RESEARCH ON WASTE TREATMENT FROM HEINEKEN VIETNAM BREWERY LIMITED COMPANY USING BLACK SOLDIER FLY LARVA *(Hermetia illucens)*

Nguyen Vu Hoang Phuong[1], Tran Thanh Tu[2,3*], Ho Thien Nhi[1]

[1]*Ho Chi Minh City University of Industry and Trade*

[2]*International University, Ho Chi Minh City, Vietnam*

[3]*Vietnam National University, Ho Chi Minh City, Vietnam*

*Email: *tttu@hcmiu.edu.vn*

Received: 2 May 2025; Revised: 20 May 2025; Accepted: 31 May 2025

ABSTRACT

This study investigates the efficacy of black soldier fly (BSF) larvae in bioconverting two types of organic waste: industrial waste (brewery spent grain) and agricultural by-product (pineapple peels), at varying substrate ratios of 100:0, 70:30, 50:50, 30:70, and 0:100. Experimental findings indicate that BSF larvae exhibit robust growth performance across all treatments. Among the tested ratios, the 70:30 mixture of brewery spent grain to pineapple peels yielded the highest efficiency, with a waste reduction rate of 87.86%, larval length of 18.6 mm, width of 5.6 mm, and a biomass conversion rate of 9.45×10^{-3} g d^{-1}. These results demonstrate the superior suitability of the 70:30 formulation for large-scale organic waste management. The study highlights the potential of BSF larvae as a sustainable, scalable solution for processing industrial and agricultural organic waste, offering significant environmental and resource utilization benefits.

Keywords: Black soldier fly larval growth, brewery spent grain, pineapple peels, biomass conversion rate, sustainable agriculture.

1. INTRODUCTION

Recycling industrial waste and agricultural by-products plays a crucial role in reducing environmental pollution while simultaneously generating substantial economic benefits. Among the most abundant and readily available sources of industrial organic waste is brewer's spent grain (BSG), a by-product inherently generated during the beer production process. BSG is primarily derived from the fermentation of cereals and is commonly produced in large quantities at major breweries, such as Heineken Vietnam Brewery Co., Ltd. On average, the production of one liter of beer results in approximately 0.5 to 1.0 kg of spent grain. According to the Vietnam Beer - Alcohol - Beverage Association (VBA) [1], the global daily generation of spent grain reaches approximately 101,918 tons, with Vietnam contributing an estimated 800,000 tons annually, equivalent to around 2,192 tons per day. Chemically, BSG is rich in protein, fiber, starch, and B vitamins. However, if not properly managed, this organic waste poses a significant environmental risk due to its high biodegradability, which can lead to rapid decomposition and the release of methane gas - a potential greenhouse gas that contributes to climate change.

In addition to spent grain, agricultural by-products such as pineapple peels represent another major source of waste from the food processing industry, particularly in beverage production. Although pineapple by-products are relatively low in protein and not considered highly nutritious, they contain numerous reusable bioactive compounds, yet are often discarded after processing. Rich in fiber and fermentable sugars, these by-products can become a source of environmental pollution if not properly managed. According to the Department of Science and Technology of Ninh Binh and Mordor Intelligence [2], approximately 17.16 to 20.02 million tons of pineapple by-products are discarded globally each year. In Vietnam, the annual volume ranges from 423,000 to 493,500 tons, or approximately 1,159 to 1,352 tons per day [2]. The treatment and disposal of spent grain and pineapple by-products present a significant environmental challenge. Conventional methods such as landfilling, incineration, or anaerobic digestion (e.g., biogas systems) are often limited in efficiency and may pose additional environmental risks. Consequently, there is an increasing demand for more sustainable and effective treatment approaches.

One environmentally friendly solution currently being studied and implemented is the use of Black Soldier Fly *(Hermetia illucens)* (BSF) larvae to process organic waste. These larvae are capable of rapidly digesting and decomposing various organic materials, converting them into valuable end-products such as organic fertilizers and protein-rich animal feed. A promising strategy involves co-feeding spent grain and pineapple by-products to BSF larvae (BSFL). This is based on the complementary nutritional profiles of the two waste streams-spent grain is high in protein, while pineapple by-products are rich in fiber and readily digestible carbohydrates. Such a combination provides a balanced substrate that supports larval development and enhances bioconversion efficiency. Furthermore, this method not only improves the degradation rate of organic waste but also increases the nutritional value of the resulting biomass. A study conducted by Cornell University [9] demonstrated that co-digesting spent grain with fruit peels (though not specifically pineapple) significantly accelerated the larvae's digestion process and improved overall waste reduction efficiency within a short time frame.

The co-treatment of spent grain and pineapple by-products using BSFL represents a promising and sustainable approach to managing organic waste while simultaneously generating value-added products. In response to this issue, the authors conducted a research project entitled “Study on Waste Treatment from Heineken Vietnam Brewery Limited Company Using Black Soldier Fly Larvae *(Hermetia illucens)*”. The study was implemented through the following stages: (1) a comprehensive literature review on the ecological and biological characteristics of BSF, focusing on key parameters such as optimal temperature and humidity ranges, preferred organic substrates, life cycle duration, and developmental stages; (2) collection, classification, and preparation of organic substrates (spent grain and pineapple by-products) for larval feeding; and (3) development of a BSF rearing protocol adapted to the ecological conditions typical of Ho Chi Minh City, Vietnam. In the final phase, the research evaluated the larvae’s growth performance, developmental efficiency, and waste conversion capacity under the experimental conditions.

2. MATERIALS AND METHODS

2.1. Materials and preparation

2.1.1. BFS larvae (BFSL)

BSF *(Hermetia illucens)* eggs were sourced from the laboratory of the Practical Experiment Center at Ho Chi Minh City University of Industry and Trade, where a BSF breeding system has been continuously maintained since its establishment in 2021. Following egg collection from adult fly breeding cages, incubation was conducted in two successive 2-day cycles until hatching occurred.

Newly hatched larvae were subsequently reared for five days on soybean residue (SBR). According to [9], SBR contains 81.0-84.5% moisture (wet weight basis), 3.6-4.8% crude protein, and 1.4-3.6% fat. These nutritional characteristics make SBR a suitable substrate for promoting early-stage larval development, particularly during the critical 1-5 days post-hatching period. This feeding phase facilitates stable physiological growth before exposure to experimental treatment substrates.

2.1.2. Brewer's spent grain (BSG)

Prior to the experiment, the research team prepared the substrates by collecting, sorting, and performing preliminary processing. The larval feed utilized in this study comprised brewer's spent grain (BSG) obtained from the production process at Heineken Vietnam Brewery Co., Ltd. (170 Le Van Khuong Street, Thoi An Ward, District 12, Ho Chi Minh City), and pineapple by-products sourced from Nguyen Do Cung Market.

The combination of BSG and pineapple by-products as a feed substrate for BSFL offers several notable advantages (Table 1). BSG is characterized by a high protein content but limited carbohydrate levels, whereas pineapple by-products, primarily peels and cores, exhibit the opposite nutritional profile, being rich in carbohydrates, vitamins, and minerals (Table 2). This complementary composition allows for the formulation of a nutritionally balanced feed that supports optimal larval growth and enhances organic waste bioconversion efficiency. Furthermore, the substantial fiber content in pineapple by-products contributes to odor mitigation and improves the decomposition of organic matter, thereby creating a more conducive environment for larval development.

Table 1. The nutritional composition of brewer's spent grain

Test Parameters	Result	Unit	Methods
Moisture	77.00	%	TCVN 10788:2015
Protein	27.11		TCVN 8125:2015
Total Carbohydrate	15.39		AOAC 986.25-1988 (2002)

Table 2. The nutritional composition of pineapple by-products

Test Parameters	Result	Unit	Methods
Moisture	88.57	%	TCVN 10788:2015
Protein	5.69		TCVN 8125:2015
Total Carbohydrate	16.09		AOAC 986.25-1988 (2002)

Substrate preparation: brewer's spent grain and pineapple by-products were mixed in varying ratios and placed into pre-prepared trays. The pineapple peel was ground to a particle size of 3–5 mm, while the brewer's spent grain was used in its original form.

2.2. Experimental design

The experiment was conducted from June to December 2024 at the Practical Experiment Center, Ho Chi Minh City. During the study period, ambient temperatures ranged from 25°C to 36°C, with an average relative humidity of approximately 80%. Larvae were fed at multiple intervals, with the quantity of substrate provided at each feeding determined by three main factors: (i) the volume of pineapple peels collected from food vendors, (ii) the amount of partially decomposed substrate remaining in the rearing trays, and (iii) the developmental stage of the larvae in relation to their nutritional requirements. Each treatment was replicated three times, with substrate trays prepared in accordance with the established feeding schedule (Table 3).

Five-day-old BSFL were uniformly distributed into five experimental treatments (NT1 to NT5) using white plastic trays measuring 32 × 20.6 × 17 cm (Table 3). All trays were covered with mosquito netting to ensure adequate ventilation while preventing the entry and infestation of other insect species, particularly the house fly (*Musca domestica*).

Table 3. The diagram details the experimental treatments

Experiments	NT1	NT2	NT3	NT4	NT5	Detailed description
Mixing ratio (%) (Beer lees: pineapple by-product)	100:0	70:30	50:50	30:70	0:100	According to the study by Zhongyi and colleagues, a protein:lipid:carbohydrate ratio of 2:1:2 was found to be beneficial for larval development [4],[5],[6].
Larval density (Larvae/cm^2)	2 larvae/cm^2					According to the study by Parra Paz and colleagues, the optimal larval density ranges from 1.2 to 5 individuals per cm^2 [3],[15].
Diet	125 mg/ larvae/day					According to the study by Parra Paz and colleagues, the optimal feeding rate ranges from 95 to 163 mg/larva/day [3],[4].

2.3. Monitoring and analysis of physicochemical parameters

Temperature was recorded daily, while substrate and BSFL samples were manually collected and analyzed five times at three-day intervals throughout the feeding period. Each sampling and measurement were conducted in triplicate to ensure accuracy and reproducibility.

2.3.1. Substrate temperature

Substrate temperature during BSFL processing was monitored using five handheld thermometers, which were placed directly into five feeding trays. Temperature readings were recorded daily from the beginning to the end of the experiment to capture fluctuations and assess thermal conditions within the substrate environment.

2.3.2. Substrate moisture content (MC)

Moisture content was determined by drying a 10 g sample of each substrate type at 105°C in a UN55 drying oven until a constant weight was obtained. This gravimetric method ensured an accurate assessment of water content in the substrates.

$$MC\ (\%) = \frac{m_1 - m_2}{m_1} \times 100\% \qquad (1)$$

m_1: Wet weight (g)

m_2: Dry weight (g)

2.3.3 Substrate pH

A 2 g sample of each substrate type was diluted to 100 mL with deionized water in an Erlenmeyer flask, shaken at 150 rpm for 2 hours, and then allowed to settle for 1 hour at room temperature prior to pH measurement. The pH was subsequently determined using a calibrated pH meter (TruLab pH 1110, YSI).

2.3.4. Larval weight and length

Twenty BSFL were manually collected from each treatment group, rinsed with deionized water, and gently dried using paper towels without the application of heat. The larvae were then weighed using an analytical balance (Entris 224i-1S) and their lengths measured using a millimeter-scale ruler. Average larval weight and length were calculated for each treatment. Following measurement, the larvae were returned to their respective rearing trays for continued development and observation.

2.4. Calculation and analysis method

The team collected and compiled data to compare indicators such as larval width, length, mass, and the mass of waste before and after treatment. This information was used to assess the growth potential and waste processing capability of the larvae under different treatment conditions.

To select a substrate with an appropriate ratio to be used as feed for BSFL for various purposes under natural conditions in the laboratory and to evaluate their ability to process organic waste, the team applied the following formulas in sequence [8],[10],[11]:
a) Mortality rate (N)

$$N\ (\%) = \frac{N_T - N_S}{N_T} \times 100\% \qquad (2)$$

N_T: Number of larvae before waste treatment

N_S: Number of larvae after waste treatment

b) Biomass Conversion Efficiency (BCE)

$$BCE = \frac{(\text{Larvae Biomass Output})}{\text{Organic waste input}} \times 100\% \qquad (3)$$

c) Growth rate (GR)

$$GR\ (g\ d^{-1}) = \frac{\text{Final Value} - \text{Initial Value}}{\text{time}} \times 100\% \qquad (4)$$

d) Waste treatment efficiency (H)

$$H\ (\%) = \frac{M_T - M_S}{M_T} \times 100\% \qquad (5)$$

M_T: Initial waste mass before larval treatment (g)

M_S: Remaining waste mass after larval treatment (g)

Statistical analyses were conducted using Python (version 3.9.14). Descriptive statistics, including mean values and five-number summaries, were calculated for substrate temperature, moisture content, and pH. To evaluate the effects of decomposition time on substrate conditions and to compare differences among treatment methods, Repeated Measures Analysis of Variance (RM ANOVA) was applied with a 95% confidence interval. This approach allowed for the identification of statistically significant variations in the monitored parameters over time and across experimental treatments.

3. RESULTS AND DISCUSSION

3.1. Sensory Evaluation of Odor

A sensory evaluation was conducted to assess odor characteristics during the rearing of BSFL on substrates with varying mixing ratios of brewer's spent grain (BSG) and pineapple by-products. The assessment revealed significant variations in both odor intensity and qualitative characteristics throughout the bioconversion process.

In NT1, which utilized 100% BSG, a strong and unpleasant odor was consistently detected. This odor was primarily attributed to the microbial decomposition of protein-rich organic matter inherent in the beer waste. Among all treatments, NT1 exhibited the highest odor intensity, suggesting that the exclusive use of BSG results in a malodorous rearing environment.

As the proportion of pineapple by-products increased in subsequent treatments, a progressive improvement in odor profile was observed. In NT2, although the odor from BSG remained dominant, it was partially masked by the mild, fresh scent of the pineapple by-products. However, due to the relatively high BSG content, the overall odor was still assessed as moderately unpleasant.

In NT3, which featured a balanced ratio of BSG and pineapple by-products, a substantial reduction in odor intensity was noted. The strong, characteristic smell of the BSG was significantly diminished, while the fruity aroma of the pineapple components became more perceptible, contributing to a more neutral and acceptable odor.

In NT4, the odor profile shifted further toward a pleasant olfactory experience, with the scent of pineapple by-products clearly prevailing and only minimal traces of the original beer waste odor remaining. Notably, in NT5, with the highest proportion of pineapple by-products, produced a faint and fresh fragrance, free from any unpleasant characteristics.

These findings suggest that adjusting the substrate composition by increasing the proportion of carbohydrate-rich pineapple by-products effectively reduces odor intensity and improves the sensory environment during BSFL rearing.

Table 4. Sensory evaluation of odor during BSFL rearing on different substrate ratios

Treatment Code	Substrate Ratio (BSG : Pineapple)	Odor Intensity	Odor Characteristics	Overall Assessment
NT1	100 : 0	Very strong	Strong, unpleasant, pungent (from BSG)	Highly unpleasant
NT2	70 : 30	Strong	Dominant beer waste odor, slightly fresh note	Still unpleasant
NT3	50 : 50	Moderate	Balanced; mild pineapple aroma emerging	Noticeably improved
NT4	30 : 70	Mild	Pleasant sweet aroma from pineapple dominates	Pleasant
NT5	0 : 100	Very mild	Fresh, fruity, no unpleasant notes	Very pleasant / Neutral

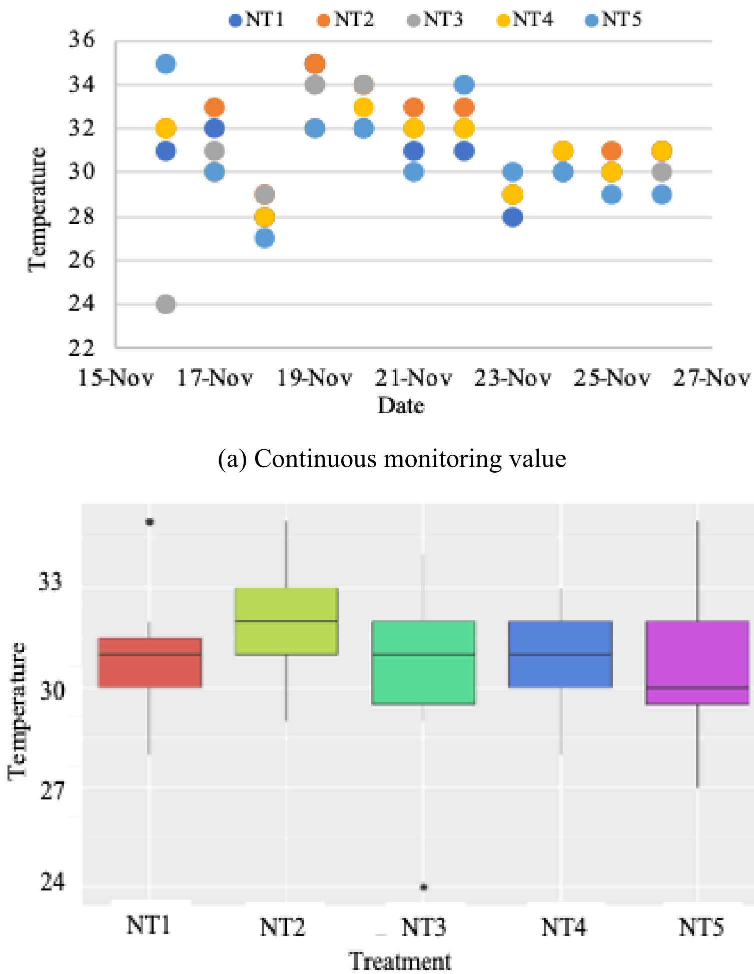
This difference demonstrates that pineapple by-products not only serve as a substrate that helps reduce odor but also significantly enhance the sensory quality when mixed with beer waste. Increasing the proportion of pineapple by-products in the substrate not only reduces odor intensity but also creates a more pleasant rearing environment.

Environmental factors such as odor, pathogens, and flies in tropical conditions are not considered inherent risks if managed properly. Odor can be effectively controlled through natural ventilation and the application of dry cover materials to maintain aerobic conditions. The thermophilic phase of organic waste treatment significantly reduces pathogen levels, meeting the World Health Organization's biosafety standards. In addition, flies and other insects can be managed through regular covering and sanitation practices, or by employing BSFL to rapidly process organic waste. Therefore, with proper technical operation, these factors can be safely managed without causing negative environmental impacts.

3.2. Physicochemical indicators of substrates

3.2.1. Substrate's temperature

Substrate temperatures in the five experimental treatments were continuously monitored and recorded daily using handheld thermometers. As decomposition progressed, the substrates underwent natural physicochemical transformations, which were reflected in temperature variations over time (Figure 1).



(a) Continuous monitoring value

(b) Five-number summary

Figure 1. Temperature of substrate in five BSFL treatments (Unit: °C)

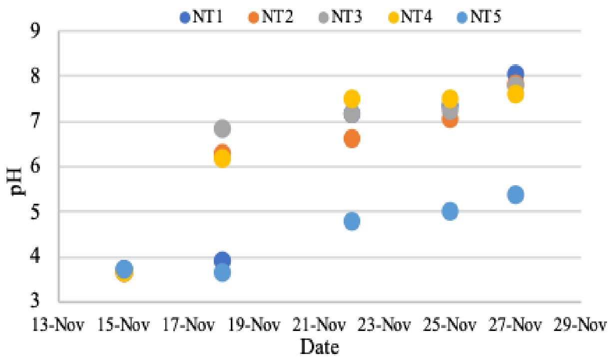
Following each feeding event - specifically on November 18 and 21 - a notable increase in substrate temperature was observed across most treatments, with average rises ranging from 1 °C to 3 °C. These temperature elevations were indicative of heightened microbial and larval activity associated with the initial stages of organic matter decomposition. Subsequently, the temperature in each treatment exhibited a characteristic inverted U-shaped trend, peaking shortly after feeding and gradually declining as decomposition stabilized.

This thermal pattern, however, was less prominent in NT5. Unlike the other treatments, NT5 showed minimal temperature fluctuations and lacked the pronounced post-feeding spike, suggesting a more stable and less intense decomposition process, likely due to its higher proportion of pineapple by-products and lower protein content.

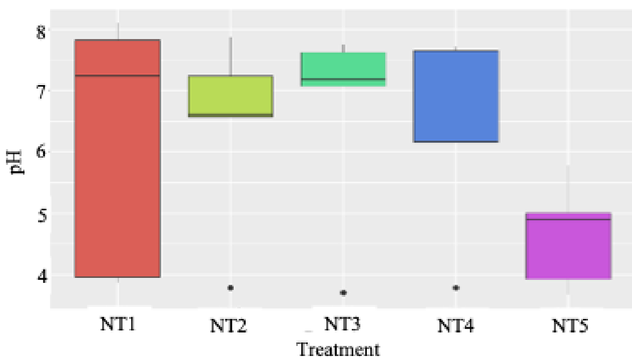
The highest mean substrate temperature was recorded in NT2 (31.9 ± 2.2 °C), followed by NT3 (31.2 ± 2.67 °C), NT1 (30.8 ± 2.37 °C), NT4 (30.8 ± 2.1 °C), and NT5 (30.3 ± 1.1 °C). These results indicate that substrate composition significantly influences thermal dynamics during BSFL rearing, with higher protein content (as in NT2 and NT1) contributing to greater microbial activity and heat generation.

3.2.2. Substrate's pH

As illustrated in Figure 2, the pH of the substrates across all five treatments increased significantly during the decomposition process. During the initial week, the substrates exhibited predominantly acidic conditions. However, in the following days, the pH gradually shifted toward alkaline values, indicating progressive changes in substrate chemistry as decomposition advanced.



(a) Discrete monitoring value



(b) Five-number summary

Figure 2. pH of substrate in five BSFL treatments

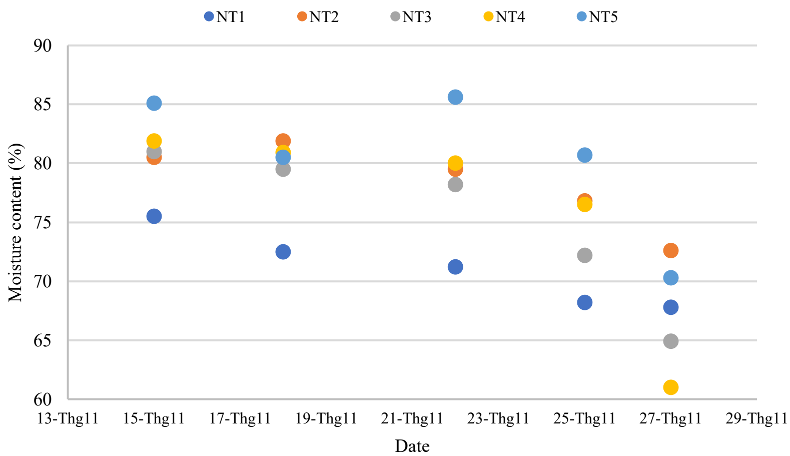
Overall, the differences in mean pH values among the five treatments were relatively small, reflecting comparable trends in microbial and larval activity across the experimental conditions. The pH dynamics observed correspond to distinct stages of organic matter breakdown, from initial acidogenesis to subsequent ammonia accumulation and buffering.

The average pH values recorded were lowest in NT5 (4.66 ± 2.19), followed by NT1 (6.2 ± 1.81), NT2 (6.42 ± 1.73), NT4 (6.6 ± 2.31), and highest in NT3 (6.67 ± 1.47). Notably, NT5 demonstrated a slower rate of decomposition relative to the other treatments. This delayed progression is likely attributable to the imbalanced nutritional profile of the pineapple waste, which contains high levels of carbohydrates but lacks sufficient protein and other nutrients essential for optimal microbial and larval activity.

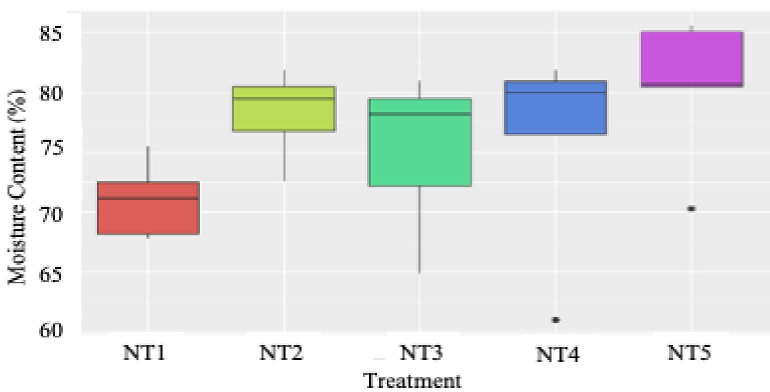
As a result, BSFL in NT5 processed the substrate at a slower rate, leading to a prolonged larval development cycle compared to those in the other treatments, consistent with findings reported by [16].

3.2.3. Substrate's moisture content

The moisture content (MC) of the substrate was calculated using Equation (1). As shown in Figure 3, NT2 exhibited the highest average moisture content (72.6 ± 1.52%), followed by NT5 (70.3 ± 0.91%), NT1 (67.8 ± 0.91%), NT3 (64.9 ± 3.29%), and NT4 (61.0 ± 4.12%).



(a) Discrete calculated value



(b) Five-number summary

Figure 3. Moisture content of substrate in five BSFL treatments (Unit: %)

Throughout the decomposition process, a gradual decrease in moisture content was observed across all treatments. This reduction is primarily attributed to the biological activity of the BSFL, whose feeding and movement generate thermal energy. The heat produced through larval metabolism and microbial decomposition accelerates water evaporation from the substrate, thereby lowering its moisture content over time.

Moisture content plays a critical role in the efficiency of larval bioconversion. Excessively low moisture levels can hinder larval feeding and movement, ultimately reducing substrate degradation efficiency. Conversely, overly high moisture content can lead to larval migration out of the substrate in search of more favorable conditions. Additionally, persistently high moisture in the latter stages of the experiment can complicate the separation and collection of BSF prepupae from residual substrate, posing challenges for downstream processing.

These findings highlight the importance of maintaining an optimal moisture balance to ensure effective waste bioconversion and ease of larvae harvesting.

3.3. BSFL growth

Larval development was assessed through periodic measurements of weight, length, and width. From Day 00 to Day 05, BSFL in treatments NT1 to NT4 exhibited rapid weight gain, with body mass increasing approximately 30–50 times compared to their initial weights. In contrast, larvae in NT5 displayed only minimal growth during the same period, indicating slower development.

At the final monitoring point, the mean larval weights ranked in descending order as follows: NT2: 287.1 ± 5.76 mg; NT3: 281.6 ± 4.78 mg; NT4: 265.4 ± 12.94 mg; NT1: 259.3 ± 4.10 mg and NT5: 257.6 ± 3.94 mg.

Table 5. The length of the larvae in the experiments

Experiments	Length (mm)											Average (mm)	Standard deviation (mm)
	Day												
	1	2	3	4	5	6	7	8	9	10	11		
NT1	12	10	13	13	11	13	11	10	10	12	12	11.5	± 1.2
NT2	17	18	18	15	19	21	17	16	22	21	22	18.8	± 1.3
NT3	18	18	18	18	20	20	17	17	18	17	21	18.3	± 1.3
NT4	15	14	14	16	13	16	15	16	14	15	14	14.7	± 1.0
NT5	12	12	14	13	14	16	16	13	15	12	13	13.6	± 1.5

Significant differences in larval length and width were observed among the treatment groups, reflecting the varying growth performance of *Hermetia illucens* larvae under different substrate compositions.

In terms of length, larvae in NT2 exhibited the greatest average size at 18.8 mm, closely followed by NT3 at 18.3 mm. These results suggest that the nutrient composition in NT2 and NT3 - characterized by a balanced mix of brewer's spent grain (BSG) and pineapple by-products - provided an optimal environment for larval development. In contrast, larvae in NT4 and NT5 reached average lengths of 14.7 mm and 13.6 mm, respectively, indicating moderate growth. Notably, NT1 produced the shortest larvae, with an average length of only 11.5 mm, highlighting the nutritional limitations of using BSG as the sole feedstock.

Table 6. The width of the larvae in the experiments

Experiments	Width (mm)											Average (mm)	Standard deviation (mm)
	Day												
	1	2	3	4	5	6	7	8	9	10	11		
NT1	4	3	3	4	2	4	3	3	3	4	4	3.4	± 0.6
NT2	4	6	6	5	6	6	6	5	6	6	6	5.7	± 0.6
NT3	5	5	4	4	5	5	4	4	4	4	5	4.5	± 0.5
NT4	4	5	5	6	4	6	5	4	4	4	5	4.7	± 0.7
NT5	3	2	3	5	4	3	2	4	4	4	4	3.5	± 0.9

A similar pattern was observed in larval width. NT2 recorded the greatest average width at 5.7 mm, followed by NT3 at 4.5 mm, further confirming that these treatments supported consistent and robust larval growth. NT4 and NT5 yielded intermediate widths of 4.7 mm and 3.5 mm, respectively, whereas NT1 again showed the smallest average width at 3.4 mm.

In addition to average dimensions, the standard deviations associated with larval measurements provided insight into intra-treatment variability. NT2 and NT3 exhibited relatively low standard deviations for both length and width, suggesting uniform growth rates and consistent nutrient availability within the substrates. In contrast, NT4 and NT5 demonstrated slightly higher variability, which may be attributed to uneven nutrient distribution or differential larval adaptation to the feedstock composition.

Overall, NT2 and NT3 supported the most favorable larval morphometrics, underscoring the importance of a balanced nutritional profile. The poorest performance was recorded in NT1, likely due to the lack of carbohydrates and essential micronutrients in BSG alone. NT4 and NT5, despite achieving moderate growth, were significantly less effective, suggesting that excessive inclusion of pineapple by-products may dilute the nutritional quality of the substrate and hinder larval development.

These findings reinforce the conclusion that an optimal substrate for BSFL must maintain a higher proportion of protein-rich components, such as BSG, while incorporating pineapple by-products in moderation to enhance substrate balance without compromising growth performance.

3.4. Valuation of waste processing efficiency by larvae

To assess the waste processing efficiency of BSFL or their effectiveness in reducing waste, parameters such as processing efficiency and daily waste processing volume must be considered. Based on these data, the efficiency of waste processing from a mixture of brewer's spent grain and pineapple by-products can be calculated and evaluated.

As shown in Figure 4, NT2 exhibited the highest decomposition rate (87.86%), indicating that this substrate combination optimized the consumption process of BSFL. This effect may be attributed to the balanced composition of protein from brewer's spent grain and nutrients from pineapple by-products, which likely facilitated improved nutrient absorption and metabolism by the larvae.

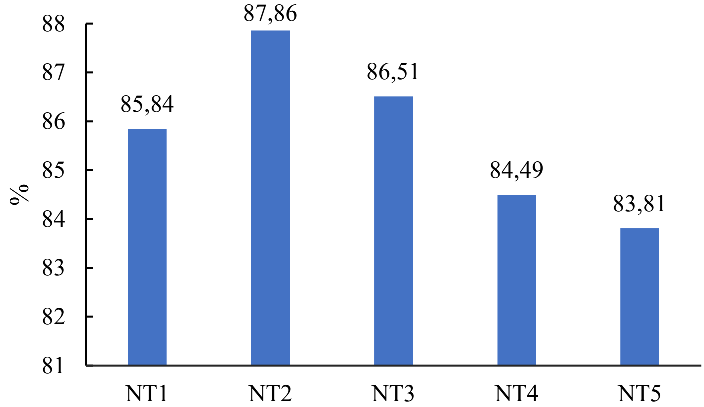


Figure 4. Waste treatment efficiency of the treatments

A study by A. Resconi *et al.* (2024) [12] demonstrated that incorporating brewer's spent grain into the BSFL diet enhanced substrate decomposition efficiency and improved larval digestion. These findings are consistent with the present study, in which trays containing a high proportion of brewer’s spent grain (e.g., NT2 and NT3) showed significantly higher decomposition rates than trays with little or no brewer’s spent grain (e.g., NT4, NT5).

Research by Chia *et al.* (2020) [7] examined the effects of beer industry by-products and concluded that combining brewer’s spent grain with other substrates optimized decomposition. This aligns with the performance of tray NT2 in the current study, which achieved the highest decomposition rate, further supporting the idea that a well-balanced mixture of feedstocks enhances BSF larval efficiency in substrate utilization.

In summary, the results confirm the synergistic effect of mixing brewer’s spent grain with pineapple by-products, enhancing both organic waste treatment efficiency and BSF larval development. Trays with a balanced mixture (NT2, NT3) demonstrated superior waste bioconversion efficiency compared to those fed with either 100% brewer’s spent grain or 100% pineapple by-products. These findings are consistent with international research on the optimization of BSF-mediated bioconversion.

Additionally, during the transition to the pupal stage, prepupae naturally migrate out of the substrate. Therefore, feeding trays should be placed within larger containers to facilitate passive collection as prepupae climb out. This method reduces labor associated with manual collection. Moreover, BSFL may escape prematurely if the substrate moisture exceeds 80%. Hence, it is critical to regulate the moisture content of the diet both before and during the rearing process.

BSF frass possesses superior fertilizer properties due to the larvae’s efficient bioconversion. Studies have shown that BSF frass typically contains 3.1-4.2% nitrogen, 1.8-2.5% phosphorus, and 1.2-2.0% potassium - representing a 20-30% higher nutrient density compared to conventional compost [12]. With waste conversion efficiencies of 90-95%, BSF frass production results in nutrient recovery rates that are 30-40% higher than those from traditional aerobic composting methods [14]. This translates into a stabilized organic fertilizer that delivers 15-25% higher crop yield responses in controlled agronomic trials [15].

3.5. Larval survival rate after the bioconversion process

The survival rate refers to the proportion of larvae that remain alive following the waste treatment process. This metric serves as an indicator for evaluating various factors that may influence larval survival, including competition for food resources, environmental stressors, and abiotic conditions such as substrate temperature and moisture content. To calculate the survival rate, the initial number of larvae introduced at the beginning of the treatment must be compared to the number of larvae recovered at the end of the process.

Table 7 shows that NT2 exhibited the highest larval survival rate (98.02%), suggesting that the combination of brewer's spent grain (BSG) with a small proportion of pineapple by-products created optimal nutritional conditions for BSFL. This formulation likely offered a more balanced nutrient profile - delivering essential proteins from BSG while complementing the diet with micronutrients and bioactive compounds from pineapple by-products.

These findings are consistent with previous research, in which BSG is rich in protein and fiber, supporting BSF larval growth and development. This may explain the high survival rates observed in NT1 and NT2, where BSG was the primary or sole dietary component. Similarly, Resconi *et al.* [12] reported that BSG not only enhances larval survival but also promotes beneficial gut microbiota, which may further account for the superior performance observed in NT2. The addition of pineapple by-products in NT2 may have improved digestive efficiency and nutrient uptake, thereby contributing to the observed high survival rate.

Table 7. The survival rate of the larvae after treatment

Experiments	Initial number of larvae	Number of remaining larvae	Survival Rate (%)
NT1	1,318	1,278	96.97
NT2	1,318	1,292	98.02
NT3	1,318	1,262	95.75
NT5	1,318	1,270	96.36
NT5	1,318	1,256	94.77

3.6. Biomass conversion efficiency

The biomass conversion capacity of BSFL is a critical parameter for evaluating the efficiency of organic waste treatment. These larvae not only facilitate the decomposition of organic matter but also transform it into nutrient-rich biomass with significant value across multiple industries. A comprehensive understanding of their conversion capacity is essential for optimizing rearing conditions and enhancing conversion efficiency across various substrates, thereby minimizing waste and producing valuable end products.

Table 8. The biomass conversion efficiency of larvae

Experiments	Average Larval weight before treatment (g)	Average Larval weight after treatment (g)	Life cycle duration (days)	Biomass Conversion Efficiency (g/day)
NT1	0.12	0.259	20	6.95×10^{-3}
NT2	0.11	0.287	20	9.45×10^{-3}
NT3	0.12	0.281	20	7.35×10^{-3}
NT5	0.12	0.265	20	7.2×10^{-3}
NT5	0.12	0.257	25	5.04×10^{-3}

As shown in Table 8, NT2 exhibited the highest biological conversion rate among all treatments (9.45×10^{-3} g d^{-1}), indicating that a blend of brewer's spent grain and pineapple by-products supplied a balanced nutrient profile that enhanced biomass conversion efficiency. In contrast, treatments NT3 and NT4 achieved rates of 7.35×10^{-3} g d^{-1} and 7.20×10^{-3} g d^{-1}, respectively, reflecting a gradual decline in efficiency as the proportion of pineapple by-products increased. Treatment NT5 recorded the lowest conversion rate (5.04×10^{-3} g d^{-1}), suggesting that pineapple by-products alone are a less effective substrate.

When compared to Resconi *et al.* (2024) [12], who reported biomass conversion rates of 8.00×10^{-2} to 1.10×10^{-2} g d^{-1} on brewer's spent grain, the rate observed in NT2 (9.45×10^{-3} g d^{-1}) approaches the upper bound of their findings. This concordance suggests that the synergistic combination of brewer's spent grain with pineapple residues significantly augments larval biomass conversion.

BSFL demonstrated considerable potential as a sustainable livestock feed due to their high biomass conversion efficiency. Under optimized rearing conditions, their rapid growth and ability to thrive on organic waste substrates yield superior biomass production, simultaneously mitigating waste management challenges and generating valuable feed ingredients. This efficient bioconversion process also offers marked reductions in production costs relative to traditional feed crops.

4. CONCLUSION

Among all treatments, NT2 (70% brewer's spent grain : 30% pineapple by-products) was identified as the most optimal, exhibiting superior performance in organic waste processing efficiency, larval growth, and biomass conversion capacity. These findings highlight the effectiveness of combining brewer's spent grain with pineapple by-products, not only in improving waste degradation but also in producing high-value, reusable biomass.

The strategic blending of these two substrates capitalizes on their respective nutritional benefits while minimizing the limitations observed when used individually. This approach shows great potential in the field of organic waste treatment using BSF *(Hermetia illucens)* larvae, particularly for managing industrial by-products such as spent grain and agricultural residues like pineapple waste. Furthermore, the study underscores the potential for practical application in sustainable waste management systems. By reducing environmental pollution and promoting the efficient use of readily available resources, this method offers a scalable and environmentally friendly solution aligned with circular economy principles.

Future research should also focus on evaluating the waste reduction potential at specific developmental stages of the BSF life cycle. Although the larval stages are known for their bioconversion capabilities, the pupal and adult stages do not contribute to waste degradation. A deeper understanding of stage-specific waste processing capacities could improve the precision and efficiency of larval rearing systems and optimize their application in large-scale waste management.

It is essential to develop supportive policies, including financial and technical assistance, to promote and expand the application of BSFL in organic waste treatment across Vietnam.

Acknowledgement

This work was financially supported by Ho Chi Minh City University of Industry and Trade under Contract No. 161/HD-DCT dated 15 July 2024.

REFERENCES

1. VBA (Vietnam Beer, Alcohol, Beverage Association) - Report of spent grain in the world and in Vietnam (2023).
2. Ninh Binh portal - Ninh Binh maintains growth in five months (2024). https://english.ninhbinh.gov.vn/news-and-events/ninh-binh-maintains-growth-in-five-months-339123
3. Parra Paz, A. S., Carrejo, N. S., & Gómez Rodríguez, C. H. - Effects of larval density and feeding rates on the bioconversion of vegetable waste using black soldier fly larvae *Hermetia illucens* (L.), (Diptera: Stratiomyidae). Waste and Biomass Valorization **6** (2015) 1059-1065. https://doi.org/10.1007/s12649-015-9418-8.
4. Amrul, F. N., Ahmad, I. K., Basri, N. A., Suja, F., Abduj Jalil, N. A., & Azman, A. - A review of organic waste treatment using black soldier fly (*Hermetia illucens*). Sustainability **14** (2022). https://doi.org/10.3390/su14084565
5. Bonelli, M., Bruno, D., Brilli, M., Gianfranceschi, N., Tian, L., Tettamanti, G., Caccia, S., & Casartelli, M. - Structural and functional characterization of *Hermetia illucens* larval midgut. Frontiers in Physiology **10** (2019) 204. https://doi.org/10.3389/fphys.2019.00204
6. Booth, D. C., & Sheppard, C. - Oviposition of the black soldier fly, *Hermetia illucens (Diptera: Stratiomyidae)*: Eggs, masses, timing, and site characteristics. Environmental Entomology **13** (1984) 421–423. https://doi.org/10.1093/ee/13.2.421
7. Chia, S. Y., Tanga, C. M., Osuga, I. M., Mohamed, S. A., Khamis, F. M., & Salifu, D. - Effects of waste stream combinations from brewing industry on performance of black soldier fly, *Hermetia illucens* (Diptera: Stratiomyidae). Waste Management **100** (2020) 84–91. https://doi.org/10.1016/j.wasman.2019.09.009
8. Indriyani, I., Arioen, R., Santoso, A. B., Arifin, Z., & Santosa, P. E. - Improving the chemical quality of compost from bioconversion of multi types of organic waste using black soldier fly larvae and EM-4. Journal Penelitian Pendidikan IPA **9** (2023) 2068–2074. https://doi.org/10.29303/jppipa.v9i4.3442
9. Liu, Z., Minor, M., Morel, P. C. H., & Najar-Rodriguez, A. J. - Bioconversion of three organic wastes by black soldier fly *(Hermetia illucens)* larvae. Environmental Entomology **47** (2018) 1609–1617. https://doi.org/10.1093/ee/nvy141
10. Mutafela, R. N. - High value organic waste treatment via black soldier fly bioconversion. Thesis, KTH Royal Institute of Technology (2015). https://www.diva-portal.org/smash/record.jsf?pid=diva2%3A855378
11. Nguyen, V.H.P., Tran, T.T., Nguyen, T.T.T., Nguyen, T.N.H., Huynh, T.T.T., Tran, L.H.G., Do, M.T., & Huynh, Đ.K- Research on the treatment of dragon fruit waste using black soldier fly *(Hermetia illucens)* larvae with different mixing ratios. Journal of Science on Natural Resources and Environment **45** (2023) 121–134. https://tapchikhtnmt.hunre.edu.vn/index.php/tapchikhtnmt/article/view/483/505
12. Resconi, A., Oddon, S. B., Ferrocino, I., Loiotine, Z., Caimi, C., & Gasco, L. - Effects of brewery by-products on growth performance, bioconversion efficiency, nutritional profile, and microbiota and mycobiota of black soldier fly larvae. Animal **18** (2024) 100567. https://doi.org/10.1016/j.animal.2024.100567
13. Beesigamukama, D., Mochoge, B., Korir, N., Musyoka, M. W., Fiaboe, K. K. M., Nakimbugwe, D., Khamis, F. M., Dubois, T., Subramanian, S., Wangu, M. M., Ekesi,

S., & Tanga, C. M. - Nutrient quality and maturity status of frass fertilizer from nine edible insects. Science of The Total Environment **704** (2020) 135385. https://doi.org/10.1016/j.scitotenv.2019.135385

14. Gold, M., Tomberlin, J. K., Diener, S., Zurbrügg, C., & Mathys, A. - Decomposition of biowaste macronutrients, microbes, and chemicals in black soldier fly larval treatment: A review. Waste Management **102** (2020) 932-942. https://doi.org/10.1016/j.wasman.2019.12.003
15. Sarpong, D., Oduro-Kwarteng, S., Gyasi, S. F., Buamah, R., Donkor, E., Awuah, E., & Baah, M. K. - Biodegradation by composting of municipal organic solid waste into organic fertilizer using the black soldier fly *(Hermetia illucens) (Diptera: Stratiomyidae)* larvae. Journal of Cleaner Production **211** (2019) 1437-1445. https://doi.org/10.1016/j.jclepro.2018.11.204
16. Pradabphetrat, P., Sathawong, S., & Pimsen, M. - Effects of Rearing Black Soldier Fly Larvae *(Hermetia illucens)* from Organic Wastes. ASEAN Journal of Scientific and Technological Reports **27** (2024). https://doi.org/10.55164/ajstr.v27i4.252644

TÓM TẮT

NGHIÊN CỨU XỬ LÝ CHẤT THẢI TẠI CÔNG TY TNHH NHÀ MÁY BIA HEINEKEN VIỆT NAM BẰNG ẤU TRÙNG RUỒI LÍNH ĐEN (*Hermetia illucens*)

Nguyễn Vũ Hoàng Phương[1], Trần Thanh Tú[2,3*], Hồ Thiên Nhi[1]

[1]*Trường Đại học Công Thương Thành phố Hồ Chí Minh*

[2]*Trường Đại học Quốc tế, ĐHQG-HCM*

[3]*Đại học Quốc gia Thành phố Hồ Chí Minh*

*Email: *tttu@hcmiu.edu.vn*

Nghiên cứu này đánh giá hiệu quả của ấu trùng ruồi lính đen (BSF) trong việc chuyển hóa hai loại chất thải hữu cơ: chất thải công nghiệp (bã hèm bia) và phụ phẩm nông nghiệp (vỏ dứa), với các tỷ lệ phối trộn khác nhau: 100:0, 70:30, 50:50, 30:70 và 0:100. Kết quả thực nghiệm cho thấy ấu trùng BSF phát triển tốt ở tất cả các công thức. Trong số các tỷ lệ được thử nghiệm, hỗn hợp bã hèm bia và vỏ dứa theo tỷ lệ 70:30 cho hiệu quả cao nhất, với tỷ lệ giảm khối lượng chất thải đạt 87,86%, chiều dài ấu trùng đạt 18,6 mm, chiều rộng 5,6 mm, và tốc độ chuyển hóa sinh khối là $9,45 \times 10^{-3}$ g/ngày. Những kết quả này cho thấy tỷ lệ phối trộn 70:30 là tối ưu cho việc quản lý chất thải hữu cơ quy mô lớn. Nghiên cứu khẳng định tiềm năng của ấu trùng ruồi lính đen như một giải pháp bền vững và có khả năng mở rộng để xử lý chất thải hữu cơ công nghiệp và nông nghiệp, mang lại lợi ích đáng kể về môi trường và tận dụng tài nguyên.

Từ khóa: Sự tăng trưởng của ấu trùng ruồi lính đen, hèm bia, vỏ thơm, tỷ lệ chuyển đổi sinh khối, nông nghiệp bền vững.