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Effect of locally generated food waste on bioconversion and nutrient parameters of black soldier fly larvae, *Hermetia illucens* L.

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Abstract
Black soldier fly larvae (BSFL) are well known for its high digestibility to reduce any type of organic waste, including fruits, vegetables, farm waste, municipal wastes etc. Appropriate BSF farming methodology not only can generate enough income to the farmers, but reduces environmental pollution which leads to sustainable development. In developing countries, in urban as well as rural areas early perishable fruits like banana, papaya, muskmelon, watermelon and vegetables undergo wastes if not properly handled and stored. In these areas expired floor and bakery wastes are also common. For this study BSF larvae were fed on waste separately to explore the effect of locally available organic wastes as feed for the production of black soldier fly larvae. BSF larvae were fed separately on Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and on Kitchen waste (KW). The efficiency of BSF larvae to consume these locally generated wastes and therefore reduce the waste loads of different substrates was studied. Various bioconversion parameters were evaluated, like feed consumed, Total larval yield, survival%, larval growth %, total waste reduction %, bioconversion % and feed conversion rate (FCR). BSF converts waste into biomass so the nutrient parameters like crude protein, lipid and amino acid composition were also analysed. From this study BSF larvae are proved to be a potential insect to reduce these organic wastes efficiently, but may be because of BSF larvae were fed continuously on the same type of food waste, the nutrients like protein, fats and amino acids in BSF found to be very low. This study concluded that for commercialization, it is essential to feed BSF larvae on mixed types of food waste rather than only on single type of waste.

Keywords: Organic waste management, feed conversion rate, waste reduction, biomass, larval growth percent

Introduction

Today number of developing countries are facing waste disposal and dumping problems as the landfills are already occupied with garbage, reaching their capacity, reducing the available space for future waste disposal, which will create a need to occupy the new lands. It was estimated that approximately one third of the food produced for human consumption get lost as wastage globally each year (FAO, 2019) (Gustavsson *et al.*, 2020) [17]. Food waste harms the environment in multiple ways and leads to loss of finite resources such as land, water and fuel utilised during food production and distribution. Not only this but food waste in landfills is contributor to climate change, contributes 4.4 gigatons of carbon dioxide (CO_2) in the atmosphere annually as well as emits Green House Gas (methane) (Scialabba *et al.*, 2013) [33]. Sustainable methods for recycling wastes can reduce this problem as the valuable components of the wastes will be utilised.

World will face hunger when the population will increase at its extreme and the natural resources will be limited for the production of food. To reduce, recycle and reuse will be the motive for our survival in future. Now it's time to use each and every part of our food, produced by our hard work in limited natural resources. Food and other organic wastes are a valuable resource that everyone should not waste as it contains a lot of nutrients and energy value that could be beneficial to both humans and the environment if reintegrated into the value chain (Bloukounon *et al.*, 2017) [4].

Black soldier fly (BSF) organic waste management technology is the key to reduce the organic waste generated by us which will be consumed by these insects, so the nutrients present in the wastes will get converted into insect biomass. BSF larvae are voracious feeders, they feed on different types of organic waste and incorporate nutrients in their body in the form of protein, fats, vitamins and minerals, not only this but they convert waste into valuable organic fertilizer (frass). These insects can be used as animal feed or used as feed ingredient for livestock as well as for the production of biodiesel and biologically active substances (Cickova *et al.*, 2015) [6].

Various work done on BSF larvae (BSFL) shows that these larvae can feed on a wide variety of feed substrates like kitchen food wastes, agricultural waste, animal waste, meat etc. (Surendra *et al*., 2020, Raksasat *et al*., 2020) [37, 32], where larvae showed the differences in the growth period, survival %, bioconversion %, the nutrient contents etc. (Broeckx *et al*., 2021) [5]. Variable macronutrient contents in the feed substrate (i.e., protein, fat, carbohydrate) has a significant influence on the performance and composition of BSFL (Barragan 2018), (Gligorescu *et al*., 2018) [14]. Several studies showed that substrate macronutrient content influences BSFL growth performance and nutrient composition (Gold *et al*., 2020, Laganaro *et al*., 2021, Danieli *et al*. 2019, Pliantiangtam *et al*., 2021, Nguyen *et al*., 2015, Meneguz *et al*., 2018, Spranghers *et al*., 2017, Lim *et al*., 2019, Sideris *et al*., 2021) [17, 20, 8, 31, 28, 24, 36, 22, 35]. Even same type of waste side-stream varies in nutritional content, affect the BSFL performance, which is demonstrated by Gold *et al*. (2018) [16].

Hermetia illucens L. commonly called black soldier fly belongs to order Diptera, family Stratiomyidae, commonly found all over the world. The life cycle of this fly consists of four stages, egg, larva, pupa and adult. Larval stages last for 15 to 20 days depending on temperature and humidity and larval stages may extend to more than three months when temperature falls or food is less. When larvae reach their last stages, they stop feeding and convert into dark brown stage called pre-pupa. Pre-pupa will search for dry place to pupate and if the rearing tray is wet, they crawl out of the trays, undergo pupation. Pre-pupae convert themselves to pupae and within 10 to 14 days adult flies emerge from the exoskeleton. After emergence adult flies attract towards sunlight or artificial light and start the process of mating. Adult female flies after mating search for the proper space near smelly food and start egg laying by inserting its ovipositor in the cracks or in the gaps of prepared eggies. BSF female flies have high power of reproduction, lays about 500 to 800 eggs at a time.

In the present study some local food wastage which are generated regularly like rotten damaged fruits, discarded vegetables from market and from homes, expired flours from kitchens, bakery wastes from bakery shops, were utilised and considered as local wastes or feed substrates for BSFL, where still the valuable nutrients remain available. By saving the nutrients from these wastes we can improve the future food security as well as can save environment from getting polluted.

Material and Methods

The study was performed in Dr. R. G. Bhoyar Arts, Commerce and Science College, Seloo, Dist. Wardha (Maharashtra- India), during the summer season (March-April 2022), when Room temperature ranges between 32-36^0 C and Humidity between 15-30%. Eggs of BSF were collected from love cage. Harvested eggs were weighted, and kept for hatching on a sieve above the primary chicken feed which was prepared as 70% moist with water. After hatching of eggs on the 4th day, larvae fall from sieve to this primary chicken feed, larvae started to feed on this food for first five days, and on fifth day they were separated from their feed with the help of sieve and transferred to another tray for experiment. 5-day old BSF larvae (5 DOL) were counted to 500 in number and kept in separate 6 trays. These 6 trays with each having 500 number of BSF larvae were labelled as 1) Waste Summer Fruits (WSF) 2) Waste Papaya (WP) 3) Waste Banana (WB) 4) Waste Vegetables (WV) 5) Bakery Waste (BW) and 6) Kitchen Waste (KW).

The wastes were collected from local vegetable market, fruit market, bakery shops and from kitchen. During Summer season, fruits like water melon, musk melon, grapes, mango etc goes waste in major quantity which was considered as waste summer fruits (WSF). Vegetables from vegetable market include rotten, discarded vegetables like tomatoes, brinjal, beans, ladyfinger, cauliflower etc. were collected and taken for this study called as Waste vegetable (WV). Bakery waste (BW) include expired breads, bread crumps and crushed toasts. Kitchen wastes (KW) contained expired wheat and gram flours as well as old or discarded meals. Throughout the year papaya production is more in the study area, where wastage of papaya fruit is common so taken for waste treatment (WP). The study area is also well known for production of banana which also undergoes waste if not properly stored and cannot sold on time, it can lose nutrients if its waste treatment not done immediately, so considered for the experiment (WB).

On the first day of experimentation, 500 number of 5DOL BSF larvae were fed with these wastes in separate trays, on every alternate day wet weight of these larvae, wet weight of waste provided and wet weight of waste remained as residue were recorded and feed consumed by the larvae were calculated (Table 1). The wastes like waste summer fruits (WSF), waste papaya (WP) and waste vegetables (WV) before giving as a feed, was grinded and water is strained. All wastes weighed in same quantity and then provided to the 5-day old larvae. The wastes that are, Bakery waste which include bread crumps, expired bread, toast etc. made moist with water up to 50-60% before feeding to larvae. The kitchen waste (KW) when included expired and discarded flour from kitchen, was also made moist in the same way, while the waste banana was served with its peels to the BSF larvae only by cutting it with knife, without grinding. In this way these 6 types of local waste utilized as feed substrate, was served to BSF larvae in same quantity every time.

On every alternate day, 50 larvae were taken out from feed substrate, weighted with the help of digital weighing balance and weight recorded. From the weight of 50 larvae, weight of 500 larvae were calculated. On every alternate day the remaining waste called residue was separated from the larvae, discarded and new feed substrate was added in same quantity in all respective trays. When 70% larvae in trays reached to pre-pupal stage, they were separated from the residue by sieve as well as manually and final larval wet weight of larvae was recorded.

The amount of waste food given, weight of residue discarded, larval weight and feed consumed were recorded on every alternate day from the 5th day old larvae up to 70% Pre-pupae formation are shown in Table 1. By recording this data various bioconversion parameters like, last larval wet weight (yield), survival %, larval growth (LG %), Total waste reduction (WR %), bioconversion rate (BR %), feed conversion rate (FCR), were calculated as per the formulae given below and the recorded data is shown in Table 2. As larvae were fed on new feed on every alternate day and residue was discarded, feed consumed was calculated, so the larval growth (LG %) and waste reduction (WR %) was also calculated for every alternate day which is given in Table 3 (Figure 1 and 2). BSF converts these local wastes into biomass in the form of nutrients, the nutrient parameters like crude protein, lipid and amino acid composition were also analysed as shown in Table 4 and 5. BSFL bioconversion parameters were calculated as follows (Irfana *et al*., 2021, Daniel *et al*., 2021) [18, 7]

1) Feed Consumed = Weight of food given-Weight of residue

2) Total larval yield
The final weight of wet larvae harvested from each tray when 70% of larvae turned to pre-pupae and was measured using an electronic balance readable to 0.01 gm.

3) **Larval survival (SR %)**

$$= \frac{\text{Number of larvae harvested}}{\text{Number of five-day old larvae taken for treatment}} \text{ x } 100$$

4) **Larval growth**

$$LG\% = \frac{T - B}{B} x100$$

B = Initial weight of larvae at time t
T= weight of larvae after alternate day

5) **Waste reduction (WR %)** = Waste reduction (WR %) was estimated for each treatment by taking wet weight of the substrate and residue by using the formula.

$$WR\% = \frac{\text{(Feed added - residue feed)}}{\text{Feed added}} x100$$

6) **Bioconversion rate (BR %)**

$$BR\ \% = \frac{\text{Total Last larval wet weight}}{\text{Total feed added}} \text{x } 100$$

7) **Feed conversion rate (FCR)**

$$FCR = \frac{\text{Total Feed added}}{\text{Total larval yield}}$$

In each tray when 70% of BSF larvae reached to pre-pupal stage, they were harvested, washed with tap water and live pre-pupae sent to the Anacon laboratory, situated in Nagpur (Mah., India) for nutritional component testing i.e., crude protein (CP), Lipids and amino acids, as these nutrients present in pre-pupae will show the nutritional quality of BSFL, which can be processed or utilized for livestock feed.

Results
From the 5th day of BSF larvae up 70% pre-pupae formation, larvae were fed separately on every alternate day with 6 local wastes like Waste summer fruits (WSF), Waste papaya (WP), Waste Banana (WB), Waste vegetables (WV), Bakery wastes (BW) and Kitchen waste (KW). At the start of the experiment, weight of 500 larvae (5DOL) was recorded as 3gm, which were taken for the experiment and fed with equal quantity of wastes i.e., 100 gm of these local wastes in each respective tray. On every alternate day that is on 7th, 9th, 11th, 13th, 15th, 17th etc. weight of larvae found to be gradually increasing in all 6 trays.

Table 1: Waste added (gm), residue (gm), waste consumed (gm) and increased larval weight (gm) for 500 number of BSF larvae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Days	Weight (gm)	Type of Waste Treatment on the BSF larvae					
		WSF	WP	WB	WV	BW	KW
5^{th} Day	Waste added	100	100	100	100	100	100
	Residue	-	-	-	-	-	-
	Waste consumed	-	-	-	-	-	-
	Larval weight	3	3	3	3	3	3
7^{th} Day	Waste added	200	200	200	200	200	200
	Residue	90	87	81	86	85	82
	Waste consumed	10	13	19	14	15	18
	Larval weight	8	7	9	9	7	9
9^{th} Day	Waste added	300	300	300	300	300	300
	Residue feed	152	160	155	170	178	165
	Waste consumed	48	40	45	30	22	35
	larval weight	13	10	15	15	12	16
11^{th} Day	Waste added	300	300	300	300	300	300
	Residue feed	180	189	169	180	202	179
	Waste consumed	120	111	131	120	98	121
	larval weight	18	30	20	25	20	66
13^{th} Day	Waste added	400	400	400	400	400	400
	Residue feed	120	138	127	118	140	156
	Waste consumed	180	162	173	182	160	244
	larval weight	30	50	30	30	30	80
15^{th} Day	Waste added	400	400	400	400	400	400
	Residue feed	162	159	150	170	186	177
	Waste consumed	238	241	250	230	214	223
	larval weight	40	70	60	50	60	130

17th Day	Waste added	400	400	400	400	400	400
	Residue feed	154	145	132	126	155	140
	Waste consumed	246	255	268	274	245	260
	larval weight	60	80	80	90	90	240
19th Day	Waste added	200	200	200	200	200	-
	Residue feed	350	327	333	320	311	-
	Waste consumed	50	73	67	80	89	-
	larval weight	90	120	100	122	90	-
21th Day	Waste added	100	-	100	-	-	-
	Residue feed	130	-	154	-	-	-
	Waste consumed	70	-	46	-	-	-
	larval weight	158	-	118	-	-	-
	Number of larvae survived	490	480	380	450	377	380

Table 2: Larval growth (LG%) and waste reduction (WR%) of BSF larvae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Days	WSF		WP		WB		WV		BW		KW	
	LG %	WR %	LG %	WR %	LG%	WR %	LG%	WR %	LG %	WR %	LG%	WR %
5th	-		-		-							
7th	166	10	133	13	200	19	200	14	133	15	200	18
9th	333	24	233	20	400	23	400	15	300	11	433	18
11th	500	40	900	37	566	44	733	40	566	33	2100	40
13th	900	60	1566	54	900	58	900	61	900	53	2566	48
15th	1233	59.5	2233	60	1900	63	1566	58	1900	54	4233	56
17th	1900	61.5	2566	64	2566	67	2900	69	2900	61	7900	65
19th	2900	12.5	3900	18	3233	17	3966	20	2900	22	-	-
21th	5166	35	-	-	3833	23	-	-	-	-	-	-

Table 3: Bioconversion Parameters of BSF larvae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

	Waste	Total larval yield (gm)	Total Feed added (gm)	Total Feed consumed (gm)	Total WR%	BR %	FCR	Survival (SR %)
1	WSF	158	2400	968	40	6.6	6.1	98
2	WP	120	2400	895	42	5	7.4	96
3	WB	118	2400	999	58	5	8.4	76
4	WV	122	2400	930	39	5	7.6	90
5	BW	90	2400	843	35	3.7	9.3	75
6	KW	240	2400	901	38	10	3.7	76

Table 4: Larval growth (LG%) and waste reduction (WR%) of BSF larvae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Days	WSF		WP		WB		WV		BW		KW	
	LG%	WR %	LG %	WR %	LG %	WR %	LG %	WR %	LG %	WR %	LG %	WR %
5th	-		-		-							
7th	166	10	133	13	200	19	200	14	133	15	200	18
9th	333	24	233	20	400	23	400	15	300	11	433	18
11th	500	40	900	37	566	44	733	40	566	33	2100	40
13th	900	60	1566	54	900	58	900	61	900	53	2566	48
15th	1233	59.5	2233	60	1900	63	1566	58	1900	54	4233	56
17th	1900	61.5	2566	64	2566	67	2900	69	2900	61	7900	65
19th	2900	12.5	3900	18	3233	17	3966	20	2900	22	-	-
21th	5166	35	-	-	3833	23	-		-	-	-	-

Table 5: Crude Protein (CP%) and lipids % in BSF Prepupae larvae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Test	Test Method	Types of Wastes fed to BSF larvae					
		WSF	WP	WB	WV	BW	KW
Crude protein %	IS 7219	19.35	20.20	19.97	21.34	20.94	18.55
Lipids (Total fat) %	FSSAI Manual 2016	0.40	0.33	0.39	0.43	0.36	0.28

Table 6: Amino acids profile of BSF prepupae fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Amino acid profile (gm/100gm) Test Method Lab SOP (by using LCMS/MS)	Types of Local Wastes					
	WSF	WP	WB	WV	BW	KW
Lysine	1.43	0.93	1.78	1.93	1.90	1.70
Arginine	1.51	1.87	1.29	1.40	2.04	1.58

Glycine	Absent	Absent	0.004	0.005	Absent	0.003
Serine	3.91	2.26	4.09	4.44	1.85	2.83
Glutamic acid	3.65	5.62	5.47	5.93	3.79	7.49
Alanine	14.14	13.01	17.42	18.90	9.29	22.93
Aspartic acid	3.30	5.58	14.08	15.28	5.90	6.46
Proline	3.91	4.20	4.54	4.92	3.96	5.47
Histidine	0.73	0.92	1.28	1.39	1.14	1.088
Valine	3.70	2.67	3.39	3.68	2.71	0.189
Methionine	0.49	0.80	0.87	0.94	0.71	1.09
Leucine	1.77	1.56	1.42	1.54	1.49	2.44
Phenylalanine	1.31	1.28	1.12	1.21	1.51	1.91
Tyrosine	1.97	2.37	2.22	2.41	2.29	2.66
Isoleucine	0.68	0.72	0.68	0.74	0.57	1.09
Tryptophan	1.77	3.35	2.50	2.71	2.65	3.63
Threonine	2.50	3.50	4.71	5.11	1.77	8.00
Cysteine	1.09	3.18	1.005	1.09	4.37	Absent

Larval period and final larval weight (yield)

In WSF tray 70% pre-pupae formed on 21st day of larvae, the final larval weight on this day was 158gm. In WP tray 70% pre-pupae formed on 19th day and final larval weight was 120gm. In WB tray, larvae took 21 days while final larval weight was 118gm. In WV and BW trays final larval weight were 122 gm and 90 gm respectively while in both trays larvae took 19 days to form 70% pre-pupae. In KW tray 70% pre-pupae were formed on 17th day which is the shortest period as compared to other larval trays, not only this but final larval weight for this treatment was found to be high i.e., 240gm. (Table 1).

Survival %

In all trays, lastly larvae were counted to check their survival number and survival percent was calculated and found to be more in WSF i.e., 98% and less survival % was in BW and KW tray. i.e., 75% and 76% respectively. (Table 1 and Table 2).

Total Waste reduction (WR %)

Waste reduction% in all trays gradually increased up to 17th day of larvae, but after this period it decreased due to Pre-pupae formation. On 17th day WR% were 61.5%, 64%, 67%, 69%, 61% and 65% in WSF, WP, WB, WV, BW and KW respectively. In all trays WR% decreased after 17th day as the Pre-pupae formed which do not feed. On 19th day 70% of BSF larvae turned to Pre-pupae in WP, WV, BW trays where WR% was suddenly decreased, while 70% Pre-pupae formed only on 17th day in KW and WR% recorded was 65% (Table 3) (Figure 1). From the 1st feeding of local wastes i.e., on 5DOL up to the final larval stage, Total WR% was found to be 40, 42, 58, 39, 35 and 38 in WSF, WP, WB, WV, BW and KW respectively (Table 2).

Larval Growth (LG %)

From 7th day onwards LG% found to be increased. BSF LG% reached highest i.e., 7900%, only on 17th day, which were fed on Kitchen waste, while it was less i.e., 2900% for larvae fed on bakery waste on 19th day. LG% for WP, WB and WV found to be similar i.e., 3900%, 3833% and 3966% respectively on the 19th day, while BSF larvae fed on WSF, larval period extended up to 21 days and LG% found to be 5166% (Table 3) (Figure 2).

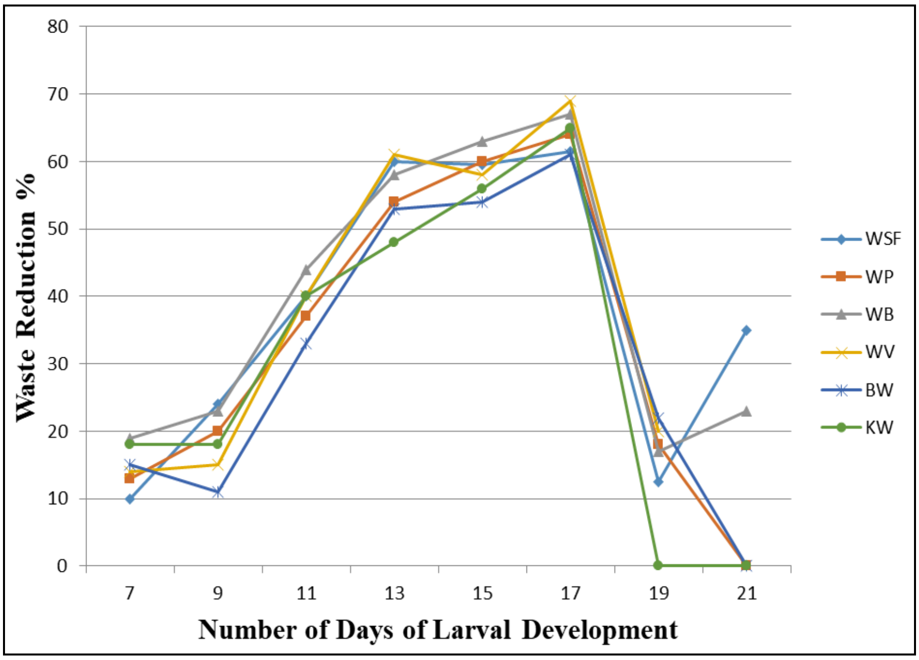

Fig 1: Waste reduction (WR %) on alternate days when BSF fed on 6 local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

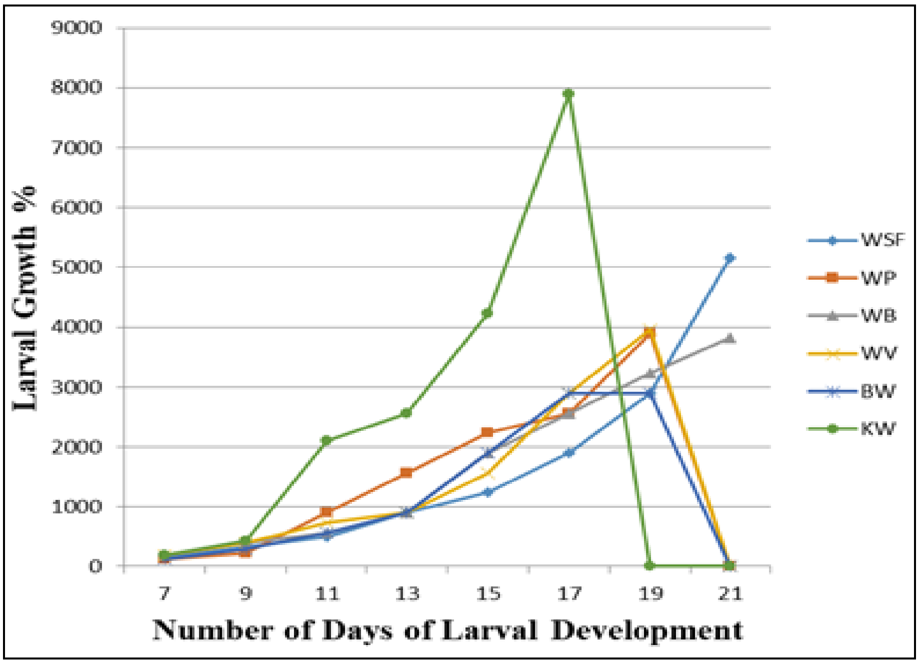

Fig 2: Larval growth (LG%) on alternate days where BSF was fed on 6 types of local wastes, Waste Summer Fruits (WSF), Waste Papaya (WP), Waste Banana (WB), Waste Vegetables (WV), Bakery Waste (BW) and Kitchen Waste (KW)

Bioconversion rate (BR) %

BR % was 6.6, 5, 5, 5, 3.7 and 10 in WSF, WP, WB, WV, BW and KW respectively (Table 2).

Feed conversion rate (FCR)

FCR was 3.7 for KW fed larvae while it was more i.e., 9.3 and 8.4 for BW and WB fed BSF larvae respectively (Table 2).

Crude protein and lipid % of BSF larvae

Crude protein found to be less i.e., 18.55% in KW fed larvae, while in other waste treated larvae it found to be slightly more. Lipid % in BSF larvae was also low in BSF larvae fed on KW i.e., 0.28 %, while it was slightly more in WSF and WV fed larvae (Table 4).

Amino acid Profile of BSF larvae

Amino acid, Glycine was absent in BSF larvae fed on WSF, WP and BW while it was present in very less amount in other wastes fed BSF larvae. Amino acid, alanine was found to be more in all types of wastes fed larvae, as compared to other amino acids. Cysteine was absent in KW fed larvae while it was present in other wastes fed BSF larvae (Table 5).

Discussion

We evaluated the different bioconversion parameters of BSF larvae fed on 6 different types of local wastes. The aim of this study was to evaluate the BSF larvae, whether they can survive on local wastes, reduce it efficiently and integrate the waste to biomass, so that these larvae can be reared in small scale on locally generated wastes. This study showed that these different types of local wastes, which had different properties like water holding capacity, fibre -non fibre content, carbohydrate, protein content etc. played important role in larval growth, although the substrate parameters were not included in this study.

The effect of individual feed substrates on larval weight was analysed and our study results showed variable response of BSFL at different stages of growth (Table 1, 2 and Fig 2). The substrate protein content was the only factor closely correlated with the maximal larval weight, bioconversion efficiency, and waste reduction (Broeckx 2021) [5]. In the study done by Nguyen *et al.* (2015) [28], kitchen waste which contained both animal and plant matter, ranging from hamburgers to salads, and was obtained from restaurants, black soldier fly larvae may prefer kitchen waste because it has the greatest fat and calorie content as compared to other wastes, excluding fish. Author observed that the high fat and calorie content in kitchen waste may have been responsible for producing the heaviest larvae. In our study BSFL fed on KW which includes expired flours and discarded meals, took only 19 days to form 70% Pre-pupae and reached final larval weight i.e., 240 gm during this period, which is a short larval period and high yield as compared to BSFL fed on other wastes. BSF larvae prefer feeding low cellulosic plant materials and delay their feeding on high cellulosic plant materials until it starts to decay whereas those high in lignin content are often avoided by the larvae (Manurung *et al.*, 2016) [23]. The balanced nutrient in the mixture substrates helps the BSFL to utilize the available nutrients to a higher degree (Lalander *et al.*, 2019) [21]. Larval development and weight gain positively correlates with the protein content of the diet (Oonincx *et. al.*, 2015) [30]. In our study as the BSF larvae were fed on the same type of waste continuously so that both larval final yield and final larval weight were highly influenced.

In our study, total WR% in SFW, WP and WB found to be more i.e., 40%, 42%, 58% as compared to other three wastes WV, BW and KW i.e., only 39%, 35% and 38% respectively. Although this study was done in small scale in laboratory, it showed that use of black soldier flies as a potential agent for waste management is worthwhile. Study done by the author, Irfana *et al.* (2021) [18], showed WR% by BSFL fed on fruit waste was 57% and larvae fed on boiled and raw vegetables was 49% and 32% respectively. Study done by Daniel *et al.* (2021) [7] also found that larval WR% were higher with fruit waste compared to chicken manure and chicken feed. Such observations were also found by Nguyen *et al.* (2015) [28] where he observed that reduction rates of fruits and vegetables by BSF larvae were higher compared to standard chicken feed. He said that the energy content of the substrate can affect its reduction efficiency by BSF larvae. In our study also BSFL fed on waste fruits i.e., SFW, WP and WB showed good WR% as compared to the WV, BW and KW fed BSF larvae, this may be because of low fibre content in these fruits which make it easily digestible and high energy content within these fruits.

The results of FCR are relatable to the results of BR%, meaning that high BR% corresponds to low FCR and vice versa. In our study BR% was found to be 10 and FCR was 3.7 for BSFL fed on KW which are satisfactory values as compared to larvae fed on other wastes. FCR indicates the proportion of digested food that is assimilated and therefore ends up as biomass. The lower the value, the higher the efficiency of conversion of substrate to biomass. The higher FCR indicates that the substrate is digestible but of little nutrient value and therefore largely excreted (Nyakeri *et al.*, 2017) [29]. BR% was 22.3% with human manure at 100 mg/larva/day diet as observed by Nyakeri *et al.* (2017) [29] and 20.73% with kitchen waste at 100mg/larva/day as observed by Joly (2018) [19], but these values were calculated based on the dry weight of these substrates. The BR% values calculated based on the wet weights are much lesser than the values obtained in the study done by Nana *et al.* (2018) [25] and Diener *et al.* (2011) [40] due to the influence of the water content of the substrates. In our study also, the results of BR% values of BSFL, fed on 6 local wastes, found to be low as compared to above authors work may be due to wet substrates weight were calculated for BR%.

It has been previously reported that heterogeneous nature of substrate improves its nutritional quality (Tschirner *et al.*, 2015) [38]. Work done by Nyakeri *et al.* (2017) [29] results showed that, the CP content decreased with increase in age of the larvae, irrespective of the rearing substrate used. The effect of sclerotization responsible for the decrease of protein, as the age of BSF larvae increases, CP in body get utilised for build-up of chitin layer of exoskeleton. Sclerotization process which causes enzymatic degradation of proteins to build up the chitin layer of exoskeleton (Aniebo *et al.*, 2010) [2]. Diener *et al.* (2009) [30] also concluded that Crude protein formed in BSFL is utilised for chitin content in prepupa. Therefore, BSF Pre-pupae should preferably be harvested before the exoskeleton is fully hardened on the 16th day. In the present study harvesting of final larvae was not on the 16th day, but done when 70% of larvae turned to Pre-pupae, where sclerotization occurred and may be the reason that CP utilised for chitin formation and the value for CP found to be low i.e. 19.35%, 20.20%. 19.97%, 21.34%, 20.94%, 18.55% in WSF, WP, WB, WV, BW and KW respectively.

The author Xiu *et al.* (2017) [39] fed BSF larvae on commercial broiler chicken feed and found out that crude protein CP at larval phase was 39.2% while it rose up to 40.2% in pre-pupal stage. Many other authors also reported that CP ranged from 34% to 42% in larval phase and from 31% to 46.2% in pre-pupal phase respectively (Oonincx *et al.*, 2015, Diener *et al.*, 2009) [30, 10]. It was also previously reported that the level of protein content in BSF depended on feed types (Oonincx *et al.*, 2015) [30] and feed rate (Diener *et al.*, 2009) [10]. In the present study larvae continuously feed on the same type of food waste, which have less nutrients variety so the BSF larvae get less nutrients, they gained less crude protein as compared to other author's work. Therefore, it is certain that CP content in BSF varies with diverse feed sources that they feed on.

In our study total fat % in pre-pupal stage was found to be very less i.e., 0.40%, 0.33%, 0.39%, 0.43%, 0.36% and 0.28% in WSF, WP, WB, WV, BW and KW respectively. Fat content in BSFL was reported previously to vary with diet types. Fat content in mature larvae and early pre-pupal stage was found to be 28% when larvae fed on commercial broiler chicken feed (Xiu *et al.*, 2017) [39]. 34% of fats was reported when BSFL fed on beef cattle and poultry manure, 28% on swine manure (Newton *et al.*, 2005, Newton 1977) [26-27]. Author Xiu Liu *et al.* (2017) [39] reported that fat content in BSFL enhanced by applying different feed supplements. In our study as larvae were continuously fed on same waste with no other feed supplements showed the above results.

The impact of rearing substrate on BSF protein and amino acid profile was studied by many authors. Fuso *et al.* (2021) [13] concluded that Lysine, Leucine and Valine are most correlated with the presence of nutrients of the feeding diet. Our study showed the presence of these amino acids in BSFL fed on all 6 types of feed substrates. Leucine and valine strongly dependent on the content of protein and lipid in the diet, while lysine is correlated to the amount of carbohydrates. In our study, excluding Glycine all essential amino acids are found to be present in BSFL fed on 6 feed substrates.

Conclusion

Black soldier fly larvae may play important role in a circular economy by upcycling low-value organic streams into high value biomass. In this study 6 locally generated wastes were fed to BSF larvae and analysed their suitability as feed substrate for *H. illucens* larvae, by evaluating them with various bioconversion and nutrient parameters. From our study and also study done by (Shumo *et al.*, 2019, Irfana *et al.*, 2021) [18], it is clear that the different feed substrates play an important role on growth performance, waste reduction and nutritional composition of black soldier fly larvae. From this study, it is concluded that different local wastes can be suitable for rearing of BSF larvae. The nutrients present in feed substrate are definitely responsible for the growth, waste reduction and nutrient profile of BSF larvae and due to easy availability of these local wastes, these can be utilised for production of BSF larvae both at small and large scale, where the valuable nutrients are saved, so this BSF technology brings sustainable development. It is also concluded that several low value, organic, locally generated wastes can successfully be processed by BSF larvae, therefore the possibility of lowering costs of BSF farming increases. Potentially mixing nutritionally variable mono-streams into a mixed substrate might improve BSF performance. More research is needed to be done for optimizing diets for guaranteed production of BSF larvae for constant yield and quality.

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