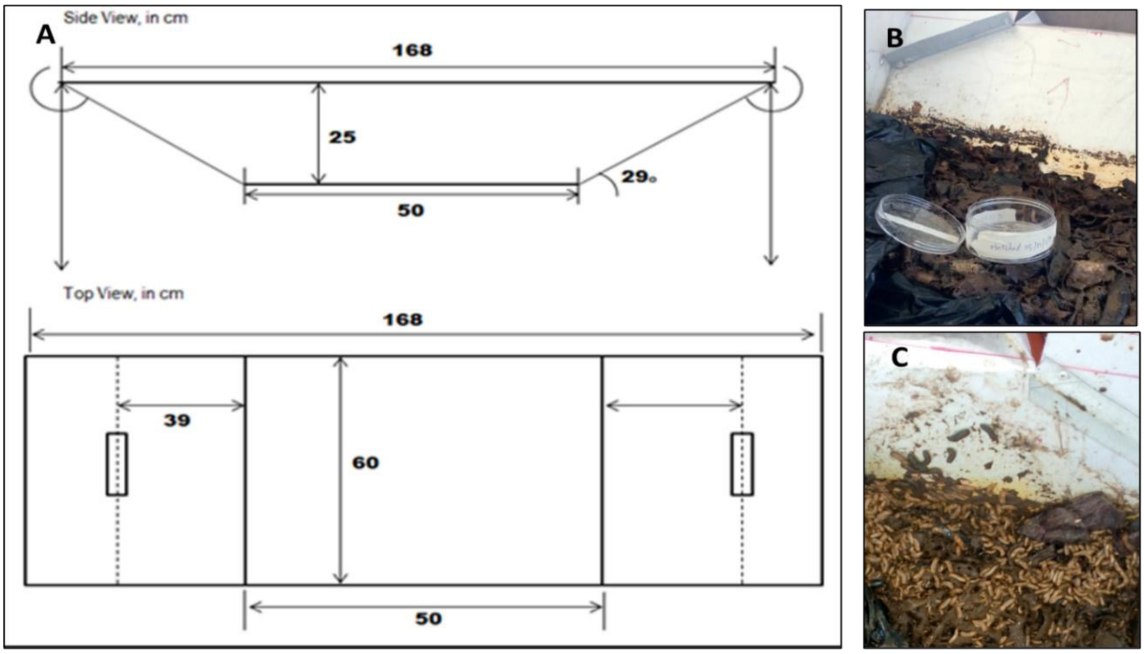

Figure 2: BSFL biodigesters used for the bioconversion of collected kitchen waste; **Insert A:** A prototype biodigester was modified for rearing black soldier fly larvae from a shared video link: https://www.youtube.com/watch?v=ycl3B6-y73 [20] **Insert B:** Eggs clutches laid around the biodigesters collected and seeded into the waste matrix. **Insert C:** BSFL feeding after being seeded after approximately 14 days.

The study indicated that there was a natural decline in larval biomass during the 90-day period observation suggesting a natural decline in the population within the open shed. This may be case of BSF selecting more preferred mediums such as pig manure around the farm. It appears that breeding BSF to maintain regular supply of eggs for seeding waste mediums would be a pre-requisite in initiating breeding stock. While current BSFL rearing practices are small and growing exponentially with technological advancements [26] natural BSF populations may be inconsistent because of their variability to source feeding medium [9]. Artificial breeding may perhaps be more consistent for larval mass production considering organic waste inputs are more heterogenous and reliable [9].

For better utility in the application of BSF in managing household for MSW, the ‘reduce, reuse, recycle’ concept for waste management also fits well with household composting systems that are rarely considered. BSFL may be proposed as a concept idea to complement the proposed vermicomposting for MSW for Lae city waste management hierarchy systems [7]. However, an awareness into segregating wastes would probably be required in terms of the benefits of organic composting and green fertilizer applications for MSW and smallholder farms. BSFL adds value to composting and reduces acidic leachates into interconnected ecological water ways and biological systems [25].

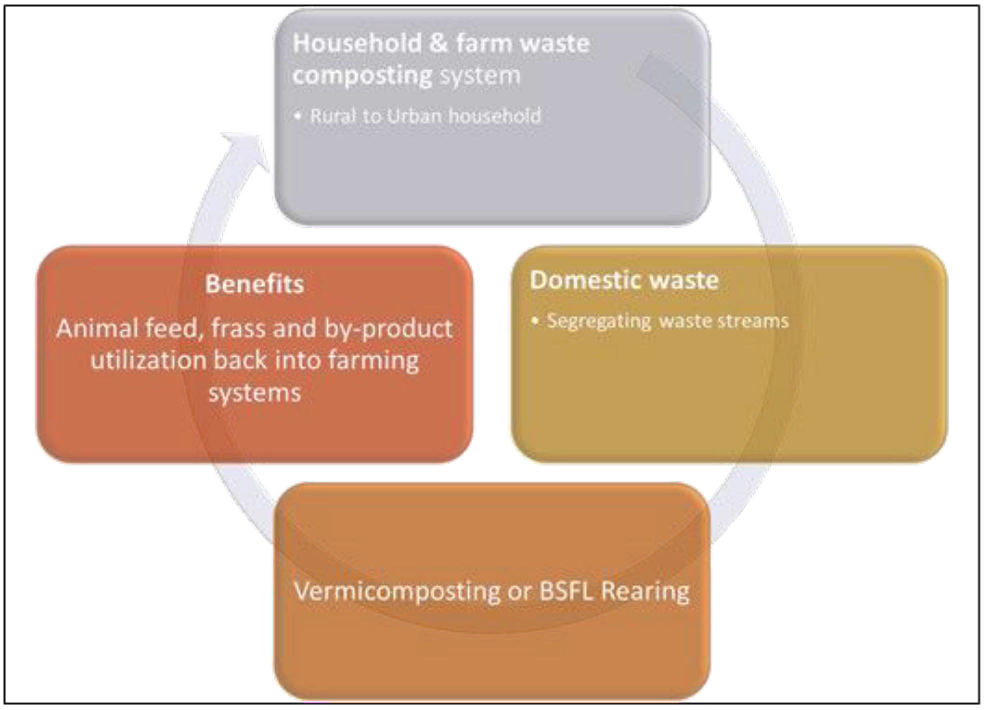

Fig 3: Suitable household composting system concept with BSFL rearing for managing MSW [7].

5. Conclusion

The application of the black soldier fly as a recycling technology in converting biowaste into useful products is undeniable. BSFL can be an easily sourced protein source as feed for fish, chickens or pigs and addresses some of the nutritional aspects of livestock rearing while adding value to food gardens by use of frass for smallholder farmers. It is environmentally friendly and has a diverse versatility for waste streams demonstrating its novelty and appealing potential for recycling organic wastes to BSFL for smallholder farms or households producing poultry or fish as a supplementary feed.

Acknowledgement

Supported by Papua New Guinea National Agriculture Research Institute (PNG NARI) with funding from the Public Investment Programme (PIP) Livestock Research & Development Project ID: U10014 - Phase 2.

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