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Bioconversion of Fermented Kitchen Waste or Sweet Potato Roots by Black Soldier Fly (*Hermetia illucens*) Larvae in an Open Shed Environment

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ABSTRACT

This study examined the utilization by Black Soldier Fly (BSF) for recycling organic waste into larvae as a protein rich feed for fish and chicken farmers. Research on the black soldier fly larvae (BSFL) for waste management has gained worldwide interest, however information is needed on its practical application at smallholder level. Bioconversion units referred to as "bio-digesters" were designed to incubate, hatch, feed and harvest BSFL into its last instar life cycle. Six bio-digester units were placed in a randomized block design in an open-shed environment allowing free access for natural repopulation by BSF. A 45-day life cycle was allowed for three sampling periods for collection of BSFL and evaluation of bioconversion of fermented household kitchen waste (KW) and sweet potato silage (SPS). Average wet weight of 50.71±0.12 kg SPS and KW media was seeded at the start of each period with 215±0.12 g of 10 - 14-dayold BSFL. Mean harvested weight was 379.3 and 100.6 g for KW and SPS respectively ($p<0.001$) from yields of 22.6 and 14.5 g per day for the two types of waste, respectively ($p<0.001$). Waste reduction was 48% for KW and 35% for SPS ($p<0.05$). However, bioconversion rate was low at 2% for both KW and SPS ($p>0.05$). KW provided better yield than SPS demonstrating a 60% linear-log increase ($p<0.01$). The lower pH within the fermented media was critical in SPS than in KW despite having stable environmental conditions in the medium where mortality was observed in the SPS media at pH 2. Open-shed production of BSFL within bio-digester units demonstrated recycling of almost 50% of fermented kitchen waste into high protein larvae.

Keywords: Black Soldier Fly Larvae, Bioconversion, Kitchen Waste, Sweetpotato

INTRODUCTION

Biological conversion of organic waste using larvae of the Black Soldier Fly, *Hermetia illucens* L. (Diptera: Stratiomyidae), as a nutrient recycling technology has the potential for large scale generation of animal feed and even bio-fuel (Surendra *et al.*, 2016). This makes rearing of Black Soldier Fly (BSF) a highly promising technology for smallholder farmers producing the larvae as an animal protein feed source, at low investment costs, by recycling of abundant organic waste (Diener *et al.*, 2011a).

The feed product of interest is the last instar stage (pre-pupae) of the BSF larvae (BSFL). The pre-pupae larvae generate up to 42% crude protein and 30% fat from bioconversion of organic wastes (Sheppard et al., 1994). There is extensive research into the nutritional value of BSFL and its feeding value to pigs, chickens and fish (Bondari and Sheppard, 1981; Newton et al., 2014). However, few studies have been conducted for examining food scraps, household wastes or fecal sludge (or piggery and poultry slurry) in developing countries (Diener *et al.*, 2011b; Supriyatna et al., 2016) where recycling organic waste into animal feeds may have greater utility at farm level.

Although Black Soldier flies are found naturally in tropical countries, there is little research evidence on the use of BSF larvae as a feed resource in Pacific island countries such as Papua New Guinea (PNG). In PNG the use of insects as animal feed has had limited practical or research emphasis, although studies have been conducted on earthworms (*Lumbricus terrestris*) as a protein source for village pigs (Rose, 1981) and tilapia (Gebo, 2009) and the African giant snail (*Achatina fulica*) as a protein supplement for egg production in Shaver Brown layer birds (Diarra *et al.*, 2015).

Studies using BSFL on cassava pilings conducted in Indonesia and municipal waste in Costa Rica support its potential application to agricultural based economies in the tropics (Diener *et al.*, 2011b; Supriyatna *et al.*, 2016). In those reports the means of utilizing the migratory behaviour of the BSFL when rearing for mass harvesting was unclear. Nevertheless, Diener *et al.*, (2011b) successfully produced over 252 g of pre-pupae per day from municipal organic wastes, demonstrating a potential yield of up to 92 metric ton per year, which would provide 38 metric ton of animal protein (DM basis). With a high abundance of organic waste produced from households, village gardens, on smallholder farms, vegetable markets, agro-industries, on-shore fishery and pig and poultry processing plants in PNG; the utility of BSF larvae as a bio-converted feed resource could prove environmentally justifiable and economically valuable when grain feeds for animals are increasingly costly.

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The objective of this study was to examine the bioconversion rates of stored fermented kitchen waste and sweet potato silage into BSFL (pre-pupae). Ensiled sweetpotato (*Ipomoea batatas*) prepared for animal feed was observed to host natural infestation of BSF in research station environments, whereas discarded kitchen waste naturally hosts a multitude of insect life. The study was designed to test which organic material was better for faster larval growth and development, and higher biomass output.

MATERIALS AND METHODS

Study location

The research was conducted at the National Agriculture Research Institute (NARI) Livestock Research Station in Lae Morobe Province, approximately 16 m above sea level at Latitude 06° 41' south and Longitude 146°04' east. The area experiences an average annual rainfall of 2,000 - 2,400 mm, and daily temperature range between 27 - 30°C and relative humidity of 70 - 80% (NARI Bubia Station weather data).

Population of Black Soldier Fly

BSF populations were maintained near the Labu Station Pig Trial Shed reared on waste feed and pig manure from which initial larvae were sourced (Figure 1). In the experimental set-up SPS was used to initiate a new colony at a separate location. A sample population was seeded and maintained in four large buckets (48 L) to which naturally occurring BSFL were also expected to be lured by the relatively strong odor of SPS, in particular attracting ovipositing females (Tomberlin and Sheppard, 2002a). The experiment BSFL seed populations were bred in a fly-proof enclosure. Clutches of BSFL eggs were collected using stripped cardboard boxes with 20.0 × 1.0 cm flute opening (Tomberlin and Sheppard, 2002a). An estimated 100 - 300 egg per clutch was randomly collected and hatched in pantry dishes (50 mm) at room temperatures of 27 - 34°C. Eggs hatched within two to four days were placed into SPS buckets prepared to grow colonies and collection of larvae for the experiment. An average of 215 g larvae (i.e. approximately 900 - 1000 larvae) aged between 10 - 14 days was used as seeded stock for implanting into SPS and KW growth media in six bio-digesters.

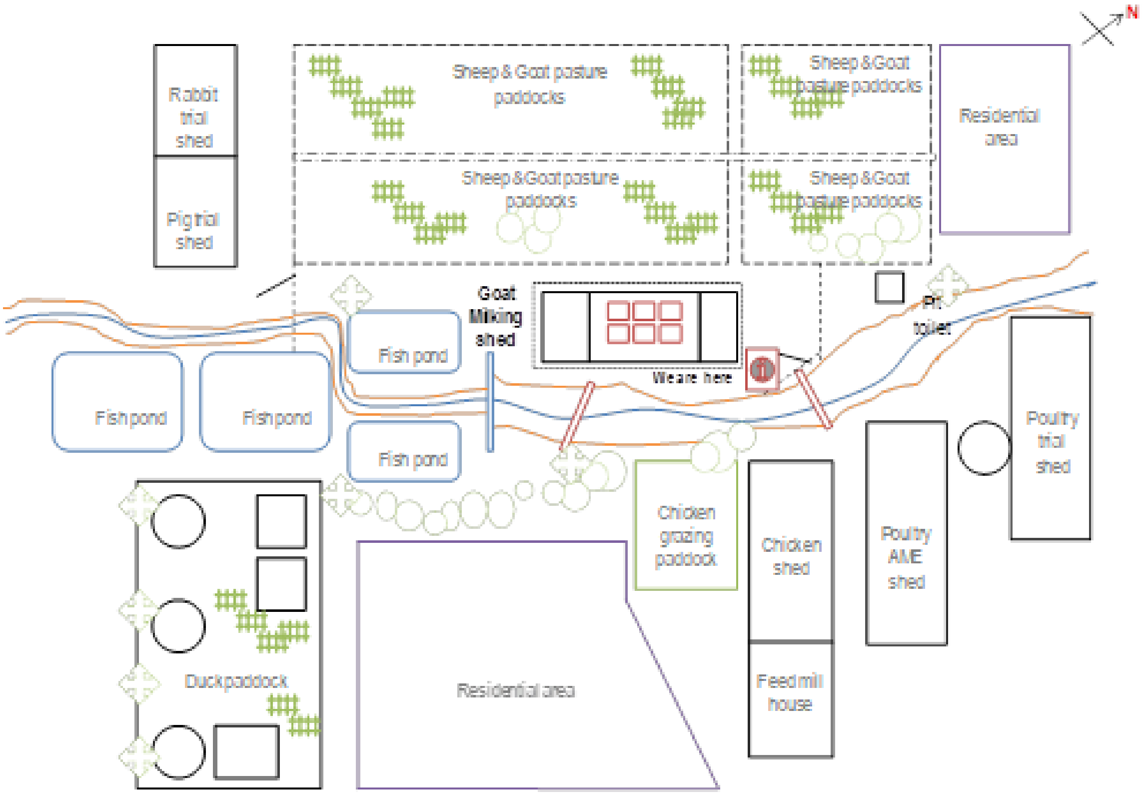

Figure 1: Experiment shed location within the vicinity of sheep and goat paddocks, with a natural stream flowing past and about 60m from the Labu Pig Trial Shed where BSFL infestation was originally detected

Bio-digester units & experimental setup

BSFL bioconversion was conducted inside of units made from zincalume trapezoid-shaped containers (60 cm x 50 cm x 25 cm) inserted into wooden frames with lids affixed and referred to as "bio-digesters" (Figure 2). Six bio-digesters were made incorporating a feeding chamber for feeding larvae and harvesting box for evacuating the wet feed matrix. Exiting ramps at a 29°angle from the base of the containers to the upper end of each short-sided panel was cut to allow larvae to migrate out of the wet growth medium environments. Guide rails riveted at a 105° to the top edge angling toward the exit points facilitated larvae crawl-off. Buckets were placed at the bottom of the exit for collecting the migrating pre-pupae. Six bio-digesters were placed in two rows, two meters apart from each other. The bio-digester set-up was located in an open-walled shed exposed to natural surroundings in order to encourage natural repopulation by BSF.

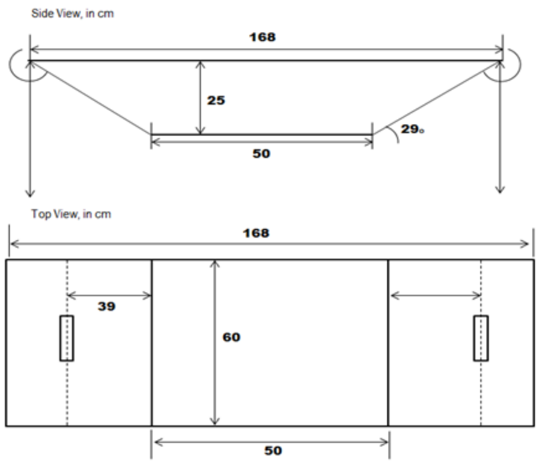

Figure 2: Dimensions of the prototype was modified for rearing black soldier fly larvae from a shared video link: https://www.youtube.com/watch?v=ycl3B6-y73I

Growth media

Sweet potato silage was chosen as a growth medium since infestations of BSFL of the stored feed was apparent at Labu Station Piggery. SPS was the "control" growth medium (homogenous) for comparison with kitchen waste KW growth medium (heterogeneous). Growth media were fermented using a modified ensiling procedure (Dom, 2007). Sweetpotato was grated using a manual chipper and, after addition of 1% table salt (w/w), compacted inside air-tight polythene garbage bags placed in buckets, fermented for over two weeks for storage and use thereafter. A total of 455 kg sweet potato was prepared and stored in buckets.

KW was collected over several weeks from the station resident households in garbage bins lined with air-tight polythene bags. The content of each waste batch was sorted for removing inedible and inorganic material such as bone and plastic. Bulk waste was cut into suitable pieces for packing, storage and preservation by the same ensiling technique. An average of 13.2 kg waste was processed at any one time depending on the waste output collected. A total of 467 kg KW was collected from five different households. The fermented material was mixed thoroughly using a shovel to increase O2 supply before placing in the bio-digesters. Each bio-digester received 50.71±0.12 kg wet weight of SPS and KW over three periods. The available amount of food according to a volume area was 0.05 m3 (i.e. bio-digester volume 0.1635 m3; depth of 25 cm). Supply of growth media from either KW or SPS at each period was estimated as sufficient for the initial 215 g seeded BSFL. Leachate (i.e. organic alcohols) from the ensiled SPS or KW was removed where pH value was measured below 2 - 3 in order to allow the media to stabilize (Alattar, 2012).

Chemical nutrient analysis

Chemical proximate analysis was conducted at the National Analytical and Testing Services Laboratory Ltd (Lae, PNG) using AOAC Official Methods (2012). Samples of growth media and collected larvae was oven dried for 72 hrs at 65°C for nutrient analysis of at least 1.0 kg and 0.2 kg media and BSFL in two batches, respectively. Dry matter (DM) calculated after determining moisture (AOAC 930.15), crude protein by Total Kjeldahl Nitrogen (AOAC 954.0), total fat content (AOAC 920.39), crude fiber (AOAC 978.10), and ash (AOAC 942.06). Calcium (AOAC 927.02) and phosphorus, determined as total P (AOAC 964.06), by spectrophotometry. Organic matter (OM) was calculated by OM% = DM% – Ash%. Energy in the dry media and larvae was assessed by bomb calorimetry.

Measured parameters and equipment

Larvae collections were counted and weighed (1.00±0.01) using a Constant© gram scale (Model: F2-14192). Media moisture was determined daily using a handheld electronic meter (Delta-T Model: HH2). Environmental conditions within the growth media include daily air and media temperatures (°C), relative humidity (%) and pH, using a dual electronic meter (Cyber scan: Model: U10). A handheld humidity meter (Deli Model: 9013) was placed inside each bio-digesters.

Data collection metrics

Bioconversion was calculated as the amount of dry matter food consumed and the amount of larvae harvested. The following calculated individual larvae weight, waste reduction and bioconversion rate as a percentage. The variables are as described by Zhou et al. (2013);

a) Larvae weight is the actual weight (g) of the live larvae after feeding

b) Waste reduction is the percentage of off-take on dry matter basis calculated as,

$$Waste\ reduction\ (\%) = \frac{(Start\ dry\ matter\ weight\ -\ End\ dry\ matter\ weight)}{Start\ dry\ matter\ weight} \times 100$$

1. c) Bioconversion rate is the amount of dry matter off-take converted to larvae expressed as a percentage and calculated as,

$$\text{Bioconversion Rate (\%)} = \frac{Larvae\ weight}{Amount\ of\ dry\ matter\ off-take} \times 100$$

Statistical analysis

Growth media environment and BSFL harvest parameters were measured daily and all data was log transformed to meet Normality (Shapiro-Wilk's test) and Homogeneity (Levene's test) assumptions for the analysis of variance (ANOVA). Simple linear regression of the log10 daily collection count was used to assess mean BSFL harvest over time. A repeated measures ANOVA using GenStat17th Edition statistical software® package (VSNi, 2014) tested the treatment parameters for triplicate samples made over three separate periods. Tukey's Honest Significant Difference (HSD) test was used for separation of the treatment means at 95% confidence level.

RESULTS

Growth media and bio-digester environment

In Table 1, KW medium was higher in dry matter (DM), organic matter (OM) and all DM nutrients compared to SPS. Analyzed samples of BSFL grown in KW were higher in DM, OM, fats and ash, whereas crude protein and fiber was about the same as for larvae grown in SPS. Interestingly the pH values of SPS-larvae were slightly acidic (pH 5.8) whereas KW-larvae were alkaline (pH 8.9). Table 2 shows the means of relative humidity and temperature measured in the bio-digesters and the pH in the growth media during the experiment. While environmental temperature and humidity were stable there were significant differences in media pH ($p<0.01$) between higher moisture SPS (64.3%) and lower moisture KW (18.3%).

Table 1: Chemical nutrient composition, pH and energy in kitchen waste (KW) and sweetpotato silage (SPS) growth media and reared black soldier fly larvae

Nutrients*	**Growth media and reared larvae**			
(%DM)	**KW**	**SPS**	**KW-larvae**	**SPS-larvae**
Moisture	18.3	64.3	15.8	27.0
Dry matter	81.7	35.7	84.2	73.0
Organic matter	64.8	32.7	68.2	62.1
Crude protein	9.9	2.9	34.1	34.1
Total fats	15.0	1.9	30.4	25.8
Crude fiber	5.2	1.0	8.8	8.3
Ash	16.9	3.0	16.0	10.9
Calcium	1.8	1.0	3.9	3.0
Phosphorus	0.03	<0.01	0.1	0.5
pH value	4.6	3.9	8.9	5.8
Energy (MJ/kg)	16.01	15.35	23.36	23.43

*Source: Approximate chemical analysis from food samples and larvae from the national analytical testing services laboratory (NATSL), University of Technology, PNG.

Table 1: Mean temperature, humidity inside six bio-digesters and pH in KW and SPS growth media measured over three 45-day experimental periods

Environmental conditions	**Grand mean**	**Treatment means (Log_{10})**		**sem**	***Significance***	**cv%**
		KW	**SPS**			
Temperature (^{0}C)	30.78	31.58 (1.70)	29.97(1.69)	0.48	ns	1.9
Relative humidity (%)	68.73	68.97 (1.84)	68.48 (1.84)	1.58	ns	2.2
pH value	4.81	5.30 (1.84)[a]	4.33 (1.84)[b]	0.18	**	8.2

Within-row means bearing different superscripts differ significantly ($p<0.05$*; $p<0.01$**; $p<0.001$***; sem = standard error of means; ns = not significant); cv = coefficient of variation, KW = kitchen waste, SPS = sweetpotato silage

Larvae output

Total and daily counts and weights of BSFL larvae harvested from the two growth media are shown in Table 3. KW was much more productive in the total and daily larvae output however the mean larvae weight was similar to SPS (p<0.05).

Table 2: BSFL counts and weights from KW and SPS media over three 45-day experimental periods

Larval growth	Grand mean	Treatment means (Log_{10}) KW	Treatment means (Log_{10}) SPS	sem	*Significance*	cv%
Total count	1103.5	1808.44 (2.84)[a]	398.56 (2.25)[b]	316.1	**	34.2
Daily count	82.83	107.99 (1.72)[a]	57.68 (1.42)[b]	23.46	*	39.4
Total weight (g)	240.11	379.26 (2.12)[a]	100.59 (1.62)[b]	65.51	**	47.3
Daily weight (g)	18.59	22.66 (1.07)[a]	14.52 (0.85)[b]	5.21	*	60.3
Larvae weight (g)	0.20	0.19 (0.07)	0.22 (0.08)	0.01	ns	24.9

Within-row means bearing different superscripts (a, b) differ significantly = p< 0.05*; p< 0.01**; p< 0.001***; sem = standard error of means; ns = not significant; cv = coefficient of variation, KW = kitchen waste, SPS = sweet potato silage

Figure 3 (a) SPS and (b) KW, display the highly erratic daily output of collected larvae, for which the data were consequently transformed to log10 for linear comparison. The linear increase of collected larvae was stronger for KW (R2 = 60%) than SPS (R2 = 12%). Daily larvae crawl off increased from bio-digesters containing kitchen waste (p<0.01) and SPS (p<0.021). The first crawl off of BSFL within 7 days was most likely endemic population and not the seeded larvae which were still immature. Major larvae crawl off started at 11 - 16 days and most likely included seed population which by this time would have been at the 5th instar stage. After day 21 the mean larvae output was markedly higher although still erratic until day 45.

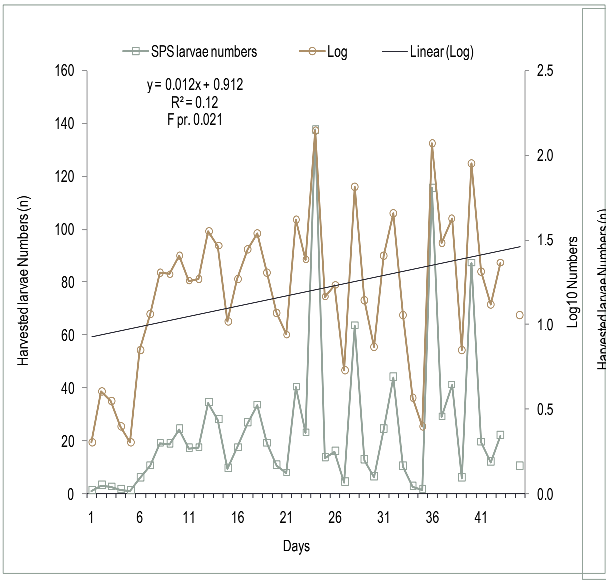

Figure 1 (a): Mean of the daily BSFL output from sweetpotato silage (SPS) calculated as Log10 for estimating the linear increase

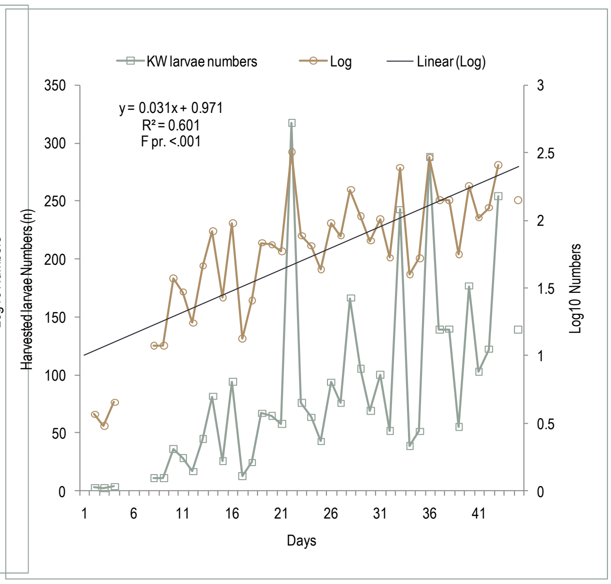

Figure 3 (b): Mean of the daily BSFL output from kitchen wastes (KW) calculated as Log10 for estimating the linear increase

Figure 4 displays the total weight of BSFL output from the two growth media during three experimental periods. KW produced more larvae than SPS (p<0.005) during two out of three experimental periods (p<0.001). In the last period there was a catastrophic fall in larvae output from both KW and SP silage.

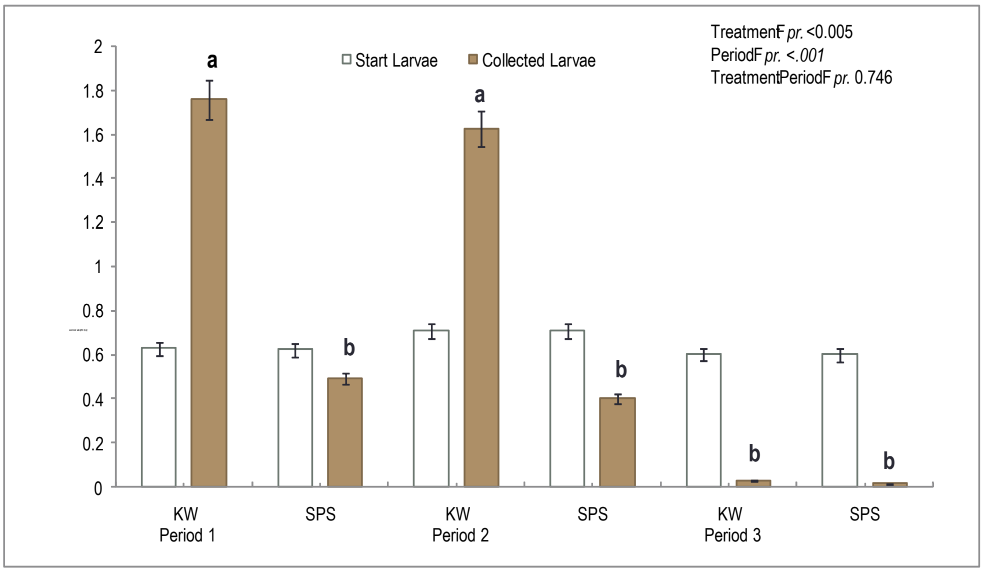

Figure 2: Mean total weight of BSFL output from fermented kitchen waste (KW) and sweetpotato silage (SPS) during three experimental periods

Waste reduction and bioconversion rates

The summary of parameter means used to calculate the percentage organic waste reduction are shown in Table 4 while the estimated bioconversion by using the BSFL output total weight are on Table 3. The bulk weight of fermented KW and SPS growth media were similar however the dry matter feed available to BSFL was much higher in KW ($p<0.01$). Therefore, with a significantly higher population of BSFL in KW media (Table 3) the estimated rate of waste reduction was consequently much greater than from SPS ($p<0.01$). However, the estimated bioconversion rates from larvae output was 2% for both KW and SPS ($p>0.05$).

Table 3: Growth media parameters, estimated organic waste reduction and bioconversion rates for black soldier fly larvae feeding on KW and SPS

Growth media parameters	**Grand mean**	**Treatment means (Log10)** KW	SPS	**sem**	***Significance***	**cv%**
Total media (kg)	50.71	50.76 (1.71)	50.67 (1.71)	0.12	ns	0.25
Moisture (kg)	20.94	9.29 (1.01)^{a}	32.58 (1.52)^{b}	2.83	**	20.8
Dry matter (kg)	29.78	41.47 (1.62)^{a}	18.09 (1.28)^{b}	2.84	**	12.2
Dry matter refusal (kg)	16.39	21.18 (1.33)^{a}	11.6 (1.08)^{b}	1.58	**	13.83
Dry matter off-take (kg)	13.39	20.29 (1.31)^{a}	6.49 (0.83)^{b}	1.98	**	28.43
Waste reduction (%)	42.41	48.98 (1.69)^{a}	35.83 (1.51)^{b}	3.86	*	14.4
Bioconversion rate (%)	2.51	2.09 (0.40)	2.93 (0.42)	0.78	ns	84.95

Within-row means bearing different superscripts differ significantly ($p<0.05$*; $p<0.01$**; $p<0.001$***; sem = standard error of means; ns = not significant; cv% = coefficient of variation; KW = kitchen waste, SPS = sweetpotato silage.

DISCUSSION

This study is the first in the Pacific region reporting on the small-scale production of black soldier fly larvae using bio-digester units for converting organic waste into high protein feed resource for smallholder farming of inland fish and village chicken. While the larvae output from the tested sweetpotato silage and kitchen waste media was disappointingly low, the lessons learned provided valuable insights for further modification of the BSFL bio-digester technology. Moreover, the reduction of close to 50% of household kitchen waste indicates a high potential for recycling of organic matter with the resulting residues being very suitable as organic mulch material. Many factors influenced the culturing of black soldier fly populations and maintaining viable larvae output, and the parameters studied here only focused on providing suitable environmental conditions within operational limitations not too different from the smallholder farming context.

Bio-digester environment and growth media

Relative humidity within the six bio-digester units was slightly below the minimum requirement of 70% for BSFL development (Chia *et al.*, 2018a). Moisture levels in the growth mediums were within the 40 - 80% levels appropriate for effective rearing of dipterans (Tomberlin and Sheppard, 2002b). Low bioconversion rates have been attributed to lower atmospheric humidity causing water loss during post feeding and emerging pupae (Holmes, 2010). Lower humidity is known to cause dehydration in larvae with adverse effects on pupae development (Holmes *et al.*, 2012). Humidity in the bio-digesters may have affected larvae survival, prolonged larvae development and eventual crawl-off, and thereby lowered daily collection counts, observably resulting in larvae maturing within the digester cabin. Nevertheless, individual body weights of harvested larvae from either KW or SPS had similar weights (0.16 - 0.22 g) compared to controlled conditions within intensive rearing systems (Tomberlin *et al.*, 2002b; Chia *et al.*, 2018a, b).

A constant temperature of 30°C was favourable for faster egg eclosion and higher survivability of larvae (Chia *et al*., 2018b). It was expected that heat released through microbial decomposition would have raised temperature inside the growth media (Jay, 1998; Alattar, 2012). Dipteran larval masses also generate a lot of heat from their metabolic activity (Brits, 2017). However, it was likely that excess heat and odours were released into the shed environment from the partially open bio-digester units. The external environment was also relatively warm and humid and was not expected to affect the free movement of crawl-off larvae or female BSF when selecting growth media for ovipositing. Fermenting odours attract ovipositing females and temperature influences the development and survivorship of larvae (Tomberlin *et al.*, 2009; Chia *et al.*, 2018b). The open shed environment may have allowed ovipositing female BSF to select external sites other than the bio-digesters and this seems plausible given the available feed sources surrounding the experimental shed (Figure 1).

Fermented KW and ensiled SPS were acidic growth media (pH 4.81±0.77). Surprisingly, the SPS media measured as low as pH 2.0 during the experiment and may have been due to reaction with the zincalume bio-digester walls. Decomposition of fermented media at low acidity results in the accumulation of volatile leachates (Popa and Green, 2012). Decomposition was comparatively slower in low pH bio-digesters but increased gradually after the leachates were drained out. A considerable amount of corrosion was evident in the SPS bio-digesters towards the end of the experiment.

Large masses of dead larvae were observed in SPS media upon discarding decomposed material at the end of each 45-day period. The observed mortalities had a flattened body shape indicating water loss (Holmes, 2010) and this may have been the cause of death. It is considered unlikely that low pH was the cause of larvae death. The corrosive reaction of the zincalume bio-digester and leachates (i.e. organic alcohols) may have created an unsuitable feeding environment within SPS matrix. Conversely, BSFL thrives in substrates as low as pH 1.7 (Alattar, 2012) with the ability to stabilize volatile organic acids (Popa and Green, 2012; Paz *et al*., 2015) and produce heavier larvae weights (Meneguz *et al.*, 2018).

Larval feed off-take

The estimated average larval feed off-take in this study was consistent with findings for municipal and vegetable food waste averaging at a rate of 0.05 g (wet weight) per larvae per day (Diener *et al.*, 2011b; Paz *et al.*, 2015). However, SPS had a lower average consumption which could be explained by the depth and particle size of the feed matrix restricting feeding access. This study used depths of 25 cm for which below 10 cm, feed access to larvae was reduced. Other studies found particle size and depth to be a limiting point for further decomposition by larvae (Sheppard *et al.*, 1994; Brits, 2017). Larvae are known to reach depths more than 25cm with no limitations in O2 supply, moisture and movement (Holmes, 2010; Brits, 2017). Observably with KW, larger particle size assisted in hydrolysis of the organic feed matrix contributing to higher consumption rate than in the compact ensiled SPS. Moreover, it's likely that kitchen waste was the preferred feed matrix, possibly due to the stronger mixture of fermented odours attracting ovipositing females (Tomberlin and Sheppard, 2002a) Although SPS has been observed as a highly productive growth medium for BSFL, in this experiment KW showed evidence of faster development time and higher biomass (Figure 3 & Figure 4).

Larvae output

The daily collection of BSF larvae was highly variable but was expected for the naturally regenerating fly colony (Figure 3). The same is found in most studies where variability of migratory pre-pupae is inconsistent and still remains uncertain (Diener *et al.*, 2011a). The KW bio-digesters generated on average 379g of BSFL compared to

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100g BSFL from SPS. Both KW and SPS groups of bio-digesters had initially been implanted with a total of 645g larvae. KW bio-digesters produced about 1.0 kg of larvae over the first two periods, whereas SPS bio-digesters declined by 0.2 kg of larvae mass over the experiment. Both KW and SPS bio-digesters failed to produce appreciable larvae mass in the third Period (Figure 4). There was a decline in SPS larvae output whereas KW was clearly more productive.

It was suggested that zinc poisoning caused larvae mass decline in the fermented SPS media because of the corrosive reactions on the walls and bottom of the bio-digesters. This may have led to subdued feeding and eventually larvae death. Survival and fitness traits are reduced in terrestrial dipterans such as earthworms (Lumbricus terrestris) found in infected soil (Lev *et al.*, 2010). However, Black Soldier flies are well known for nutrient bioaccumulation for organic and inorganic matter (Brits, 2017). BSFL can withstand a high concentration of zinc (Van-Huis *et al.*, 2013). Nevertheless, evidence shows fecundity in BSFL was reduced by the corrosive process when zinc-coated sheets were used (Diener *et al.*, 2011a). It is advanced that the BSF colony within SPS bio-digesters was reduced by natural die-off and/or migration out of the experiment shed area for the same reasons. As a result the bioconversion rates were low but similar to reports where the depth of medium and abiotic factors influenced bioconversion in open environments (Sheppard *et al.*, 1994; Newton *et al.*, 2005).

CONCLUSION

This experiment was conducted in an open shed environment and showed the practicality and problems of using natural colonizing BSFL as a bio-converter of organic wastes into useful pre-pupae. Bio-digester units with zincalume as storage units were not appropriate for the rotting fermented kitchen waste or sweet potato silage used as larvae growth media. While the growth media were stable environments the black soldier fly was likely to migrate to other feed sources within the farm area. Nevertheless, the application of BSFL as a bio-converter of organic wastes to larvae feed demonstrated the novelty and appealing potential for recycling organic wastes to BSFL for smallholder farms or households producing village chickens and fish.

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