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RESEARCH

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From agricultural waste to chicken feed using insect-based technology

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Abstract

Background This study investigates the potential of black soldier fly (BSF) larvae to recycle agricultural waste into larval biomass for chicken feed, and was carried out at the University of Dschang, Cameroon in 2020. Fruit waste consisting of papaya, pineapple and orange peels, and cocoa pods from local sources were used for this study. They were first grinded, and the fruit waste was subjected directly to the larvae from a pre-established BSF colony. Cocoa pods on the other hand were mixed with *Tithonia* leaves at 0% (C100:T0), 5% (C95:T5), 10% (C90:T10), 15% (C85:T15) and 20% (C80:T20), and larval recycling efficiency was assessed using bioconversion parameters. At the end of the process, the BSF larvae from the fruit waste were harvested, dried, grinded, and used in chicken diet as a source of dietary protein. Their nutritional effect was assessed using chicken growth parameters.

Results Within 15 days, BSF larvae were able to reduce fruit waste by 96.05% and generated 125.33 g of fresh larvae, with an average bioconversion rate of 08.35%. The recycling efficiency of cocoa pods has been greatly improved with the incorporation of Tithonia leaves. The highest bioconversion rate was recorded with the C80:T20 treatment (17.2%). The larvae produced were concentrated in proteins, lipids, and minerals. Those harvested from recycling fruit waste consisted of 39.50% protein, 19.84% lipid and 10.37% ash. Their incorporation in chicken diet as a source of animal protein did not reveal any negative effects on the growth parameters. The growth performances recorded were comparable to that of commonly used fishmeal.

Conclusions BSF larvae can easily be reared on agricultural waste to replace or supplement fishmeal in chicken diet. Adoption of this technology could help mitigate the adverse effects of poor agricultural waste management on the environment.

Keywords Agricultural waste, Chicken feed, Food production, Insect larvae, Waste management

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Background

Despite recent economic and social improvements, several countries in sub-Saharan Africa (SSA) remain among the poorest countries in the World (rank 158 of 187 Human Development Index) with 67% of the population living in poverty. Given the ill effects of economic fragility, climate change, as well as a lack of management and planning concerning food security, the value of alternative local sources of income and production become apparent. The use of fishmeal in conventional feeds is associated with high water demand and has a severely negative impact on aquatic biodiversity (Orhan et al., 2022). With the costs of feed accounting for 60–70% of the total costs of livestock production (van Huis, 2020), having an alternative source of feed could have significant impacts on smallholder chicken producers, who are dominantly youth and women farmers.

Another pressing issue in many SSA countries is waste management. Trending in parallel with population growth and urbanization in SSA, is the substantial waste generation. Over 8% of Africa's greenhouse gas (GHG) emissions are generated from decomposition of biowastes in open dumps (Couth & Trois, 2012). Major cities in SSA are plagued by waste management problems, with more than 80% waste being discharged into the environment, leading to serious ecological issues (World Bank, 2015).

In the last decade, a waste treatment option, fly larvae composting has gained much interest due to the opportunity to tackle not only the waste management issue, but also the issues of lack of high-quality protein to replace fishmeal in animal diets (Čičková et al., 2015; Dortmans et al., 2017; Dzepe et al., 2021). The most commonly used fly for this purpose is the black soldier fly (BSF), *Hermetia illucens,* a tropical fly native to the warmer regions of the world (van Huis et al., 2020). BSF-based technology follows the principle of a circular economy and the two products generated—fly larvae biomass (that can be used in animal feed) and a waste residue, also called frass (that can be used as an organic fertilizer), together have a higher economic value than products from other organic waste treatment technologies with similar level of complexity (Lalander et al., 2019).

The increasing generation of bio-waste with few disposals' options can lead to several environmental issues. In SSA countries, composting is one of the advanced technologies usually used for recycling and recovering biowaste (Jaza Folefack, 2008; Lompo et al., 2009). This process can take several months and require the action of a great number of microorganisms to produce compost as the only valuable product (Compaoré & Nanéma, 2010; Ngnikam et al., 2002). In contrast, bio-wastes treatment using BSF-based technology does not require specific microorganisms and only takes about two weeks to produce frass as organic fertilizer, and fly larvae as a source of proteins for livestock (Dzepe et al., 2020; Kroeckel et al., 2012; Liland et al., 2017). It is a relatively new and environmentally friendly technology that offers a promising avenue for sustainable biowaste management and animal feed production. This study aimed to investigate the potential of BSF larvae to recycle two agricultural wastes (fruit waste and cocoa pods) and their adoption as a new source of animal protein in chicken diet.

Methods

Waste treatment

Fruit wastes

The experiment was conducted at the University of Dschang, Cameroon in 2020. Fruit waste was collected from the Dschang market and used in this study as a substrate for mass rearing of BSF larvae. They consisted of papaya, pineapple and orange peels and were ground and stored for two days after collection to reduce their water content before being fed to BSF larvae. The treatment was carried out in plastic containers (Ø 30 × 12 cm), covered with mosquito nets. Four plastic containers filled with 1500 g of fruit waste were seeded with a batch of 1000 neonate larvae from a pre-established BSF colony at the Dschang university farm. The experiment lasted 15 days according to the time required for BSF larvae to reach maturity (Diener et al., 2011).

Cocoa pod

Cocoa pod was collected from a local farm and ground using a hammer mill to reduce the particle size. The dough obtained was mixed with the *Tithonia diversifolia* leaves at different proportion to improve the nutritional value for BSF larvae. This plant was chosen because of its relatively high concentration of crude proteins essential for the growth of BSF larvae (about 20% of the dried mater). After harvest, the leaves were ground and mixed with cocoa pod at 0% (C100:T0), 5% (C95:T5), 10% (C90:T10), 15% (C85:T15), and 20% (C80:T20), respectively. after mixing, each substrate was sampled for chemical analyzes (Table 1).

Freshly laid BSF eggs were collected from the pre-established colony and incubated for three days following the protocol described by Dzepe et al. (2020). Newly hatched BSF larvae were fed with chicken feed for 5 days before being used for experiments. To increase homogeneity in the treatments, the larvae were sieved with a mesh diameter of 0.8 mm, and only the larvae which passed through the sieve were used for the experiment. This experiment was conducted in plastic containers (10 cm × 17.5 cm × 7 cm), covered by a lid with nylon grid to prevent larvae from escaping and allow air exchange.

Table 1 Proximate composition of cocoa pod mixed with tithonia leaves in different proportions

Parameters	C100:T0	C95:T5	C90:T10	C85:T15	C80:T20	C0:T100
Dry matter	87.81	87.1	86.4	83.38	82.53	88.72
Organic matter	71.37	71.33	74.56	70.61	73.43	74.62
Ash	16.44	15.77	11.84	12.77	9.1	14.1
Crude protein	6.37	8.33	17.24	20.35	21.51	20.5
Ether extract	3.17	1.68	4.83	1.42	6.34	4.1
Crude fiber	13.57	10.72	10.39	10.16	9.19	18.8

Three replicates were prepared for each treatment, consisting of 100 5-day-old BSF larvae and 150 g of substrate (1.5 g/larva). This experiment also lasted 15 days.

Waste conversion parameters

At the end of each experiment, BSF larvae were separated from the substrate and weighed using an electronic balance. The remaining substrates were also collected and weighed using the same balance, and the potential of BSF larvae to grow and recycle the different treatments was assessed using parameters such as: larval biomass (Eq. 1), waste reduction rate (Eq. 2), bioconversion rate (Eq. 3) and waste conversion efficiency (Eq. 4).

$$\text{Larval biomass (g)} = \text{Total weight of larvae harvested} \tag{1}$$

$$\text{Waste reduction rate (\%)} = [1 - (\text{Waste residue/Waste added})] \times 100 \tag{2}$$

$$\text{Bioconversion rate (\%)} = (\text{Havested larvae/Waste added}) \times 100 \tag{3}$$

$$\text{Waste conversion efficiency (\%)} = \text{Larval biomass/Waste added} - \text{Waste redue} \times 100 \tag{4}$$

BSF larvae in chicken diet

Prior to the application of BSF larvae meal in chicken feed, the larvae from the various experiments described above were taken to the laboratory for chemical analysis. The dry matter, protein, fat and ash contents were analysed according to the protocol described by the International AOAC (2002). While minerals such as calcium (Ca), sodium (Na), potassium (K), phosphorus (P) and magnesium (Mg) were analysed according to the protocol described by Pauwels et al. (1992).

The larvae used in broiler diet were produced from fruit waste in the first experiment previously described. After harvest, they were dried in the oven for 24 h at 105° C, and grinded to obtain the BSF larvae meal which was kept in the refrigerator until the time of the experiment. The diet was formulated by replacing fishmeal with BSF larvae meal in a standard control diet (Table 2).

Forty-eight broiler chicks, purchase from the local market were used in this study. They were initially fed with

Table 2 Formulation of experimental diets

Ingredients (%)	Starter phase		Grower phase	
	Control diet	BSF-based diet	Control diet	BSF-based diet
Maize	54	54	67	67
Cotton cake	5	5	5	5
Soybean	22	22	14	14
Premix 5%	5	5	5	5
Shell meal	1	1	1	1
Bone meal	1	1	1	1
Palm oil	3	3	3	3
Wheat bran	4	4	–	–
Fishmeal	5	–	5	–
BSFLM	–	5	–	5
Total	100	100	100	100

the standard control diet during the first week for their acclimatization. After this period, they were randomly allocated into eight groups of six chicks each. The first four groups continued to receive the standard control diet, while the second four groups received the experimental BSF-based diet in which fishmeal was totally substituted by BSF larvae meal. During the experiment, water and food were provided ad libitum and the prophylaxis plan was properly applied.

Chicken growth parameters

The experiment lasted 06 weeks and the influence of the BSF larvae meal in the diet of broiler chickens was monitored weekly using growth parameters such as: body weight (Eq. 5), body weight gain (Eq. 6), feed intake (Eq. 7) and feed conversion ratio (Eq. 8).

$$\text{Body weight}(g) = \text{Average individual broiler weight on a weekly basis} \quad (5)$$

$$\text{Body weight gain}(g) = \text{Initial body weight} - \text{Body weight at the end of the week} \quad (6)$$

$$\text{Feed intake}(g) = \text{Broadcast flow} - \text{Remaining flow} \quad (7)$$

$$\text{Feed conversion ratio} = \text{Feed intake}/\text{Body weight gain} \quad (8)$$

Statistical analyses

One-way analysis of variance (ANOVA) followed by Tukey's HSD (honestly significant difference) was performed to compare the recycling performance of cocoa pods according to the different treatments. While Student's t-test was used to compare the growth performance of broilers fed the BSF-based diet to those fed the control diet. Analyses were performed using IBM SPSS Statistics software and tests were considered significant at $p < 0.05$.

Results

Waste recycling efficiency

In 15 days, the BSF larvae were able to reduce 1500 g of fruit waste to 96.05% and generated 125.33 g of fresh larvae, giving an average bioconversion rate of 08.35%. The recycling parameters of cocoa pods were significantly affected by the different treatments ($p < 0.05$). The living biomass of the harvested BSF larvae ranged from 7.84 g to 11.49 g, and the highest value was recorded in C80:T20. The lowest biomass was recorded in C100:T0. The increasing incorporation of *Tithonia* leaves into cocoa pod had a positive impact on BSF larval biomass. A similar trend was recorded with the bioconversion rate. However, the lowest bioconversion rate (8.0%) was recorded in C85:T15. The waste reduction rate varied from 40.44 to 73.44% and the highest value was also recorded in C85:T15, followed by C90:T10. Reduction rates of 53.2% and 48.93% were recorded in C95:T5 and C80:T20, respectively. The waste conversion efficiency ranged from 10.89 to 35.14%, and the highest value was recorded in C80:T20 (Table 3).

Chemical composition

Analysis of the proximate composition of BSF larvae from fruit waste shows 39.50% protein, 19.84% fat and 10.37% ash. Their mineral composition shows a high concentration of calcium (11.80 g/kg), potassium (08.92 g/kg), phosphorus (06.16 g/kg) and magnesium (02.70 g/kg). For the larvae from the different experimental treatments with the cocoa pod, the dry matter varied from 89.47 to 90.91%, and no significant difference was observed ($p > 0.05$).

Table 3 Physicochemical characteristics and recycling parameters of cocoa pod subjected to five different treatments

Parameters	C100:T0	C95:T5	C90:T10	C85:T15	C80:T20	SEM	*p*
Physicochemical parameters							
T (℃)	26.65_c	26.67_c	26.97_c	27.07_b	27.75_b	1.16	< 0.05
H (%)	59.20_c	59.06_c	59.92_b	59.93_b	60.08_a	0.49	< 0.05
pH	6.5	6.5	6.5	6.5	6.5	0	–
Recycling parameters							
LB (g)	7.84_d	8.17_c	9.39_c	7.99_c	11.49_b	22.08	< 0.05
WR (%)	40.44_d	53.2_{bc}	67.14_b	73.44_a	48.93_c	14.98	< 0.05
BR (%)	11.77_c	10.13_c	15.71_b	8.00_d	17.2_b	10.78	< 0.05
WCE (%)	29.14_c	19.13_{de}	23.38_d	10.89_e	35.14_b	17.004	< 0.05

Means are based on three replications and values followed by different lowercase letter are significantly different among treatments ($P < 0.05$)

T temperature, *H* humidity, *pH* potential hydrogen, *LB* larval biomass, *WR* waste reduction rate, *BR* bioconversion rate, *WCE* waste conversion efficiency, *SEM* standard error of mean, *p* probability

The protein content also does not show any significant variation. It ranged from 37.89% with C100:T0 to 40.97% with C85:T15. The fat content on the other hand was significantly affected ($p < 0.05$), and the highest concentration was recorded with C95:T5 (34.56%). The ash content was also significantly affected, and the lowest value was recorded with C100:T0 (Table 4).

Effect of insect-based diet on chicken growth

No mortality was recorded during the experimental period, and chicken growth parameters were not significantly affected by the BSF-based diet ($p > 0.05$). After six weeks of treatment, a mean body weight of 1867.67 ± 27.60 g was recorded with BSF diet compere to 1842.70 ± 83.34 g recorded with the standard control diet (Fig. 1). Although no significant differences were observed, chickens fed with the BSF-based diet appeared bigger than those fed with the standard diet. The same trend was recorded with body weight gain. Throughout the experimental period, the values recorded with the BSF diet were relatively higher compared to those recorded with the control. On the other hand, the feed consumption of chickens fed with the control diet was higher compared to the BSF diet. Same trend with the feed conversion rate (Table 5).

Discussion

Processing organic waste using insect larvae is a sustainable way to improve waste management and promote urban sanitation. The application of BSF larvae to recycle bio-waste into useful products has been widely studied (Moula et al., 2018; Wang & Shelomi, 2017; Gold et al. 2018; Uushona et al., 2019; Nana et al., 2018). The larvae grow in 15 days and are highly rich in protein and dietary lipids. In this study, we investigated the potential of BSF larvae to recycle fruit waste and cocoa pods. We achieved an average waste reduction rate of 96.05% with fruit waste, which was very high compared to previous studies (Diener et al., 2011; Uushona et al., 2019). We suspect that the water content of the fruit waste influenced this parameter. The same trend was observed by Nguyen et al. (2015) who reported higher reduction rates with fruit and vegetable waste compared to chicken feed and chicken manure. On the other hand, the bioconversion

Table 4 Proximate composition of BSF larvae from cocoa pod processing

Parameters	C100:T0	C95:T5	C90:T10	C85:T15	C80:T20	SEM	*p*
Dry matter	90.91_a	90.41_a	89.47_a	90.60_a	89.76_a	0.69	> 0.05
Organic matter	83.36_a	82.81_a	80.75_b	80.37_b	78.70_c	3.31	< 0.05
Crude protein	37.89_a	38.0_a	38.48_a	40.97_a	40.28_a	6.11	> 0.05
Fat	26.80_b	34.56_a	17.27_d	19.28_c	24.40_b	5.96	< 0.05
Crude fiber	22.63_b	30.37_a	23.46_b	16.43_c	18.69_{ab}	6.43	< 0.05
Ash	07.55_c	07.60_c	08.72_b	10.23_a	11.06_a	3.52	< 0.05

Means are based on three replications and values followed by different lowercase letter are significantly different among treatments ($P < 0.05$)

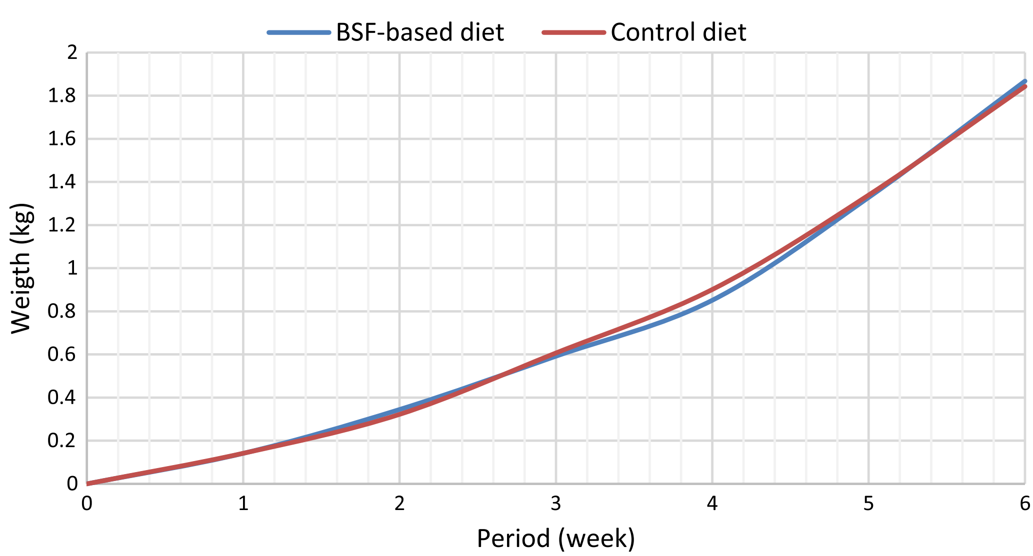

Fig. 1 Average weekly body weight of chickens during the experiment

Table 5 Average weekly body weight, body weight gain, feed intake and feed conversion ratio of broilers fed insect-based diets and a control diet

Period (week)	Body weight gain (g)		Feed intake (g)		Feed conversion ratio	
	BSF-based diet	Control diet	BSF-based diet	Control diet	BSF-based diet	Control diet
1	$99.53 \pm 08.00_a$	$99.84 \pm 13.72_a$	$332.61 \pm 41.99_a$	$321.62 \pm 3.18_a$	$2.35 \pm 0.29_a$	$2.28 \pm 0.22_a$
2	$203.33 \pm 10.68_a$	$180.41 \pm 44.12_a$	$370.89 \pm 63.02_a$	$389.00 \pm 69.83_a$	$1.07 \pm 0.16_a$	$1.22 \pm 0.28_a$
3	$247.05 \pm 22.40_b$	$284.66 \pm 23.75_{ab}$	$454.05 \pm 41.42_b$	$549.33 \pm 24.10_a$	$0.76 \pm 0.09_a$	$0.90 \pm 0.07_a$
4	$259.38 \pm 06.96_a$	$294.33 \pm 19.19_a$	$708.44 \pm 36.68_a$	$719.50 \pm 43.31_a$	$0.83 \pm 0.03_a$	$0.79 \pm 0.03_a$
5	$476.86 \pm 28.92_b$	$437.93 \pm 25.15_b$	$918.33 \pm 38.83_a$	$999.95 \pm 58.35_a$	$0.69 \pm 0.03_{ab}$	$0.74 \pm 0.03_a$
6	$539.59 \pm 09.54_b$	$503.60 \pm 10.81_b$	$1245.54 \pm 42.16_a$	$1323.13 \pm 39.97_a$	$0.66 \pm 0.03_{ab}$	$0.71 \pm 0.02_a$

Means (± SE) are based on three replications and values followed by different lowercase letter are significantly different among treatments ($P < 0.05$)

rate (08.35%) was close to those obtained by Nana et al. (2018) with kitchen manure (08.20%) and Lalander et al. (2015) with poultry manure (07.10%), although other studies report higher bioconversion rates (Joly, 2018; Nyakeri et al., 2019).

The application of *Tithonia* leaves enriched the cocoa pods and improved its recycling efficiency. As shown in Table 1, its incorporation progressively improved the protein content of the substrate and consequently the recycling parameters of the BSF larvae (Table 3). Indeed, the protein content of the substrate plays a key role in the bioconversion process. Several studies report that BSF larvae have the potential to thrive in a wide range of organic waste streams. However, most agricultural waste lacks the nutrients required for optimal growth of BSF larvae. It therefore becomes necessary to mix different wastes to improve the bioconversion of poor substrates such as cocoa pods for example. Spranghers et al. (2017) report that larvae of BSF require a protein content of 5 to 11% in the substrate for optimal growth, and that values below 5% limit their development. This observation confirms the contribution of *Tithonia* leaves in the recycling processes of cocoa pod in this study. The chemical composition of the larvae was improved as well. However, the protein content of the larvae was not significantly affected. Indeed, larvae of BSF have the ability to convert low-protein biowaste into protein-rich larval biomass (Seyedalmoosavi et al., 2022).

Insect larvae are currently presented as a promising way to replace fishmeal in the animal industry due to their high concentration of dietary proteins and lipids (Schiavone et al., 2017). The proximate composition analysis of BSF larvae from fruit waste in this study shows 39.50% protein and 19.84% lipid. These values are close to those reported by previous studies (Wang & Shelomi, 2017). However, it should be noted that the chemical composition of insect larvae varies depending on the rearing substrate. St-Hilaire et al. (2007) reported 43.6% crude protein with BSF larvae reared on pig manure, Mutafela (2015) reported 39.80% crude protein and 30.10% crude fat with organic waste municipal, and 37.80% crude protein and 41.70% crude fat with fruit waste. An ash content of 10.37% was also revealed with larvae from fruit waste. This parameter is important and makes it possible to estimate the mineral concentration of the larvae. The analysis of the mineral composition revealed 11.80 g/kg of calcium, 08.92 g/kg of potassium and 06.16 g/kg of phosphorus. Several studies also show a high concentration of calcium (Finke, 2013; Makkar et al., 2014), and Spranghers et al. (2017) reported that calcium is the main inorganic compound found in BSF larvae.

The replacement of fish meal with BSF larvae meal in the diet of chickens did not reveal any significant change in their growth parameters. The diet was really appreciated, and no mortality was recorded. Previous studies also report that insect larvae provide a sustainable source of protein for livestock (Chia et al., 2019; Dzepe et al., 2019; Moula et al., 2018). Based on these results, BSF larvae can be easily reared on organic waste to replace or supplement fishmeal in animal feed. Adopting such a source of protein will be a great step forward for the livestock sector, in a context where fishmeal is becoming increasingly rare and extremely expensive for local producers.

Conclusions

The present study investigates the potential of BSF larvae to recycle agricultural waste into a new protein source for chicken feed. Within 15 days, BSF larvae were able to effectively convert fruit waste and generate a concentrated biomass of 39.50% protein and 19.84% lipid. Its application in chicken feed as a source of animal protein did not reveal any negative effects. On the contrary, the growth performance recorded was comparable to that of commonly used fishmeal. The treatment of cocoa pod was not very effective, but this study shows that an association with *Tithonia* leaves can significantly improve its efficiency of bioconversion by BSF larvae. This study is relevant and could contribute to mitigating the harmful effects of poor management of agricultural waste on the environment.

Abbreviations

ANOVA	Analysis of variance
AOAC	Association of official analytical chemists
BSF	Black soldier fly
GHG	Greenhouse gas
SSA	Sub-Saharan Africa

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Not applicable.

Author contributions
DD, TT and RD conceived and designed the study, OM performed the experiments, DD and HMK analyzed and interpreted the data, DD did the original draft preparation, FM and PN reviewed and edited the paper. All authors read and approved the final manuscript.

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Availability of data and materials
All data generated or analysed during this study are included in this published article.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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