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Impact of Compost Produced With Coffee Pulp and *Hermetia Illucens* on Tomato Plant Growth.

Diana M. Cuesta-Parraa,b,\*, Carlos Enrique Montenegro-Marínb, Felipe Correa-Mahechaa, Genoveva Rosano-Ortegac, Lorena Ortegaa

a Facultad de Ingenierías, Universidad de América, Avenida Circunvalar 20-53. Bogotá-Colombia

b Facultad de Ingeniería, Universidad Distrital Francisco José de Caldas, Carrera 7 # 40B – 53 Bogotá Colombia

c  Facultad de Ingeniería Ambiental del Decanato de Ciencias Biológicas, Universidad Popular Autónoma del Estado de Puebla (UPAEP), Calle 21 Sur 1103. Heroica Puebla de Zaragoza, Puebla, México.

\*dmcuestap@udistrital.edu.co

**Abstract**

This study evaluated the bioconversion of coffee pulp by *Hermetia illucens larvae* in a controlled reactor designed to regulate temperature (27–30 °C), relative humidity (60–70%), and aeration. The system monitored environmental temperature, relative humidity, CO₂ concentration, and substrate temperature. The substrate—coffee pulp with 82.67% moisture, pH 5.32, and 38.58% total organic carbon—was supplied at 1 kg per container with 100 larvae (feeding rate: 115.53 mg dry matter/larva/day), with three replicates and a control without larvae. Larval growth was monitored for 15 days. The highest mass (0.133 ± 0.007 g) and length (18.0 ± 0.42 mm) were observed on day 14. CO₂ concentration peaked at 5553 ppm on day 10, while environmental conditions remained stable throughout the experiment. The resulting compost exhibited a pH of 9.71, density of 0.53 g/cm³, and 36.04% total organic carbon. The fertilizer was tested in germination assays using *Solanum lycopersicum* (tomato) seeds and coconut coir in various ratios. The 1:3 frass-to-coir treatment yielded the best plant performance: 96 cm height, 23 mm stem thickness, 14 leaves, and 86.67% germination over 27 days. These results demonstrate that black soldier fly larvae can effectively bioconvert coffee pulp into a nutrient-rich organic fertilizer suitable for early-stage plant development, supporting its potential application in sustainable agriculture.

1. **Introduction**

The coffee industry generates significant quantities of organic waste, particularly coffee pulp, which constitutes approximately 617 kg of solid residues and nearly 6000 L of wastewater per ton of processed coffee (Diyarma, 2019; Abd Manan et al., 2024). These by-products are rich in organic matter—including carbohydrates, proteins, fibers, and polyphenols (Heeger et al., 2017)—and are characterized by high biochemical and chemical oxygen demand, contributing to water and soil pollution (Ijanu et al., 2020; Laili et al., 2022).

Bioconversion using black soldier fly (*Hermetia illucens*) larvae has emerged as a promising strategy for managing agro-industrial waste. These larvae can efficiently degrade a variety of organic substrates while producing valuable by-products such as protein-rich biomass and frass—a residue that can serve as an organic fertilizer (Van Huis et al., 2013; Liu et al., 2022). Studies have demonstrated that H. illucens can reduce the mass of organic waste significantly and improve the physicochemical properties of the resulting fertilizer (Ma et al., 2018; Lardé, 1990).

Despite its potential, the application of coffee pulp as a substrate for BSF larvae remains underexplored due to its high polyphenol content, which may affect larval growth and development. This study evaluates the growth performance of *H. illucens* larvae on coffee pulp and examines the quality of the resulting fertilizer. Furthermore, the agronomic potential of the frass is assessed through a germination test using tomato (*Solanum lycopersicum*) seeds.

1. **Materials and Methods**

**2.1 Design and Construction of the Laboratory-Scale Reactor.**

The bioreactor is a controlled system that includes a growth chamber made of a polypropylene container with dimensions of 67.6 × 85.5 × 39.0 cm and a maximum capacity of 18 kg. The control module incorporates an STC 3028 device (-20 to 80°C, 0 to 100% RH), an electric heating element, and an ultrasonic humidifier HUM-24V (15 mL/h). Air inlet and outlet are regulated with a dual analog timer EBCHQ®, and three Phoenix® air fans with a flow rate of 170 m³/h and 3000 RPM are included. The monitoring module consists of an M135 air quality sensor for detecting harmful gases, a CCS811 CO₂ sensor with a sensitivity range of 400 to 8192 ppm, a DHT11 sensor for ambient temperature and relative humidity (0–50°C, 20–95% RH), and four K-type thermocouples Max 6675 (0–1024°C) for verifying the temperature in the substrate-larvae containers. The programming was conducted using Arduino® libraries.

In the study, coffee pulp from the Manizales region in Colombia was used, with a feeding rate of 115.53 mg dm/larva/day. Larval growth in terms of mass and length was evaluated over 15 days. The reactor's environmental temperature was programmed between 27 and 30°C, and relative humidity was maintained at 60–70%. Bioconversion indicators and the percentage of waste reduction were selected to evaluate the process using Equations 1 and 2 (Gold et al., 2020) (Villa et al., 2021)(Z. Liu et al., 2022)(Parodi et al., 2021):

**2.2. Chemical Composition of Substrate and Fertilizer**

To characterize the coffee pulp and the fertilizer obtained through biodegradation, the following analyses were conducted: pH using the potentiometric method, moisture content using the gravimetric technique, total organic carbon content using the colorimetric method (ICONTEC, 2022), and phosphorus content using the Olsen method (Recena et al., 2022).

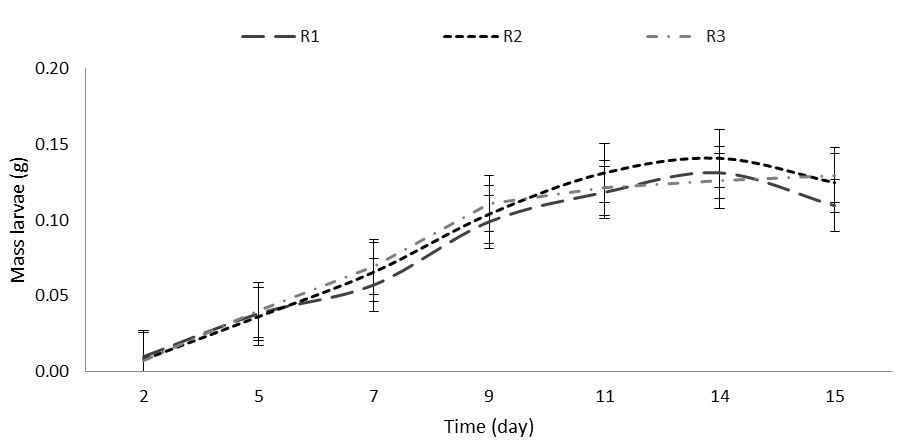
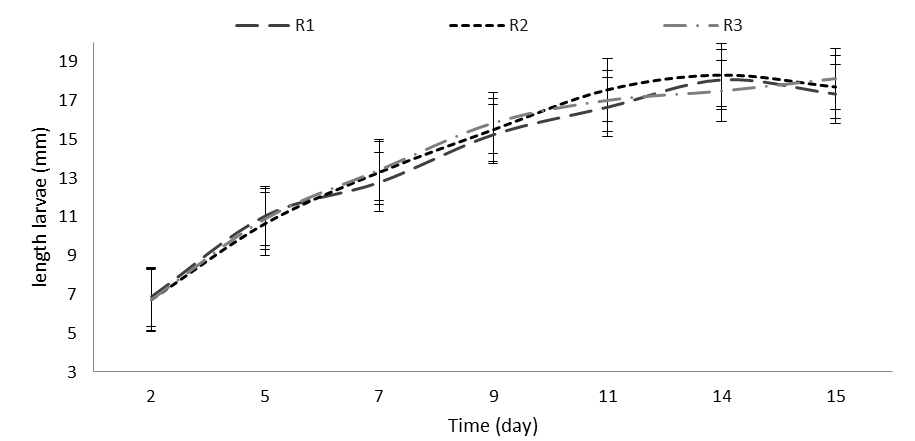
**2.3. Germination and Growth Evaluation of Tomato Plants**

For the germination and growth test of tomato seeds and seedlings, *Solanum lycopersicum* seeds were used. Soil conditioning for cultivation included BSF derived fertilizer and coconut coir in five ratios: 1:0, 3:1, 1:1, 1:3, and 0:1. The coconut fiber and frass mixtures were previously sanitized at 45°C for 24 hours. In each 3.3-ounce seedling tray, three seeds were sown, and each treatment had ten replicates. A vernier caliper was used to measure the size and thickness of plant structures, leaves and stems, on a daily basis.

1. **Results**

The experiment was conducted using five-day-old *Hermetia illucens* larvae. A total of 100 larvae per kilogram of coffee pulp (moisture content: 82.67%) were introduced into each treatment. The setup included three replicates (R1, R2, R3) and a control without larvae. The samples were incubated for 15 days in a controlled laboratory reactor under a temperature range of 27–30°C and a relative humidity of 60–70%. Larval length and mass were measured every three days.

As shown in Figures 1 and 2, larval growth increased steadily over time, reaching a maximum average mass of 0.133 ± 0.007 g and length of 18 ± 0.42 mm on day 14. A slight decrease was observed on day 15 (0.121 ± 0.010 g and 17.7 ± 0.38 mm), likely due to the mobilization of internal reserves (lipids and proteins) for metabolic processes and pupation.

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*Figure 1 and 2: Black soldier fly larvae growth (g), (mm).*

The biotransformation process achieved a waste reduction efficiency of 45.81% ± 4.48 and a bioconversion rate of 1.63% ± 0.87. These values, although slightly lower than those reported by Casallas et al. (2024) (56.56% and 66.89% over 21 days), suggest that extending the residence time could enhance waste degradation. Similarly, the bioconversion rate was lower than the range of 9.01% to 19.80% reported by Barrantes et al. (2024) for food waste mixtures, highlighting the influence of substrate type and duration on conversion efficiency*.*

*Table 1: characterization of organic fraction of BSF larvae*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Parameter** | **Allowed values in fertilizers (Colombia)** | **Coffee pulp** | **Fertilizer BSF** | **Blank\*** |
| Density (g/cm3) | (<0.6) | 1.84 | 0.53 | 0.36 |
| pH | (4-9) | 5.32 | 8.96 | 8.94 |
| %TOC | (> 15) | 38.58 | 40.41 | 39.50 |
| % Moisture | (< 20) | 82.67 | 75.96 | 82.26 |
| %Ashes | (< 60) | 7.45 | 22.70 | 17.51 |
| % P | (> 1) | <0.001 | <0.001 | <0.001 |

\*Blank:degradation without larvae

Table 1 presents the physicochemical characterization of the coffee pulp and the resulting frass (larval fertilizer). The process improved key parameters such as pH and organic carbon content, aligning with the standards of NTC 5167:2022 for use as fertilizer in Colombia. However, moisture content and phosphorus levels remained outside the recommended ranges, indicating the need for post-treatment strategies like drying or nutrient fortification.

Continuous monitoring of CO₂ levels in the reactor showed fluctuations between 400 and 5000 ppm (Figure 3), with average ambient temperatures of 29–30°C. These elevated CO₂ levels may result from inadequate aeration, as fans operated for only 5 minutes every hour. Future optimization of the aeration cycle is necessary to maintain CO₂ concentrations within ideal ranges (400–1000 ppm) for larval development and microbial activity.

3 4 5 6 7 8 9 10 11 12 13

*Figure 3:* *Monitoring temperature and CO2 concentration in the reactor*

In the germination assay, *Solanum lycoper*sicum seeds were sown in mixtures of frass and coconut coir in five different ratios. After 27 days, the 1:3 frass-to-coir mixture yielded the best plant development: an average height of 96.23 mm, 14 leaves, 1.9 mm stem diameter, and 86.67% germination rate. Treatments with 1:1 and 3:1 ratios also showed promising results. Notably, the 1:0 treatment (pure frass) failed to support seed germination, likely due to phytotoxicity or excess salt concentration. The results are shown in Table 2.

*Table 2: Germination test results using BSF fertilizer for tomato plants (Solanum lycopersicum)*

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Treatment | Frass\*:Coconut Coir Ratio | Germination (%) | Height (mm) | Number of Leaves | Stem Diameter (mm) | Number of Flowers |
| 1 | 1:0 | 0.00% | - | - | - | - |
| 2 | 3:1 | 93.33% | 31.20 | 3 | 1.1 | NA |
| 3 | 1:1 | 76.67% | 68.22 | 8 | 1.4 | NA |
| 4\*\* | 1:3 | 86.67% | 96.23 | 14 | 1.9 | NA |
| 5 | 1:1 | 93.33% | 65.05 | 9 | 1.4 | NA |

\*Frass: biomass, fertilizer produced by larvae and black soldier fly.

**4. Conclusions**

This study demonstrated the potential of black soldier fly (*Hermetia illucens*) larvae to bioconvert coffee pulp into an organic fertilizer suitable for agricultural applications. Specifically, the 1:3 frass-to-coconut coir mixture supported successful seed germination and early growth of *Solanum lycopersicum* (tomato), indicating its potential use in seedling production.

Although larval growth was not significantly affected by the polyphenol content of coffee pulp, the maximum reported larval size was not reached, suggesting that further optimization—such as extending the residence time or supplementing the substrate—may be required. Stable temperature conditions (27–30°C) proved essential for efficient waste reduction and larval development.

The reactor's aeration system showed limitations, with CO₂ concentrations reaching up to 5000 ppm. Future studies should aim to define the optimal CO₂ thresholds for larval performance to improve aeration strategies and maintain favorable environmental conditions.

Overall, the bioconversion process effectively reduced organic waste while producing a nutrient-rich fertilizer that meets several requirements established by Colombian standards (NTC 5167:2022). These findings underscore the feasibility of converting agro-industrial by-products such as coffee pulp into valuable biofertilizers, contributing to sustainable agriculture and circular economy models.

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Dear reviewers, we are very grateful for your comments, we attach the modifications and a list of the information regarding the article:

REVIEWER # 1

Paper # 199

Title IMPACT OF COMPOST PRODUCED WITH COFFEE PULP AND HE ...........

by:Cuesta-Parra D.M.,Correa-Mahecha F.,Montenegro-Mar.......

Is the contribution original and up-to-date? :.............................sufficient

Has it engineering / scientific relevance?:................................sufficient

Is the presentation clear with a good expression of English?:..............sufficient

Are references written according to Harvard Style?:........................no

The correction was made in Harvard style

Is this paper referencing any Chemical Engineering Transactions article?:..yes

decision: accept after major revisions

Comments by reviewer

English should be partly revised since there are some inaccuracies in the text.

English correction was done

The manuscript title is in “Title Case”, i.e., in capital letters for the principal words.

Impact of Compost Produced With Coffee Pulp and Hermetia Illucens on Tomato Plant Growth

Do not use capital letters for prepositions, articles or conjunctions unless one is the first word.

The manuscript was revised and intermediate capital letters were removed.

Equations do not comply with the format requested by CET Template

the equations were changed to the Journal style

The scientific name Solanum lycopersicum should be italicized, in section 2.4.

The italic in the scientific name was corrected and numeral 2.4 was changed to 2.3

The authors should decide whether to use BSF or BSFL as an abbreviation for Black Soldier Fly Larvae. In addition, the abbreviations should be introduced in the text the first time they are discussed.

BSF was established as the acronym for black soldier fly larvae. It was included in Section 1 Introduction

What does “Frass” represent (Table 2)? Never explained this.

The explanation of the phrase is included in Table 2.

White: it is not a term used. Use instead “Control” with regular NPK fertilizer and specify the quantities used in the tests.

White was replaced by Blank in Table 1, corresponding to degradation without larvae

When the authors present Graphs 1 and 2 no reference is made to R1, R2 and R3. Are they replicates? If so, please add in the text and increase the font of the legend and axes in the Plots.

The graphs are comparisons of the replicas, the reference is included in section 3 results

Table 1: last column about Phosphorus. The numerical values are in per cent or decimal? Are all the values exactly equal to 0.0010? Seems strange.

The phosphorus content is very low and the analysis shows the lower limit, the less than sign is included in the table 1.

Figure 3: there is no caption and it should be plotted in such a way as to read easily the values on the x-axis.

The title of Figure 3 is added and the graph is modified

The methods section requires clarification to ensure reproducibility and understanding. If present, the sterilization process for seeds and cultivation media should be explained. Is the BSFL-derived fertilizer and coconut coir in the specified ratios (1:0, 3:1, 1:1, 1:3, and 0:1) sterilized or pre-treated? The growth and relative measurements also require more details in the methods section. It should be clearly explained how germination was assessed, what tools were used to measure height, leaf number, and stem diameter, and at which days after germination these data were collected (reported in the abstract and not in the Methods section).

If seedlings were grown for 27 days, the cultivation medium or fertilizer used should be detailed.

the sanitization of more soil mixtures and the measuring instrument for plant growth is included in section 2.3.

Some references should be rewritten since the surnames were abbreviated by the program you used for the Bibliography: Barrantes, Casallas Martin

authors' surnames were rewritten in references

REVIEWER # 2

Paper # 199

Title IMPACT OF COMPOST PRODUCED WITH COFFEE PULP AND HE ............

by:Cuesta-Parra D.M.,Correa-Mahecha F.,Montenegro-Mar .......

Is the contribution original and up-to-date? :.............................poor

Has it engineering / scientific relevance?:................................sufficient

Is the presentation clear with a good expression of English?:..............poor

Are references written according to Harvard Style?:........................yes

Is this paper referencing any Chemical Engineering Transactions article?:..yes

decision: accept after major revisions

Comments by reviewer

.......

IMPACT OF COMPOST PRODUCED WITH COFFEE PULP AND HERMETIA ILLUCENS ON TOMATO PLANT GROWTH.

The abstract enters into too much detail of the experimental conditions, while the meaningful results are not clearly highlighted

The introduction is fairly repetitive. The same concept is mentioned twice with different words and detail. However, I wasn’t eventually able to understand what is the coffee pulp in Authors’mind (notwithstanding collaboration with industries producing coffee powder for instant, domesticand commercial machines), nor the goal of the study, whether it is growing larvae of Hermetiaillucens or obtaining some other product, like a compost to grow tomatoes.

the abstract, introduction and results were reviewed and improved. Although the germination test focused on tomatoes, the resulting fertilizer has potential for application to other crops, warranting further agronomic evaluations to expand its use in sustainable agriculture.

BSF as an acronym appears without specifying this black soldier fly (I guess) You should not give for granted that the reader knows what is an STC 3028 device ‘a feeding rate of 115.53 mg DM/larva/day’ is not clear what that means in terms of mass flow of pulp

BSF was established as the acronym for black soldier fly larvae. It was included in Section 1 Introduction.

STC 3028 is the control module mentioned in the text as controlling temperature and relative humidity.

The abstract includes "feeding rate: 115.53 mg dry matter/larva/day".

The equations 1 apparently conveys a different meaning, it looks like a specific production of larvae. In the second equation (1 – grams) suggests some inconsistency of units All the parameter investigated (pH, moisture,…) suggest that some design of experiment or at least some combination of different experiments was performed (not mentioned) As a curiosity, I wonder how the mass of larvae is measured. I assume they are growing within the whole mass of the pulp, so their amount is based on the weight of the whole chamber (expected>10kg). If that is the case how increases in the mass by 0.01g or less is reproducibly measured?

the results of the application are discussed in the paragraph before table 1. and corresponds to the efficiency of the larvae in the transformation of the substrate.

To answer your questions all larvae were removed from the substrate every third day and weighed together generating an average mass of the larvae.

Loss of weight by moisture removal should also be expected, I guess.

loss of mass in larvae is due to protein and fat transformation conditions during morphological change

Assuming a waste reduction efficiency of 45% means that 45% of the original waste has beentransformed into something else, what is the product of the reduction?

yes, the residues and transformed into proteins and fats fixed in larvae.

Table 1 is not clear, nor explained; apparently properties of the larvae compared to the standard expected for fertilizers are reported. I guess the last column is the amount of phosphorus and none of the larvae meet the standard; is this correct?

the address of the table is modified to explain the results of the fertilizer obtained, in this article no chemical or nutritional characteristics of the larvae are included.

What is the stem thickness? Perhaps it’s the length, being much larger than the diameter?

“development: an average height of 96.23 mm, 14 leaves, 1.9 mm stem diameter, and 86.67% germination rate. Treatments with 1:1 and 3:1 ratios also showed promising results”

What is frass mentioned in Table 2?

The explanation of the phrase is included in Table 2.

The sampling of CO2 concentration is too coarse (1 sample/day) to determine whether it is connected to the ventilation cycle.

the data is a summary of the daily average for 13 days, if all the inflow is included the graph would be too large.

Finally, I wasn’t able to understand how some conclusions about the stability of the process have been taken.

the conclusions were improved in English language wording for better understanding, the article underwent a style review.

I never saw before citations like ‘Casallas Martin, B. D. C. S. N. C. M. F. C.-P. D. M. G.-T.

J. F. (2024).’

authors' surnames were rewritten in references