

RESEARCH PAPER

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Valorisation of table waste and fruit waste by black soldiers (*Ullicens hermetica*)

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ABSTRACT

This study addresses the growing challenge of organic waste accumulation and the increasing demand for sustainable protein sources by exploring the potential of black soldier fly (*Hermetia illucens*) larvae for waste valorization. The importance of this work lies in its contribution to developing an eco-friendly and economically viable solution that simultaneously reduces organic waste and produces protein-rich biomass suitable for animal feed, thereby supporting circular economy practices. To achieve this, a comparative experimental approach was used in which larvae were reared on two types of substrates: mixed table waste and fruit waste. Equal quantities of each substrate were prepared, processed, and maintained under controlled environmental conditions. Larvae were seeded into the substrates and monitored over a period of 10 to 20 days. Waste reduction efficiency was determined by comparing initial and residual substrate masses, while larval biomass production was assessed by measuring growth before and after the rearing period. The results revealed that table waste was significantly more effective than fruit waste. Residual mass from table waste was 48 kg compared to 72 kg from fruit waste, indicating higher degradation efficiency. Waste reduction rates ranged from 73% to 80%. In addition, larval biomass increased dramatically, with an approximate 430-fold increase observed during the experimental period. Fruit waste showed lower performance, likely due to high moisture content and lower nutritional value. In conclusion, black soldier fly larvae demonstrate strong potential for efficient organic waste conversion, with table waste identified as the more suitable substrate for maximizing both waste reduction and biomass production.

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## INTRODUCTION

The rapid increase in global population and urbanization has led to a significant rise in the generation of municipal solid waste. Current estimates indicate that billions of tonnes of waste are produced annually worldwide, posing serious environmental and public health challenges (Banque mondiale, 2018). In many developing regions, including Africa, waste management systems remain inadequate, resulting in the accumulation of organic residues that contribute to ecosystem degradation and disease burden.

At the same time, the growing global population is expected to intensify the demand for food, particularly protein sources. It is projected that food production will need to increase substantially in the coming decades to meet this demand. Paradoxically, a significant proportion of food produced globally is lost or wasted along the supply chain, including at the household level. This dual challenge—rising waste generation and increasing protein demand—calls for innovative and sustainable solutions.

In this context, insects have emerged as promising agents for organic waste valorization. Among them, the black soldier fly (*Hermetia illucens*) has received considerable attention due to its ability to efficiently convert a wide range of organic substrates into biomass. The larvae of this species are highly voracious and capable of reducing large quantities of biodegradable waste while producing protein-rich biomass that can be used as animal feed. In addition, the residual material generated after larval activity can be utilized as organic fertilizer, contributing to circular economy approaches.

Previous studies have shown that the efficiency of bioconversion by black soldier fly larvae depends largely on the nature and composition of the substrate. Nutritional balance, moisture content, and organic matter composition are key factors influencing larval growth, development, and waste reduction efficiency. However, there is still a need to better understand how different types of commonly available organic waste, such as table

waste and fruit waste, affect these processes under local conditions.

Therefore, the objective of this study is to compare the effectiveness of table waste and fruit waste as substrates for the production of black soldier fly larvae. Specifically, the study aims to evaluate waste reduction efficiency and larval biomass production in order to identify the most suitable substrate for optimizing both waste valorization and protein generation.

## MATERIALS AND METHODS

### Study area

The experiment was conducted in a greenhouse at the International Institute of Tropical Agriculture (IITA), Abomey-Calavi, Benin (6°25' N; 2°20' E; altitude ≈ 15 m above sea level). Environmental conditions, including temperature, humidity, and light, were maintained as constant as possible throughout the experiment to ensure uniformity.

### Experimental design

A comparative experimental approach was used to evaluate the bioconversion efficiency of black soldier fly (*Hermetia illucens*) larvae on two types of substrates: mixed table waste and fruit-only waste. Equal initial masses of substrates were used for each treatment, and all experimental units were maintained under identical environmental conditions.

### Collection of substrates and larvae

Table waste, consisting of food residues, vegetables, and fruits, was collected from households, restaurants, and agro-industries in Abomey-Calavi and Cotonou. Fruit waste was obtained from vendors at Dantokpa market. The larvae used in the experiment originated from a locally maintained colony at IITA, ensuring consistency in biological characteristics (Wang and Shelomi, 2017).

### Substrate preparation

Collected table waste was finely crushed to improve larval accessibility and feeding efficiency. Fruit waste

was also crushed and subjected to partial dewatering using baskets to reduce excessive moisture, which can negatively affect larval growth and nutrient utilization (Nguyen *et al.*, 2013).

### Larval seeding and rearing

Newly hatched larvae were introduced into the prepared substrates. Multiple experimental units were established for each substrate type to assess larval growth performance and waste degradation. The rearing period ranged between 10 and 20 days, which corresponds to the typical developmental cycle of black soldier fly larvae under controlled conditions (Lalander *et al.*, 2013).

### Measurement of waste reduction

The efficiency of waste degradation was evaluated by comparing the initial mass of the substrate with the residual mass after larval activity. The abatement rate was calculated as:

$$\text{Abatement rate} = (Q_1 - Q_2) / Q_1$$

where  $Q_1$  represents the initial mass of the substrate and  $Q_2$  represents the remaining residue after the experimental period. This approach is commonly used to assess bioconversion efficiency in organic waste treatment systems (Lalander *et al.*, 2013).

### Larval biomass assessment

Larvae were harvested between 14 and 18 days after seeding. The total biomass was measured to evaluate growth performance. The increase in larval mass was used as an indicator of substrate conversion efficiency, reflecting the ability of larvae to transform organic waste into protein-rich biomass (Shishkov *et al.*, 2019).

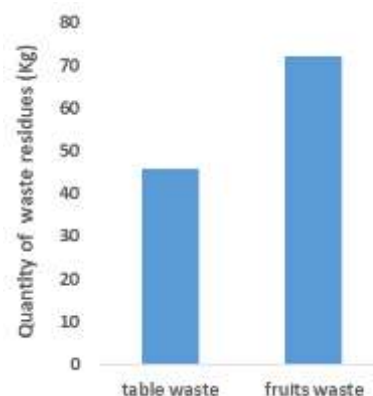
### Statistical analysis

All collected data were recorded and analyzed using R statistical software. Regression analysis was performed to evaluate the relationship between the quantity of waste introduced and the amount of residual material, providing insight into the efficiency and consistency of the bioconversion process.

## RESULTS

### Comparison of substrate types

The comparison between the two substrate categories revealed clear differences in degradation efficiency. As shown in Fig. 1, both substrate types had an identical initial mass (165 kg), but the residual mass differed significantly. Table waste produced 48 kg of residues, whereas fruit waste generated a higher residual mass of 72 kg.



**Fig. 1.** Quantities of residues depending on the types of waste

Additionally, visual observations indicated that larvae reared on table waste were larger and more developed compared to those reared on fruit waste. This suggests that table waste provides a more suitable nutrient composition for larval growth.

### Waste reduction efficiency (table waste)

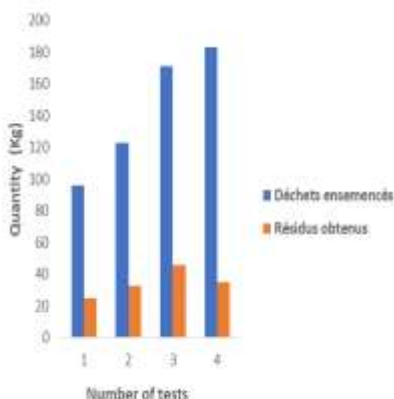
The degradation performance of table waste was further evaluated using different initial quantities. The results presented in Fig. 2 and Table 1 show that the reduction rates ranged from 73% to 80%.

**Table 1.** Variations in the quantities of residues obtained according to the quantities of waste seeded

Test number	Q1 quantity of waste seeded (kg)	Quantity Q2 of residues (kg)	Abatement rate $(Q_1 - Q_2) / Q_2$
1	96	25	0,74
2	123	32,45	0,74
3	171	46	0,73
4	183	35,1	0,80

Despite variations in the initial quantities of waste, the proportional reduction remained relatively consistent,

indicating that black soldier fly larvae maintain stable degradation efficiency across different substrate loads.

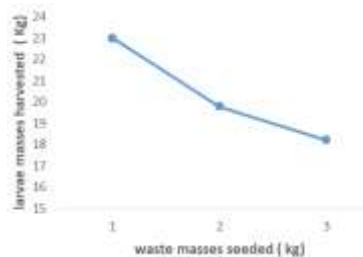


**Fig. 2.** Variations in the amounts of residues obtained according to waste seeded

**Larval biomass production**

Larval growth performance showed a substantial increase in biomass. As illustrated in Fig. 3 and summarized in Table 2, the average larval mass

increased from approximately 2.88 g at the beginning of the experiment to about 1250 g at harvest.



**Fig. 3.** Variations of the larvae masses harvested according to the waste masses seeded

**Table 2.** Quantities of waste seeded

Test number	1	2	3
Quantity of waste (kg)	57	48	45

This represents an increase of nearly 430 times, demonstrating the strong capacity of black soldier fly larvae to convert organic waste into protein-rich biomass. Higher substrate quantities were generally associated with increased larval biomass production.

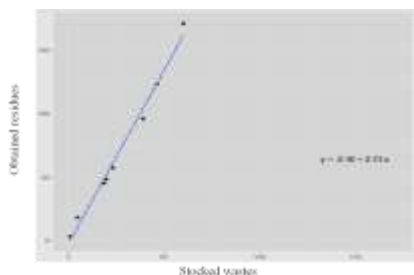
**Table 3.** Validation of the regression model between the amounts of seeded waste and residues harvested

	degree of freedom	sum squares	average squares	F	critical value of F
Regression	1	21888,249	21888,249	488,893	5,59e-07
Residues	6	268,626	44,771		
Total	7	22156,875			

Coefficient of determination  $R^2 = 0,99$

**Table 4.** Results of the regression model

	Coefficients	Error-type	Statistical Type t	Probability
Constante	-2,155	4,035	-0,534	0,6124
Quantity of Waste Residues in kg	2,730	0,123	22,111	5,59e-07***



**Fig. 4.** Variations in the amount of residues obtained according to the amount of waste seeded

**Relationship between waste input and residue output**

The relationship between the quantity of waste introduced and the residual mass obtained is presented in Fig. 4, with statistical details provided in

Table 3 and Table 4. The regression analysis yielded a high coefficient of determination ( $R^2 = 0.99$ ), indicating that most of the variation in residue quantity is explained by the initial waste input.

However, while the overall regression model was statistically significant, the coefficient associated with waste quantity was not always significant, suggesting that other factors—such as substrate composition and moisture content—also influence the outcome.

**Substrate influence on larval development**

Overall, the results confirm that substrate type plays a critical role in larval development. Table waste supported faster growth, higher biomass

accumulation, and lower residual output compared to fruit waste. In contrast, fruit waste resulted in smaller larvae and higher residual mass, indicating lower bioconversion efficiency.

## DISCUSSION

The findings of this study clearly demonstrate that substrate composition plays a decisive role in the efficiency of bioconversion by black soldier fly (*Hermetia illucens*) larvae. The superior performance of table waste compared to fruit waste can be attributed primarily to differences in nutrient balance and moisture content. Table waste, which typically contains a mixture of carbohydrates, proteins, and lipids, provides a more complete diet for larval development. In contrast, fruit waste is generally characterized by high moisture content and lower levels of protein and fat, which are essential for optimal larval growth. This observation is consistent with the work of Nguyen *et al.* (2013), who reported that nutrient-rich substrates significantly enhance larval development rate and biomass accumulation.

The higher residual mass observed in fruit waste further reflects its lower degradation efficiency. Excess moisture in fruit substrates can limit oxygen availability and create less favorable conditions for larval feeding activity. Moreover, dilution of nutrients due to high water content may reduce the effective intake of essential macronutrients. Similar limitations of high-moisture substrates have been reported in previous studies, where substrate quality directly influenced both waste reduction and larval growth performance (Wang and Shelomi, 2017).

The reduction rates obtained for table waste (73–80%) confirm the strong capacity of black soldier fly larvae to process organic waste efficiently. These values are in close agreement with those reported by Lalander *et al.* (2013), who demonstrated that larvae can reduce organic waste mass by up to 80% within a short period. This high degradation efficiency highlights the potential of *H. illucens* larvae as a sustainable solution for organic waste management, particularly in rapidly urbanizing regions where waste accumulation is a growing concern.

Larval biomass production in this study was notably high, with a substantial increase in mass during the rearing period. This reflects the remarkable ability of black soldier fly larvae to convert low-value organic waste into high-value protein biomass. The observed growth trend aligns with the findings of Shishkov *et al.* (2019), who emphasized the rapid metabolic and growth rates of larvae under favorable feeding conditions. Such efficiency makes black soldier fly larvae an attractive option not only for waste reduction but also for the production of alternative protein sources for animal feed.

The strong relationship identified between the quantity of waste introduced and the amount of residual material suggests that input mass is an important factor in determining overall system performance. However, the limited statistical significance of this relationship in some cases indicates that other variables, such as substrate composition, moisture level, and microbial activity, may also play critical roles. This highlights the complexity of the bioconversion process and suggests that optimizing substrate characteristics may be more important than simply increasing input quantities.

Overall, the results reinforce the importance of substrate quality in black soldier fly-based waste valorization systems. Mixed table waste appears to provide the most favorable conditions for both efficient degradation and larval growth. These findings are consistent with broader literature, which emphasizes that balanced nutrient profiles enhance larval performance and bioconversion outcomes (Salomone, 2017; Wang and Shelomi, 2017).

From a practical perspective, the use of table waste as a primary substrate could improve the efficiency of waste management systems while simultaneously generating valuable by-products such as protein-rich larvae and nutrient-rich compost. This dual benefit supports the growing interest in circular economy approaches, where waste is transformed into resources. However, further research is needed to better understand the influence of specific substrate components and to optimize rearing conditions for large-scale applications.

## CONCLUSION

This study demonstrates that black soldier fly larvae are highly effective in converting organic waste into valuable biomass. Among the tested substrates, table waste showed superior performance compared to fruit waste, supporting better larval growth and producing lower amounts of residual material. This indicates that a balanced substrate composition plays a crucial role in efficient bioconversion.

The waste reduction efficiency observed in this study ranged from approximately 73% to 80%, confirming the strong capacity of the larvae to degrade organic matter. At the same time, a substantial increase in larval biomass was recorded during the rearing period, highlighting the ability of the larvae to transform low-value waste into high-value protein-rich material.

In contrast, fruit waste exhibited lower efficiency, mainly due to its high moisture content and lower nutritional balance, which negatively affected both larval development and waste degradation. These findings suggest that substrate quality is more important than the quantity of waste in determining overall system performance.

Overall, the use of black soldier fly larvae represents a sustainable and practical solution for organic waste management, with the added benefit of generating valuable by-products such as protein-rich biomass and nutrient-rich residues.

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