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Promising Technology for Organic Waste Management using Black Soldier Fly Larvae (*Hermetia illucens L.*) (BSFL) in Port Harcourt, Rivers State, Nigeria

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Abstract:- This study used one control group i.e. BSFL fed with spent grain from the hatching to prepupa stage while the experimental group were BSFL fed with pig manure only, chicken manure only, fruit wastes only with other combinations. The objectives of this study were to establish a small pilot facility for testing the various organic wastes streams at a farm level, determine the waste reduction efficiency from different wastes streams tested at the farm with spoilt fruit sourced from fruit market, determine efficiency of digestion of wastes by BSFL. The results revealed larvae grown on spent grain (SG) grew from 80mg on day4 to 118mg on day7 and by day13 it achieved a weight of 225mg. The larvae raised on pig manure (PM1) grew from 82mg on day4 to 124mg on day7 and to 243mg on day13.Those raised on (CM1) grew from 77mg on day4 to 249mg on day13. Those raised on FV1 grew from 75mg on day4 to 268mg on day16, while those raised on PM2 grew from 82mg on day4 to 262mg on day16. The larvae raised on CM2 grew from 77mg on day4 to 249mg on day16 and those raised on FV2 grew from 78mg to 251mg on day16. Bioconversion rate (BCR) of BSFL fed with SG recorded was 3.65, PM1 was 4.02, CM1 4.47, FV1 was 4.36 while PM2 was 4.31. The CM2 was 4.44 while FV2 was 4.09. Feed conversion rate (FCR) for BSFL fed with SG recorded was 22.37, PM1 was 24.85, CM1 22.36, FV1 was 22.92 and PM2 was 23.22. The FCR for CM2 was 22.51 while FV2 was 24.47. The best-fit equation for SG showed an exponential growth with R^2 equal to 0.9971. For PM1, the best-fit equation showed an exponential growth with R^2 equal to 0.9971 while the best fit equation for CM1 showed an exponential growth with R^2 equal to 0.9954. For FV1, growth rate had the best-line of fit as polynomial with R^2 equal 0.9724 while for PM2, growth rate had the best-line of fit as linear function with R^2 equal 0.9785. For CM2, this growth rate revealed a polynomial function with R2 equal to 0.9661 while FV2 revealed best-line of fit as polynomial with R^2 equal 0.981. Waste reduction rate (WR) ranged from 55.2% to 62.58%. Results showed BSFL grown on SG had performed better (62.58%) followed by PM1 (59.6%) and CM1 (58.8%). The waste reduction index (WRI) revealed BSFL fed with SG recorded better waste reduction index (4.81) followed by PM1 (4.58) and CM1 (4.52). The WRI from CM2 was (3.45).Further studies on the quality of the BSFL raised with these agricultural wastes and the safety is required to enable NESREA consider BSFL as an option for managing organic wastes in Nigeria.

I. INTRODUCTION

There is increasing effort by stakeholders in Nigerian agricultural sector to reduce food import while encouraging local food production in order to increase food availability locally and ensuring food security. According to [1], smallholder farmers are responsible for the basic global food production and their farms are less than 2ha of land. One of the main features of agriculture today is waste, which is inevitable on farmlands. Organic wastes can amount up to 80 percent of the total solid wastes generated in most farmlands [2]. Organic waste is the single largest component of land fill waste particularly in the developing nations [3]. These wastes constitute one of the environmental problems. Hence, a sustainable approach is required for the management of waste in a circular economy.

One of such sustainable approach to manage organic wastes is through the larvae of black soldier fly larvae (*Hermetiaillucens L.*) otherwise known as BSFL. The agricultural and food sector require sustainable system of production that can reduce waste and increase nutrient recycling [4]. In Nigeria, several environmental regulations have been put in place to address brown environment by National Environmental Standards and Regulations Enforcement Agency (NESREA). The brown environment refers to areas of the environment impacted by industrial activities [5]. These industrial activities are generally classified into various sectors under the Manufacturers Association of Nigeria (MAN) sectoral groupings and general services [5]. One of the sectoral groupings where BSFL can be utilized is the Food, Beverages and Tobacco sectoral group. The current regulations on this sectoral group [National Environmental (Food, Beverages and Tobacco Sector) Regulations, 2009, S.I. No. 33] along with the [National Environmental (Sanitation and Waste Control) Regulations, 2009 S.I. No. 28] are yet to incorporate BSFL as organic waste management option in its regulations. The BSFL is an insect which can feed on organic matter up to 2 times of its body mass [6,7,8]. The adult stage insects measure about 16 millimeters[6,7,8]. This species is found where there is decaying matter where one female fly lays around 500 eggs [3,7,8]. Once the eggs are laid it takes 18 days for it to form larva and stays in this stage for 18-21 days [3,6,7]. After the larva stage it transforms into the pupa stage (14 days) and then to the adult stage (4-9 days) [3,7,8]. Each larva weighs around 0.1grams [6]. The species usually feeds on organic matter only during the larva stage during which it can feed on all organic material, food waste/scraps, carrion (dead animals) and manure [9]. There are various advantages of using these flies. They are not attracted to humans and do not spread diseases and do not let other insects to lay eggs in their habitat. [10]noted that the treatment of biowaste by black soldier fly larvae (BSFL) is an emerging waste management technology. This process converts waste into larval biomass, reduces waste dry mass and generates the raw materials for the production of soil conditioner and fertilizer [11]. Treatment of waste with BSFL provides a good example of treating farm biowaste at the source of waste generation. It is not uncommon practice among integrated farmers to stockpile and apply manure (pig and chicken wastes) directly into the soil. These practices have the potential to increase greenhouse emission, increase the nutrient load of the soil, possible percolation of nitrates to the water table. In addition, runoff can carry this nutrient and deposit them on water body.This study was carried out in an integrated farm where all manners of wastes (poultry, piggery wastes) are generated with a view to better managed these organic wastes while fruit wastes were sourced from fruit market. The objectives of this study were to establish a small pilot facility for testing various organic wastes streams at the farm level, determine the waste reduction efficiency from different waste streams by BSFL, determine the growth rate of BSFL over time, and determine the bioconversion and feed conversion rates of BSFL.

II. MATERIALS AND METHODS

A. *Study Area*

➢ *Location of Farm and Extent*

The pilot study of Black Soldier Fly Larvae (*Hermetiaillucens*) was carried out at Ibiteinye Integrated Farms (IIF) located in Port Harcourt metropolis. The farm covers approximately 19,590 square meters with its perimeter fence of approximately 776m. It is bounded by latitudes 4.853623ºN to 4.855295ºN and longitude 7.087622ºE to 7.089713ºE. The farm (Figure 1) is located within Port Harcourt. Port Harcourt is located on latitude 04º45'N to 04060'N and longitude 060 50'E to 0800'E and situated 15.0 metre above sea level; it is a relatively low land area [12]. Port Harcourt is the capital of Rivers State and the entire South – South states of Nigeria. It is generally a low land area. It is the only city or mega city in Rivers State (with the idea of greater Port Harcourt) [12]. Temperature of Port Harcourt is about 28ºC and during the few dry month and especially December and January relative humidity is about 80% [13, 14].

Fig. 1: Google Earth Map Showing Location of Ibiteinye Integrated Farms

B. *Research Design*

The experimental research design was grouped into experimental group and a control group. One control group was formed i.e. BSFL fed with spent grain from the hatching to prepupa stage while the experimental group were BSFL fed with pig manure only, chicken manure only, fruit wastes only. Others are combination of these group are shown in Table 1. In all a total of seven (7) experiment was carried out.

Table 1: Treatment Formulation of BSFL with Different Substrates

Spent Grain (%)	Pig Manure (%)	Chicken Manure (%)	Fruits (%)
100%	-	-	-
-	100	-	-
-	-	100	-
-	-	-	100
-	50	25	25
-	25	50	25
-	25	25	50

C. Selection and Sourcing of Feeding Substrates

Waste generated as source with sustained availability in large quantities, at no cost of purchase, and requiring recycling and disposalwas considered. The substrates that were used included piggery manure, chicken manure, fruit wastes and spent grain from the integrated farm. Fruit wastes was sourced from fruit market in Port Harcourt and were packed in air tight bags and transported to the farm facility. 5-day old larvae (5-DOL) were bought from a cultivar and kept in a plastic can with the spent grain used to feed them during the hatching process this was in line with the works of [15]. The container with larvae were transferred to Ibiteinye Integrated Farm (IIF) facility. These larvae were then fed with the wastes as control group. Each group were weighed on an electronic weighing scale model SF-400.

D. Substrate Preparation

All the substrate with larger sizes were shredded into smaller sizes particularly for the fruit wastes while others (piggery manure, chicken manure and spent grain) were used in feeding experiments in their original form. The performance of the substrates was evaluated in terms of the effect on growth rate of the larvae (BSFL).

E. Larval Feeding and Sampling

5-day old larvae (5-DOL) were weighed to reach 250g and were fed inside a plastic container containing 5000g of each of the substrates on a batched system. The dimension of the container was 42cm x 30cm x 13cm deep for the first three days. After the first three-day, 50 random sampling of larvae, were removed from each of the container containing the larvae with substrate and weighed. On the fourth day the larvae in each of the plastic container were transferred to cement floor partitioned with wood. The reason was to prevent heat generation from the plastics and to prevent predators such lizard to have access to the larvae. In addition, mosquito nets were used to keep off other fly species from ovipositing on the substrates according to [15]. The weight of 50 larvae were initially obtained and recorded after every 3-day until dry mass of the substates were observed and the experiment was stopped.

F. Efficiency of Larvae to Degrade Organic Wastes

Larvae growth over time was estimated by the equation:

$$G = \left(\frac{A-B}{B}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 1$$

Where B was the weight of larvae at time t, and A was the weight of larvae after time t.

The waste reduction rate (WR) was estimated for each substates treatment based on the dry weight of the substrates and is given as WR by:

$$WR\% = \left[1 - \left(\frac{subtrates\ redidue(g)}{substrates\ added(g)}\right)\right] x\ 100\% \ldots\ldots\ldots\ldots\ldots 2$$

Waste reduction Index (WRI) takes into account not only the overall material reduction but also the time required by the larvae to reduce the amount of waste and was estimated by the following equation:

$$\text{WRI} = \frac{Waste\ reduction\ (mg)}{time\ (days)} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3$$

$$\text{Bioconversion ratio (BCR)\%} = \frac{Prepupa\ finished\ weight\ (mg)}{Feed\ added\ (mg)} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4$$

$$\text{Feed conversion ratio (FCR)\%} = \frac{Feed\ added\ (mg)}{prepupa\ finished\ weight\ (mg)} x\ 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 5$$

III. RESULTS

A. Growth of BSFL

The results of larva fed in a single batch with different substrates which were measured every three days is presented in Table 2. Average growth weight of each BSFL fed with different substrates are presented in Table 3.

Table 2: Results of Weight of 50 larvae after every day-3

time (days)	SG (g)	PM1 (g)	CM1 (g)	FV1 (g)	PM2 (g)	CM2 (g)	FV2 (g)
4	4	4.1	3.85	3.75	4.1	3.85	3.9
7	5.9	6.2	6.1	6.35	6.15	5.95	5.85
10	7.8	8.3	8.2	8.35	8.15	8.1	7.95
13	11.25	12.15	12.45	12.6	11.95	12	11.45
16				13.4	13.1	12.45	12.55

SG= Spent Grain (100%); PM1 = Pig Manure (100%); CM1 = Chicken Manure (100%); FV1 = Fruit Wastes (100%), PM2 = Pig Manure (50%), Chicken Manure (25%) and Fruit Wastes (25%); CM2 = Chicken Manure (50%), Pig Manure (25%) and Fruit Wastes (25%); FV2 = Fruit Wastes (50%); Pig Manure (25%) and Chicken Manure (25%).

Table 3: Growth of BSFL on Different Substrates after Every 3 Days

time (t) (day)	SG	PM1	CM1	FV1	PM2	CM2	FV2	Mean
	(mg)	(mg)	(mg)	(mg)	(mg)	(mg)	(mg)	(mg)
4	80	82	77	75	82	77	78	78.7
7	118	124	122	127	123	119	117	121.4
10	156	166	164	167	163	162	159	162.4
13	225	243	249	252	239	240	229	239.6
16	-	-	-	268	262	249	251	268

SG= Spent Grain (100%); PM1 = Pig Manure (100%); CM1 = Chicken Manure (100%); FV1 = Fruit Wastes (100%), PM2 = Pig Manure (50%), Chicken Manure (25%) and Fruit Wastes (25%); CM2 = Chicken Manure (50%), Pig Manure (25%) and Fruit Wastes (25%); FV2 = Fruit Wastes (50%); Pig Manure (25%) and Chicken Manure (25%).

- *Growth Rate of BSFL Fed with Spent Grain*

Figure 2 showed the growth rate of the of BSFL fed with spent grain. The 9-DOL which correspond to day4 of feeding recorded a weight of 80mg, the 12-DOL corresponding to day7 showed a weight of 118mg, 15-DOL was 156mg corresponding to day10 of feeding while 18-DOL corresponding to 13day feed was 225mg. The best-fit equation showed an exponential growth with R^2 equal to 0.9971.

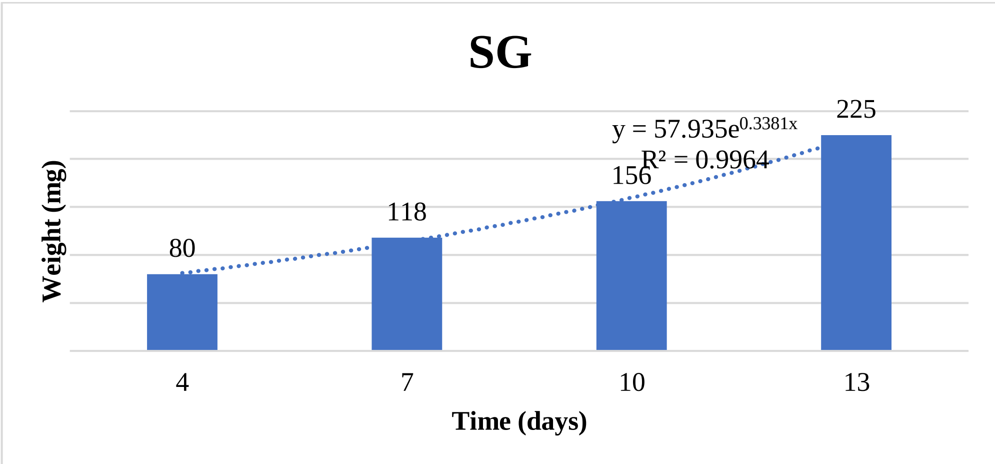

Fig. 2: Growth Rate of BSFL Fed with 100% Spent Grain

- *Growth Rate of BSFL Fed with Pig Manure*

The growth rate of BSFL fed with pig manure increased from 82mg to 118mg between day4 (9-DOL) and day7 (12-DOL) and 166mg to 243mg between day10 (15-DOL) and day13 (18-DOL), this is shown in figure 3. The best-fit equation showed an exponential growth with R^2 equal to 0.9971.

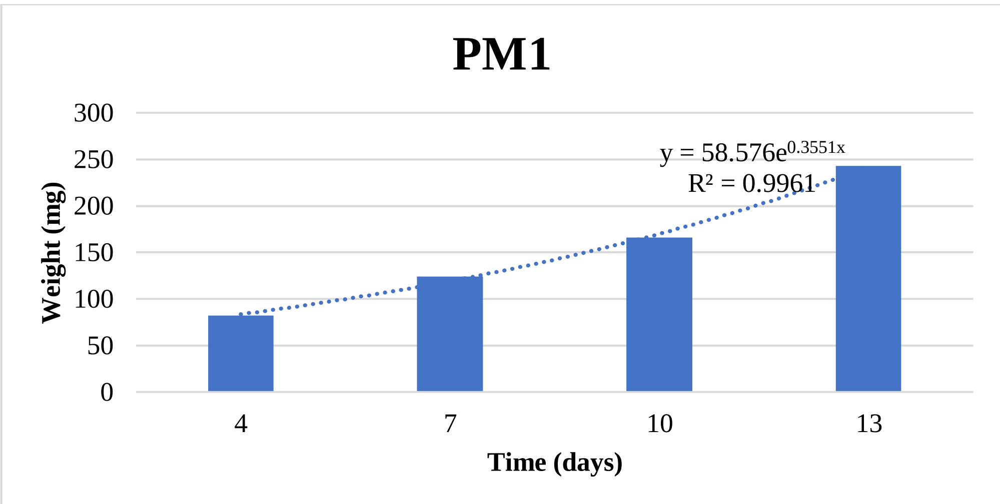

Fig. 3: Growth Rate of BSFL Fed with 100% Pig Manure

➢ *Growth Rate of BSFL Fed with Chicken Manure*

BSFL fed with 100% chicken manure increased in weight from 77mg to 122mg i.e. 4th day of feeding (9-DOL) to 7th day (12-DOL) and from 164mg to 249mg i.e. 10th day of feeding (15-DOL) to 13th day (18-DOL) as shown in figure 4. The best-fit equation showed an exponential growth with R^2 equal to 0.9954.

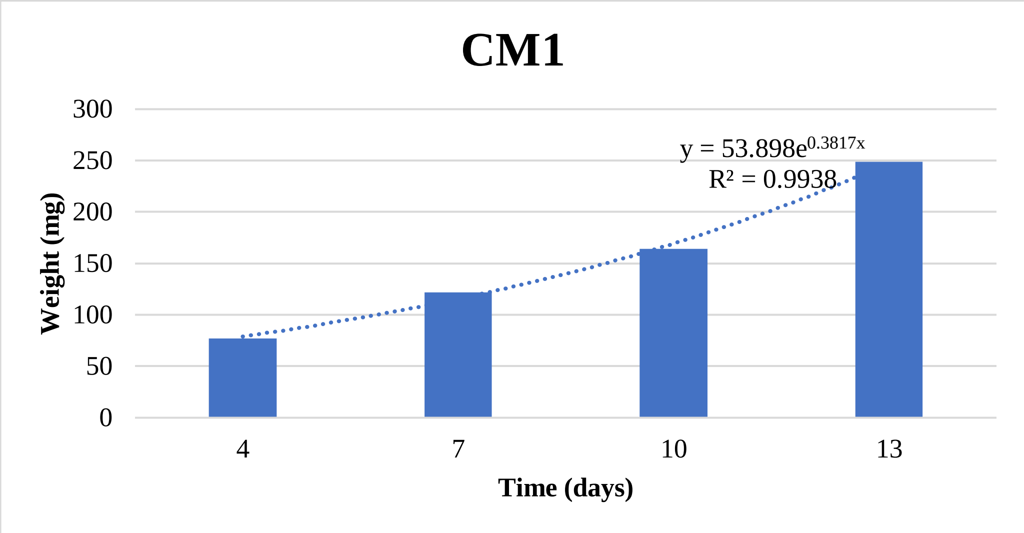

Fig. 4: Growth Rate of BSFL Fed with 100% Chicken Manure

➢ *Growth Rate of BSFL Fed with Fruit Wastes*

The BSFL fed with 100% fruit wastes grew in weight from 75mg to 127mg right from day4 (9-DOL) to day7 (12-DOL) and from 167mg on day10 (15-DOL) to 252mg on day13 (18-DOL) while on day16 (21-DOL) it grew to 268mg(figure 5). This growth rate had the best-line of fit as polynomial with R^2 equal 0.9724.

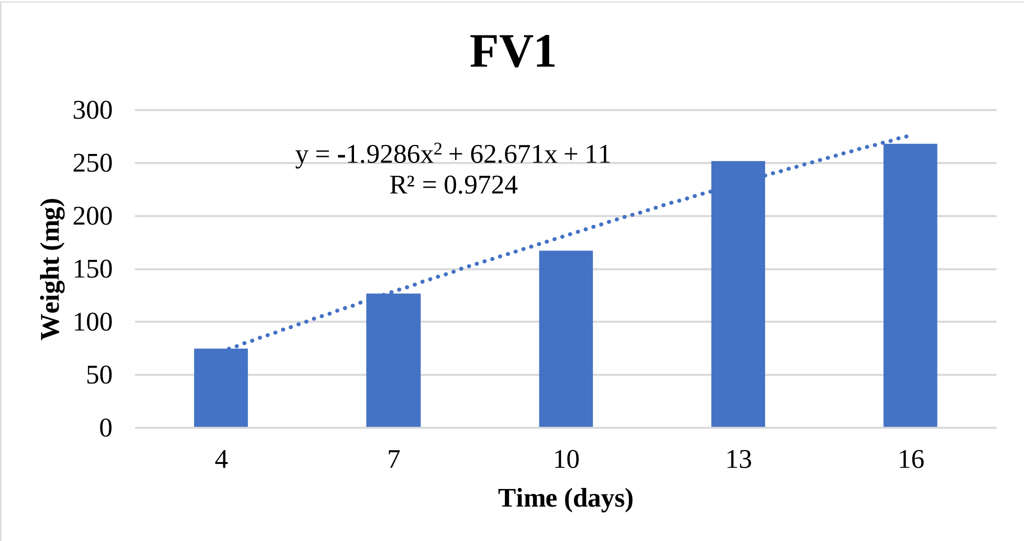

Fig. 5: Growth Rate of BSFL Fed with 100% Fruit Wastes

➢ *Growth Rate of BSFL Fed with Pig Manure Combinations*

The BSFL fed with pig manure (50%), chicken manure (25%) and fruit Wastes (25%) as PM2 grew in weight from 82mg on day4 (9-DOL) to 123mg on day7 (12-DOL) and further grew from 163mg on day10 (15-DOL) to 239mg on day13 (18-DOL) and finally to 262mg on day16 (21-DOL) (figure 6). This growth rate had the best-line of fit as linear function with R^2 equal 0.9785.

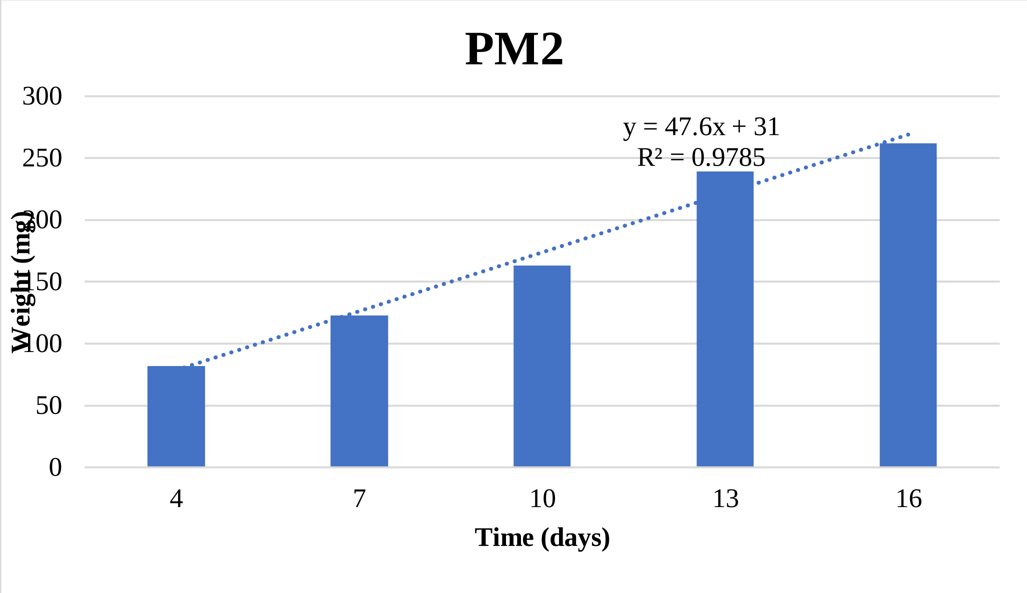

Fig. 6: Growth Rate of BSFL Fed with Pig Manure (50%), Chicken Manure (25%) and Fruit Wastes (25%).

- *Growth Rate of BSFL Fed with Chicken Manure Combinations*

The result of BSFL fed with chicken manure (50%), pig manure (25%) and fruit wastes (25%) showed growth in weight from 77mg on day4 (9-DOL) to 119mg on day7 (12-DOL) and grew from 162mg on day10 (15-DOL) to 240mg on day13 (18-DOL) and finally to 249mg (figure 7). The best-line of fit on this growth rate revealed a polynomial function with R2 equal to 0.9661.

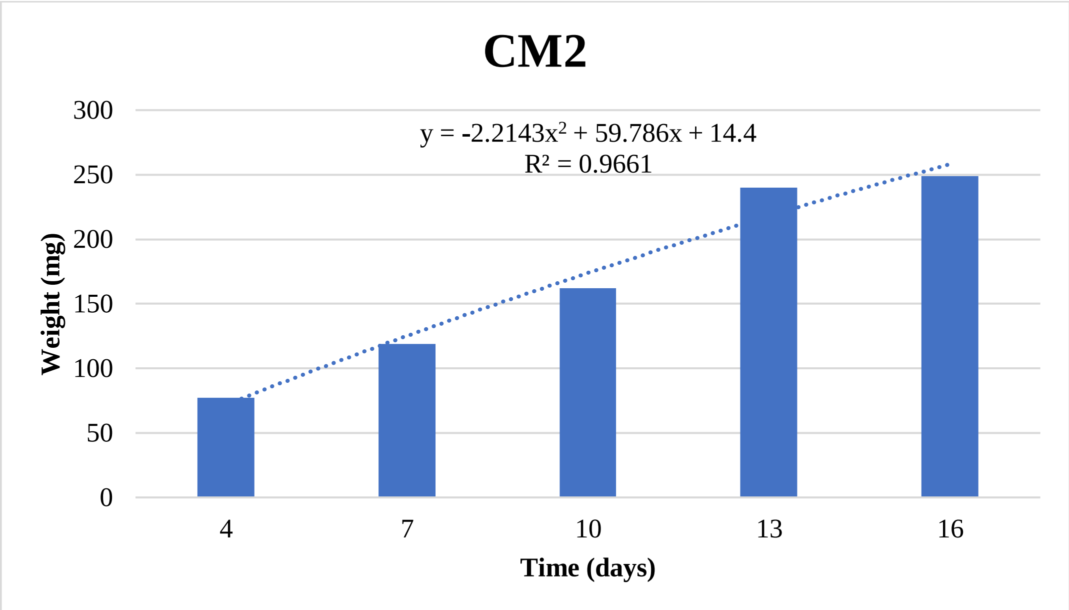

Figure 7: Growth Rate of Chicken Manure (50%), Pig Manure (25%) and Fruit Wastes (25%).

- *Growth Rate of BSFL Fed with Fruit Wastes Combinations*

Results of BSFL fed with fruit wastes (50%), pig manure (25%) and chicken manure (25%) grew in weight from 78mg on day4 (5-DOL) to 117mg on day7 (12-DOL) and further from 159mg on day10 (15-DOL) to 229mg on day13 (18-DOL), while on day16 (21-DOL) it grew to 251mg (figure 8). This growth rate had the best-line of fit as polynomial with R^2 equal 0.981.

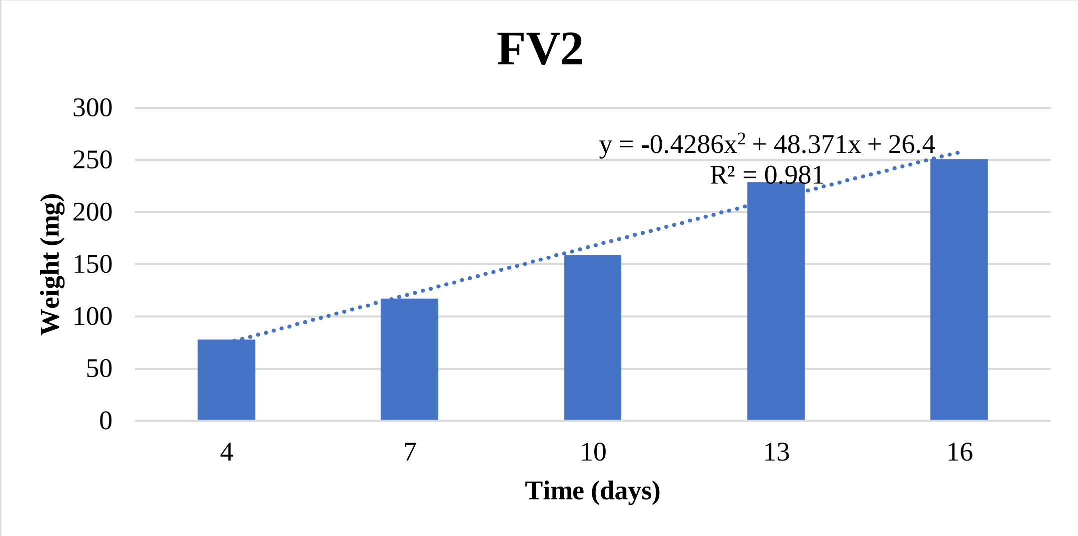

Fig. 8: Growth rate of BSFL Fed with Fruit Wastes (50%), Pig Manure (25%) and Chicken Manure (25%).

B. Bioconversion Rate

Bioconversion of SG by BSFL recorded was 3.65, PM1 was 4.02, CM1 was 4.47, FV1 was 4.36 while PM2 was 4.31. The CM2 was 4.44 while FV2 was 4.09 (Table 4).

Table 4: Results of BCR

	Substrates						
	SG	PM1	CM1	FV1	PM2	CM2	FV2
Sampled Finished weight (mg)	225	243	249	268	262	249	251
Feed added (g)	5,000	5,000	5,000	5,000	5,000	5,000	5,000
Total number of prepupa	812	828	898	814	822	892	814
total weight (mg)	182,700	201,204	223,602	218,152	215,364	222,108	204,314
BCR	3.65	4.02	4.47	4.36	4.31	4.44	4.09

BCR = Bioconversion rate; SG= Spent Grain (100%); PM1 = Pig Manure (100%); CM1 = Chicken Manure (100%); FV1 = Fruit Wastes (100%), PM2 = Pig Manure (50%), Chicken Manure (25%) and Fruit Wastes (25%); CM2 = Chicken Manure (50%), Pig Manure (25%) and Fruit Wastes (25%); FV2 = Fruit Wastes (50%); Pig Manure (25%) and Chicken Manure (25%).

C. Feed Conversion Rate

Feed conversion rate of SG by BSFL recorded was 27.37, 100% PM1 was 24.85, 100% CM1 was 22.36, FV1 was 22.92 while PM2 was 23.22. The CM2 was 22.51 while FV2 was 24.47 (Table 5).

Table 5: Results of FCR

	Substrates						
	SG	**PM1**	**CM1**	**FV1**	**PM2**	**CM2**	**FV2**
Sampled Finished weight (mg)	225	243	249	268	262	249	251
Feed added (mg)	5,000	5,000	5,000	5.000	5,000	5,000	5,000
Total number of prepupa	812	828	898	814	822	892	814
Prepupa weight (mg)	182,700	201,204	223,602	218,152	215,364	222,108	204,314
FCR	27.37	24.85	22.36	22.92	23.22	22.51	24.47

FCR = Feed conversion rate; SG= Spent Grain (100%); PM1 = Pig Manure (100%); CM1 = Chicken Manure (100%); FV1 = Fruit Wastes (100%), PM2 = Pig Manure (50%), Chicken Manure (25%) and Fruit Wastes (25%); CM2 = Chicken Manure (50%), Pig Manure (25%) and Fruit Wastes (25%); FV2 = Fruit Wastes (50%); Pig Manure (25%) and Chicken Manure (25%).

D. Substrates and Frass Analyses

Results of substrates weight used with frass recovered is presented in figure 9. From the equal weight of substrates used, the frass recovered from the different substrates range from 1871g to 2240g. The SG recorded the lowest frass (1871g) followed by PM1 (2020g) and CM1 (2060g). The highest weight of frass recorded were from CM2 (2240g). Waste reduction rate ranged from 55.2% to 62.58%. Results showed larvae used on SG had performed better (62.58%) followed by PM1 (59.6%) and CM1 (58.8%) (Figure 10). The waste reduction index revealed SG recorded better waste reduction index (4.81) followed by PM1 (4.58) and CM1 (4.52). The lowest waste reduction index came from CM2(Figure 11).

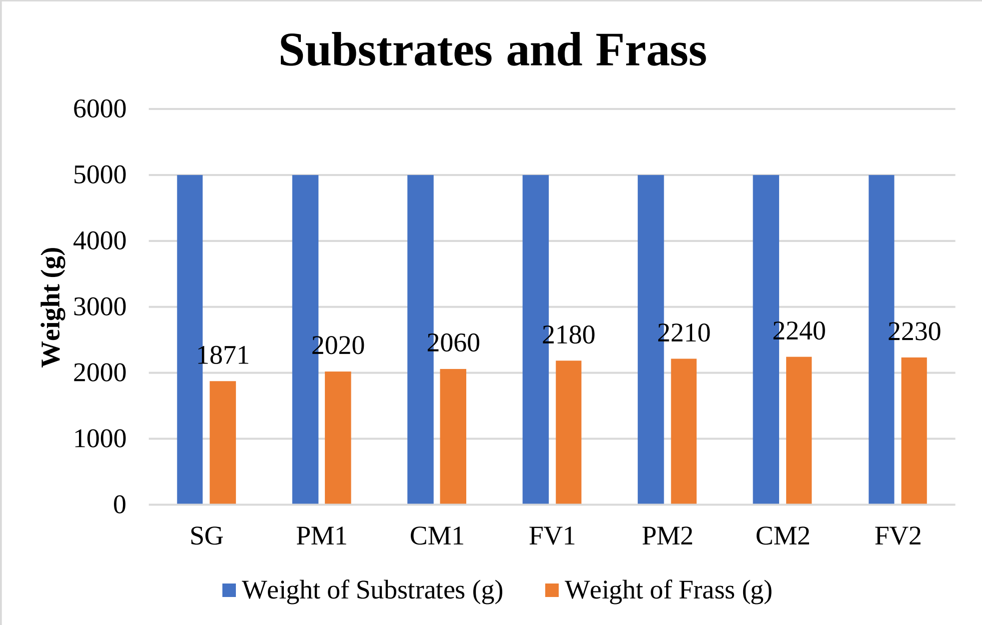

Fig. 9: Weight of Substrate to Frass

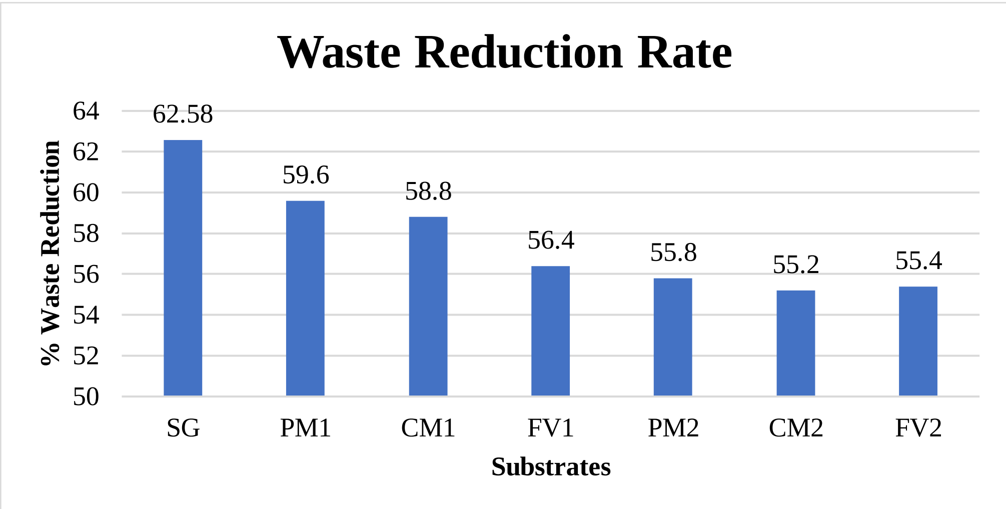

Fig. 10: Waste Reduction Rate

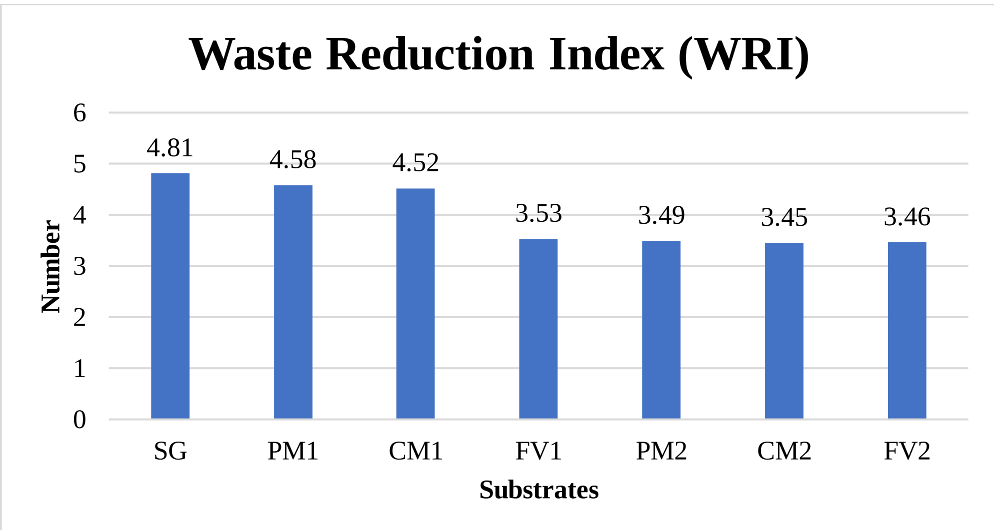

Fig. 11: Waste Reduction Index

IV. DISCUSSION

The average initial weight of 50 larvae (9-DOL) was 80mg for SG, 82mg for PM1, 77mg for CM1, 75mg for FV1, 82mg for PM2, 77mg for CM2 and 78mg for FV2. Comparing these results with the work of [9], this study's value for BSFL fed with FV1 and BSFL fed with FV2 reported a slightly lower initial weight value of 75mg and 78mg respectively while [9] reported between 80mg and 90mg. In this study, BSFL fed with FV1 and FV2 recorded 181% and 222% growth respectively from their initial weight while [9] reported 1,700% growth. The variation in growth may have been based on the fruit wastes used. This study used carrot, watermelon and green pepper while [9] used papaya, banana, pineapple and apple. In this study and from the equal weight of substrates used, the frass recovered from the different substrates ranged from 1871g to 2240g. The SG recorded the lowest frass (1871g) followed by PM1 (2020g) and CM1 (2060g). The highest weight of frass recorded were from CM2 (2240g). Waste reduction rate ranged from 55.2% to 62.58%. Results showed larvae used on SG had performed better (62.58%) followed by PM1 (59.6%) and CM1 (58.8%). The waste reduction index (WRI) revealed SG recorded better WRI (4.81) followed by PM1 (4.58) and CM1 (4.52). The lowest WRI came from CM2. In terms of waste reduction rate (WR) and comparing this work with [9], FV1 recorded 56.4% and FV2 recorded 55.4% WR respectively while [9] reported between 55% and 57% WR respectively.

This study bioconversion rate (BCR) was in variance with the work of [16]while using chicken manure, pig manure and chicken wastes, their bioconversion BCR for all the treatments and waste sources ranged between 5.5 and 10.5%. Their chicken manure registered the highest bioconversion rate (10.5%) while kitchen waste registered the lowest (5.5%). In feed conversion rate (FCR), this study recorded higher values as compared with the work of [16]. Their highest feed FCR was recorded with pig manure (8.7) in batch feeding and the lowest (6.7) was recorded with kitchen waste. In this study highest FCR was achieved with SG (27.37) while CM1 FCR was 22.36. FV2 recorded 24.47 FCR which is more than twice that achieved by [16]. This study also recorded higher values of FCR for all substrates used when compared with the work of [17] which recorded 4.84 to 20.54.

V. CONCLUSION AND RECOMMENDATIONS

BSFL can serve as a promising technology to manage organic waste in Nigeria. From this study waste reduction rate (WR) by BSFL ranged from 55.2% to 62.58%. larvae raised on SG had performed better (62.58%) followed by PM1 (59.6%) and CM1 (58.8%). The waste reduction index (WRI) revealed larvae fed with SG recorded better waste reduction index (4.81) followed by PM1 (4.58) and CM1 (4.52). The WRI from CM2 was (3.45). Bioconversion rate (BCR) of BSFL fed with SG recorded was 3.65, PM1 was 4.02, CM1 4.47, FV1 was 4.36 while PM2 was 4.31. The CM2 was 4.44 while FV2 was 4.09. Feed conversion rate (FCR) for BSFL fed with SG recorded was 22.37, PM1 was 24.85, CM1 22.36, FV1 was 22.92 and PM2 was 23.22. The FCR for CM2 was 22.51 while FV2 was 24.47.Further studies on the quality of the BSFL raised with these agricultural wastes and the safety is required to enable NESREAconsider BSFL as an option for managing organic wastes in Nigeria.

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