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Economic Prospect of Volarization of Organic Waste at Mandate Modern Market in Ilorin with Black Soldier Fly Larvae (BSFL) (*Hermetia illucens* L) (Diptera; Stratiomyidae)

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Abstract: The improper disposal of solid organic waste (SOW) in urban markets contributes significantly to environmental degradation, health hazards, and greenhouse gas (GHG) emissions. This study evaluated the viability and efficiency of Black Soldier Fly Larvae (BSFL) technology in biodegrading vegetable waste and cattle cud from Mandate Modern Market, Ilorin, Nigeria. Vegetable waste and cattle cud from abattoir were processed and inoculated with 6-DOL BSFL, assessing parameters such as waste reduction rate (WRR), bioconversion efficiency (BCE), and larval biomass yield. Results showed vegetable waste achieved the highest WRR (73.78%) and BCE (8.38%), significantly outperforming cattle cud and control feeds ($p < 0.05$). Proximate analysis revealed BSFL-prepupae from vegetable waste were rich in protein (33.52%) and lipids (22.11%), while the frass retained high ash content, indicating potential for organic fertilizer use. Economic assessment demonstrated that processing 100 kg of vegetable waste could yield up to 20 kg of protein-rich larvae and valuable frass, turning waste liabilities into productive assets. The study confirms BSFL's potential as a sustainable, low-cost waste management and protein production solution for urban markets in Nigeria.

Keywords: *Solid Organic Waste, Black Soldier Fly Technology. Biodegradation, Waste Reduction.*

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I. INTRODUCTION

The global effect of solid organic waste (SOW) is alarming, mainly food waste at retailing stage, giving rise to global warming among other effects (Rohini *et al*., 2020). Solid organic wastes are mostly generated in markets and they end up in dumpsites and landfills (Nnoli *et al*., 2024). Mandate modern market Ilorin is situated along Olorunshogo road, Western Avenue, Ilorin-West Local Government Area; Latitude 8.5º N and longitude 4.5º E; it's one of the government formally established markets in Ilorin town synonymous with sales of perishable food items including vegetables, fruits, meat, fish and other dried food items.

The disposal of wastes generated in the market poses a great challenge to the market management and Kwara State Ministry of Environments (Highprofile.com, 2023). Solid organic wastes are disposed in a single fabricated metal dumpster (3.5 x 3 x 3 m) placed at the southern end of the market, the excess wastes that cannot be contained in this dumpster ends up in the drains and on road median (RCDIJ, 2023). Accumulation of this waste constitutes nuisance and aggravates several health challenges including disease transmission (Jibrilla *et al*, 2023).Wastes from cattle processing at the abattoir after fleshing of beef and other edible organs comprise of the cattle cud (partly digested food from the gut). These waste products (figure 1 and figure 2) eventually generate stench (Salam, *et al*., 2021) which is inimical to the health of the market users and the nearby environ. This may result in health challenge and could also lead to transition of diseases by house flies and other disease transmitting organisms. The accumulated wastes causes emission of greenhouse gases (GHG) (Couth and Trois, 2009) which contributes to global warming that result into climate change (United Nations Environment

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Programme, 2010). According to RCDIJ (2023) Kwara state government earmark over eight hundred million naira (N800 million) for waste management in 2019 and 2021, which does not solve the challenge of accumulation of solid organic wastes especially at the markets. Volarization of the SOW that is generated mainly in the abattoir and vegetable section of the market with black soldier fly larva (BSFL) will help in fast bio-gradation of the waste (Park, 2016) and at the same time give it value (Ezeudu *et al*. 2021; Ebenebe, 2021). The wastes are transformed into larvae biomass (Ezeudu *et al*., 2021) useful in livestock feed (Olutegbe and Ojuoluwa, 2022), frass useful as bio fertilizer (Gonz´alez *et al*., 2020; Da Silver and Hesselberg, 2020) and other value products. Likewise BSFL degrade the SOW at a low cost (Salam *et al*. 2021) and mitigates the emission of GHG (Parodi *et al*. 2020; Pang *et al*. 2020).

The objective of this study is to determine viability, efficiency and potential economic value of BSFL waste management technology in biodegradation of SOW generated at abattoir and vegetable section at mandate modern market Ilorin; as a compliment or substitute to dumping in dumpster and eventually in landfill.

Fig 1 Dumpsite at the Abattoir

Fig 2 Dumpsite of Vegetable and Fruit Section; Mandate Market

II. MATERIALS AND METHOD

- *Study Area*

The study area is Mandate modern market Ilorin, situated along Olorunshogo road, Western avenue, Ilorin-West Local Government Area. Latitude 8.5^{o} N and longitude 4.5^{o} E.

- **Study Site:** The study site is the dump site of the abattoir and fresh vegetable section in Mandate modern market, Ilorin.

- *Larvae Culture (Phase One)*

BSF eggs were collected from a maintained colony in a private experimental laboratory situated at Olorunshogo area along Western reservoir road in Ilorin under room condition range of 23 and 37^{o} C and 48 and 99 % temperature and relative humidity. 3.0 g of eggs were kept in a tray (15 x 9 x 5 cm) above starter larva feed made from 500 g dry chicken (broiler starter) feed made to 70 % moisture with water in hatching tray (23 x 32 x10 cm) where newly hatched larvae drops (Dortmans *et al.*, 2021). 30.0 g of 6-DOL were collected, blanched and oven dried at 105^{o}C for 24hours for the dry weight (Broeckx *et al*., 2021) prepared for proximate nutritional analysis for the initial composition status before feeding with the waste substrates (Meneguz *et al*. 2018; Singh *et al*., 2021; Gougbedji *et al*., 2021).

- *Waste Sample Collection (Phase Two)*

The organic wastes were sourced from dumpster of abattoir and vegetable section of mandate modern market Ilorin. Waste from the abattoir section comprise of cattle cud (semi digested food) dispensed from the gut of the slaughtered cattle. Wastes from fresh vegetable section in partially rotten state is composed by mass of cabbage outer leaf cover (30 %), carrot leaf and stem off-cut (20 %), green beans pod (1 %), cucumber (10 %), rotten Irish potato (3 %), orange peel (1 %), papaya peel (5 %), green pepper (15 %), spoilt/rotten plantain (5 %) and pineapple peel (5 %). Both categories of wastes were used exclusively as feeding substrate throughout the experimental period.

- *Preparation of Waste Substrate (Phase Three)*

The collected samples were careful sorted by removing inorganic waste materials as much as possible. Three different samples were prepare viz; 1. Vegetable waste denoted by (V), 2. Cattle cud (C) and 3. Control setup made of broiler starter chicken feed ($C_{control}$) (150 g made to 90 % moisture). 150 g of sample of C and V were weighed in the state they were collected from the dump site into a 15 x 9 x 5 cm plastic container, thoroughly mixed to achieve homogeneity (Diener *et al.*, 2011) and all including control were replicated three (3) times. The substrate tray bottoms of sample V have pinhole perforation to allow draining of excess water from the substrate; they were placed in a bigger plastic tray (18 x 10 x 5cm) that collect the excess drained water and discarded.

- *Inoculation of Waste with 6-DOL (Phase Four)*

Using Harnden and Tomberlin (2016); Nyakeri *et al*. (2017) method 150 6-DOL are used to inoculate 150g of

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prepared organic waste substrates in a (15 x 9 x 5 cm) substrate tray for each sample. The organic waste substrate depth in each tray is not more than 2cm thickness to allow good aeration and to maintain optimum substrate temperature (Dortmans *et al.*, 2017). A weighed sample is added ad libitum to each substrate and its replicates depending on larval feeding rate.

- *BSF Larvae Grow-Out, Measurements and Harvesting (Phase Five)*

Ten (10) developing larvae samples were randomly taken from each substrate and their replicates for weight measurement (g) by collectively weighing the 10 larvae to determine the average weight (g), each larvae length measurement (mm) was taken when the larvae extend its full length from the tip of its head to the tip of last posterior segment and width (mm) measured across at the mid region of the larvae. These recordings were taken every four days until the first 50 % prepupae is attained (Meneguz *et al*., 2018) marking the end of the feeding and larvae development experiment. Harvesting is done by separating the residue (frass) and pre-pupae manually and with sieves of 0.25 cm mesh size by moving the sieve containing the frass and the larvae side to side till only the larvae and prepupae remains in the sieve.

Fresh and dry weight of prepupae and remaining larvae of each substrate is recorded at the end of the experiment to determine larvae growth from the start of the experiment. Weight of the frass of each sample is recorded using digital scale with readability of 0.001 g (Electronic balance type; ATY224) after harvest to determine waste reduction efficiency.

- *Nutritional Proximate Analysis of Samples Dry Matter (DM) (Phase Six)*

30.0 g of each of dried samples of 6-DOL, harvested prepupa, frass and initial substrate sample before feeding were subjected to nutritional proximate analysis at Central Research Laboratory, University of Ilorin to determine their ash content, crude protein, crude fat, crude fibre, moisture content and carbohydrate content.

- *Data Analysis:*

Data collected from the study is used to evaluate feeding consumption, waste reduction efficiency (WRE), bioconversion efficiency and digestible feed conversion efficiency (DFCE) of BSFL (Gougbedji *et al.*, 2021; Sari *et al*., 2023). Nutritional proximate analysis is conducted on the processed samples to determine their nutritional composition. Economic viability of the technology is determined by costs-benefit analysis of production of crude protein from BSFL technology in comparison with crude protein cost of commercial chicken feed, and the cost of the nominal waste management method at the market and that of BSFL technology. Bioconversion rate, bioconversion efficiency, waste reduction rate and waste reduction efficiency were subjected to ANOVA at $p<0.05$ using SPSS version 20. Post Hoc Test determines which group pairs differ significantly.

III. RESULT

Table 1 presents the results of the evaluation of three different substrates; vegetables waste (V), cattle cud (C), and a broiler starter control (Ctr) based on various growth and biodegradation efficiency parameters. The values are reported as means with their corresponding standard deviations.

The Relative Growth Rate (RGR %) was highest in the control group at (93.47 ± 8.24) %, followed by vegetables waste (67.60 ± 3.12) %, and lowest in cattle cud (15.00 ± 1.57)%. Similarly, the Larval Biomass Yield (LBY) was greatest in the control (0.05 ± 0.01), slightly lower in V (0.04 ± 0.01), and least in C (0.01 ± 0.00).

The Feed Conversion Efficiency (FCE%) among the substrates was best in cattle cud at (18.13 ± 0.38) %, vegetables waste trailing at (11.40 ± 1.82)% and control (6.30 ± 0.82)%. The Feed Conversion Rate (FCR), (where a lower value indicates better efficiency; less feed needed to produce 1 unit of biomass), was lowest in vegetables waste (12.02 ± 1.24), followed by cattle cud (29.50 ± 1.24), and highest in the control (49.93 ± 5.80). In terms of Total Feed Intake (TFI), the control group consumed the most feed at 80.48 ± 2.23, followed by V (54.20 ± 2.29) and C (9.21 ± 0.23). The Bioconversion Rate (BCR %) and Bioconversion Efficiency (BCE) were highest in vegetables waste, with values of 8.37 ± 0.90% and 8.38 ± 0.92, respectively. The Bioconversion Ratio (BCR) was also greatest in V (0.08 ± 0.01), compared to C (0.03 ± 0.01) and Ctr (0.02 ± 0.00).

For waste processing performance, the Waste Reduction Index (WRI) was highest in the control (6.10 ± 0.04), but the Waste Reduction Efficiency (WRE) was best in vegetables waste at 73.78 ± 3.25%, outperforming Ctr (32.19 ± 0.90%) and C (18.71 ± 0.38 %). The same trend was seen in Waste Reduction Rate (WRR), where V was 73.77 ± 3.28 %, much higher than Ctr (32.20 ± 0.87 %) and C (18.73 ± 0.40 %).

Table 1 Mean and Standard Deviation (Std) value of the Parameters Tested on the Substrates Fed to *Hermetia illucens* (Diptera: Stratiomyidae)

Substrate	RGR %	LBY	FCE %	FCR	TFI	BCR %	BCE	BCR	WRI	WRE	WRR	ECDF
V	67.60 ± 3.12	0.04 ± 0.01	11.40 ± 1.82	12.02 ± 1.24	54.20 ± 2.29	8.37 ± 0.90	8.38 ± 0.92	0.08 ± 0.01	3.66 ± 0.02	73.78 ± 3.25	73.77 ± 3.28	0.11 ± 0.02
C	15.00 ± 1.57	0.01 ± 0.00	18.13 ± 0.38	29.50 ± 1.24	9.21 ± 0.23	3.37 ± 0.15	3.39 ± 0.14	0.03 ± 0.01	3.66 ± 0.02	18.71 ± 0.38	18.73 ± 0.40	0.18 ± 0.00

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Ctr	93.47 ± 8.24	0.05 ± 0.01	6.30 ± 0.82	49.93 ± 5.80	80.48 ± 2.23	2.03 ± 0.21	2.02 ± 0.22	0.02 ± 0.00	6.10 ± 0.04	32.19 ± 0.90	32.20 ± 0.87	0.06 ± 0.01

Means ± SE, n = 3, RGR = Relative growth rate; LBY = Larva biomass yield; FCE% = Feed conversion efficiency; FCR = feed conversion rate; TFI = Total feed intake; WRR = waste reduction rate; WRI = waste reduction index; WRE = waste reduction efficiency; BCE = bioconversion efficiency; BCR% = bioconversion rate; BCR = bioconversion ratio; ECD = efficiency of conversion of digested food

Efficiency of Conversion of Digested Feed (ECDF) was highest in cattle cud (0.18 ± 0.00), followed by vegetables waste (0.11 ± 0.02), and lowest in the control group (0.06 ± 0.01).

➢ *Viability Assessment of Biodegradation and Waste Reduction*

The viability of Black Soldier Fly Larvae (BSFL) reared was evaluated using four parameters; Bioconversion rate, bioconversion efficiency, waste reduction efficiency and waste reduction rate, shown in figure 3. BSFL reared on Substrate V achieved the highest performance across the four parameters. Substrate C resulted in considerably lower values compared to V. The control Ctr recorded WRR at 32.20 ± 0.87 %, WRE at 32.19 ± 0.90, BCR at 2.30 ± 0.21 % and BCE at 2.02 ± 0.22; Ctr waste reduction was higher than in Substrate C, the conversion of waste into larval biomass remained the lowest in Ctr, indicating limited efficiency and viability for large-scale application.

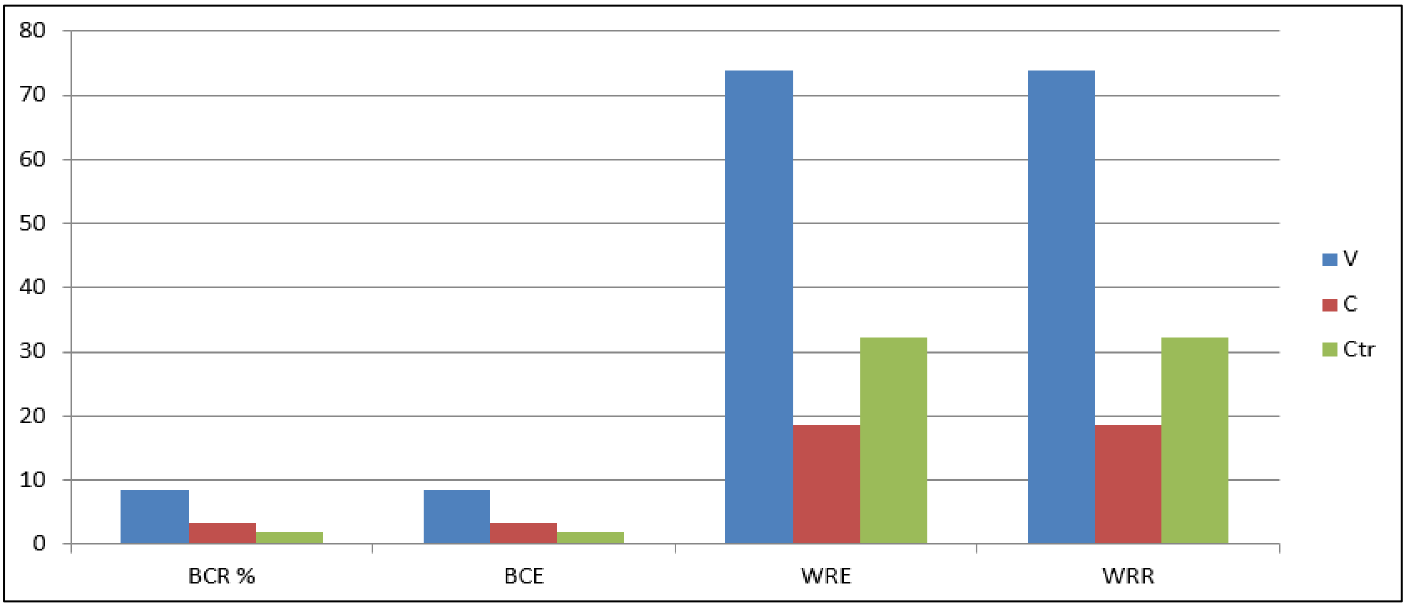

Fig 3 Viability of Biodegradation
BCR%=Bioconversion rate; BCE=Bioconversion efficiency; WRE=Waste reduction efficiency; WRR=Waste reduction rate

➢ *Proximate Analysis Report*

Each sample type was analyzed for its content of protein, lipid, fibre, carbohydrate, ash, and moisture, offering insights into how well larvae utilize the nutrients and how efficiently they convert the feed as shown in Table 2 and figure 4.

➢ *Vegetable-Based Samples*

The vegetable waste was high in fibre (57.47%) and ash (16.34%) but low in protein (6.29%) and carbohydrate (2.58%). After being consumed by the larvae, the resulting prepupae showed a significant increase in protein (33.52%) and lipid (22.11%) — evidence of efficient nutrient uptake. The frass (waste left after digestion) retained moderate protein (7.00%) and high ash (20.24%), indicating good nutrient extraction by the larvae.

➢ *Cattle Cud-Based Samples*

Cattle cud was similarly high in fibre (59.82%) and ash (17.57%) but low in protein (9.04%). After digestion, the prepupae's protein content rose to 32.48%, while fibre and lipid levels dropped, showing effective nutrient concentration in the larvae. The frass had lower nutrients but rich in ash (20.59%).

➢ *Chicken Feed Control Samples*

The control feed, made from chicken feed, had the highest nutritional value, especially in lipids (40.00%) and carbohydrates (43.00%). After digestion, the larvae had the highest protein (37.19%) and lipid (37.21%) content among all groups, confirming this feed’s superior suitability for larval growth. The frass showed reduced nutrients, reflecting efficient digestion.

➢ *Six-Day-Old Larvae (6-DOL):*

The larvae at six days old already exhibited high protein (29.75%) and balanced levels of lipid (12.86%), ash (10.81%), and fibre (19.56%), indicating good growth and feed utilization by this stage.

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Table 2 Proximate Nutrition Composition of the Formed Prepupa, Frass, Initial Substrates State and the 6-DOL

S/N	SAMPLE	% CRUDE PROTEIN	%CRUDE LIPID	%MOISTURE CONTENT	% TOTAL ASH	%CRUDE FIBRE	% CARBOHYDRATE
1	V pp	33.52	22.11	6.95	12.02	19.53	5.86
2	V sub	6.29	8.79	8.53	16.34	57.47	2.58
3	V frass	7.00	6.83	6.70	20.24	37.58	21.64
4	C pp	32.48	6.80	6.14	21.61	23.42	9.56
5	C sub	9.04	5.45	8.36	17.57	59.82	0.99
6	C frass	8.64	1.00	8.23	20.59	56.80	4.77
7	Ctr pp	37.19	37.21	6.00	5.88	16.67	0.05
8	Ctr sub	22.00	40.00	8.30	7.00	5.00	43.00
9	Ctr frass	21.22	4.81	8.44	9.75	39.64	16.24
10	6-DOL	29.75	12.86	6.93	10.81	19.56	9.35

V=vegetable, C=cattle cud, Ctr=control, pp=prepupa, sub=substrate, frass= (uneaten feed, exuvie and digestive waste), DOL= day old larva

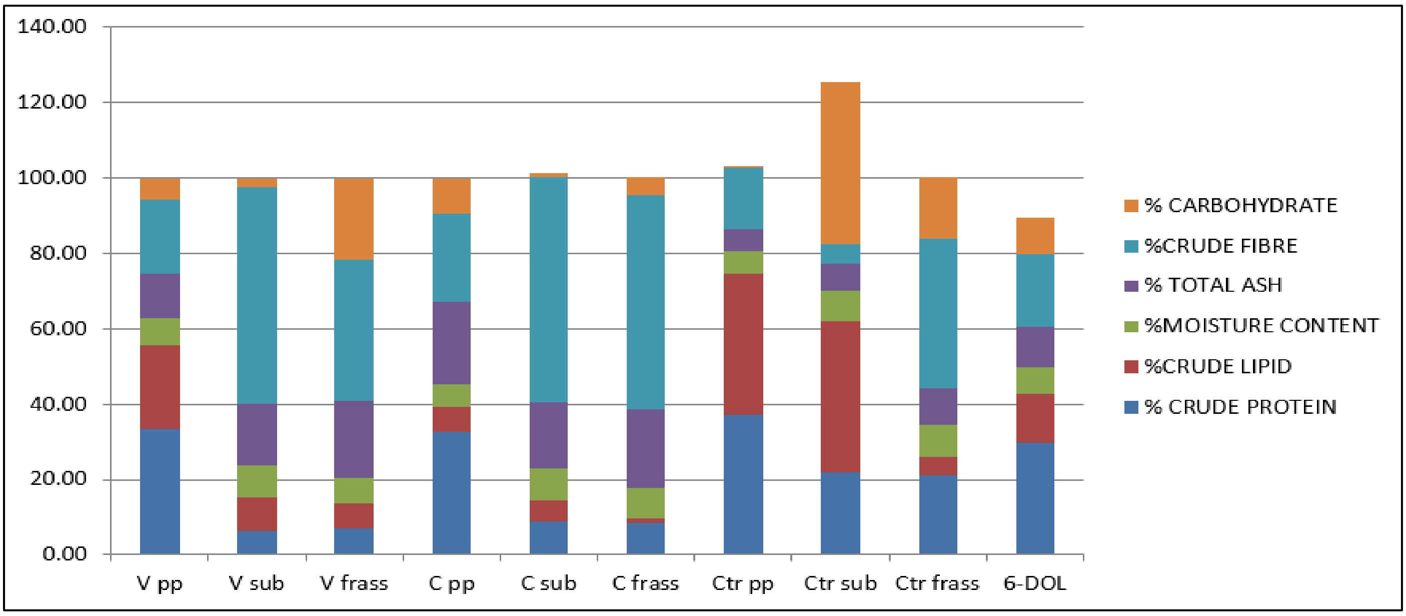

Fig 4 Proximate Constitution of C, V and Ctr Samples Prepupae, Frass and Initial Substrate State 6-DOL

The ANOVA results (Table 3) revealed significant differences ($p < 0.05$) among the three substrates for Bioconversion Rate, Bioconversion Efficiency, Waste Reduction Rate, and Waste Reduction Efficiency. Post Hoc tests indicated that vegetable waste had significantly higher performance in all parameters compared to cattle cud and control.

IV. DISCUSSION

The study investigation focused on both viability in biodegradability, bioconversion and economic potential of BSFL for managing solid organic waste of cattle cud and vegetable waste from mandate modern market Ilorin.

BSFL biodegradation and bioconversion performance varied by substrate. The control substrate consistently showed the highest growth rates, followed by vegetable waste, with cattle cud lagging behind; this is in line with the work of Liu *et al*. (2018) where the semi-digested grass similar to cattle cud showed reduced performance in larvae growth and biodegradation due to its high lignin content.

In terms of waste reduction, vegetable waste outperformed other substrates. The waste reduction efficiency (WRE) and waste reduction rate (WRR) were highest in the vegetable waste group at 73.78% and 73.77% much better than the control and cattle cud, contrary to the finding of Nguyen *et al*. (2015) which could be a result of rearing conditions. This indicates BSFL's ability to efficiently convert high moisture, fibrous vegetable waste into biomass, making it a promising substrate for organic waste management.

The bioconversion rate (BCR) and bioconversion efficiency (BCE) were also highest in the vegetable waste group, showing that not only was the waste being reduced, but a good proportion of it was being converted into larval biomass. The relative growth rate (RGR %) was highest in the control (Ctr) at 93.47 % but vegetable waste followed at a respectable 67.60 % which is supported by the work of Rampure and Velayudhannair (2023) where vegetable waste outperformed the other substrates, while cattle cud recorded a low 15.00 %, confirming that cattle cud is a less suitable substrate for rapid BSFL production.

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Feed conversion efficiency (FCE %) was best in cattle cud (18.13 %), suggesting that while overall growth was slower, the larvae converted the digestible portion of cud more effectively per unit of feed consumed which may be adduced to being partly digested by the cattle before expelling from the stomach, hence ease of absorption and conversion.

Figure 3 confirms that BSFL significantly differs at ($p<0.05$) in viability and efficiency in biodegrading vegetable waste compared to the two other substrates.

Table 3 Post Hoc Tests (Games-Howell) BCR %

Pairwise Comparison	Mean Diff.	Sig.
Vegetable vs Cattle	5	0.003
Vegetable vs control	6.34	0.002
Cattle vs Control	1.34	0.059

* Same for BCE, WRR, WRE *Shows Vegetable Waste Significantly Outperformed Both Cattle Cud and Control

Proximate analysis highlights that BSFL efficiently digest and convert nutrients from different organic wastes; especially vegetable waste and chicken (control) feed into valuable larval biomass rich in protein and lipids — supporting vegetable waste potential as a sustainable waste management and protein production solution.

The nutrient-rich frass produced after digestion had high ash content, indicating potential for use as an organic fertilizer. Vegetable frass had a protein content of 7.00% and ash content of 20.24%, making it suitable for soil amendment and organic farming applications.

➢ *Economic Value Assessment*

The economic drivers from the study;

- High biodegradation and bioconversion rates for vegetable waste (WRR and WRE at 73.7%)
- Good protein- and lipid-rich larval biomass
- Nutrient-rich frass usable as organic fertilizer
- Low-cost, abundant feedstock sources (market vegetable waste and cattle cud)

Table 4 Market Overview and Sample Economic value Projection Per Month (Per 100kg 0f Vegetable Waste), 2024

SN	Item	Average Price/kg (₦)	Remark
1	BSFL meal market price	1,050.00	Protein source for poultry, fish feed
2	Frass (organic fertilizer)	85.00	Depending on nutrient content
3	Vegetable waste disposal cost	35,000.00/month	Usually a liability for markets

Table 5 Assumption Based on the Study's Rates

Parameter	Value (from Study/Estimates)
Waste reduction rate (WRR)	73.77% (reduces 100 kg to 26.23 kg)
Larval biomass yield	~20 kg per 100 kg of vegetable waste
Frass produced	~50 kg per 100 kg of vegetable waste
Cost of waste collection	Negligible (free/raw from market waste)

Table 6 Potential Revenue

Product	Quantity	Market Price (₦/kg)
Larval biomass	20 kg	₦1,050
Frass	50 kg	₦85

Table 7 Estimated Cost (Per 100kg of Waste)

Item	Estimated Cost (₦)
Labour (sorting/harvesting)	₦3,000
Rearing containers and water	₦1,500
Utilities (electricity, etc.)	₦500
Miscellaneous (transport, etc.)	₦500
Total Operational Costs	**₦5,500**

➢ *Net Profit (Per 100kg of Waste)*

- *Scalability Potential:*

✓ 500 kg/day waste → approximately ₦92,500 net profit/day
✓ Monthly (25 days) → approximately ₦2.3 million

- *Value Proposition*

✓ Profitable, low-cost organic waste management
✓ High-value BSFL protein for animal feed industry (Nigeria's livestock and aquaculture markets are growing)
✓ Organic fertilizer for sustainable agriculture

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V. CONCLUSION

Vegetable waste is the most economically viable substrate for BSFL rearing, offering high waste reduction efficiency, protein-rich biomass, and valuable organic fertilizer, with a strong profit margin of ~77% per production cycle and Waste management cost savings for Mandate market Ilorin considering Nigeria's 2024 market rates. Although cattle cud was not as effective overall, it did show a decent feed conversion rate, meaning the larvae made good use of what little digestible material it had. The larvae also produced nutrient-rich frass (organic fertilizer) and protein-packed biomass suitable for animal feed, both valuable by-products.

This highlights the strong business potential BSFL technology has in creating employment, improve sanitation, reduce waste management costs, and support Nigeria's push for sustainable protein sources and organic farming inputs.

RECOMMENDATION

BSFL farming should be employed to manage solid organic wastes of vegetable and abattoir section in Mandate market and by suggestion, other markets in the metropolis. A commercial BSFL farms should be encouraged among farmers to build a steady market for BSFL products since it is cost-effective and profitable. The government and private investors involved should fund BSFL projects in order to cut down waste, and create jobs. Farmers, traders, and entrepreneurs should be trained on how BSFL farming works and the opportunities it offers.

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