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BIOCONVERSION AND NUTRITIONAL PERFORMANCE OF BLACK SOLDIER FLY, HERMECIA ILLUCENS L. NURTURED ON CHICKEN & FISH MARKET WASTE

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ABSTRACT

Black soldier fly, *Hermecia illucens* L., a dipteran insect native to Neotropical region, becoming popular due to its high attribute on transforming organic waste into salubrious vittles' for poultry and livestock. Black soldier fly larvae fed on organic waste, reduces the environmental pollution and convert organic waste into insect biomass containing protein, fats and essential nutrients which can be utilized for livestock feed. Costly protein diet, fat supplement and compound feed diet formulations made of fish and soyabean can be replaced with Black soldier fly larval biomass production and can be a remedy for the future food and feed demands. The waste generated in chicken/meat slaughter houses and fish market are not recycled in villages as well as in urban areas and these are thrown in open places which can nurture pathogens and vectors that may lead to spread of diseases. BSF larvae are capable to recycle these market wastes and can gain nutrient rich insect biomass. In this study BSF larvae from fifth day old till prepupal stage were fed continuously on chicken slaughter house waste and fish market waste. When larvae reached last larval stage, larval biomass conversion and nutrient parameters were recorded. It is concluded that these two-market wastes can be recycled efficiently by using BSF larvae and various nutrients rich larvae can be utilized for livestock feed. Findings from the larval nutrient composition can provide data for food and feed industry for formulating their molecular nutritional constituent intakes into the diet of livestock.

KEYWORDS: Black soldier fly, *Hermecia illicens* L., recycling, organic waste, biomass conversion, nutritional parameters, Fish market waste, Chicken market waste, livestock stock feed.

INTRODUCTION

The solid waste management in a country must be one of the priorities while forming policies at the National level (Abas, M.A. et. al. 2014). Among the entire solid waste stream, organic waste accounts for more than 78% in developing countries (Bhada-Tata et. al. 2012), it is often dumped in landfills without separation leading to the loss of valuable organic resources that could be recycled (Njoroge, B. et. al. 2014). Human health is very much related to the environmental degradation (Shukla, S.R. et. al. 2000). The health risk increases and there are the chances of infection of gastrointestinal parasites to the people who live near dumping areas and if workers do not use gloves or safety equipment (Giusti, L., 2009). Open dumps release methane after decomposition of biodegradable waste under anaerobic conditions which is a major contribution to the global warming (Slagstad, H. et al. 2013). Biodegradable waste produces odour and leachates which migrates to water source and in soil causes pollution (Unnikrishnan, H. et al. 2006, Muhammad, N. et al. 2020, Dasgupta, B. et al. 2013).

In increasing world population human and animal feed production are expected to increase from agriculture by 60% (Tomberlin JK, et al. 2015). Maize, rice, wheat and soybean shortage will be approximately 67%, 42% 38% and 55% respectively (Ray DK, 2013). There is an urgent need to search for new sources of feed which contain good amount of protein, fats, amino acids, fatty acids, minerals, vitamins etc. Edible insects are more considerable group of organisms in the world as they have efficient food conversion rate, short lifespan and high nutrient contents. (Oonincx DGAB et al. 2015, Van Der Fels-Klerx HJ et al. 2016). One study revealed that the nutritional quality of edible insects was enough to fight against human malnutrition (Payne CLR, 2016). Insects having enough quantity of crude protein, crude fat and good economic value can replace traditional protein sources required in the food of poultry, aquaculture and other livestock feed products (Makkar HPS et al. 2014, Stamer A., 2015). BSF is appropriate to be used as feed for livestock animals, for cosmetics or pharmaceuticals industries, for biodiesel production and larvae contain high chitin content. Li Q. et al. (2011) verified the feasibility of converting organic waste into biodiesel using black soldier fly larvae (BSF). BSF rearing residue with larval frass can be a used as soil fertilizer (Salomone R., et al. 2016) (Rehman Kur, 2017).

Hermecia illucens L. belongs to order Diptera, family stratiomyidae, distributed all over the world commonly called as black soldier fly (BSF). The larvae of this fly are voracious feeders of organic waste like putrefying fruits, vegetables, animal manure and municipal organic waste etc. The life cycle of BSF consists of four stages, egg, larva, pupa and adult. Larval stage lasts for 14 to 20 days or up to 3 months, depending on temperature, humidity and availability of food. Last larval stage turns todark brown in colour, crawl out of the wet tray in search of dry place, called as prepupa stage. Prepupa stage do not feed and turn into pupa stage. Pupae are stiff, non-motile, remain for approximately 14 days and then turn into adult stage. Male and Female adults emerge from pupae, attract towards light and start mating. Adult flies do not feed on any food but drink water and can survive up to one or two weeks (Tomberlin, J.K. 2002). Gravid female flies search for smelly and rotten food and lay her eggs by inserting ovipositor in cracks and crevices near to food. A Single female fly can lay 500 to 800 eggs at a time which shows high power of reproduction in these flies. BSF adult flies are not strong fliers, do not spread any pathogens, or not spread any diseases. Feeding larval stages secrete some chemical that keeps away other flies' larvae, repel other insect pests and disease carrying vectors, like house fly (Erickson, M.C. et al. 2004).

Poultry farming, aquaculture and other livestock sectors are the major sources of income in developing countries like India which can lessen poverty and can enhance food security. But because of food feed competition, food like Soybean meal and fish meal can increase the cost of feeds in these sectors. There is an urgent need to replace such high-cost food into some advanced, economically beneficial environmentally sustainable one (Tschirner, M. et al., 2017). Makkar et al. (2014) stated that insects are good candidates for finding new protein sources at low cost and less breeding space requirements. BSF could replace conventional poultry feed constituents, like soybean meal, which have a high ecological impact (Newton L et al. 2005). BSF larvae can provide high-value feed as they are rich in protein i.e. 37% to 63% and have better amino acid profile than soybean meal (Barragan-Fonseca KB 2017). BSF contain high amount of lipids i.e., 15% to 49%, which can be extracted and used for preparation of biodiesel, while the rest part could be used as a protein rich source for feed industry (Sihem D. et al. 2018).

MATERIALS AND METHODS

The rearing of Black soldier fly (BSF) was done at Vidyabharti College, Seloo, Dist. Wardha Maharashtra, India, duringthe month of September-October 2021. 3gm of eggs of BSF were kept on sieve above the moist primary poultry food. As eggs hatched on the fourth day, they fall from the sieve to the poultry food and start feeding. Newly hatched larvae for the first five days survived on poultry food till they reached five-day old larvae (5DOL). Fifth day old larvae were separated into two equal batches as Batch I (fed on waste fish) and Batch II (fed on waste chicken flesh). Both the batches started to consume fish waste collected from fish market and on waste flesh of chicken collected from poultry slaughter market. Before providing this waste to respective batches it was weighted every time and recorded. These wastes provided to the larvae every alternate day till they reach prepupae stage. During feeding larval trays were not allowed to dry completely, so sprinkled water occasionally to maintain the humidity. During larval feeding period room temperature and humidity was 26±2^{0}C and 60-75% respectively. BSF larvae fed voraciously on these waste flesh except bones and scales of fishes. When larvae reached prepupal stage after fourteenth day rate of feeding gradually reduce and at this stage larvae were separated from the residue by sieving as well as manually from both batches, total larval weight gain, residue weight were recorded and various bioconversion parameters were calculated.

BSF Larvae biomass Conversion - When organic waste fed to the BSF larvae, gradually its low value biomass converts into higher value insect biomass rich in protein and fats. Biomass conversion is very important feature in the BSF farming and it depends on the amount of food consumed and the ability of the feed consumption and it was calculated as follows. (Paulin N., 2018, Zhou F. et al. 2013, Banks IJ 2010).

1. Larval weight (LW)- Larval weight is the final weight of wet larvae when 50% of larvae converted into prepupae.
2. Waste reduction (WR)- When larvae reached prepupae stage, they were separated from residue, residue weight was taken and waste reduction was calculated by applying following equation.
3. WR (%) = [1-(feed residue/feed added)] x 100
4. Bioconversion rate (BR) – It is the quantity of the diet converted into larval biomass, expressed as a percentage and calculated as
5. BR (%) = (Larval weight gain/ feed added) x 100
6. Feed Conversion Rate (FCR) – It is the ratio of feed consumed to the total larval weight or biomass, calculated as FCR = Feed consumed / larval weight

BSF Larvae Nutrient Composition- Nutrient composition of BSF larvae analysed at Anacon Laboratory, Nagpur Maharashtra, India. When larvae reached to prepupae stage, sample of BSF larvae from both the batches were sent to the laboratory, where both batches kept in deep freezer at -20^{0}C for further analysis. Various nutrient parameters like dry matter (DM), organic matter (OM), Crude protein (CP), Ether insoluble matter (EI), Total fibre content (TFC), Total flavonoids (TF), Vitamins, Fatty acids, Amino acids and Minerals were analysed by Lab Standard Operating Procedures (Lab SOP).

RESULTS

1. BSF Larvae biomass Conversion

When 3gm of eggs of BSF were hatched, larvae fed for first five days on moist primary poultry feed and on the fifth day, larvae separated into two equal groups as Batch I and Batch II. Batch I were fed constantly on waste, discarded fishes collected from fish market and Batch II also fed constantly on waste, discarded parts of chicken flesh till larvae reached the prepupa stage. In both the batches when 50% larvae turned to prepupae, they were separated from residue, and the total larval weight as well as residue weight were recorded. During complete larval feeding period Batch I and Batch II feed given was 5600 gm and 5950 gm respectively. The residue weight recorded of batch I and batch II were 700gm and 900gm respectively. From this data total feed consumed by both the batches found to be 4900gm and 5050gm respectively. Final weight of larvae was taken and it was recorded as 1600gm in batch I and 1450gm in batch II. Waste reduction (WR) was calculated as 87.5% in batch I and85% in batch II. Bioconversion rate (BR) found to be 28.57% in batch I and 24.36% in batch II. Feed conversion rate (FCR) calculated as 3.06 for batch I and 3.48 for batch II. (Table 1).

Table 1: Larval biomass conversion parameters of last larval stage of BSF (before prepupa) fed on two organic wastes, i.e., Waste Fish (BatchI) and Waste Chicken (Batch II).

S.N.	Larval Biomass conversion parameters	Batch I(Fed on Waste Fish)	Batch II(Fed on Waste chicken)
1	BSF eggs used for experiment	3gm	
2	Total feed added during rearing (gm)	5600	5950
3	Feed consumed (gm)	4900	5050
4	Residue (gm)	700	900
5	Final larval wet weight gained (gm)	1600	1450
6	Waste reduction (WR)%	87.5	85
7	Bioconversion rate (BR)%	28.57	24.36
8	Feed conversion rate (FCR)	3.06	3.48

2. BSF Larvae Nutrient Composition

2.1 Different test parameters observed in BSF – There was an effect of type of waste utilized for BSF rearing on its nutrient parameters (Table 1). Nutrient values like, Dry matter (DM), Organic matter (OM), Crude protein (CP), Ether insoluble (EI), Total fibre content (TFC) and Total flavonoids (TF) of Batch I i.e., BSF fed on waste fish were found to be slightly higher than the nutrient values of batch II fed on waste chicken flesh (Table 2).

Author A.C. Fanatico (2018) reviewed the nutrient content in fishmeal and soybean meal of poultry feed. Crude protein content in these meals was 67.9% and 47.6% respectively. (Table 2) Crude protein content in these two poultry meals is higher than the amount found in our study i.e., crude protein found to be 42.89% and 41.22% in batch I and batch II BSF larvae respectively. (Table 3).

Table 2: Nutrient composition of fishmeal and Soybean meal as poultry feed.

Poultry feed	Dry matter	Crude protein	Methionine	Cysteine
Fishmeal %	91	67.9	1.81	0.57
Soybean meal%	88	47.6	0.63	0.68

Presented as a percent of ingredient (Fanatico A.C, 2018)

Table 3: Test parameters of last larval stage of BSF (early prepupa) fed on two organic wastes, i.e., Waste Fish (Batch I) and Waste Chicken (Batch II).

S.N.	Test Parameter	Measurement Unit	Test method	Test result	
				Batch I (Fed on Waste Fish)	Batch II (Fed on Waste chicken flesh)
1	Dry matter (DM)	%	Lab	36.91	35.96
2	Organic matter(OM)	%	SOP	98.23	97.88
3	Crude protein(CP)	%	IS 7219	42.89	41.22
4	Ether insoluble(EI) matter (Lipids)	%	Lab	62.32	61.08
5	Total fibre content(TFC)	%	SOP	9.61	8.23
6	Total flavonoids (TF)	mg/l		151.46	148.32

2.2 Vitamin Profile of BSF – Analysis of vitamins fed on these two wastes shows that Vitamin A is present in Batch I which was fed on waste fish, while Vitamin A is absent in Batch II fed on waste chicken flesh. Vitamin B12 is more in batch II i.e. 2.09mg/100g while in batch I, it is less i.e. 1.31 mg/100g. Vitamin C is not detected in both batches. Vitamin D is found more in Batch II i.e. 49.34 µg/100 g while it is less i.e. 27.60 µg/100 g in batch I. Vitamin E content in batch I is 74.7 mg/100g while it is very less 2.39 mg/100g in batch II. (Table 4).

Table 4: Vitamin profile of last larval stage of BSF (early prepupa) fed on two organic wastes, i.e., Waste Fish (Batch I) and Waste Chicken (Batch II).

S.N.	Vitamin Profile	Measurement unit	Test Method	Test Result	
				Batch I Waste Fish	Batch II Waste chicken
1	Vitamin A	µg/100g	Lab SOP (by usingLCMS/MS)	55.00	Absent
2	Vitamin B12	mg/100g		1.31	2.09
3	Vitamin C	µg/100g		Absent	Absent
4	Vitamin D	µg/100g	Lab SOP (by using HPLC)	27.60	49.34
5	Vitamin E	mg/100g	Lab SOP (by usingLCMS/MS)	74.7	2.39

2.3 Fatty acid profile of BSF- Fatty acids like butyric acid, lauric acid, myristic acid, palmitic acid, palmitoleic acid, Linoleic acid are found to be present in batch I which were fed on waste fish but all types of fatty acids found to be absent in batch II, fedon waste chicken flesh. (Table 5).

Table 5: Fatty acid profile of last larval stage of BSF (early prepupa) fed on two organic wastes, i.e. Waste Fish (Batch I) and Waste Chicken (Batch II).

S.N.	Fatty Acid profile	Measurement unit	Test method	Test Result	
				Batch I Waste Fish	Batch II Waste chicken
1	Butyric acid	g/100g	AOAC 996.06	0.009	Absent
2	Caproic acid			Absent	Absent
3	Caprylic acid			Absent	Absent
4	Capric acid			Absent	Absent
5	Undecylic acid			Absent	Absent
6	Lauric acid			0.016	Absent
7	Tridecylic acid			Absent	Absent
8	Myristic acid			0.006	Absent
9	Myristoleic acid			Absent	Absent
10	Pentadecylic acid			Absent	Absent
11	CIS-10 PENTADECENOIC ACID			Absent	Absent
12	Palmitic acid			0.016	Absent
13	Palmitoleic Acid			0.008	Absent
14	Margaric acid			Absent	Absent
15	Heptadecenoic acid			Absent	Absent
16	Stearic acid			Absent	Absent
17	ELAIDIC ACID			Absent	Absent
18	Oleic acid			Absent	Absent
19	LINOLELAIDIC ACID			Absent	Absent
20	Methyl-octadeca-9,12-dienoate			Absent	Absent
21	Arachidic acid			Absent	Absent
22	Linoleic acid			0.007	Absent
23	Gadoleic acid			Absent	Absent
24	Linolenic acid			Absent	Absent
25	Heneicosylic acid			Absent	Absent
26	Icosadienoic acid			Absent	Absent
27	Behenic acid			Absent	Absent
28	Icosatrienoic acid			Absent	Absent
29	Methyl cis-13-docosenoate			Absent	Absent
30	Methyl 11,14,17-eicosatrienoate			Absent	Absent
31	Tricosylic acid			Absent	Absent
32	Arachidonic acid			Absent	Absent
33	13,16-Docosadienoic acid			Absent	Absent
34	Lignoceric acid			Absent	Absent

35	Eicosapentaenoic acid			Absent	Absent
36	Nervonic acid			Absent	Absent
37	Cervonic acid			Absent	Absent

2.4 Amino acid profile of BSF- The rearing substrates affect the total protein and amino acid composition in BSF. Results of amino acid in both batches showed that, Aspartic acid is present in highest amount i.e. 11.94 g/100gm in batch I and 11.44g/100gm in batch II. Amino acids profile showed variable quantities in both batches indicates that food variation impacts amino acid content in BSF. Amino acids lysine, arginine, glycine, serine, alanine, valine, leucine, isoleucine, cystine showed marked differences in amount in both batches. (Table 6).

Table 6: Amino acid profile of last larval stage of BSF (early prepupa) fed on two organic wastes, i.e., Waste Fish (Batch I) and Waste Chicken(Batch II).

S. N.	Amino acid profile	Measurement Unit	Test method	Test Result	
				Batch I Waste Fish	Batch II Waste chicken
1	Lysine	g/100g	Lab SOP (by using LCMS/MS)	2.41	1.39
2	Arginine			3.13	2.11
3	Glycine			2.14	1.63
4	Serine			2.16	1.72
5	Glutamic acid			1.02	1.15
6	Alanine			4.28	5.27
7	Aspartic acid			11.94	11.44
8	Proline			1.59	1.48
9	Histidine			1.89	1.08
10	Valine			1.12	0.81
11	Methionine			0.42	0.26
12	Leucine			2.17	1.41
13	Phenylalanine			0.80	0.50
14	Tyrosine			1.63	1.07
15	Isoleucine			1.95	5.50
16	Tryptophan			1.03	0.81
17	Threonine			0.74	0.77
18	Cysteine			0.71	1.03

2.5 Mineral profile of BSF- The two rearing substrates used for study affect the accumulation mineral composition in BSF. Seven types of minerals were detected that are sodium, potassium, calcium, magnesium, iron, copper and zinc. Calcium is present in more concentration in both batches i.e., 5268.39 mg/kg and 4112.62 mg/kg in batch I and batch II respectively. Copper and zinc are present in lower concentration in both batches. (Table 7).

Table 7: Mineral profile of last larval stage of BSF (early prepupa) fed on two organic wastes, i.e. Waste Fish (Batch I) and Waste Chicken (Batch II).

S.N.	Mineral profile	Measurement unit	Test method	Test Result	
				Batch I Waste Fish	Batch II Waste chicken
1	Sodium	mg/kg	Lab SOP	2298.21	2022.72
2	Potassium			4057.65	3011.27
3	Calcium			5268.39	4112.62
4	Magnesium			1937.57	1811.26
5	Iron			392.05	200.12
6	Copper			1.67	2.02
7	Zinc			16.54	10.26

DISCUSSION

Black soldier flies feed voraciously on these two types of organic wastes i.e., waste, discarded fishes collected from the fish market and on waste discarded flesh from poultry slaughter house market. Larval biomass conversion parameters showed excellent values so this experiment was done successfully. We found that waste reduction in both the batches were 87.5% and 85% which shows BSF larvae has high capacity to reduce these organic wastes most efficiently. Bioconversion and waste reduction of organic waste by earthworms and microorganisms is well recognized by authors, Suthar and Sing (2008) and Pathmaand Sakthivel (2012). Moritz G et al. (2020) studied bioconversion of BSF fed on different organic wastes i.e., mill by-products, Canteen waste, Human faeces, poultry slaughterhouse waste, cow manure, vegetable canteen waste and on poultry feed, estimated the values of waste reduction % in dry matter of biowaste, it was found to be 56.4%, 37.9%, 39.1%, 30.7%, 12.7%, 58.4%, 67.7% respectively. Utilization of food waste as rearing substrate for BSFL could be suitable at industrial scale, as during the 14 months of industrial scale production, 190 kg of food waste was bio converted into approximately 79kg of BSFL (Anton G. et al., 2020). Author Karuna G. reviewed the application of potential black soldier fly in solid waste management in low- and middle-income countries like India (Karuna G. 2022a).

Study done by author Anton G et al. (2020), where 8.7kg of fresh food waste was converted into 550 gm BSF larvae and 530 gm insect frass (DM basis) in period of 10 days. Similar study was also done by Ermolaev et al. (2019)[36] where BSF larvae bio convert approximately 15kg fresh food waste into 1 kg BSFL and 1 kg insect frass (DM) over period of 21 days, indicated that the production of BSFL on food waste can be achieved in different setups. Work done by Paulin N et al., (2018) estimated FCR values high i.e., 15.3 in continuous feeding and 8.2 in batch feeding when fed with chicken manure. Our study estimated FCR values 3.48 and 3.06 in batch I and batch II respectively.

Insects are natural protein sources for livestock like turkeys, poultry and can replace fishmeal in organic poultry diets. Because of its good nutritional value, high reproductive potential, low water and space requirements, ability to use organic waste as food and less environmental impact, insects are the future for livestock feed (Oonincx D.G.A.B. et al 2010, Smetana S. et al. 2016). Insects contain about 70% water, 40-60% crude protein. Black soldier fly larvae contain 42% protein and 35% of fat (Sheppard, D.C. 2002). Crude protein in our study was found to be low as compared to the CP present in Soybean meal and fish meal of poultry feed, i.e. 42.89% and 41.22% in batch I and batch II BSF larvae respectively. (Table 1 and 2)

Author Finke M.D. (2013, 2015) analysed nutrient composition of six type of insects like, house crickets' nymphs, yellow mealworm larvae, super-worm larvae, wax-worm larvae, house fly adults and black soldier fly larvae. Crude protein in these insects found to be 60%, 59.8%, 50.27%, 40.11%, 78.17% and 45.1% respectively. The author also analysed the amino acid profile of these insects and found that in most of the cases, insect meal is lower in methionine than in fishmeal (Jozefiak, D.,et al. 2016, Jozefiak, D.,et al. 2015). Finke, M. D (2015) found that arginine and methionine to be co-limiting when applied the insects as a primary source of protein for the diets of growing chicks, however he found high methionine content in protein of adult house flies. (Finke, M.D. 2002, Finke, M.D. 2013, Finke M.D. 2015)

Soybean meal is the most popular protein used for poultry and live-stock industries throughout the world. Dehulled soybean meal found to have 53.9% protein and amino acid profile of Arginine, Cysteine, Lysine, Methionine, Threonine and Valine. (Stein H.H. et. al.2008)

Especially amino acids like lysine and tryptophan are present in soybean meal (Baker, 2000). Soybean meal is especially good foundation of lysine, no other oilseed contains a good source of lysine as soybean meal, however, soybean meal is not a perfect protein source (Stein H.H. et. al. 2008). When compared to perfect amino acid contents needed for poultry, the protein in soybean meal is deficient in methionine, cysteine, threonine and valine. Poultry chicks cannot produce arginine, so its requirementis high for poultry. Soybean is a good source of arginine. Our study resulted to get 3.13 g/100gm and 2.11 g/100gm of arginine in both batches, also estimated 18 essential amino acid profile from the wastes utilized in this study. Aspartic acid is found to be highest in amount i.e. 11.94 g/100gm in Batch I and 11.44g/100gm in Batch II. (Table 6)

The impact of rearing substrate on BSF protein and amino acid profile studied by many authors. The protein content in BSF showed clear differences, ranging from 32 to 58% on dry matter (Gold, M. et. al., 2018), while amino acid profile is unpredictable, this is true for other insect species too (Gere, A. et. al., 2019). BSF larvae fed on animal manure were lacking some essential amino acids, such as cysteine, methionine and threonine (Newton, G.L et. al., 1977) whereas BSF larvae had sufficient threonine amounts when reared on conventional diet supplemented with increasing quantities of seaweed (Liland, N.S. et.al., 2017). When fed on vegetable mix, BSF showed high amounts of aspartic acid, glutamate and arginine (Cappellozza, S. et. al., 2019), and also of leucine. (Spranghers, T. et al., 2017). Our results also showed high amount of aspartic acid and all essential amino acids are found to be present in both the batches. Fuso A. et. al.(2021) concluded that Lysine, leucine and valine are most correlated with the presence of nutrients of the feeding diet. Leucine and valine strongly dependent on the content of protein and lipid in the diet, while lysine is correlated to the amount of carbohydrates. Author Karuna G. (2022b) reviewed that the use black soldier fly larvae generated protein and fat could be used as replacement for other protein and fat sources in livestock feed industries. Our objective of this study is to provide knowledge of nutritional value of BSF larvae so that these larvae can replace or reduce the use of soybean and fishmeal used in poultry and in other livestock feed, it can reduce the feed cost and can develop a sustainable nation.

Lipid content in BSF reported by various authors fed on varied diet types. In prepupae 15% - 34.8% lipid was reported by (Makkar HPS et. al. 2014). BSF grew on cattle beef and poultry manure reported 34% of crude fat, on swine manure 28% (Newton L et. al. 2005, Newton GL, 1977) and on oil rich feed source 42% -49%. (Barry T. 2004). In our study we continuously fed BSF larvae on waste fish and on waste flesh of chicken so observed high accumulation of lipids i.e. 62.32% and 61.08% at early prepupal stage. Fatty acid profile showed complete absence of fatty acids in batch II while fatty acids like butyric acid, lauric acid, myristic acid, palmitic acid, palmitoleic acid, Linoleic acid are found to be present in batch I which were fed on waste fish (Table 5). BSF are high in lauric acid, which is a saturated fat (Finke, M.D. 2002), while most other commercial insects have mainly monounsaturated and polyunsaturated fatty acids (Finke M.D. 2013). Findings of Nils Ewald et al. (2020) concluded that irrespective of diet, larval fat consisted mainly lauric acid and other saturated fatty acids and these were found to be synthesised by the larvae. Fatty acid profile of larvae depends upon both the fatty acid composition of substrate and on larval weight. High weight larvae contained a higher percentage of saturated fatty acids and lower percentage of unsaturated fatty acids like eicosapentaenoic and docosahexaenoic acid. The author also concluded that the BSFL fat may not be suitable to replace fish oil, but can replace contents of other food and fuel products. Study done by Alifian MD (2019) reared BSF on palm kernel meal and on 80% industrial waste mix with 20% organic waste, the results of ether extract content is different in both substrate but fatty acid of both substrates are almost same and most dominant are lauric acid, oleic acid, palmitic acid and myristic acid and conclusion of his study is the larvae reared on different substrates affect lipid content but the fatty acid composition is same.

Dry matter content of BSF larvae depends on the rearing period (Mahmud ATBA et. al., 2020). If rearing periods is long so as the dry matter content is high, due to the increase of crude fibre and crude fat content (Manurung R et. al., 2016). The author found the dry matter content of BSF larvae 26.61% at five days to 39.97% at 25 days. Our study found dry matter content 36.91% and 35.96% in batch I and batch II respectively during the period of 14 days of larvae.

Dynamic changes in nutrient composition of BSF studied by Xiu Liu (2017) showed that Vitamin E content in larval stage 6.68 mg/100g and in early prepupa stage 3.26 mg/100g which is less than Vitamin E content in batch I of our study. Our study shows Vitamin E content in BSF early prepupae larvae in batch I is 74.7mg/100g, while in batch II is 2.39 mg/100g. Vitamin E is major lipid soluble antioxidant in the cell antioxidant defence system, so it can be applicable as a feed additive in human feed, it may protect against many heart diseases and cancers caused by reactive free radicles. (Xiu Liu et al., 2017). Vitamin A in batch I is 55.00 µg/100g while it is absent in batch II. Vitamin B12 is present in both batches i.e., 1.31mg/100g and2.09mg/100g. Vitamin C is absent in both batches. Vitamin D in both batches are 27.60 µg/100g and 49.34 µg/100g. Our study indicates that vitamin content of BSF larvae depends on food substrate they fed on.

Black soldier flies differ from other insects as they have a mineralized exoskeleton contain high amount of calcium (Finke, M. D. 2002). BSF contain numerous minerals like calcium, phosphorous, sodium, iron and zinc (Xiu Liu et al., 2017). Mineral profile found in our study showed that calcium content is highest i.e., 5268.39 mg/kg in batch I and 4112.62 mg/kg in batch II. As BSF found to be abundant with vitamin and minerals can reduce the consumption of meat, dairy and animal protein products. (Van Huis A et. al., 2013, Millward DJ et al. 2010, Veldkamp T. et. al., 2012) The high amount of fats and minerals in BSF larvae pulls attention for its use for feeding livestock (Barragan F. et. al., 2017) also these larvae can also be pressed for oilas a biofuel.

CONCLUSION

This innovative, organic and environment friendly BSF technology can provide sources of protein and various amino acids for organic poultry, aquaculture and other livestock feed industries. Although these two wastes utilised for the present study are not commonly recycled in developing countries and cannot be commercialised on large scale but it is possible to recycle these wastes at small and medium scale. Information obtained in this study is supportive for insect cultivators, poultry farmers, aquaculture farmers, pet owners, researchers and for all feed manufacturing industries of livestock. The study reveals that the mass production of nutritive BSF can be one of the potential waste bio-converter in itself and vital solution for future requisite of food demand and supply of livestock, poultry etc. delivering safe protein rich diet. With BSF biotransformation technology most of our country's bio-waste management can be handled consciously in near future as these challenges are increasing with respect to anticipated population growth.

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