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Production Performance and Nutritional Quality of Black Soldier Fly Larvae Nurtured in Different Organic Waste

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Abstract

Nutritionists are beginning to pay attention to black soldier fly (*Hermetia illucens L.*) larvae (BSFL) as an alternative to expensive soybean and fish meal in animal feed which is abundant in different nutrients. Additionally, organic wastes including leftover food, animal excreta, and agricultural wastes, can be used to efficiently raise and spread BSFL. This study was carried out to evaluate the yield, production performance and proximate composition of BSFL nurtured on different organic waste namely, broiler starter feed (BF); rice bran (RB); market-sourced vegetable wastes (VW); chicken manure (CM) and kitchen waste (KW). The BF fed group had the highest observed larval yields (16.2 kg in total; $P<0.05$). Raising BSFL on BF, VW and KW resulted in the greatest body weight (0.149, 0.147 and 0.150 g, respectively) and growth rate (0.012 g), whereas the KW fed group had the longest body length ($P<0.05$). The fed groups that received CM and BF had the highest and lowest mortality rates, respectively ($P<0.05$). All fed groups except RB had improved feed conversion ratios, while VW and KW fed groups had higher protein conversion ratios (2.626 and 2.852, respectively; $P<0.05$). All the group had better substrate reduction rate compared to CM fed group ($P<0.05$). The dry matter and ash contents of BSFL reared on BF, VW and KW were higher than the RB and CM group ($P<0.05$). The KW supplemented BSFL had the highest ether extract level, whereas the BF fed group had the highest protein content (43.58%, $P<0.05$). In conclusion, BSFL can be successfully reared on kitchen and vegetable scraps. It is anticipated that the cost of black soldier fly farming and animal production will decrease since these organic waste shown favorable effects on BSFL growth performance and nutritional quality comparable to broiler feed in the current study.

Keywords: *Hermetia illucens*, Yield, Growth Efficiency, Composition, Organic Wastes.

Introduction

The world's population is predicted to reach 9.1 billion By 2050, with developing countries accounting for the vast majority of this growth. To feed this expanding population, food output will need to increase by 70% between 2005/07 and 2050 (FAO 2017). In order to feed a growing population with shrinking land resources, the agriculture sector must find ways to produce more food and fiber and implementing more effective and sustainable production techniques while minimizing negative impacts on the environment. Despite the world's high

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population, increasing urbanization, economic growth, and awareness of nutritional needs, dietary patterns have recently shifted considerably in favor of more animal-based foods, such as milk, meat, fish, and eggs. It is projected that these preferences will rise over time (Makkar *et al*., 2014). For instance, the production of chicken meat increased from 83.3 million metric tons to 101 million metric tons between 2012 and 2022 (Statista, 2022). According to FAO (2012), there is an expectation that the demand for meat and milk would increase by 58% and 74%, respectively, by 2050 compared to 2010 levels. A significant portion of this increase is predicted to come from developing nations.

The scarcity and high cost of good-quality feed ingredients, however, have emerged as the main obstacle to animal production in developing nations. The most commonly utilized ingredients in feed formulations for fish and poultry as a source of protein are fish meal and soybean meal (Agazzi *et al*., 2016). According to Leschin-Hoar (2017), fishmeal manufacturing uses around 25% of the total fish catch worldwide. Feed ingredients that are acceptable for direct human consumption, such as fish and soybeans, are costly due to the competition between food and feed, which drives up the cost of feeds and leaves farmers with extremely small profit margins (Rana *et al*., 2009; van Huis *et al*., 2013; Onsongo *et al*., 2018). This condition affects the production of meat, eggs, and fish. According to Alves (2023), population expansion is also predicted to result in a 70% rise in garbage output (3.5 billion tonnes) by 2050. This increase is associated with a number of environmental issues, such as soil, air, and water contamination. As a result, more sustainable alternatives are needed to meet future food and feed needs, as well as the need for an effective way to address the waste accumulation issue (Khan, 2018).

Due to their significant feed conversion efficiency, insects can be reared and produced in large quantities on a range of organic waste streams (van Huis *et al*., 2013). Recently, scientists have become increasingly interested in the possibilities of using insect-based protein and other nutrients as animal feed ingredients, including poultry and fish (van Huis *et al*., 2013; van Huis and Tomberlin, 2017; Fauzi and Sari, 2018). *Hermetia illucens* L. (Diptera: Stratiomyidae), the black soldier fly (BSF), has the most potential for large-scale production among the insect species suggested for animal feed (van Huis *et al.*, 2013; Rumpold *et al*., 2018). The crude protein (CP) content of black soldier fly larvae (BSFL) ranging from 216 g/kg (Yildirim-Aksoy *et al*., 2020) to 655 g/kg (Schiavone *et al*., 2017), with an average of 414.7 g/kg and fat content ranged from 294 g/kg (Onsongo *et al*., 2018) to 515.3 g/kg (Tyshko *et al*., 2021), with an average of 353.2 g/kg and have an amino acid profile that is similar to that of fishmeal.

Numerous research (Lalander *et al*., 2019; Shumo *et al*., 2019a, 2019b; Seyedalmoosavi *et al*., 2022; Naser El Deen *et al*., 2023) have demonstrated the high efficiency of BSF larvae (BSFL) in converting organic wastes (waste from abattoirs, food waste, waste from fruits and vegetables, and human feces) into protein. However, according to our knowledge no research has been conducted in Bangladesh in this regard. Because BSF production can turn trash into protein, it is a desirable option for cutting waste and improving the sustainability of animal feed production. The features of the substrate, particularly its nutritional content, had a substantial impact on the growth performance, nutritional makeup, and conversion efficiency of the larvae (Diener *et al*., 2009; Spranghers *et al*., 2017; Wong *et al*., 2019; Hosseindoust *et al*., 2023). However, according to our knowledge very limited research (Rana *et al.*, 2015; Paul *et al.*, 2023) has been conducted in Bangladesh to understand BSFL growth performance using local substrate.

Therefore, this study was set out to evaluate the yield, growth performance, and nutritional quality of BSFL nurtured on various organic waste matter.

Materials and Methods

Study Area

The experiment was carried out in the Department of Agribusiness of Atish Dipankar University of Science and Technology, Dhaka, Bangladesh. The university is located in the northern area of Dhaka, which is mostly dry, and sunny throughout the year, and sparsely inhabited. For this experiment, a calm environment inside the university grounds was chosen to rear the black soldier fly larvae (BSFL).

Feeding Materials

Five ingredients were chosen as BSFL feeding materials based on their availability in the experimental area, namely broiler starter feed (BF); rice bran (RB); market-sourced vegetable wastes (VW); chicken manure (CM) and kitchen waste (KW). The proximate composition (Table 1) of the feeding substrates was determined using the method outlined by AOAC (2005).

In order to investigate the seasonal impacts on larval growth, the larvae were produced at ambient temperature in the months of April, August, and December of 2022 when the average temperature of the experimental house was 31.4ºC, 30.3ºC and 18.5ºC, respectively. Eggs of the BSF were collected from the Horticultural Center of the Bangladesh Agricultural Development Corporation (BADC) in Kashimpur, Gazipur, Bangladesh. About 5 g of eggs were kept onto a net placed on a two side open plastic pot. The plastic pot was put into a plastic bowl which was filled with 500 g of each feeding materials (BF, RB, VW, CM and KW). The BF, RB and CM, were mixed with 300 mL of water (60%) to provide optimal moisture for larval feeding and growth. In contrast, VW and KW were kept at room temperature for two days before to being used in order to lower the water content in accordance to Addeo *et al*. (2021).

Growth Trial

The eggs began hatching after 3 to 4 days. When the larvae reached the sixth day, they were pass through a 1.2 mm mesh screen, and those that made it through were determined to be of equal weight and size. Then, 2000 larvae from each feeding group were picked (with forceps) and their weight was recorded on an electronic weighing scale to determine the collective average weight of the 2000 larvae and, as a result, the average weight of individual larvae after 6 days. These 2000 larvae were maintained separately to determine the growth performance characteristics, and when the ultimate yield was calculated the weight of these was combined with the remaining larvae weight. As feeding structures for the larvae, identically sized plastic bowls with a capacity of 18 liters were used. Each group (BF, RB, VW, CM, and KW) had five replicate bowls containing 400 larvae each. The larvae had free access to food, and all feeding supplies were replenished weekly with fresh feed and water as needed. The amounts of feed given were recorded.

After 15 days of growth, the larvae were sorted from the remainder using sieves and forceps, and the final larval weight and number were recorded to calculate the growth rate and mortality. To ensure that the majority of the larvae were at the same stage of development, they were collected before 5% of them developed into pupae. According to Charlton et al. (2015), a 48-hour feed withdrawal interval was used to avoid errors in yield computation as well as undigested feed and microbial load in the insect gastrointestinal tract becoming part of the final insect meal. Each replication contained one hundred randomly selected larvae for measuring body length on day 15. The growth rate, larval mortality, feed conversion ratio and substrate reduction (%) was calculated using the following formula applied by Addeo *et al*. (2021).

Table 1. Proximate composition of the feeding substrate used to grow larvae

Feeding substrate	Type of feeding substrate used	Dry matter (%)	Ash (%)	CP (%)	CF (%)	EE (%)
BF	Broiler feed	92.1	8.7	22.34	5.9	4.9
RB	Rice bran	93.8	8.4	15.60	6.1	18.9
VW	Vegetables and fruits wastes from the market	12.9	15.1	14.79	38.9	2.1
CM	Chicken manure	81.6	20.7	19.04	20.6	2.9
KW	Kitchen waste	49.8	8.7	13.40	33.1	13.3

Values are expressed as the mean of 3 replications.

Growth rate (GR), % = (FLW, g − ILW, g)/d

Larval mortality (LM), % = (ILN− FLN) * 100/ILN

Substrate reduction (SR), % = (AFM, g − RFM, g)/AFM, g * 100

The feed conversion ratio was calculated by using the formula suggested by Broeckx *et al*. (2021).

FCR = AFM/(LFW−IFW)

Where, where ILN = initial larval number; FLN = final larval number; FLW = final larval weight; ILW = initial larval weight; d = days of the trial; AFM = administered feeding materials; RFM = residual feeding materials.

The larvae were then washed under tap water to remove any feeding materials attached with them. After washing the BSFL was killed by immersion in ice water according to Fu *et al*. (2014) and air dried. The dried BSFL were then grinded using a kitchen grinder and the ground samples were used to analyze the dry matter (DM), crude protein (CP), ash, and crude fat (EE) according to the method described by AOAC (2005).

The protein Efficiency ratio (PER) was calculated according to the formula suggested by Lan *et al*. (2020): PER = Larvae protein gain/protein intake.

Statistical Analyses

Data were presented as mean and standard error of mean (SEM). Data were statistically analyzed by a one-way ANOVA, using the GLM procedure of Statistical Package for Social Science (SPSS, version 23). Each replication was considered as the experimental unit. The Tukey test was used to compare the means of the treatments, and a *P*-value less than 0.05 was considered statistically significant.

Results and Discussion

Yield of BSFL in Different Feeding Materials

Larvae were produced in three different months of the year — April, August, and December — to assess the effectiveness of season on BSFL yield maintained on various organic wastes. The feeding material and the season both had notable impact on the larval yield in this study. The larval yield in August and April was approximately the same, while in December it was lower in all the supplemented groups (Figure 1). The BSFL grow well at a temperature range from 27 and 35◦C and humidity of 70–75% (Cheng *et al.*, 2017). The average temperature of the experimental area at April and August were 31.4ºC and 30.3ºC, respectively. Rana *et al.* (2015) found that BSFL production fluctuated with the varying temperature and stopped at 15^0C or less. This could be the reason for the better growth of BSFL during the mentioned period. However, average temperature of December was 20.5ºC, which might be responsible for the lower growth of BSFL. Nyakeri *et al*. (2016) also found lower yield in December compared to March which also may be due temperature variation.

In addition to differences in the nutritional value of the substrate materials, variations in the quantity and strength of smells produced by food breakdown may lead to variations in larval yield (Rana *et al.*, 2015). In April and August, the BF supplemented group produced the highest yield (5.97 kg and 5.92 kg, respectively), followed by VW, RB and KW (P<0.05). The CM group had the lowest production, averaging 4.02 kg in April and 4.35 kg in August (P<0.05). Nyakeri *et al.* (2016) found the highest BSFL production in the mashed maize grain and vegetable waste supplemented group, which is comparable to our findings. Rana *et al.* (2015) discovered that rotten wheat produced the most BSFL, followed by rotten vegetables and rotten mustard oil cake, which differed from our findings. Nyakeri *et al.* (2016) found that the animal manure supplemented group had the lowest yield, which is consistent with our findings. In contrast to our findings, Nyakeri *et al.* (2017) discovered that the restaurant food waste supplemented group produced the highest output.

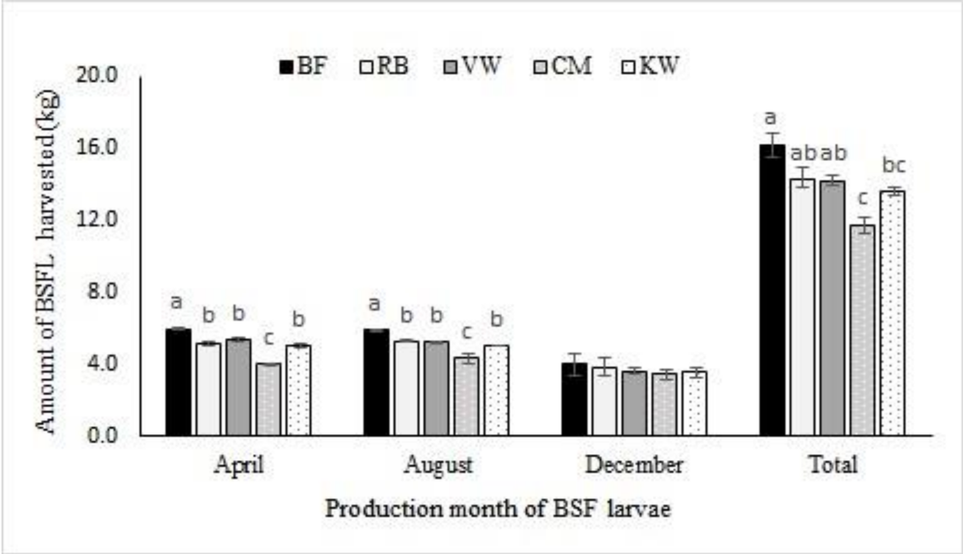

Figure 1. Effects of different feeding substrate on the yield of black soldier fly (BSF) larvae harvested in April, August and December.

BF = Broiler feed, RB = Rice bran, VW = Vegetables and fruits wastes from the market, CM = Chicken manure, and KW = Kitchen waste. [a,b,c] Values with different superscripts in the same bar differ significantly ($P<0.05$).

Growth Performance of BSFL in Different Feeding Materials

The growth performance of BSFL reared on different organic waste is reported in Table 2. Highest body weight at day 15 was recorded in the KW (0.150 g) followed by BF (0.149 g) and VW (0.147 g) groups ($P<0.0001$). The growth rate was also higher in KW, BF and VW group (0.012 g; $P<0.001$). Larvae from the RB group showed the lowest body weight (0.129 g) and growth rate (0.009g) at day 15 ($P<0.001$). No significant difference was recorded in 6 days' body

Table 2. Growth performance of BSFL reared on different feeding substrates

Parameter	Type of feeding substrate used[2]					SEM[2]	*P*-value
	BF	RB	VW	CM	KW		
Body weight at 6 days (g)	0.054	0.055	0.051	0.052	0.055	0.002	0.540
Body weight at 15 days (g)	0.149^{a}	0.129^{c}	0.147^{a}	0.138^{b}	0.150^{a}	0.002	0.000
Growth rate	0.012^{a}	0.009^{b}	0.012^{a}	0.011^{ab}	0.012^{a}	0.000	0.001
Body length at 6 days (cm)	1.124	1.140	1.152	1.148	1.136	0.007	0.067
Body length at 15 days (cm)	1.582^{ab}	1.492^{b}	1.576^{ab}	1.468^{b}	1.686^{a}	0.096	0.012
Mortality (%)	5.890^{c}	7.530^{b}	8.000^{b}	9.590^{a}	8.090^{b}	0.300	0.000
Feed conversion ratio	10.49^{b}	13.68^{a}	10.58^{b}	11.71^{b}	10.61^{b}	0.532	0.000
Protein conversion rate	1.659^{c}	2.578^{ab}	2.626^{ab}	2.259^{b}	2.852^{a}	0.096	0.000
Substrate reduction rate	46.440^{a}	44.890^{a}	45.860^{a}	41.450^{b}	47.020^{a}	0.690	0.000

[a,b,c]Values with different superscripts in the same row differ significantly ($P<0.05$).

[1]Values are expressed as the mean of 3 replications.

[2]Feeding Materials (FM)1: BF = Broiler feed; FM2: RB = Rice bran; FM3: VW = Vegetables and fruits wastes from the market; FM4: CM = Chicken manure; FM5: KW = Kitchen waste; SEM = Standard error of the means.

length of larvae, however, at 15 days' highest body length was recorded in the KW fed group (1.686 cm; *P*<0.012) compared to other group. Addeo *et al*. (2021) reported highest body weight, body length and growth rate at day 15 in the 75% vegetable +25% butchery waste and broiler fed supplemented group which is in line with our findings. Paul *et al*. (2023) reported highest larval weight and length in the Rice-Fruit-Vegetable-Fish fed group which is comparable to our kitchen waste and is consistent with the result of our study. Broeckx *et al*. (2021) also found highest mean larval weight in the industrial food waste and chicken star mash supplemented group. Hosseindoust *et al*. (2023) reported more larval weight and larval length in the food waste group compared to only vegetables. However, Nyakeri *et al*. (2017) reported highest body weight at day 16 in the food waste supplemented group. The composition of organic waste can promote the growth of BSFL (Spranghers *et al*., 2017; Naser El Deen *et al*., 2023). In this study, kitchen waste and broiler starter feed showed higher growth performance, as both contain good amount of protein.

Highest mortality was recorded in the CM supplemented group (9.59%), followed by KW (8.09%), VW (8.00%) and RB (7.53%). Lowest mortality was found in the BF fed group (5.89%; *P*<0.0001). Addeo *et al*. (2021) reported lowest mortality in the broiler feed fed group compared to others which is in consistent with our study. All the supplemented group had better FCR compared to RB (*P*<0.0001). Our findings are supported by some earlier research (Cammack *et al*., 2017; Lu *et al*., 2022) showing that larvae raised on a diet rich in carbohydrates and protein had better growth, FCR and survival rates.

The feed conversion ratio of BSFL was higher in the RB fed group (13.68) compared to other group (*P*<0.0001). In contrast to BF (1.659), the BSFL of KW group (2.852) in our study had the highest protein conversion ratio, followed by VW (2.626) group (*P*<0.0001) which is in consistent with findings of Addeo *et al*. (2021) and Hosseindoust *et al*. (2023). All the groups had statistically higher substrate reduction rate in comparison to CM fed group (*P*<0.0001). In consistent to our results Broeckx *et al*. (2021) also found better waste reduction in the food waste, chicken start mash, vegetable waste compared to chicken manure. Fitriana *et al*. (2021) also reported better waste reduction rate in the food waste and animal feed supplemented group compared to others.

Composition of BSFLM Reared on Different Feeding Substrate

The BSF has been proposed as a nutrient-dense, environmentally viable substitute for aquaculture, poultry, and conventional cattle. Previous experimental research (Oonincx *et al*., 2015; Veldkamp and Bosch, 2015) mostly focused on the final larval and prepupal stage and reported variations in the nutritional components of BSF by supplying different feed sources for larval growth. Table 3 displays the experimental BSFL's chemical composition. The findings showed that the nutritional makeup of BSFL raised on various feeding substrates varied significantly (*P*<0.05). The dry matter contents

Table 3. Proximate composition of the experimental BSFLM reared on different feeding substrate.

Parameter	**Type of feeding substrate used[2]**					**SEM[2]**	***P* value**
	BF	**RB**	**VW**	**CM**	**KW**		
Dry matter (%)	86.17[a]	82.43[b]	85.92[a]	81.27[b]	86.97[a]	0.63	0.0001
Ether extract (%)	30.15[bc]	31.33[b]	26.34[d]	28.20[cd]	34.60[a]	0.37	0.0001
Protein (%)	43.53[a]	40.20[b]	38.77[c]	42.94[ab]	38.17[c]	0.89	0.0001
Crude ash (%)	10.01[a]	8.33[b]	10.02[a]	9.79[b]	10.07[a]	0.78	0.0001

[a,b,c,d]Values with different superscripts in the same row differ significantly (*P*<0.05).

[1]Values are expressed as the mean of 3 replications.

[2]FM1: BF = Broiler feed; FM 2: RB = Rice bran; FM3: VW = Vegetables and fruits wastes from the market; FM4: CM = Chicken manure; FM5: KW = Kitchen waste; SEM = Standard error of the means.

of the experimental BSFL was higher in KW (86.97%) followed by BF (86.17%) and VW (85.92%) group compared to RB (82.43%) and CM (81.27%) group (*P*=0.0001). The ether extract (EE) content of BSFL was highest in the KW supplemented group (34.60%) followed by RB (31.33%), BF (30.15%), CM (28.20%) and lowest was recorded in the VW (26.34%) fed group (*P*=0.0001). On the contrary, the highest protein (CP) was found in the BF fed group (43.53%) followed by CM (42.94%) and RB (40.20%) compared to VW (38.77%), and KW (38.17%) supplemented group (*P*<0.05). In line with our findings Addeo *et al*. (2021) also reported highest lipid in the vegetables and butchery waste supplemented group (comparable to kitchen waste of our experiment) followed by chicken feed fed group. Addeo *et al*. (2021) also reported highest CP in the broiler feed and 100% vegetable supplemented group in consistent to our findings. Hosseindoust *et al*. (2023) found similar CP in the food waste and vegetable fed BSFL, however, the EE was higher in the food waste fed group. Contrary to our result, Nyakeri1 *et al*. (2017) reported highest CP content in the fecal sludge fed group compared to food waste. Alternatively, Fitriana *et al*. (2021) reported no effect of dietary supplement on the CP and EE content of BSFL. The EE and CP contents of the experimental BSFL groups can be explained by the EE and CP contents of the experimental feed. Our study found CP values ranging from 33 to 43%, which is lower than the range of values (39 to 43%) reported by Spranghers *et al.* (2017) for BSFL cultivated on various organic waste streams but roughly equal to the findings of Shumo *et al.* (2019a). Furthermore, Sheppard *et al.* (1994) reported 42% CP for BSFL fed on chicken dung, whereas Nguyen *et al.* (2015) reported 39% CP for BSFL raised on fruit and vegetable waste. Shumo *et al.* (2019a) reported 30.1% and 34.3% EE in chicken manure and kitchen waste fed BSFL, respectively, which is equivalent to our results. BSFL treated with KW, FB, and VW had higher ash levels than CM and RB (*P*<0.05). The positive link between dry matter and ash can be utilized to explain the greater ash content of BSFL in the BF, VW, and KW feeding groups.

Conclusions

In this experiment we assessed the production performance and nutritional quality of black soldier fly larvae (BSFL) nurtured on some organic substrates that are widely available in Bangladesh. We found that among the feeding substrates broiler feed (BF), vegetable waste (VW), and kitchen (KW) waste were more effective to increase the yield, growth performance and nutritional quality of BSFL compared to rice bran (RB) and chicken manure (CM). Therefore, it can be concluded that, the quantity and quality of BSFL can be increased by nurtured them on BF, VW, and KW. Hence improving the sustainability of feed production for poultry.

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Declaration

The authors declare no conflict of interest.

Authors' Contribution

STA conceptualized, supervised, resourced and validated the project; STA and MMH are responsible for data curation, methodology, investigation and writing of original draft; MWI, SIR and MMH also responsible for data curation together with analysis of the data. The completed manuscript has been read and approved by all authors.

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