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Comparative Analysis of Organic Waste Media on the Development and Nutrient Profile of Black Soldier Fly (Hermetia illucens) Larvae

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ABSTRACT

Organic waste management remains a major environmental challenge, particularly in agricultural sectors. One promising sustainable approach is bioconversion using *Black Soldier Fly* (*Hermetia illucens*, BSF) larvae, which can transform organic waste into high-value biomass. This study aims to evaluate the effects of different waste inputs on the growth and nutritional composition of BSF larvae. The feed media consisted of P1 (broiler chicken excreta waste), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (california papaya waste). Larvae were analyzed based on growth, survival rate, larval body coloration, and nutrient content, including moisture, ash, crude fat, crude protein, and crude fiber using proximate analysis. After a 20-d bioconversion period, the highest harvest weights and survival rates were observed in treatments P2 and P4. Among the fruit-based substrates, P2 and P4 yielded the most favorable overall performance. However, crude protein content in P2 and P4 was lower than in P1, while moisture content was higher in P4. These findings indicate that papaya (P4) and dragon fruit (P2) waste show potential as alternative bioconversion media due to their ability to support adequate larval growth, biomass production, and nutrient content.

KEYWORDS

Bioconversion; Black Soldier Fly; Larvae; Maggot; Waste

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1. Introduction

Agricultural and livestock activities generate substantial amounts of organic waste that requires sustainable innovative management strategies to enhance its value and mitigate environmental pollution. Among the livestock sector waste, chicken excreta represents a major concern due to the rapid growth of the poultry industry. According to Statistics Indonesia (2020), the broiler chicken population in Indonesia reached 3.804.779, resulting in a continuously increasing volume excreta. Each broiler chicken with an average weight of 1.27 kg produces 104 g of excreta per day (Haryanto et al., 2023), indicating a continuous and scalable nitrogen-rich waste stream with considerable potential for valorization. Poultry excreta contributes to ammonia emissions, greenhouse gas production, nutrient leaching, and pathogen proliferation, posing environmental and public health risks if not managed properly.

In addition to livestock waste, fruit waste is also one of the most abundant types of organic waste generated from agricultural production and consumption. However, high consumption and production rates have led to substantial fruit waste accumulation. Fruit waste comprises damaged, rotten, or overripe fruit, with transportation and storage being significant factors in food waste generation (Mishra and Surindra, 2025). Additionally, fruit waste has been documented for their nutritional and/or functional qualities. Fruits are an essential source of human nutrition, providing essential vitamins, minerals, dietary fiber, and other bioactive compounds (Athia et al., 2021).

In Indonesia, the utilization of fruit waste remains limited, leading to significant environmental challenges associated with improper waste management. Nur and Khairi (2020), reported that fruit waste in Indonesia reached 13.091.016 tons in 2017. Banyuwangi Regency, a major agricultural region characterized by intensive fruit cultivation, contributes substantially to this waste stream, particularly from dragon fruit, papaya, and crystal guava production. Fruit peel waste rapidly ferments due to its high sugar and moisture content, producing foul odors, leachate, methane emissions, and attracting pests (Pathak et al., 2023). These environmental risks underscore the need for biological conversion systems that transform peel residues into value-added biomass instead of allowing uncontrolled decomposition.

Bioconversion offers a promising and environmentally friendly approach for transforming organic waste into value-added products through biological processes. One promising bioconversion agent is black soldier fly (BSF/*Hermetia illucens*) larvae (Mabruroh et al., 2022; Muhlison et al., 2021). These larvae, commonly referred as maggots, exhibit considerable potential as an alternative protein source for livestock feed due to their high nutritional content (Lopez et al., 2022). Moreover, BSF Larvae demonstrate superior waste decomposition capabilities compared to microbial agents, enabling faster breakdown of organic matter and more efficient waste reduction (Fauzi and Muharram, 2019; Purnamasari and Khasanah, 2022).

Beyond their waste management potential, BSF larvae possess intrinsic antimicrobial and antifungal properties, so when incorporated into livestock diets, may enhance immunity against bacterial and fungal diseases (Salsabil et al., 2021). Their ability to grow and reproduce efficiently nutrient rich organic substrates further supports their application in waste management systems. Consequently, The utilization of BSF larvae for organic waste decomposition not only contributes to environmental sustainability but also offers socioeconomic benefits to local community (Rukmini et al., 2020).

Although chicken excreta and fruit waste differ substantially in nutritional composition, both represent abundant and biodegradable organic materials with high suitability for bioconversion. Given the high nutritional plasticity of black soldier fly larvae and their ability to utilize diverse organic substrates, comparing these waste types as growth media allows evaluation of how substrate heterogeneity affects larval growth performance and nutritional composition. Therefore, the present study aims to evaluate the effects of various locally organic waste-based feed substrates, derived from chicken excreta and fruit waste, on the growth performance and nutritional composition of BSF larvae. The findings of this study are expected to provide scientific insights into optimizing organic waste utilization through BSF bioconversion and to support the development of sustainable, low-cost feed alternatives for livestock production systems.

2. Materials and Methods

The research was carried out from March to April 2025 in Grajagan Village, Purwoharjo District, Banyuwangi Regency. Nutritional analysis was conducted at the Feed Nutrition Laboratory of the Batu City Livestock Training Center, East Java. The evaluated parameters included moisture content, ash content, crude fat, crude protein, and crude fiber.

The growth media utilized for BSF larvae in this study comprised broiler chicken excreta, red dragon fruit waste, white crystal guava waste, and California papaya waste. A total of 80 g of BSF five-days-old larvae (DOL), were allocated across four treatment groups with 4 replications each, resulting in 16 experimental units. Each replication contained 5 g larvae (Purnamasari et al., 2021a).

2.1. Hatching procedure

Black soldier fly eggs were incubated in plastic containers containing 1 kg of commercial broiler starter feed moistened to 75% water content (Purnamasari et al., 2019). Gauze was placed over the substrate as a base for the eggs, and containers ware covered with netting. Eggs were sprayed daily for five days, and observations were conducted to monitor hatching into five-day old larvae (5-DOL). After hatching, the larvae were counted and 5 g (5-DOL) were allocated to each experimental unit.

2.2. Cultivation procedure

Sixteen plastic containers (35×30×12 cm) were prepared, each filled with 350 g of treatment media: P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste), weighed using a digital scale (SF-400, maximum capacity 7 kg, resolution 0.1 g). The nutrient composition of the feed media is presented in **Table 1**, compiled from published literature to characterize substrate types. Broiler chicken excreta (P1) provides high nitrogen availability and is commonly used in BSF production, while fruit wastes (P2–P4) were selected for their high carbohydrate content, moisture, and fermentable sugars. These differences were expected to influence larval growth, metabolism, and nutrient composition. Therefore, the treatments were intentionally designed to evaluate how substrate type affects BSF bioconversion efficiency.

Each container received 5 g of 5-day-old BSF larvae (DOL). The containers were covered with netting to prevent predation. Temperature and pH were monitored daily using a digital thermometer (Taffware HTC-1) and a pH meter (PH-2011 ATC Backlight). The cultivation period lasted 15 days, during which a total of 15 kg of feed media was provided throughout the rearing period and administered each afternoon.

2.3. Harvesting procedure

Twenty-day-old BSF larvae in the waste growth medium were separated from the frass using a fine mesh. Residual frass adhering to the larval bodies was removed by rinsing the larvae with clean water.

2.4. Morphometric measurement

In each replication, the length and width of 10 BSF larvae were measured using calipers. Sample were randomly collected from five distinct points within the container: lower right, upper right, lower left, upper left, and center) (Salsabil et al., 2021). The average dimensions were calculated in centimeters.

Table 1. The nutrient composition of feed media

Treatment	Crude protein (%)	Crude fat (%)	Crude fiber (%)	Water content (%)	Ash content (%)	Saccharide	Source
P1	24–30	0.35	18.34	85–92	15	–	Dewi et al. (2017); Raharjo et al. (2016); Hendro (2017); Setiawan (2017); Puteri et al. (2022)
P2	0.64	1.98	3.80	83.16	2.86	10.35	Nur et al. (2023)
P3	0.8–1.5	0.4–0.7	2.8–5.5	74–87	0.5–1	15	Kinanti et al. (2023); Yousaf et al. (2021)
P4	0.29–1.46	0.35–0.55	6.16–11.62	81.39–89.21	2.83–4.84	9.65	Chukwuka et al. (2013)

P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste).

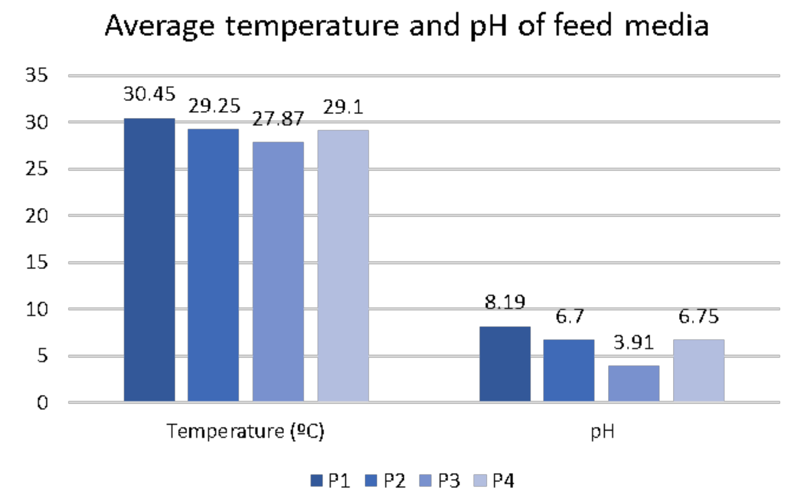

Figure 1. Average temperature and pH of feed media during afternoon maintenance P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste).

2.5. Final weight measurement

The BSF larvae separated from the medium were weighed using digital scales (Taffware Digipounds MS-K07, maks 5 kg, resolution 0.1 g) to determine the final harvest weight for each experimental unit. The recorded values were used to assess larval biomass yield.

2.6. Survival rate calculation

The survival rate of BSF larvae was determined by comparing the number of larvae at 5 days old with the number at harvest age. The experiment was initiated using 5-day-old BSF larvae, which represent an early active feeding stage after hatching. This measurement aimed to assess whether the waste media harmful substances such as pesticides, that could affect larval viability. The survival rate was calculated using the following formula:

$$\text{Survival rate (\%)} = \frac{\textit{Number of larvae at harvest}}{\textit{Number of 5-day-old larvae}} \times 100\%$$

2.7. Post-Harvest processing and proximate analysis

Following cleaning and weighing, the BSF larvae were stored in a freezer to terminate further growth. The larvae were then dried using a stove oven at a temperature of ±180°C for 75 minutes (Purnamasari et al., 2021b), reweighed, and subsequently subjected to proximate analysis to determine moisture content, ash content, crude protein, crude fat, and crude fiber.

2.8. Nutrient composition analysis

Proximate analysis was employed to evaluate the nutritional composition of BSF larvae, a standard method for assessing feed ingredients and energy value (Muza'ki et al., 2023). Moisture content was determined using the oven-drying method (SNI 01-2891-1992), while ash content was measured via furnace incineration at 550°C for 3 hours (SNI 01-2891-1992). Crude protein was analyzed using the Kjeldahl method, involving destruction, distillation, and titration (AOAC, 2005). Crude fat was assessed using the Soxhlet extraction method with a non-polar solvent (AOAC, 2005).

2.9. Statistical analysis

The study employed a completely randomized design (CRD) consisting of four treatments and four replications. Data were analyzed using one-way analysis of variance (ANOVA) with SPSS IBM 25. When significant differences among treatments were detected ($p<0.05$), Duncan's Multiple Range Test was applied for post hoc comparison.

3. Results and Discussion

3.1. Temperature and pH of the feed media

Temperature and pH of the feed media were measured daily during the study as parameters that influence the growth of BSF larvae as they regulate microbial activiry, substrate decomposition rate, and larval metabolism. The results of temperature and pH of the feed media presented in **Figure 1**.

The average temperature and pH of the feed media varied across treatments. Treatment P1 exhibited the highest temperature (30.45°C) and alkaline pH (8.19), exceeding the optimal pH range for BSF larvae development. In contrast, P3 (white crystal guava waste) recorded the lowest temperature (27.87°C) and acidic pH (3.91), which may negatively affect larval growth due to suboptimal acidity levels. Treatments P2 and P4 maintained temperatures within the optimal range and pH values close to the ideal range, suggesting more favorable conditions for BSF larval development. The optimal temperature for BSF larvae ranges from 25–30°C (Shumo et al., 2019), while the optimal pH falls between 6–9 (Meneguz et al., 2018).

The elevated temperature in P1 likely resulted from intensified microbial decomposition of nitrogen-rich poultry manure, generating metabolic heat that further stimulated larval activity. In contrast, P3 contained relatively higher protein and saccharide levels than other fruit-based substrates (**Table 1**), rapid fermentation likely promoted organic acid accumulation, resulting in a markedly low pH (Gold et al., 2018). This acidic condition may have suppressed larval activity and associated microbial metabolism, thereby reducing metabolic heat production and leading to lower substrate temperatures (Barragan-Fonseca et al., 2017).

3.2. Productivity of BSF larvae

The productivity of BSF larvae varied across different feed media, as presented in **Table 2**. The analysis of BSF larval body length

Figure 2. The different color of BSF larvae in different feed media. P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste)..

and width over a 20-day rearing period (**Table 2**) revealed that treatments P1 and P4 produced significantly longer larvae ($p<0.05$) compared to P3. In terms of body width, P1 showed the highest value ($p<0.05$) among all treatments, while P2 and P4 had similar widths, both significantly greater than P3 ($p<0.05$). These results indicate that P1 provided the most favorable conditions for larval growth, while P3 resulted in the poorest morphometric performance.

The superior growth in P1 is attributed to the nutrient-rich composition of chicken excreta, which contains high levels of organic matter and protein (Fajri and Kartika, 2021). The BSF larvae have proven to convert organic waste into high-quality nutrients (Siddiqui et al., 2022). Conversely, the low pH (3.91) and suboptimal temperature (27.87°C) in P3 likely inhibited larval metabolism and development (Meneguz et al., 2018; Mudeng et al., 2018). These findings align with previous studies indicating that BSF larvae thrive in media with pH 6–7 and temperatures around 30°C (Yuliana et al., 2024; Opare et al., 2022).

The duration of the BSF larval phase is strongly influenced by the nutritional quality of the feed medium. According to Schneider et al. (2025), low nutrient content can prolong the larval phase up to four weeks, whereas sufficient nutrients can shorten it to approximately two weeks. This observation is consistent with Herve et al. (2025), reported that BSF larvae exhibit adaptive growth patterns depending on feed quality. In the present study, larval body lengths exceeded those reported by Nur'aini (2023), who used a feed mixture of 25% rice bran and 75% fruit over a 21-day rearing period, resulting in an average length of 1.59 cm. The superior growth observed in this study suggests that the feed media provided more favorable nutritional conditions, thereby enhancing larval development within a shorter time frame.

The analysis of BSF larval harvest weight across treatments (**Table 2**) revealed significant variation. Treatments P2 and P4 yielded significantly higher harvest weights ($p<0.05$) compared to P1 and P3, while P1 also showed a significantly higher weight than P3 ($p<0.05$). These differences are attributed to the quality and nutritional composition of the feed media provided (**Table 1**). According to Hem et al. (2008) and Siddiqui et al. (2022), high-quality substrates enhance larval biomass production by supplying essential nutrients that support optimal growth and development. Thus, the superior performance of P2 and P4 suggests that these media reflects more favorable physicochemical conditions and provided a more balanced nutrient-dense environment for larval development.

Balanced nutrition for BSF larval growth refers to the provision of macronutrients in appropriate proportions, combined with physicochemical conditions that enable efficient nutrient utilization. Previous studies have demonstrated that optimal larval performance is not achieved under maximal protein or energy supply, but rather under moderate protein levels, sufficient carbohydrates, and favorable environmental conditions such as appropriate pH and moisture (Lalander et al., 2019). In the

Table 2. The productivity of BSF larvae varied across different feed media

Parameter	P1	P2	P3	P4	p-value
Length larvae (cm)	2.16±0.05^{a}	1.94±0.13^{ab}	1.64±0.11^{bc}	2.11±0.08^{a}	0.008
Width larvae (cm)	0.52±0.01^{a}	0.46±0.06^{b}	0.38±0.04^{c}	0.46±0.03^{b}	0.002
Harvest weight (g)	350.5±9.25^{b}	447.15±22.93^{a}	131.67±26.82^{c}	475.75±12.44^{a}	0.000
Survival rate (%)	87.17±13.76^{a}	94.01±0.82^{a}	69.91±2.26^{b}	92.24±2.68^{a}	0.002

P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste).
^{a,b,c} Different superscripts in the same row show significant results ($p<0.05$).

present study, significant differences in larval harvest weight among treatments further support this concept.

Conversely, the low harvest weight observed in treatment P3 is likely due to the suboptimal pH of the feed medium, recorded at 3.91 (**Figure 1**), which falls below the optimal pH range of 6–8 for BSF cultivation. Acidic conditions can disrupt digestive enzyme activity, reduce microbial symbiosis efficiency, and impair nutrient assimilation, ultimately reducing biomass accumulation (Christiansen and Eriksen, 2025).

In addition to feed quality and environmental parameters, the developmental stage of the larvae also influences final weight. Diener et al. (2011) noted that as BSF larvae transition into the pre-pupal or pupal phase, bioconversion activity declines and internal energy reserves are utilized, often resulting in reduced body mass. Therefore, synchronization of harvest timing with peak larval biomass is critical to maximizing yield.

3.3. Morphological indicators of BSF larvae

Morphological observations revealed distinct variations in BSF larval body color across treatments (**Figure 1**). Larvae in treatment P1 exhibited a noticeably darker coloration, indicating progression into the pre-pupal phase. This change is attributed to the high nutrient content of the feed medium, which accelerates larval development. Hosseindoust et al. (2024) reported that nutrient-rich substrates prompting earlier transition to the pre-pupa stage. Larval darkening in BSF is commonly associated with cuticle thickening, melanization, and chitin accumulation during later developmental stages, processes that are promoted by nutrient-dense substrates and optimal environmental conditions (Tomberlin et al., 2009).

In treatment P2, larvae displayed a reddish-purple hue. This coloration is likely influenced by the presence of anthocyanins and β-carotene in the feed medium. Anthocyanins, natural pigments found in dragon fruit peel, contribute to red and purple tones (Nizori et al., 2020), while β-carotene, a carotenoid compound, enhances reddish pigmentation (Haerawati and Sambara, 2024). The intensity of color is dose-dependent, with higher carotenoid concentrations producing more vivid hues (Yusuf et al., 2023). Inline with the study by Haetami and Meidito (2024) reported that astaxanthin and β-carotene dyes have been proven effective in enhancing the brightness of color in ornamental fish.

Larvae in treatments P3 and P4 exhibited lighter body colors white and orange, respectively consistent with typical BSF larval appearance. These results suggest that feed media composition, particularly pigment and nutrient content, plays a significant role in influencing larval body coloration and developmental stage. The lighter coloration of BSF larvae observed in treatments P3 and P4 is primarily associated with slower larval development and lower pigment accumulation compared to P1 and P2. In P3, the markedly low pH and suboptimal temperature likely suppressed larval metabolism and delayed progression toward the pre-pupal stage, resulting in larvae retaining a lighter, whitish appearance typical of earlier instars (Diener et al., 2011; Meneguz et al., 2018).

3.4. Nutrient compound of BSF larvae

The moisture content of BSF larvae varied significantly across treatments (**Table 3**). Treatment P1 exhibited the lowest moisture content ($p<0.05$) compared to P4, while treatments P2 and P3 showed similar moisture levels to P4. The elevated moisture content in P4 is attributed to the high-water content of papaya fruit, which ranges from 81.39% to 89.21% (Chukwuka et al., 2013). In addition to intrinsic fruit moisture, decomposition of residual feed further increased water content in the medium, as supported by Madu et al. (2022). BSF larvae are capable of absorbing water directly from their substrate, which influences their internal moisture levels (Fahmi, 2015). These findings highlight the importance of feed composition and degradation dynamics in shaping larval physiological traits.

The ash content of BSF larvae varied significantly across treatments (**Table 3**). Treatment P1 recorded the highest ash content, followed sequentially by P4, P2, and P3, with each comparison showing statistically significant differences ($p<0.05$). The elevated ash content in P1 is attributed to the composition of chicken excreta, which includes unabsorbed feed residues such as rice bran, corn, and concentrate (Aditama et al., 2023). Newton et al. (2005) reported that maggots reared on chicken excreta can reach ash content levels of up to 16.6%, supporting the findings of this study.

Conversely, the lowest ash content was observed in P3, likely due to the inherently low mineral content of crystal guava, particularly its seeds, which contain only 0.5–1% ash (Kinanti et al., 2023). These results underscore the influence of feed substrate composition on larval mineral accumulation. Ash content in BSF larvae reflects the mineral concentration of the feed medium (Lubis et al., 2023). While higher ash levels may indicate greater mineral availability, excessive ash can also signal potential metal contamination, reducing the suitability of the larvae for animal feed applications (Kristiandi et al., 2021).

Crude protein content analysis revealed significant differences among treatments (**Table 3**). Treatment P1 yielded the highest crude protein value ($p<0.05$) compared to treatments P2, P3, and P4, which showed statistically similar protein levels. The superior protein content in P1 is attributed to the high nutritional value of broiler chicken excreta, which contains 24–30% crude protein (Setiawan, 2017).

In contrast, the lower protein content observed in larvae reared on fruit-based media (P2, P3, P4) reflects the inherently lower protein levels in fruit waste substrates. Despite this, BSF larvae possess protease enzymes that enable them to digest diverse organic materials and convert them into protein (Kim et al., 2011). Thus, feed media quality and nutrient density directly influence the quantity and quality of protein synthesized by the

Table 3. The nutrient compound of BSF larvae varied across different feed media

Parameter (%)	P1	P2	P3	P4	p-value
Water Content	73.76 ± 0.51^{a}	81.38 ± 2.14^{ab}	78.08 ± 0.96^{ab}	84.58 ± 1.97^{b}	0.004
Ash Content	15.93 ± 0.46^{d}	5.46 ± 0.68^{b}	3.66 ± 0.13^{a}	6.60 ± 0.34^{c}	0.000
Crude Protein	41.48 ± 1.81^{a}	27.53 ± 3.30^{b}	26.87 ± 1.96^{b}	28.23 ± 1.63^{b}	0.000
Crude Fat	27.41 ± 5.65^{a}	51.10 ± 5.37^{ab}	56.40 ± 1.33^{b}	51.31 ± 0.91^{ab}	0.007
Crude Fiber	15.59 ± 3.06^{c}	8.29 ± 1.59^{a}	10.38 ± 2.12^{ab}	12.41 ± 2.56^{bc}	0.007

P1 (broiler chicken excreta), P2 (red dragon fruit waste), P3 (white crystal guava waste), and P4 (California papaya waste).
^{a,b,c,d} Different superscripts in the same row show significant results ($p<0.05$).

larvae (Aldi et al., 2018). The crude protein values obtained from fruit-based treatments in this study were comparable to those reported by (Purnamasari et al., 2023), who used fruit waste over a 24-day rearing period. Their study yielded a crude protein content of 30.3% under dry matter conditions and 6.39% under as-fed conditions, aligning with the protein levels observed in the current research. These results indicate that nitrogen-rich substrates favor protein deposition in larval biomass, whereas carbohydrate-rich substrates promote lipid accumulation and higher overall biomass yield. Thus, substrate C:N balance plays a central role in determining nutrient partitioning in BSF larvae.

Crude fat analysis revealed significant differences among treatments (**Table 3**). Treatment P3 produced the highest crude fat content, significantly greater than P1 ($p<0.05$). Treatments P2 and P4 showed crude fat levels statistically similar to both P1 and P3. The elevated fat content in P3 is attributed to the high carbohydrate and glucose levels in crystal guava, which contains approximately 12.20 g of carbohydrates per serving (Handayani, 2015). Excess glucose not utilized for energy is converted into fat and stored in the body (Faradila et al., 2023). This metabolic conversion is facilitated by lipase enzymes, which break down dietary fats into absorbable fatty acids (Santi et al., 2020).

While high crude fat levels may influence livestock health and productivity (Yuvita et al., 2021), the presence of beneficial fatty acids in BSF larvae, particularly lauric acid, adds functional value. Lauric acid, a saturated fatty acid with antimicrobial and antiviral properties, constitutes up to 64% of the total saturated fat profile in BSF larvae (Kurniati et al., 2022). Therefore, despite the elevated fat content in P3, the nutritional quality of the larvae remains favorable for feed applications.

Crude fiber content analysis revealed significant variation among treatments (**Table 3**) , reflecting the combined effects of feed substrate composition, larval developmental stage, and environmental conditions. Treatments P2 and P3 exhibited significantly lower crude fiber content ($p<0.05$) than P1, while P2 and P3 were statistically similar. The elevated crude fiber content in P1 is attributed to two main factors: the high fiber content of broiler chicken excreta and the advanced developmental stage of the larvae. Larvae in P1 were observed to have entered the pre-pupal phase, as indicated by darker coloration and hardened cuticles. This transition was likely accelerated by the higher medium temperature in P1 (30.45°C), which falls within the optimal range for larval development (Tomberlin et al., 2009; Mudeng et al., 2018). In contrast, lower temperatures in fruit-based treatments may have delayed larval maturation (Opare et al., 2022), likely associated with prolonged larval duration under acidic conditions.

The crude fiber content in P4 appears to be influenced primarily by substrate characteristics rather than thermal conditions. Papaya waste contains relatively high structural carbohydrates, and its high moisture content facilitates substrate ingestion, contributing to fiber incorporation into larval biomass (Chukwuka et al., 2013; Purnamasari et al., 2023). These findings confirm that crude fiber accumulation in BSF larvae is governed by a complex interaction between feed composition, larval physiology, and growth dynamics, underscoring the importance of evaluating multiple environmental and nutritional factors when assessing larval nutritional quality.

According to Purnamasari et al. (2023), BSF larvae in the pre-pupal and pupal stages exhibit increased crude fiber content, ranging from 10.56–15.51% and 13.67–18.82%, respectively, due to chitin accumulation. Chitin, a structural polysaccharide, is a major contributor to fiber content in insect biomass (Azis et al., 2022). Moreover, the fiber content of the feed medium directly influences the fiber composition of the larvae, reinforcing the relationship between substrate quality and larval nutrient profile.

Overall, the study demonstrates that while broiler chicken excreta yield the highest nutrient values, fruit-based media such as red dragon fruit and papaya waste also support favorable larval growth and biomass production. These findings demonstrate that substrate type influences not only larval growth performance but also nutrient partitioning patterns and highlight the potential of fruit waste as a sustainable bioconversion medium. Future research should focus on standardizing moisture levels across treatments and investigating the specific fatty acid profiles, particularly lauric acid, in high-fat larvae from fruit-based media.

4. Conclusion

Different feed media significantly affect the growth, survival, and nutritional quality of BSF maggot larvae. Broiler chicken excreta (P1) produced the highest values in protein, ash, fiber, and morphometric traits, while fruit-based media like red dragon fruit (P2) and papaya (P4) supported optimal growth and survival. Crystal guava waste (P3) resulted in the highest fat content but lower overall performance. Overall, fruit-based substrates, particularly red dragon fruit and papaya waste, are promising alternatives for BSF larvae production due to their ability to support high biomass production, survival rate, and stable growth conditions. While broiler chicken excreta enhances nutrient concentration, fruit waste media offer a more balanced environment for larval growth and more suitable for sustainable large-scale BSF production. Further research is recommended to standardize feed media composition and investigate the specific animo acid and fatty acid profiles, particularly the role of lauric acid, in enhancing the nutritional quality of BSF larvae.

5. Conflict of interest

No potential conflict of interest relevant to this article was reported. All authors have agreed with the contents of the manuscript.

6. Author's contribution

The authors confirm their contribution to the paper as follows: study conception and design: CSS, LP, JFC; data collection: CSS, LP; analysis and interpretation of results: CSS, LP, JFC, DCW, A; draft manuscript preparation: CSS, LP, JFC.

7. Ethics approval

This article does not involve animal subjects, so ethical approval for animal studies is not necessary in the present study.

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