Assessing the efficiency of maggot production, nutritional value, and frass quality from different organic waste materials

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Abstract. The larvae of the Black Soldier Fly (BSF), commonly known as maggots, could act as effective agents for decomposing organic waste and produce economically valuable by-products. This study aims to assess the performance of various organic waste feedstocks in producing maggots in terms of yield, nutritional value, and quality of frass. The study was conducted at the Faculty of Agriculture's screen house and laboratory, Siliwangi University started from February 2024 to June 2024. The research involved systematic experimentation with various organic waste types, including vegetable, fruit, restaurant, and mixed waste (a mixture of fruit, vegetable waste). Each treatment was replicated 5 times. The result showed a significant difference in maggot yield at 14 and 21 days after hatching (DAH) but no difference at 28 DAH. The maggot growth treatment using vegetable waste media showed the highest maggot yield at 14 DAH, while at 21 DAH, the highest maggot yield was observed in the restaurant waste and mixed media treatments. Different organic waste as growth media showed a significant difference in maggot nutritional value, such as water content, ash content, crude protein, crude fat, and carbohydrate (by difference). Maggots reared on mixed waste had the highest protein content, though not significantly different from those reared on vegetable waste. In contrast, maggots from fruit waste had the lowest protein content. The analysis results showed that BSF frass had different nutrient contents of nitrogen (N), phosphorus (P), and potassium (K) for each organic waste treatment. Selecting suitable organic waste for maggot cultivation enhances protein yield, making maggots a viable alternative protein source for animal feed. This process also promotes efficient food waste recycling and organic fertilizer production, supporting sustainable agriculture.

1 Introduction

Although it is the smallest emission-generating sector, the waste sector significantly contributes to the release of methane (CH_4) and nitrous oxide (N_2O). Aprilia (2021) reported

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that greenhouse gas (GHG) emissions through waste amount to 3.2% of the total GHG emissions globally [1]. According to the IPCC in 2022, GHG emissions increased by 5.5 Gt CO_2eq between 2000 and 2019, rising from 8.61 to 14.11 Gt CO_2e [2]. In Indonesia, the waste sector contributes approximately 127 billion tonnes of CO_2e, placing the country third in the global ranking of waste sector emitters [1]. As a consequence, waste management strategies should be effectively provided for the mitigation of GHG emissions, especially in countries such as Indonesia with significant contributions to the global GHG stock from the waste sector.

Landfilling has been the reference method to compare the performance of most organic waste management systems. Landfilling is claimed to be the most GHG-intensive waste management method, with close to 400 kg of CO_2eq ton^{-1} of organic waste generated for every tonne [3]. The main origin of such a high emission is the decomposition process of organic waste in landfills, giving way to methane (CH_4), a strong greenhouse gas. Landfill and incineration waste contribute 2.7% of the total emissions, amounting to 0.15 Gt CO_2e in that category [2]. Equally, incineration releases some harmful pollutants into the atmosphere, such as carbon dioxide and particulate matter, which escalate air pollution and climate change [4]. Composting is a much more sustainable and effective option compared to the traditional methods of solid waste disposal. Composting of raw organics is seen to result in substantially reduced emissions by as 41 kg CO_2-e per ton of waste [5]; however, food composting could still result in substantial levels of methane and CO_2-e at 3308.85 mg kg^{-1} DM and 365.28 kg CO_2-eq ton^{-1} DM, respectively [6]. Therefore, the environmental impact of composting processes needs further optimization for reduction.

One such innovative approach is through the bioconversion of organic waste by means of BSF larvae, otherwise known as maggots. BSF larvae processing of food waste offers opportunities for turning food waste into valuable compost for agriculture while minimizing greenhouse gas emissions, which are high when food waste is incinerated. According to Ermolaev et al. (2019), direct greenhouse gas (GHG) emissions from the treatment process involving BSF larvae were minimal. Methane (CH4) and nitrous oxide (N2O) emissions amounted to 0.38 kg CO2-equivalents per ton of food waste processed, based on a 100-year global warming potential. Meanwhile, the average total CO2 emissions were reported as 96 g CO2 per kilogram of food waste treated [7]. This system has great importance since it recycles nutrients back to the soil and, on the other hand, it dramatically lessens the environmental impact. BSF larvae efficiently feed on various organic wastes, converting them into valuable products like high-protein larvae for animal feed and nutrient-rich frass for soil amendments. As Diener et al. stated in 2011, the BSF larvae are effective in reducing the waste and producing biomass, although their effectiveness is maximized according to the type of organic waste, where their highest efficiency in reducing municipal organic waste is a 68% reduction [8].

Although the potential of BSF larvae to treat certain types of organic waste has been demonstrated in many studies, there are few comprehensive comparative analyses regarding a wide range of food waste (e.g., fruit wastes, vegetable wastes, restaurant wastes, and mixed organic wastes). Research on BSF larvae cultured on different types of waste can provide additional information on the best production and nutritional content of maggots as well as the quality of co-products (frass). The type of organic waste material chosen can affect the nutritional contents of maggots, where some of the materials lead to a better growth outcome. These larvae are nutrient-rich with approximately 50% crude protein, 35% lipids, and a good balance of amino acids, making them an essential source of nutrients for animals such as chickens and fish [9]. It is, however, established and widely recognized that BSF larvae are good protein producers with valuable frass, although little has been done to clearly explain the variability in their nutritional value according to different feedstock sources.

In this regard, detailed studies have been called for regarding the type of organic wastes, their composition, and how the nutrient value and yield of larvae as a feed material for animals, and the quantity and quality of the produced frass can be assessed. This study aims to evaluate different organic waste feedstocks for BSF larvae production in terms of yield, nutritional composition, and frass quality.

2 Literature review

The utilization of maggots, particularly those of the BSF (*Hermetia illucens*), in converting organic waste into valuable products has garnered significant interest in recent research. The maggots showed high efficiency in reducing organic waste at bioconversion rates ranging from 55.1% to 70% [7]. The rapid degradation of organic matter by maggots helps not only in waste management but also in reducing waste volume and the associated environmental problems. Moreover, this ability of maggots to convert efficiently many organic substrates into valuable nutrients makes them very important in sustainable waste management practices. Apart from maggots being effective in reducing waste, they are a rich source of nutrients, with about 40-45% protein, 30-35% lipids, and having all the essential amino acids, thus qualifying as the best feed ingredients for animals like broilers, catfish, and goldfish [10].

Several characteristics of maggot production have been tested, including the level of different rearing substrates that would produce different nutritional values for the larvae. Protein content in maggots was found to differ from one substrate to another, where usually younger maggots have a higher content of proteins due to their faster growth. Azizah et al. (2020) revealed that the protein contained in the maggot comes from the protein found in the planting medium, because the maggot uses the protein in the media to form body protein. For example, high quantity and quality of media will have a positive effect on the quantity and quality of Hermetia illucens maggot protein. Additionally, studies have explored substituting fishmeal with maggot meal in aquaculture feeds, reporting positive results in terms of growth performance and feed conversion ratios [11]. The larvae are efficient in breaking down organic wastes and thus present a more sustainable way of waste management.

Other studies had tried to show that maggots have a good opportunity in waste management and the production of fertilizers. Ellison et. al. (2023) further added that biomass produced through maggot farming can be applied to agriculture, hence enhancing soil fertility and with it, sustainable farming [12]. Based on studies, BSF frass is rich in nitrogen, phosphorus, and potassium, which are very essential elements for the growth of plants. According to Reswita et al., BSF frass contains 2.1% of total nitrogen, 1.16% of total phosphorus, and 0.17% of total potassium [13]. The nutrient content indicated that BSF frass can be an effective organic fertilizer in promoting soil fertility, thus improving the growth of various plants.

The BSF follows a four-state life cycle: egg, larva, pupa, and adult. It starts when females lay the next step, eggs, in organic waste; larvae, decomposing efficiently a wide variety of organic materials, can be located in almost anything during about 14 days. Later on, these larvae pass into the next state, called the pupae stage, which lasts approximately 10 days before they emerge as adults. They live for an additional 8 days, but during this period, the adults basically do nothing other than reproduce [14]. Figure 1: Illustrated life cycle of a BSF and its underlying principle.

Applying the BSF larvae in waste management falls squarely within the working principles of a circular economy, whereby waste is transformed into valuable resources. According to Zulkifli (2022), BSF larvae have been reported to be very effective in converting various types of organic wastes, including rice and chicken manure, while reducing a reasonable amount of waste volume within a short period for treatment [15]. BSF larvae can be incorporated into fish diets, providing a sustainable protein source while simultaneously addressing waste management challenges. The life cycle of the BSF is a critical component of its role in organic waste management and nutrient recycling. Its rapid development, coupled with its ability to efficiently decompose organic materials, makes BSF an invaluable asset in promoting sustainable agricultural practices and supporting a circular economy.

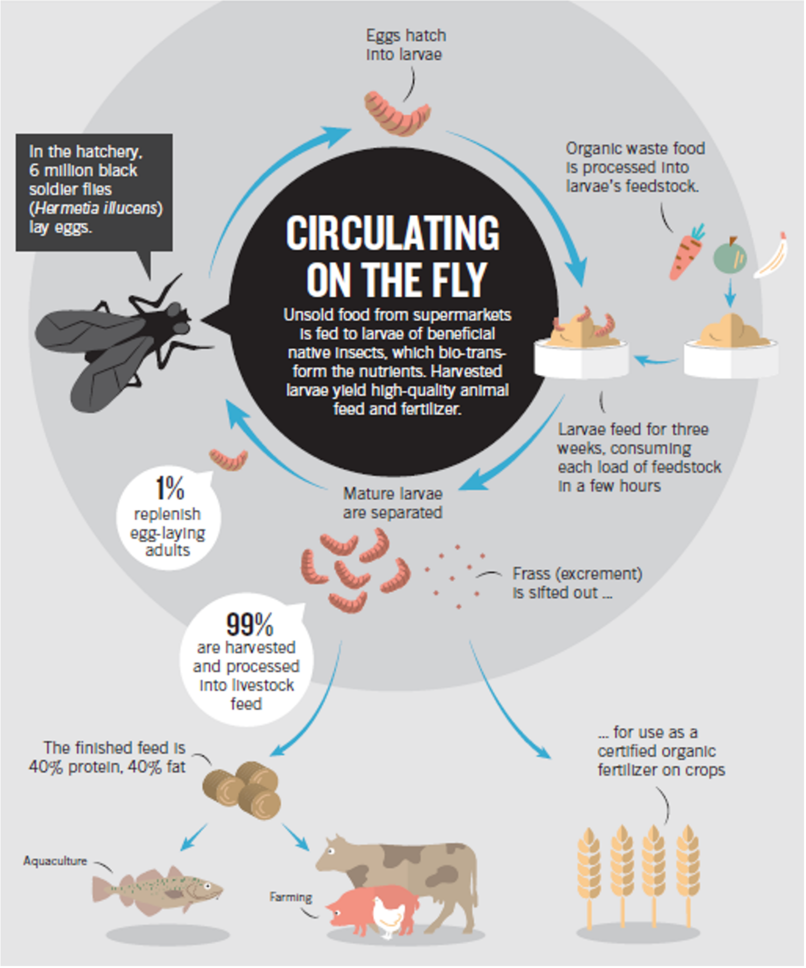

Fig. 1. Circulating the Black Soldier Fly [16]

3 Method

3.1 Research location and duration

The research was conducted from February to June 2024 and was divided into three systematic stages, which include the (1) Maggot Production Test, (2) Nutritional Content test of maggots, and (3) the Quality assessment for BSF Frass by its nutrient content from varied household organic waste types. The study was carried out across three sites in sequential stages, ensuring that each segment of the research was executed in an organized manner. The BSF larvae rearing used a screen house at the Faculty of Agriculture, University of Siliwangi, with controlled environmental conditions to obtain optimum growth. The nutrient content of the maggots was determined at the Center for Standard Testing of Rice Instruments, utilizing specialized equipment for precise measurement. Lastly, the composition of frass quality was analyzed for NPK (Nitrogen-Phosphorus-Potassium) content at the Laboratory of the Faculty of Agriculture, Siliwangi University, using the standard method for organic fertilizer analysis to determine the nutrient content present in the maggot-produced frass.

3.2 Material and method

The materials used in this study included Black Soldier Fly (BSF) eggs (*Hermetia illucens*), sourced from a local breeding facility, and four types of organic waste: vegetable waste, fruit waste, restaurant waste, and mixed waste. The vegetable and fruit waste was obtained from the traditional Cikurubuk market, while the restaurant waste was collected from several restaurants in Tasikmalaya City. A completely randomized design (CRD) was employed, with each type of waste serving as a treatment and five replications per treatment, resulting in a total of 20 experimental units. A total of 1 gram of Black Soldier Fly (BSF) eggs was placed in each treatment container. The hatching medium, consisting of rice bran combined with water, was prepared under controlled moisture conditions within a container measuring 30x20 cm. Feedstock was added to the containers 5 days after hatching, with each container filled with 3 kg of the respective waste type. Maggot yield was measured at three intervals: 14, 21, and 28 days after hatching (DAH).

Weight loss percentage was measured by using Gravimetric methods, drying at 105^{o}C of temperature for 24 hours. Nutritional content of the maggots was analyzed at 28 DAH, with parameters including water content, ash content, crude protein, crude fat, and carbohydrates (by difference). Additionally, the frass produced by the larvae was collected and analyzed for nitrogen (N), phosphorus (P), and potassium (K) content. The data obtained were subjected to statistical evaluation using one-way Analysis of Variance (ANOVA) to assess the significance of differences among treatments. Duncan’s Multiple Range Test (DMRT) was used as a post-hoc test to determine specific differences between treatment means, with a significance threshold set at $p < 0.05$. The data analysis was performed using Microsoft Excel, IBM SPSS 25, and R Studio with R version 4.4.1 (2024-06-14 ucrt) — 'Race for Your Life,' Copyright © 2024 The R Foundation for Statistical Computing.

4 Results and discussion

4.1 Maggot production

The study of maggot yield from various organic waste materials—specifically fruit waste, vegetable waste, restaurant waste, and mixed waste—over a 28-day period reveals significant insights into the nutritional dynamics influencing maggot growth (Figure 2). At 14 days after hatching (DAH), the yield across all treatments was notably low, with mixed waste yielding the highest quantity, followed by restaurant waste. In contrast, fruit and vegetable waste produced significantly lower yields. This initial difference in results could be due to the varying nutrient profiles found in mixed waste and restaurant waste, which are likely more conducive to early maggot growth compared to the more uniform organic nitrogen sources found in fruit and vegetable waste.

By 21 DAH, a marked increase in maggot yield was observed across all treatments, with mixed waste consistently producing the highest yield. This trend suggests that the balanced nutrient composition of mixed and restaurant waste supports sustained maggot growth over time, as these substrates release a richer variety of nutrients that are beneficial for larval

 https://doi.org/10.1051/bioconf/202517501001

development. The results align with findings that indicate the importance of substrate composition in influencing maggot productivity, where more complex organic materials tend to enhance growth rates [17].

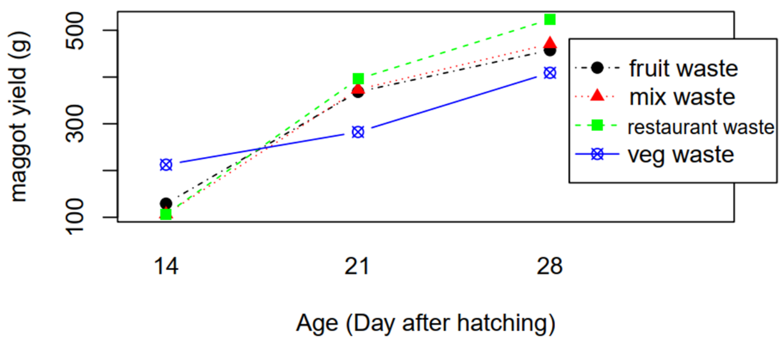

Fig. 2. The production of maggots from different organic waste

At 28 DAH, the maggot yield plateaued across most treatments, with mixed waste showing a marginal increase over the others. The yield from restaurant waste also increased, although to a lesser extent, while fruit and vegetable waste yields remained low, primarily due to nutrient depletion. This observation underscores the potential of mixed waste as a superior substrate for maggot production, while fruit and vegetable wastes exhibit limited capacity for supporting high maggot yields over extended periods. The findings suggest that optimizing the substrate composition is crucial for enhancing maggot production efficiency, particularly in waste management applications where organic waste is converted into valuable protein sources for animal feed.

Different organic waste as feedstock maggot showed a significant difference in weight loss percentage (Table 1). Maggots fed with vegetable waste had the highest weight loss percentage at 76.27%, which was statistically different from restaurant and mixed waste at 58.26% and 69.15%, but not different from fruit waste of 75.88%. In contrast to the other feed stocks, restaurant waste resulted in the least amount of weight loss (58.26%). This may indicate that the waste from restaurants contains more fats that lessen the drying process. The significant variations in weight loss percentages indicate that the yield of dried maggots was significantly influenced by the type of feedstock. Wastes that are high in moisture or low in fats might lead to greater weight loss upon drying, as observed with vegetable and fruit wastes.

Table 1. Weight loss percentage of maggots from different feedstocks

Treatment	Fresh Maggot (g)	Dried Maggot (g)	Weight Loss (%)
Vegetable waste	10.01	2.38	76.27c
Fruit waste	10.00	2.41	75.88c
Restaurant waste	10.01	4.18	58.26a
Mixed waste	10.01	3.09	69.15b

Notes: Values followed by the same letters are not significantly different at P ≤0.05, as determined by Duncan's Multiple Range Test (DMRT).

4.2 Maggot nutrition content

The statistical analysis of the nutritional content of maggot biomass from different organic waste is shown in Table 2. The result showed the significant differences in the nutritional content based on the type of organic waste used. Water content recorded differences among the treatments and peaked in vegetable waste, registering 4.3%; in fruit waste, it was slightly lower, accounting for 4.2%. The quantity of water in mixed waste was further reduced, to 2.3%, and in restaurant waste, it was still the lowest and equal to 1.6%. Haetami et al. (2021) found in their research that the different growing media (including vegetable and fruit wastes) affect the maggots' water content, which differs depending on the duration of the fermentation and the type of fermenting substance (the substrate) [18]. In such a way, it can be observed that with the increasing volume of vegetable and fruit wastes in the rearing process, there are corresponding increases in the moisture content of the maggot biomass. On the other hand, mixed waste produced the least amount of water content, thus showing a drier biomass that may turn out to be most helpful in applications in which moisture content has to be kept at lower levels.

Table 2. Analysis of the nutritional content of maggot biomass from different organic waste

Treatment	**Nutrition Content**				
	WC (%)	AC (%)	CP (%)	CF (%)	CBD (%)
Vegetable waste	4.3 d	17.2 d	27.3 bc	7.0 a	44.1 c
Fruit waste	4.2 c	13.8 b	26.3 b	19.1 c	36.6 b
Restaurant waste	1.6 b	11.5 a	22.5 a	33.2 d	31.3 a
Mixed waste	2.3 a	15.4 c	28.2 c	17.9 b	36.2 b

Notes:

- WC = water content, AC = ash content, CP = crude protein, CF = crude fat, CBD = carbohydrate by difference
- Values followed by the same letters are not significantly different at $P \leq 0.05$, as determined by Duncan's Multiple Range Test (DMRT).

The ash content showed a high variation depending on the kind of wastes taken into account. In this respect, ash contents were 17.2% for vegetable wastes and 15.4% for mixed wastes, with fruit and restaurant at 13.8% and 11.5%, respectively. Ash content is one of the important indicators of the mineral matter biomass it contains. These results suggest that the mineral loads in the maggots from vegetable waste will be higher, hence likely improving the nutritional value of the biomass with respect to essential minerals. The ash content of maggots can be variable, and it mostly depends on the substrate, which is, in turn, expressed in dry matter, with a wide range of values reported between 9% to 28% [19]. Decreased ash content in mixed waste may imply that it is a less rich mineral feed source and may, therefore, have implications for the overall nutritional balance in maggot biomass.

Analysis showed that the protein content was highest in mixed waste at 28.2%, followed closely by vegetable waste at 27.3%, and lastly fruit waste at 26.3%. Restaurant wastes showed the lowest protein content at 22.5%. These results support the claim that mixed wastes have better potentials for protein supplementation than restaurant and fruit wastes, meaning it can enhance protein content in the maggot biomass much more easily, and this is desirable for cases where high dietary protein is required. This would mean that, therefore, the relatively lower amount of protein concentration in the restaurant waste may be a limiting factor over and above any consideration to increasing the concentration of protein per unit, but it still could be useful for producing nutritionally balanced biomass.

The crude fat differed appreciably with regard to source: restaurant waste yielded the highest crude fat value of 33.2%, followed by fruit wastes at 19.1%, mixed wastes at 17.9%, and lastly vegetable wastes with 7.0%. This increase in fat content is probably due to the fact that the waste itself contains grains of fatty parts of food preparation and cooking. On the contrary, the vegetable waste showed the lowest among other crude fats. It is, in contrast, inversely proportional to the water content. The waste from vegetables had the highest concentration of CBD at 44.1%, whereas that from restaurant wastes was rated very low at a value of 31.3%. This shows how different waste classes can be used in a complementary manner to match the macronutrient composition of maggot biomass to meet specific food or industrial needs.

Maggots require essential nutrients such as proteins, lipids, and carbohydrates, along with adequate moisture content to support their metabolism, enzymatic activities, and overall biomass accumulation. In order to optimize maggot production, carbohydrates form about 30-40% of the dry feed, protein must be at least 25%, fat should not be more than 10-20%, and moisture levels should be maintained in aerobic conditions to prevent dehydration. In terms of nutritional value, mixed waste seemed the most balanced formulation, while vegetable and fruit waste appeared to lack some essential nutrients for the optimal growth of larvae. Further studies should be done to determine the most effective composition of waste for the highest amount of maggot biomass together with the most nutrients.

4.3 Nutrient content of maggot frass

Maggot frass, the by-product of Black Soldier Fly (BSF) larvae cultivation, is rich in essential nutrients, making it a valuable resource in organic waste management and agricultural applications. Analysis of the nutrient concentration of maggot frass produced from various organic wastes is shown in Figure 3. The main nutrients examined include Nitrogen (N), Potassium (K_2O), Phosphorus (P_2O_5), and Water Content. Based on the analysis results, maggot frass derived from fruit waste has the highest moisture content, followed by restaurant waste, mixtures, and vegetables, with respective values of 18.54%, 15.28%, 13.78%, and 13.7%. According to Ahmad et al. (2023), fruit waste tends to be more water-rich than vegetable waste, which is consistent with the increased moisture content seen in the frass made from it [20]. Maggot frass from restaurant waste resulted in the highest total N content at 0.96%, total K2O at 3.46%, and total P2O5 content of 2.385%. In contrast, the total N-P_2O_5-K_2O contents from vegetable waste showed the lowest with respective values of 1.79%, 1.85%, and 0.67%. The high nutrient content of restaurant and mixed waste-derived frass suggests its potential as a superior organic fertilizer, capable of enhancing soil fertility and plant growth more effectively than frass from vegetable waste and fruit waste.

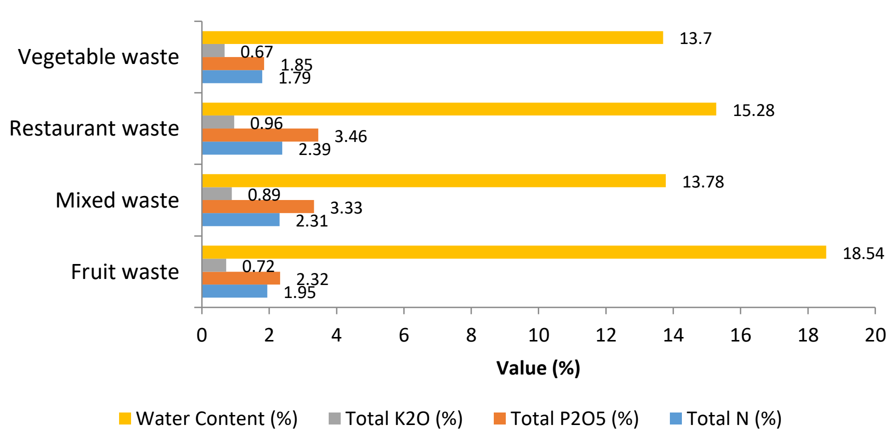

Fig. 3. Nutrient and water content of maggot frass from different organic waste of cultivation media

5 Conclusion

In conclusion, this study highlights the significance of organic waste composition in optimizing maggot production, nutritional value, and frass quality. Mixed waste emerged as the most effective substrate, yielding the highest maggot biomass and crude protein content. Restaurant waste resulted in maggots with the highest fat content, while vegetable waste produced the highest carbohydrate levels. The findings emphasize the potential of tailored organic waste selection to enhance maggot production for sustainable animal feed. Additionally, the nutrient composition of maggot frass varied based on the waste type, underscoring its potential as an organic fertilizer. Overall, utilizing mixed waste offers a dual benefit—efficient food waste recycling and the production of nutrient-rich biomass and frass for sustainable agriculture.

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