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ORIGINAL RESEARCH

Bioconversion of municipal organic solid waste in to compost using Black Soldier Fly (*Hermetia Illucens)*

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Abstract

Purpose The study assessed the quality of compost produced by the Black Soldier Fly Larvae (BSFL) in terms of the compost nutrient level, microbial activities, and the bioaccumulation of possible heavy metals in the organic solid waste.

Method The study used the pre-experimental study design, one-group pretest-posttest to obtain the data. Five experimental units were used for the study, which include the daily feeding rate for the five different groups of larvae. The experiments were replicated three times. The nutrient level, heavy metal content and presence of microbes were analyzed before and after the decomposition process.

Results The study discovered that the Nitrogen, Phosphorus and Potassium (NPK) content increased in the compost produced. Cross-contamination of Total Coliform from feed to the prepupae were significant while regrowth of Total Coliform in compost were insignificant. After the composting process most heavy metals like Fe had insignificantly increased in the compost.

Conclusion It can be concluded that larval composting enhance the regrowth of pathogens since the process is entirely mesophilic. Bioaccumulation of most heavy metals was minimum, increasing the level of these heavy metals in the compost. The nutrients were extremely high in the compost to the extent that can cause phyto-toxicity. Post-treatment of the compost is needed to make BSFL compost viable for the market.

Keywords Nutrients, Heavy metals, Microbes, Activities, Bioaccumulation

Introduction

Many studies have been conducted on the Black Soldier Fly Larvae (BSFL) composting technology (Lalander et al. 2015; Choi and Hassanzadeh 2019; Quilliam et al. 2020; Beesigamukama et al. 2021), including assessing the quality of BSFL compost and comparing it to compost produced by other composting technologies (Alattar 2012). Cultivating crops in BSFL compost amended soil provides several advantages such as improving the overall crop growth and yield, nutrient uptake, and plants resistance against diseases (Choi and Hassanzadeh 2019; Quilliam et al. 2020). However, Alattar (2012) reported poor performance of BSFL compost in corn cultivation. According to their study, corn plants grown in soil amended with Micro-aerobic Fermentation (MF) technology residues were 109% taller and had 14% more leaves than those grown in traditional aerated compost, whilst corn planted in BSFL compost amended soil were 39% shorter and had 19% fewer leaves. This may mean that the larvae could not break down the nutritional component of the organic feed into available forms that the crop could absorb for maximum growth (Urra et al. 2019), or most of the nutrients were

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absorbed by the larvae of BSF for biomass formation (Suantika et al. 2017; Shumo et al. 2019). It is necessary to allow other microbial organisms to further process the compost to maturity before using the compost as soil conditioner.

Additionally, this suggests that BSFL produced compost can have an imbalanced nutritional composition. Previous studies confirm that the larvae of BSF absorb a significant amount of nutrients like protein from organic feeds for its biomass formation hence reducing the nutritional composition of the compost produced (Rehman et al. 2017). Suantika et al. (2017) reported low levels of nitrogen but high levels of phosphorus and potassium in compost produced by BSFL. The study further explained the utilization of nitrogen by the BSFL for biomass formation. BSFL targets protein and fat components of their feed and whilst accumulating nitrogen to build biomass, phosphorus and potassium are excreted (Oonincx et al. 2015).

Besides, the BSFL has high waste reduction efficiency between 65 – 79% (Diener et al. 2011) and can reduce mass and concentration of most elements, including heavy metals by 50% – 60% (Newton et al. 2005; Attiogbe et al. 2019) and produce high abundance and diversity of microbial decomposers (Vogel et al. 2018). The gradual accumulation of heavy metals in the biomass of the larvae of BSF during the bioconversion process produces compost with low levels of heavy metals (Biancarosa et al. 2018). Numerous pathogenic microorganisms invade the waste stream with a tendency of regrowth in the compost (der Fels-Klerx et al. 2018). However, pathogens are eliminated during the thermophilic phase in the first three days of composting, but BSFL composting are mainly mesophilic (Piceno et al. 2017). Some studies have reported significant destruction of bacteria in the digestive tract of larval insects resulting in the production of faeces with sterile or minimal number of bacteria (Mumcuoglu et al. 2001)

It is presumed that antibacterial substances might be present in larvae of BSF, which can reduce pathogens even in its mesophilic composting. The compost is expected to enter the world market as a soil conditioner or fertilizer for crop production and free from pathogenic microorganisms. The study investigates the bioconversion of BSFLinto compost using Municipal Organic Solid Waste (MOSW) as decomposition substrate. It tested the following hypothesis;

- BSFL composting does not affect the nutritional composition of compost produced
- BSFL composting does not affect the bioaccumulation of heavy metal and microbial activities.

Materials and methods

Experimental design

The study used the pre-experimental study design, one-group pretest-posttest to obtain the data. The data obtained were nutritional composition, heavy metal and microbial content analyzed in the organic feeds and the compost. The data obtained before the decomposition process (organic feeds) were compared with those obtained after the decomposition process (compost).

Schematic diagram for the study

Fig. 1 is a schematic diagram for the study, which shows neonate larvae of BSF introduced to the five experimental units for the larval decomposition process.

Fig. 2 is depicting some pictures of the experimental study which shows the neonate larvae of BSF introduced into the dried and milled MOSW for the decomposition process.

The analysis was carried out under five (5) experimental units (see Table 1).

Laboratory analysis

The organic waste and final compost samples were analyzed for moisture content, ash content, crude proteins, heavy metals and microbial content. Moisture content was determined by drying organic waste and compost samples in an oven at 105 ºC for about 24 hours (Appiah–Effah et al. 2020). After determining the moisture content, the waste and compost samples were put into a muffle furnace at a temperature set at 600 ± 10 ºC to determine the ash content. Kjeldhal method adopted from (Mádlíková et al. 2018) was used to determine the crude protein. Digestion, distillation and titration processes were used to determine the total nitrogen content of the samples (Mádlíková et al. 2018). For percentage crude protein, a conversion factor of 6.25 was used.

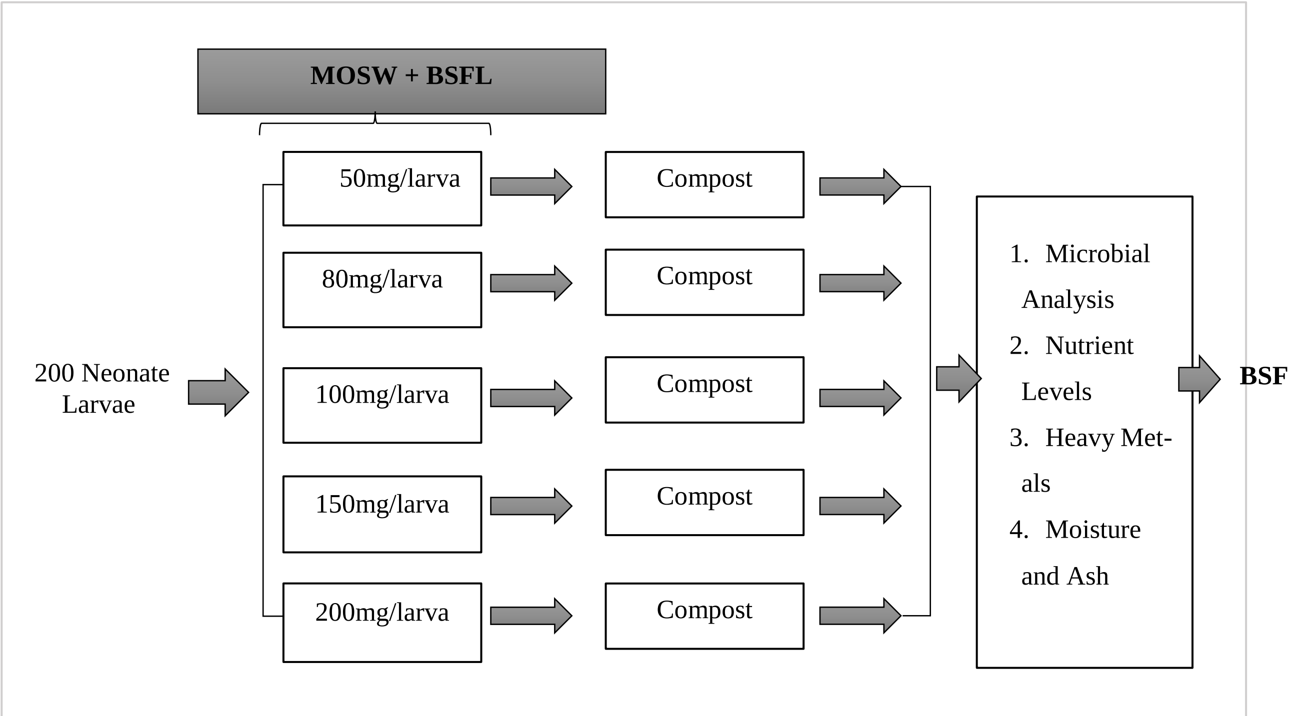

Fig. 1 The schematic diagram of the study

Decanted-5 day old neonate larvae | Municipal organic Solid waste(MOSW) | Larvae decomposing MOSW

Larvae turning into prepupae during decomposing | Most prepupae separating from organic feed as compost is maturing | Larval matured compost

Fig. 2 Some pictures of the experimental design

All reagents used for heavy metal analysis were analytical grade. The heavy metals such as Iron (Fe), Magnesium (Mg), Calcium (Ca) and Aluminium (Al) were measured based on floatation and sedimentation method by (Schwartzbrod et al. 1989). Deionized water, Siemens was used in the preparation of diluted acid. For the preparations of standards for the instrument calibration, the stock solution was serially diluted with 0.1% hydrochloric acid (HCl) to obtain calibration solutions of different concentrations. Analyte – free solution (0.1% HCl) was used as the blank during the instrument calibration. Flame atomic absorption spectroscopy (FAAS) measurements were carried out on Analytikjena model novAA400P atomic absorption spectrophotometer using the single-beam optical mode. Hollow cathode lamp (HCL) for the respective elements were used as light source for the analysis. An air (compressed air) and acetylene (N26 quality, Air Liquide, Ghana) were employed as the oxidant and the fuel gas. This method was adopted and modified by what was reported by Hossain et al., (2021).

Microorganism such as *E.coli*, Enterocci, Mould (fungi), total Coliform and faecal Coliform were analyzed in the samples. Peptone water, selenite brooth, slanetz bartley agar, MacConkey brooth and Potato dextrose agar were prepared according to the instructions from producers. These media were sterilized by autoclaving at 121˚C for 15 minutes. The samples were introduced into the media as reported in the studies by Guo et al. (2021). The MPN table was used to quantify the total Coliform, faecal Coliform and *E.coli*. Peptone water, Selenite brooth and Salmonella shigella agar were used to examine colonial morphology of Salmonella spp.

Table 1 Formulations and compositions of treatments

S/N	Treatments	Type of Feed mg/larva/day	Description mg/larva/day
1	T1	MOSW	50
2	T2	MOSW	80
3	T3	MOSW	100
4	T4	MOSW	150
5	T5	MOSW	200

Statistical analysis

The IBM Statistical Package for the Social Sciences (SPSS) version 25 was used to generate descriptive statistics. Analysis of variance (ANOVA) with a 95% confidence interval was performed to identify the significant differences between treatments. When means differ significantly, the Tukey post-hoc test with 95% confidence interval was performed. The significant difference in crude protein and crude fat observed in organic feed, BSFL, compost, and prepupae were determined using a paired-sample test. Graphical illustrations were carried out using the software GraphPad Prism 7.04.

Results and discussion

Ash and moisture content analysis of BSFL composting

The moisture and ash content increased in the compost produced in all 5 experimental unit as compared to the MOSW. The increase in moisture content were only significant in the third unit

Moisture content and ash content of BSFL compost

The average moisture content recorded for the MOSW was 11.06% (Fig. 3A). The compost produced by BSFL fed with 50mg/larva daily exhibited the highest moisture content of 41.33% and BSFL fed with 200mg/larva daily recorded the lowest moisture content of 28.33%. (Fig. 3A). The average moisture content recorded for the MOSW used for the larval decomposition process was observed to be low as compared to the moisture content reported in other studies. Many studies have reported high moisture content in municipal solid waste prior to composting. (Ayeleru et al. 2016)., for instance, reported a range of 62.5 – 65.78% and another reported 65.29% for food waste collected from a university dining center and 70.81% for food waste collected from a service area for two military facilities (Ferreira et al. 2018). According to some studies, moisture content reduced to less than 40% because of microbial activities are reduced (Moqsud et al. 2011).Then again, Moqsud et al. (2011) further explained that moisture content above 60% displaces air in compost heap hence reducing oxygen concentration leading to anaerobic condition. However, anaerobic bacterial activities produce methane and generate odor. From the previous studies, it can be deduced that the MOSW having a moisture content of about 11.06%, may have minimized microbial activites so that larval decomposition is maximized. It can be observed from Fig. 3A that compost produced by BSFL fed with 200mg/larva/day will not support further decomposition since its moisture content were observed to be less than 40%, while compost produced by BSFL fed with 50mg/larva daily would require post treatment like curing to become stabilized and mature, since moisture content were above the 40%.

The range of ash content in the compost was 10.3–14.89% (Fig. 3B). There were significant increase in the ash content of the MOSW to the compost stage in all the experimental units. The highest ash content (14.89% ± 3.12) was recorded in compost produced by BSFL fed with 200mg/larva/day while the least (10.34% ± 2.58) were recorded in compost produced by BSFL fed with 50mg/larva/day (Fig. 3B).

The ash content recorded in the compost produced in the study were higher than that reported by (Becher et al. 2018) in humic acid (0.97% and 1.31%) but far lower than that reported by (Ogundare and Lajide 2013) in chemical fertilizer, NPK (47.58% ± 0.52). Lower ash content means higher organic matter content. BSFL composting increased the organic content of the compost produced in all experimental unit. However, compost produced by BSFL fed with 50 mg/larval daily had the highest organic matter content. This is an indication that the larval compost has the ability of exhibiting high water holding capacity, aggregate stability, cation exchange capacity and so on (Mohidin et al. 2015).

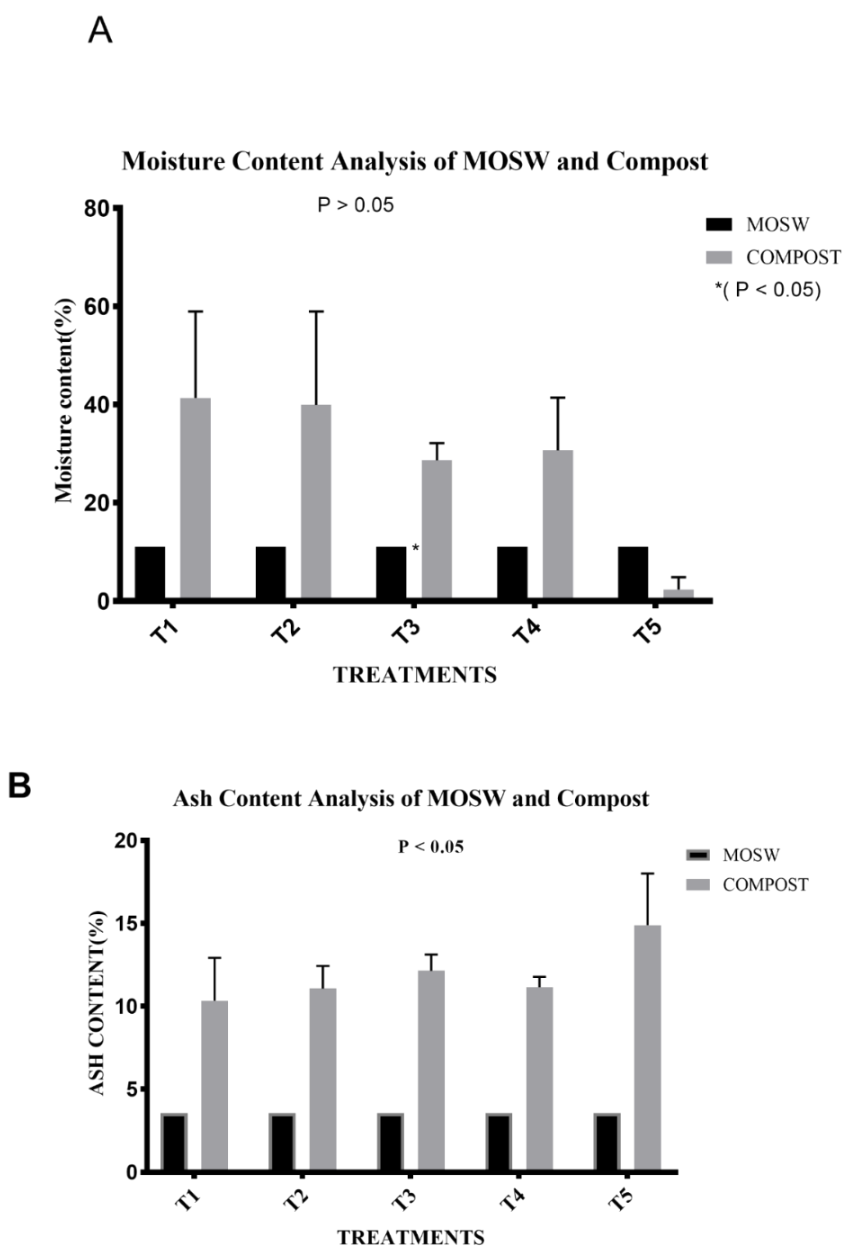

Fig. 3 Ash and moisture content analysis of MOSW and compost

Graph bar with * have p<0.05; Mean (3) ± standard deviation. Mean measured in %.

Treatments (T1) 50mg/larvae, (T2) 80mg/larvae, (T3) 100mg/larvae, (T4) 150mg/larvae and (T5) 200mg/larvae.

Nutritional composition of BSFL compost

Table 2 presents the nutritional composition of BSFL compost. It is observed that Nitrogen content of the compost increased with increasing daily feeding rate. One way ANOVA determined no significant difference (p= 0.108, F= 2.516) between experiment units. The highest amount of Nitrogen was observed in compost produced by BSFL fed with 200mg/larva daily (80.99 mg/g ± 10.17 mg/g) while the lowest content was observed by BSFL fed with 50mg/larva daily (52.69 ± 75.39 mg/g) (Table 2). The phosphorus content of the compost produced by the BSFL ranged between 55.14 ± 5.8 mg/g to 75.40 ± 31.47 mg/g (Table 2). The BSFL fed with 200 mg/larva daily (T5) produced the compost with highest phosphorus content of 75.40 ± 31.47 mg/g while BSFL fed with 150 mg/larva daily (T4) recorded the lowest phosphate content of 55.14±5.8 mg/g (Table 2). The range of potassium content of compost produced by BSFL is 1.45±0.07 mg/g and 3.08±2.11 mg/g (Table 2). Compost produced by BSFL fed with 50 mg/larva daily exhibited the highest potassium content and compost produced by BSFL fed with 150 mg/larva daily exhibited the lowest potassium content. The carbon content of the compost range from 64.43±1.22 mg/g to 68.86±3.52 mg/g (Table 2). It was observed that the C:N ratio ranges from 6:1 to 10:1 with compost produced by BSFL fed with 200 mg/larvae daily exhibiting the lowest C:N ratio of 6:1 while compost produced by BSFL fed with 50 mg/larva daily exhibiting the highest ratio of 10:1 (Table 2). The C:N ratio decreased with increasing feeding rate though not gradual. According to Mohidin et al. (2015), 0.1 mg/g of nitrogen gives a significant yield while higher level of nitrogen produced toxicity and retard plant growth. Clearly, the amount of nitrogen content in the compost produced by BSFL are greater than what was reported. It is an indication that for every 1 g of fertilizer, 0.1 mg of nitrogen is needed for significant yield but every 1 g of BSFL compost contains an average range of 53 mg–81 mg of nitrogen. Although BSF larvae target nitrogen in their feeds for biomass formation, the N-content of BSFL compost are observed to beextremely high (Beesigamukama et al. 2021). But if the BSFL composts are not well distributed in soil, then it may cause plant to look lavish and green, they may reduce greatly the ability of the plants to fruit and flower, and these plants may also experience stunted growth as reported since the Nitrogen content are higher than required for normal plant growth (Mohidin et al. 2015; Quilliam et al. 2020). Application of such compost may require other remedies to reduce the N-content. Some studies suggests the use of plants such as cabbage, broccoli, corn as sponges but not food purposes. These plants use up large amount of nitrogen while growing; sawdust could be used as mulch after application of such compost, these sawdust use higher amount of the N as they break down (Rhoades 2021). The P-content observed in BSFL produced compost were extremely higher than that reported by the Fertilizer Association of Ireland (Li et al. 2011). Every 0.1 mg/g of fertilizer applied to the soil increases the P-content by 40% more (8.1 mg/L), which is still far less than what was observed in the compost produced by the BSFL. Many studies reported a range of 0.0003 mg/g to 0.0005 mg/g of Phosphorus per hectare per day during rapid growth phase of plants (Syers et al. 2008; Wan Ngah et al. 2011). However, every 1g of BSFL compost contains an average of 55 mg to 75 mg of phosphorus, which are higher than the recommended amount per hectare per day for rapid growth of plants (Lalander et al. 2015; Beesigamukama et al. 2021). Excess P-content may reduce plants ability to take up required micronutrients, poor plant growth or death in plants. The excess P-content can be controlled by the amount of the compost needed to be applied per hectare to reduce its level to a desirable amount. Studies have reported a range of 0.16 mg/g to 0.2 mg/g as optimal soil potassium for rapid alfalfa growth (Diener et al. 2011; Hunter et al. 2012). Low levels of K-content in the compost could be as a result of bioaccumulation of K by the BSFL or K- content of organic feed used. Every 1g of BSFL compost is observed to contain 1.45mg - 3.08mg of K (Table 2), though upper range is a little higher, it can be concluded to be in required range. However, comparing the results with that of Zhang et al. 2014 soil organic carbon of 9.4 mg/g in crop land and 6.2 mg/gin native land it is realized that the carbon content of the compost produced by BSFL for the current study is higher than what has been reported in previous studies. The high carbon content of the BSFL compost may have been as a result of high carbon content of the MOSW. The BSFL treatment process was able to maintain the high carbon content, resulting in the production of carbon rich compost. This implies that the BSFL compost will ensure a good soil structure, retain soil water and supply nutrients plants need while serving as a source of feed for soil vital organisms (Zhang et al. 2014; Quilliam et al. 2020; Menino et al. 2021). Several studies have reported enhanced overall crop growth and yield, Nitrogen use efficiency, and disease suppression in different plants grown using compost produced by BSFL (Choi and Hassanzadeh 2019; Beesigamukama et al. 2020).

Table 2 Nutritional composition of BSFL compost

Treatment	Nitrogen (mg/g)	Phosphorus (mg/g)	Potassium (mg/g)	Calcium (mg/g)	C/N
T1	52.69 ± 75.39	75.34 ± 19.94	3.08 ± 2.11	531.71 ± 11.72	10:1
T2	59.02 ± 45.62	61.50 ± 13.69	2.11 ± 0.31	531.71 ± 4.42	9:1
T3	68.98 ± 29.51	64.44 ± 17.03	2.25 ± 0.52	509.47 ± 18.87	7:1
T4	71.66 ± 44.11	55.14 ± 5.8	1.45 ± 0.07	541.38 ± 33.87	8:1
T5	80.99 ± 10.17	75.40 ± 31.47	1.69 ± 0.24	506.57 ± 24.66	6:1

The Treatments (T); (T1)50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg /daily, (T4)150 mg/larvae daily and (T5) 200 mg/larvae daily.

Assessment of bioaccumulation of heavy metals in BSFL composting

Fe and Mg in BSFL composting

Table 3 presents the Fe and Mg detected in the organic feed, BSFL, compost and Prepupae. The content of Fe increased insignificantly in compost ($p = 0.298$) but Mg content increased significantly ($p < 0.05$) (Table 3). The results of the study revealed Fe-content ranging from 0.05±0.01 mg/g to 0.63±0.01 mg/g (Table 3). Fe is an essential micronutrient (Rout and Sahoo 2015), and is responsible for the synthesis of chlorophyll, maintenance of chloroplast structure and its function, among other functions, hence its presence in soil fertilizer is of good importance to plant growth. Iron content recorded were low compared to that of Ferreira et al. (2018). Magnesium concentration in compost significantly increased after the composting process ($p < 0.05$). Mg is an essential macronutrients which is the key elements of the chlorophyll molecule in leaves of plants. It is also essential for photosynthesis by giving plants leaves their green character and activates most plant enzymes needed for growth and protein synthesis (Senbayram et al. 2015). In a study where Mg was 0.0244 mg/g to 0.398 mg/g in organic fertilizer, a significant increase was observed in banana biomass and yield. The study further explained the consistent increase in the Mg concentrations in the banana leaves over the period of 2 years. These are observed to be high in the BSFL compost for the study as compared to findings from previous studies (Ferreira et al. 2018).

Table 3 The Fe and Mg detected in the organic feed, BSFL, compost and Prepupae

Iron (mg/g)			Magnesium (mg/g)	
Treatments	**Food Waste**	**Compost**	**Food Waste**	**Compost**
T1	0.13	0.60 ± 0.00	0.67	2.69± 0.17
T2	0.12	0.63 ±0.01	0.67	2.56± 0.39
T3	0.54	0.08± 0.02	0.68	2.09± 0.37
T4	0.03	0.12±0.06	0.68	2.25± 0.44
T5	BDL	0.05± 0.01	0.64	2.53± 0.17

The Treatments (T); (T1) 50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg /daily, (T4) 150 mg/larvae daily and (T5) 200 mg/larvae daily. Paired sample test analysis of Fe; MOSW and Compost ($p=0.298$). Paired sample test analysis of Mg; MOSW and Compost, MOSW and Prepupae, BSFL and compost, BSFL and Prepupae ($p= 0.000$).

Ca and Al in BSFL composting

Table 4 shows the Ca and Al detected in the organic feed, BSFL, compost and Prepupae. The Ca concentration was within the range 0.02 – 0.08 mg/g in the organic feed (Table 4). After the BSFL composting process, using the paired sample analysis, the concentration of the Ca are observed to have significantly increased in the compost. The Ca concentration is observed to be within a mean range of 1.58–2.60 mg/g in the compost (Table 4). The concentration in the compost may be as a result of Calcium excreted in feaces and undigested Calcium in feed. Calcium is a macronutrient which is involved in plants physiological processes such as plant growth and development, cell division, cytoplasmic streaming, photosynthesis and intracellular signaling transduction (Huang et al. 2017). The BSFL composting process is capable of producing significant amount of calcium available for plant utilization. Using the pair sample test analysis, Al concentrations was observed to reduce significantly in compost ($p<0.05$). The level of Al concentration was between the ranges 0.05 mg/g - 0.08 mg/g in the organic feeds (Table 4). The concentration of Al was reduced to a level of 0.03 mg/g - 0.04 mg/g in the compost (Table 4). Ingested Aluminum usually poorly absorbed and cause depressed utilization of some dietary nutrients or their metabolism (Allen 1984). The low levels of aluminum may be as a result of Al may have passed through the gut of the larvae and might be absorbed by digestive microbes leading to low level of Al in the compost.

Table 4 The Ca and Al detected in the organic feed, BSFL, compost and Prepupae

	Calcium (mg/g)		**Aluminum (mg/g)**	
Treatments	**Organic Feed**	**Compost**	**Organic Feed**	**Compost**
T1	0.04	2.17 ± 0.26	0.05	0.026±0.01
T2	0.03	2.60 ± 0.74	0.08	0.03 ± 0.00
T3	0.03	1.58 ± 0.21	0.06	0.04 ± 0.03
T4	0.08	1.96 ± 0.83	0.06	0.04 ± 0.06
T5	0.02	2.26 ± 0.29	0.06	0.04 ± 0.03

The Treatments (T); (T1) 50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg /daily, (T4) 150 mg/larvae daily and (T5) 200 mg/larvae daily. Paired sample test analysis of Al; MOSW and Compost, MOSW and Prepupae, BSFL and compost, BSFL and Prepupae (p= 0.00). Paired sample test analysis of Ca; MOSW and Compost (p=0.00).

Analysis of microorganism in BSFL compost

Total coliform (TC)

Table 5 presents the total coliform count in BSFL composts. The level of TC count in the feed were higher than that of the larvae with a 1-log difference in population. The study observed regrowth of TC in the compost and on the prepupae. Cross-contamination of TC from feed to the prepupae were significant ($p=0.001$, $t=-4.115$, df = 14) while regrowth of TC in compost were insignificant ($p=0.067$, $t= -1.988$, df= 14). Cross-contamination from larvae to compost were also insignificant ($p=0.067$, $t=-1.988$, df = 14) while regrowth of TC from larvae to prepupae was significant ($p=0.001$, $t= -4.11$, df = 14) (Table 5). The highest level of infection is observed in the compost produced by larvae fed with 150 mg/larvae daily (T4) while the least infection is observed with compost produced by larvae fed with 200 mg/larvae daily (T5). The highest regrowth of TC on prepupae is observed with prepupae fed with 200 mg daily while the least regrowth is observed with prepupae fed with 50 mg daily.

Table 5 Total coliform count in BSFL composting process

Treatment	**Organic Feed**	**Compost**	**BSFL**	**Prepupae**
T1	3.87E+12	1.02E+18 ± 1.16E+18	5.22E+11	2.27E+13 ± 1.44E+12
T2	3.87E+12	1.97E+17 ±1.05E+17	5.22E+11	1.03E13 ±1.15E+13
T3	3.87E+12	1.37E+17 ±8.65E+16	5.22E+11	6.67E+12 ± 7.23E+12
T4	3.87E+12	3.93E+18 ±4.64E+18	5.22E+11	4.03E+12 ± 1.10E+12
T5	3.87E+12	1.23E+17 ± 1E+17	5.22E+11	2.78E+13 ±2.06E+13

The Treatments (T); (T1)50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg/daily, (T4) 150 mg/larvae daily and (T5) 200 mg/larvae daily. Measured in Total coliforms/100 mg cfu. Paired sample T-Text; Feed and Compost (p = 0.067), Feed and Prepupae (p =0.001), BSFL and compost (p = 0.067), BSFL and Prepupae (p = 0.001).

Faecal coliform (FC)

Table 6 shows the Faecal Coliform detected in BSFL compost. The highest level of FC count were observed in compost produced by larvae fed with 150 mg/larvae daily whilst the least count observed in that of the larvae fed with 50 mg/larvae daily (Table 6). Regrowth of FC were observed in the compost produced, however, the reactivation was slightly slower at the lower feeding rate but this was not a trend observed down the treatments. Additionally, the results revealed a significant regrowth of FC from feed to compost (p=0.001, t= -4.318, df=14) with a 7- log difference in population. The prepupae exhibited a reduction in FC population in some of the treatments (T2, T3 and T4) but regrowth of FC were observed in prepupae fed with 50mg and 200 mg daily with 1-$\log_{10}$ difference in population while the other treatments show a reductive growth difference of 1-$\log_{10}$. These were non-significant (p= 0.129).

Table 6 Faecal coliform detected in BSFL composting

Treatment	Organic Feed	Compost	BSFL	Prepupae
T1	5.13E+11	9.4333E+15 ± 5.43E+15	1.23E+11	1.5105E+12 ± 2.9E12
T2	5.13E+11	4.7167E+16 ± 3.86E+16	1.23E+11	5.5050E+10 ± 6.31E+10
T3	5.13E+11	2.1883E+16 ± 1.72E+16	1.23E+11	8.0733E+16 ± 6.31E+10
T4	5.13E+11	5.1333E+16 ± 3.63E+16	1.23E+11	5.1333E+10 ± 3.63E+10
T5	5.13E+11	1.1667E+16 ± 1.08E+16	1.23E+11	3.0792E+12 ± 5.26E+12

The Treatments (T); (T1)50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg /daily, (T4)150 mg/larvae daily and (T5) 200 mg/larvae daily. Measured in Faecal coliforms/100 mgcfu. Paired sample text; Feed and Compost (p = 0.001), Feed and Prepupae (p =0.135), BSFL and compost (p = 0.001), BSFL and Prepupae (p = 0.129).

Salmonella population in compost

Analysis for these pathogens were made but were not detected in the feed and on the larvae used for the study. There were also no infection of such pathogens in the compost and prepupae during BSFL composting. (Lalander et al. 2013) observed that BSF treatment had negative influence on the concentration of Salmonella spp in faecal sludge and this may account for the absence of reinfection of the Salmonella spp in the compost.

Total fungal population

Table 7 shows fungal count detected in BSFL compost. The depression of fungal growth were least detected in the compost produced by larvae fed with 80 mg/larvae (T2) daily while compost produced by larvae fed with a daily feed of 200 mg/larvae (T5) had the highest fungal population (Table 7). Depression of growth from feed to compost were significant (p=0.000, t= 299566.520, df =14). Cross contamination of fungi from feed on prepupae were significant (p=0.000, t= 215668.871, df =14) and regrowth of fungi from larvae to prepupae were also significant (p=0.000, t=28028.747, df =14). The highest fungi contamination was observed on prepupae fed daily with 50mg/larvae while the prepupae fed daily with 150 mg /larvae exhibited the least fungi infection (Table 7). It can be deduced that the fungi were inactive in compost of lesser weight but these were not consistent.

Table 7 Fungi count in BSFL compost

Treatment	MOSW	Compost	BSFL	Prepupae
T1	6.78E+11	462248.33 ± 4.4E+4	8.82E+10	201070 ± 1.4E+5
T2	6.78E+11	407382.53 ± 4.6E+4	8.82E+10	109900.83 ± 9E+4
T3	6.78E+11	478940 ± 3.4E+4	8.82E+10	138365 ± 2.02E+5
T4	6.78E+11	536250 ± 1.8E+4	8.82E+10	2758.33 ± 4.15E+2
T5	6.78E+11	630583.33 ± 7.17E+4	8.82E+10	73437.5 ± 5.21E+4

The Treatments (T); (T1) 50 mg/larvae daily, (T2) 80 mg/larvae daily, (T3) 100 mg/daily, (T4) 150 mg/larvae daily and (T5) 200 mg/larvae daily. Measured in Total count/1mg cfu. Paired sample text; Feed and Compost (p = 0.000, t= -28028.747, df= 14), Feed and Prepupae (p =0.000, t= 215668.871, df=14), BSFL and compost (p = 0.000, 38916.956, df=14), BSFL and Prepupae (p = 0.000, t=28028.747, df=14).

Escherichia coli

Table 8 presents population of *Escherichia coli* detected in BSFL compost. E.coli infections were significantly reduced in the compost but cross contamination of prepupae from feed were significantly high (p=0.010, t= 2.965, df =14), however, *E.coli* infections were higher in the feed than on the larvae. Regrowth of *E.coli* from larvae to prepupae were not significant (p= 0.304, t=1.067, df=14). The highest infections were identified with the prepupae fed with 50mg/larvae daily while the least infections were identified with prepupae fed with 150mg/larvae daily (Table 8). It can be deduced that inactivation of *E.coli* was observed in compost and on some prepupae. Findings were similar to Erickson et al. (2004), who reported accelerated inactivation of pathogens (*E. coli*) in the presence of larvae. However, ability of BSFL to reduce *E. coli* population in the feed and compost is dependent on temperature. According to Liu et al. (2008), temperature significantly influenced the ability of BSFL to develop and reduce *E. coli* counts with maximum suppression occurring at 27 °C. It has been recognized that BSFL were able to inactivate pathogens when treating MOSW. Wynants et al. (2019) reported decreased population of pathogens in growing substrate owing to antimicrobial abilities of the BSFL. BSFL amendment could reduce up to 93% of pathogenic microorganism contents in composts (Awasthi et al. 2020)

Table 8 *Escherichia coli* population in BSFL compost

Treatment	MOSW	Compost	BSFL	Prepupae
T1	66125.8	541 ± 5.42E+2	43174.17	74615.33 ± 4.63E+4
T2	66125.8	381.67 ± 394.98	43174.17	51943.17 ± 8.45E+4
T3	66125.8	545.67 ± 260.45	43174.17	8023.33 ±4.84E+3
T4	66125.8	1638.33 ± 772.21	43174.17	5663.33 ± 2.01E+3
T5	66125.8	3438.33 ± 3.84E+3	43174.17	11147.5 ± 1.35E+5

Measured in Total count/1mg cfu. Paired sample text; Feed and Compost (p = 0.000, t= 130.506, df=14), Feed and Prepupae (p =0.010, t=2.965, df=14), BSFL and compost (p = 0.000), BSFL and Prepupae (p = 0.304).

Faecal Enterococci (FE)

Table 9 presents Faecal Enterococci detected in BSFL composting. The study detected a significant depression in growth of FE from feed to compost in some of the higher feeding rate compost (T4) but these were not consistent. The highest infections were observed with compost produced by larvae fed with 50 mg/larvae daily while the least infections were identified with compost produced by larvae fed with 150 mg/larvae daily (Table 9). The level of FE infections of the larvae were detected to be higher than that of the feed. There were non-significant cross contamination from feed to prepupae (p= 0.993, t=0.010, df=14). The study observed a significant depression of FE growth from larvae on prepupae (p= 0.010, t=2.987, df=14) except on prepupae fed with 80 mg/larvae daily which exhibited regrowth of FE. The highest infections were observed with prepupae fed with 80 mg/larvae daily while the least infections were identified with prepupae fed with 200 mg/larvae daily.

Table 9 Faecal Enterococci detected in BSFL composting

Treatment	MOSW	Compost	BSFL	Prepupae
T1	610	2233.33 ± 1715.41	1026.67	520 ± 396.61
T2	610	1893 ± 1163.98	1026.67	1340 ± 730
T3	610	893 ± 435.01	1026.67	390 ± 306.43
T4	610	540 ± 301.16	1026.67	603 ±335.46
T5	610	1166.67 ± 1005.50	1026.67	190 ± 104.40

Measured in Total count/100mg cfu. Paired sample T-text; Feed and Compost (p = 0.022, t=-2.577, df=14), Feed and Prepupae (p =0.993, t=0.010, df=14), BSFL and compost (p = 0.283, t=-1.117, df=14), BSFL and Prepupae (p = 0.010, t=2.987, df=14).

Conclusion

The composts produced using the BSFL as an agent of decomposition were not deficient in nutrients, though the larvae use these nutrients for their biomass formation. The nutrients content were extremely high. The N, P-content of the compost exceeded what was required for plant growth. The K-contents were a little above the requirement. In total, the high level of N and P can impede plant growth and retard plant development if the compost is used as soil conditioner. Despite the challenge of high N and P-content, the larval compost produced contained very high organic matter. The larvae also produced composts which were more stable and support very little microbial activities. As a result of the low moisture content exhibited by most of the compost produced, microbes such as *E.coli*, fungal and Faecal Enterococci infections were depressed. The inactivation of the microbes may also be as a result of larval ability to destroy such microbes in its digestive tract hence producing composts with very little microbes. The larva of the BSF has the ability to produce compost which can support plant growth, even when the substrate of decomposition is MOSW. This study therefore rejects the hypothesis which states that BSFL composting does not affect nutritional composition, bioaccumulation of heavy metals and microbial activities of compost, since the larval composting process made available very high levels of NPK, C and other elements such as Fe, Mg, Al and Ca. Significant reduction of most microbes were observed in the compost produced.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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