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Bioprocessing of organic wastes from poultry and bovine slaughterhouses as food substrate for *Hermetia illucens* larval developmentA.P. Luperdi¹, S.S. Flores-Calla^{1,*}, X.J. Barriga¹, V. Rivera¹, I. Salazar¹, P.L. Manrique^{1,2}, J.E. Reátegui¹¹Universidad Católica de Santa María, Postal address 04013, Perú²Instituto de Investigación y Desarrollo para el Sur, Postal address 04018, Perú

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ABSTRACT

BACKGROUND AND OBJECTIVES: In the meat industry, inefficient management of organic waste exists, therefore the study aims to evaluate different bovine and poultry organic residues as food substrates during larval development of the black soldier fly, such as a sustainable alternative to obtain high protein meal.**METHODS:** The research evaluates the use of organic waste from cattle and poultry slaughterhouses, as food substrate for black soldier fly larvae, including raw beef blood T1, raw beef viscera T2, cooked beef blood T3, cooked beef viscera T4, raw chicken viscera T6 and cooked chicken viscera T7; further, as a control measure balanced feed (7 treatments and 5 replicates). Larvae were fed for 5 days and processed to make meal by drying and grinding; evaluating mortality, weight, size, proximal chemical composition, and apparent digestibility to determine the most viable substrate, analyzing effects and significance by multifactorial ANOVA and Kruskal-Wallis.**FINDINGS:** The results show Mortality ($F = 917,81$, $p < 0,0001$): T1 y T3 with $76,40 \pm 2,86$ (%) ($F = 917,81$, $p < 0,0001$), following T6 with $69,67 \pm 4,55$ %, T7 with $24,00 \pm 3,48$ %, T2 with $4,60 \pm 1,92$ %, T5 y T4, both with $4,20 \pm 2,00$ %. Weight ($F = 825,62$, $p < 0,0001$): T2 with $1,78 \pm 0,22$ gram outperformed the control T5 ($1,76 \pm 0,50$ gram), T4 with $1,45 \pm 0,06$ g and T7 with $1,66 \pm 0,07$ gram. Size ($F = 248,95$, $p < 0,0001$): T5 with $16,03 \pm 0,34$ mm, T2 with $15,86 \pm 0,22$ mm, T4 with $14,72 \pm 0,35$ mm and finally, $14,51 \pm 0,14$ millimeter in T7. Proximal chemical analysis of crude protein and fat: T2 resulted in the following results $50,81$ % and $21,88$ %, T4 with $53,90$ % y $15,04$ %, T7 with $42,63$ % and $32,03$ %, and T5 con $41,1$ % and $19,55$ %, respectively. Digestibility: T5 with $20,39$ %, T2 with $12,66$ %, T4 with $10,61$ % and T7 with $5,97$ %. T2 raw beef viscera were determined to be the most viable substrate, followed by T4 cooked beef viscera and T7 cooked chicken viscera.**CONCLUSION:** Testing the effectiveness of cattle viscera as substrate, the experimental data presented may help design a process for an effective treatment method for slaughterhouse waste, which might benefit developing nations in managing their waste effectively, generating high protein meal, with the potential for a circular bioeconomy.DOI: [10.22034/gjesm.2023.01.03](https://doi.org/10.22034/gjesm.2023.01.03)

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INTRODUCTION

Globally, waste generation is expected to reach 3.4 billion tonnes by 2050, currently, 44% of total accumulated waste comprises biodegradable materials, with a higher proportion in low to middle-income countries; most of these are disposed of in landfills (37%) or open dumps (33%) (Lopes et al., 2022). These forms of biodegradable waste disposal are considered important threats to the environment, due to the greenhouse gases (GHG) released into the atmosphere and the contamination of soil and water with toxic compounds, among other factors (Koda et al., 2017). A promising method for treating biodegradable waste that could contribute to the current challenge; black soldier fly (BSF) larvae treatment represents an efficient and economical option for recycling biological matter (Gold et al., 2018; Salam et al., 2022). BSF, *Hermetia illucens* (Diptera: Stratiomyidae), is a generalist saprophytic detritivorous species that colonize a wide variety of matter (Guo et al., 2021; Morais, 2020). Its potential is related to the biological characteristics of its larval stage (Giannetto et al., 2020), capable of reducing 60 to 90 percent (%) of the organic matter volume of substrates (Morales Quintana, 2021). *Hermetia illucens* presents a bioconversion rate of 140 %, with larvae consuming their own weight in food every 12 h (Makkar et al., 2014; Oonincx et al., 2015), accumulating around 40% or more as protein (Ebenezar et al., 2021). This high protein concentration and the content of other nutrients such as fatty acids, pigments, vitamins, and minerals, allow its inclusion in poultry, livestock, and aquaculture diets (El-Hack et al., 2020; Giraldo J., 2019; Liland et al., 2017). It is important to note that in the adult stage, its jaw is atrophied and it does not need feed to produce viable offspring, being easy to control (Giraldo J., 2019). In addition, BSF is not a vector for the spread of diseases (Singh and Kumari, 2019) compared to other insects, favoring safe breeding and its application in biotechnologies. Like other animal species used for feeding, the nutrient content of biowaste is assumed to have the greatest influence on yield (Gold et al., 2020; Tinder et al., 2017). Biowaste nutritional quality is determined by factors including the density (humidity), proportion, and type of nutrients they contain, as the sum of macronutrients, organic matter, protein, non-fibrous carbohydrates (NFC), fiber, and lipids (Barragán-

Fonseca et al., 2018; Gold et al., 2018). Biowaste nutritional quality like the sum of macronutrients, organic matter, protein, non-fibrous carbohydrates (NFC), fiber quantity (cellulose, lignin, hemicellulose), and lipids, is important to determine the level of nourishment provided (Barragán-Fonseca et al., 2018; Gold et al., 2018; Gold et al., 2020; Tinder et al., 2017). BSF feeding experiments suggest that proteins, NFC, and lipids are highly digestible and therefore their supply improves performance (Barragán-Fonseca et al., 2018; Beniers and Graham, 2019). Fiber, on the contrary, is less digestible and tends to decrease larval growth rates (Liu et al., 2018). Faced with these different nutritional conditions, fly larvae adjust their growth rate and nutrient accumulation, with the primary goal of amassing sufficient reserves to complete the non-feeding life stages of metamorphosis and adulthood (Danielsen et al., 2013). In this insect-based treatment, biodegradable waste is converted into products like larval biomass rich in lipids and proteins (Lalander et al., 2019) that can be used in animal feed; and in residues like exoskeleton with chitin processing (Siddiqui et al., 2022), frass considered fertilizer (Beesigamukama et al., 2020; Siddiqui et al., 2022; Xiao et al., 2018), as valuable products are generated, this technology fulfills with the principles of a circular bioeconomy, in which the waste from one process becomes the resource in another (Slorach et al., 2019). There are different organic wastes of high environmental impact that have the ability to be used as food substrate for *Hermetia illucens*; this is the case of waste from the meat industry, which generates liquid effluents from the washing of livestock and poultry, bleeding area, removal of hides, fur, feathers, viscera and cleaning operations, resulting from the processing of meat. Blood and viscera represent approximately 25% of the total weight of a 1000 kg carcass, generating effluents with raised amount of organic compounds High biochemical oxygen demand BOD 520 milligram per liter (mg/L)), as well as suspended solids 1728 mg/L, and a high concentration of phosphorus 63 mg/L, a parameter related with matter putrefaction (Ruiz Sánchez, 2019), exceeding by far MPL (250 mg/L, 300 mg/L, 40 mg/L, respectively) (Salas and Condorhuamán, 2008). Therefore, the objective of this study, is the conversion of cattle and poultry slaughterhouse wastes into high protein meal, taking advantage of *Hermetia illucens* larval development,

which reduces organic matter and treatment costs. The overall findings of this study could be very helpful to the scientific society, and animal and meat industries, providing baseline knowledge and guidance on how BSF treatment facilities may systematically operate using biowastes of varying types, eventually, low-cost protein food will be produced by giving added value and making the production sustainable. This study has been carried out at the Catholic University of Santa María, Arequipa, Peru in 2019.

MATERIALS AND METHODS

For the experimental tests, aseptic conditions, sterilized materials, and supplies were used, applied an autoclave (Ecoshel CVQ-B100L, Mexico).

Obtaining Black soldier fly

Oviposition units were obtained from adult black soldier fly BSF, *Hermetia illucens*, reared under a controlled environment from the pilot plant of the Catholic University of Saint Mary, located at Fundo "La Católica", district of Pedregal, Province of Caylloma, Arequipa region, Peru. Geographically located at South Latitude 16° 20' 08.35", West Longitude 72° 09' 08.56" at an altitude of 1498 meters above sea level (m.a.s.l.), (MAP, 805. Pampa de Majes, Ubigeo Code 040520).

Larval growth on different substrates and meal production

Blood and beef viscera were collected as organic waste from "Santa María de la Colina" metropolitan animal slaughterhouse, likewise, chicken viscera from "Gamboa" poultry processing center, both located in Majes city; the biomass was packaged at 4 °C for 24 h and brought to the experimental temperature prior to each feeding experiment, to avoid external conditions that could affect the feeding. All viscera were processed in a mincer (Thomas TH-9010 400 w, Germany) to get a uniform puree and facilitate the *Hermetia illucens* larvae consumption. Half wastes were cooked for 5 minutes on a hot plate electric stove (Star JX – 6121B, Spain). Thereby 6 food substrates for the larvae were obtained: raw beef blood T1, raw beef viscera T2, cooked beef blood T3, cooked beef viscera T4, raw chicken viscera T6, and cooked chicken viscera T7; also a standard balanced feed (50 % bran, 20% corn meal and 30% alfalfa mixture) T5; moisture content

at 60% was monitored, adding solid standard feed or water (purified using Reverse Osmosis Water Purifier PREC PRO7/D1 – 100, Peru). A growth system was established in a controlled environment at 28°C; with a minimum development temperature of 19°C (Holmes *et al.*, 2016) and 60 % humidity (Purkayastha and Sarkar, 2022), insects are ectothermic organisms that regulate their physiological functions according to environmental conditions (Abram *et al.*, 2017); applying 7 treatments and 5 replications for each one, 35 experimental units in total. In the oviposition unit, hatched BSF eggs at larval stage 1 were carefully collected in porous cardboard structures called eggies, approximately 10,000 to 15,000 eggs were sown in moist balanced feed; 5 days later, once the secondary larvae had reached stages 2 to 3, 500 g of larvae were randomly transferred to individual trays containing 3 kg of each feed substrate (T1 – T7). Then, after 5 days of treatment, larvae were in larval 5 and prepupal stage, the optimal point for food processing (Lalander *et al.*, 2018), characterized by whitish color and soft exoskeleton. Larvae were sifted and several parameters were registered as weight using a digital electronic balance (ABranddeals SF-400, Mexico) and size measured using an electronic vernier (Uberman RM813, Chile). Moreover, humidity (H), mortality (M), total dry matter (TDM), crude protein (CP), ethereal extract (EE), ash (A), crude fiber (CF), nitrogen-free extract (NFE), volatile organic matter (VOM) and apparent digestibility (AD) were evaluated in the percentage of dry matter (%DM), according to The Association of Official Analytical Chemists (AOAC) International protocols, before and after growth, to control the organic residues degradation. At the end of the larval growth period, larvae were manually separated, dried in a hot air dehydrator (Own manufacturing, Peru) at 70 °C for 5 h, and pulverized in an electric mill (Own manufacturing, Peru) to obtain larvae meal, which was characterized according to the AOAC protocol (Feldsine *et al.*, 2002).

Statistical analysis

Treatment effects were analyzed by multifactorial ANOVA, using substrate type and time as main variables. Means and standard deviations were calculated from the data obtained. The Kruskal-Wallis test was applied to determine the significance ($\alpha = 0.05$) between treatments.

RESULTS AND DISCUSSION

All the experimental treatments were performed with 5 repetitions, considering statistical analysis.

Waste degradation

Table 1 shows the quality parameters of each waste substrate at the beginning and end, being the most outstanding, CP levels of T3 with 89.35%, while the control T5 only contains 12.83 %, explained by its high fiber composition. T6 and T7 raw and cooked chicken viscera respectively have 26.23 % and 25.79 % but a low level of EE indicating a low level of CF. The content of dry matter, protein, lipids, ash, and

fiber also varied among the wastes. Wastes have an amount of highly digestible lipids and protein and will have a greater impact on development up to prepupae (Barragán-Fonseca *et al.*, 2018; Beniers and Graham, 2019).

Larval growth on different substrates

Weight and size analyses showed a significant difference ($P < 0.0001$) over 5 days and between treatments. Fig. 1 shows the weight through 5 days, it was observed that T2 (1.78 ± 0.02 g) and T5 (1.76 ± 0.05 g) are practically equal, demonstrating their effectiveness, followed by T4 (1.45 ± 0.06 g) and

Table 1: Comparison of initial and final nutritional parameters for each of the seven different treatments

Treatments nutritional parameters	T1		T2		T3		T4		T5		T6		T7	
	Initial	Final												
TDM (%)	35.73	20.56	33.17	43.55	21.90	45.75	29.13	38.15	31.30	27.75	38.73	27.79	43.50	72.46
H (%)	64.27	79.44	66.83	56.45	78.10	54.25	70.87	61.85	68.70	72.25	61.27	72.21	56.50	47.54
CP (%DM)	54.57	48.60	65.17	51.88	89.35	36.07	57.44	59.59	12.83	14.69	26.23	26.88	25.79	24.25
EE (%DM)	0.09	2.01	6.38	5.22	0.53	0.50	2.89	2.27	1.06	1.59	31.55	25.76	25.93	22.59
A (%DM)	3.85	8.54	7.46	6.81	3.65	5.11	6.11	8.34	9.27	6.18	3.95	4.38	4.40	5.12
CF (%DM)	4.57	18.81	2.03	3.66	0.06	7.72	0.42	2.44	22.52	8.56	4.64	4.74	6.03	8.33
NFE (%DM)	36.92	2.04	18.95	32.44	6.41	50.61	33.14	27.37	54.33	68.98	33.63	38.24	37.84	39.70
VOM (%DM)	96.15	91.46	92.54	93.19	96.36	94.46	93.89	91.66	90.73	93.82	96.05	95.62	95.60	96.05

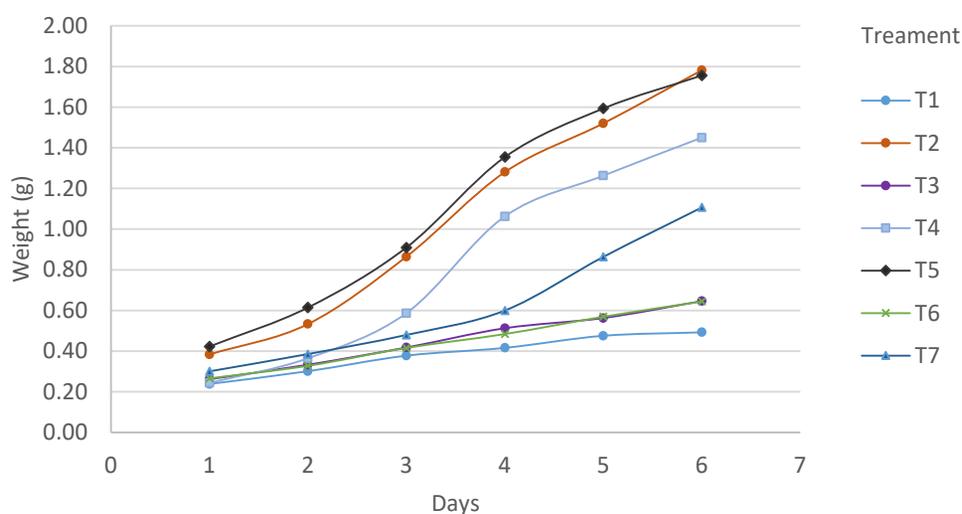


Fig. 1: Weight of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera)

Table 2: ANOVA *Hermetia illucens* larvae weight at day 5

Source	Sum of Squares	Gl	Half-square	F	P
Substrate	21.7665	1	21.7665	825.62	0.0000
Cooking	0.071286	1	0.071286	2.70	0.1021
Interaction	5.28469	1	5.28469	200.45	0.0000
Residue	4.11277	156	0.0263639		
Total (correct)	31.265	159			

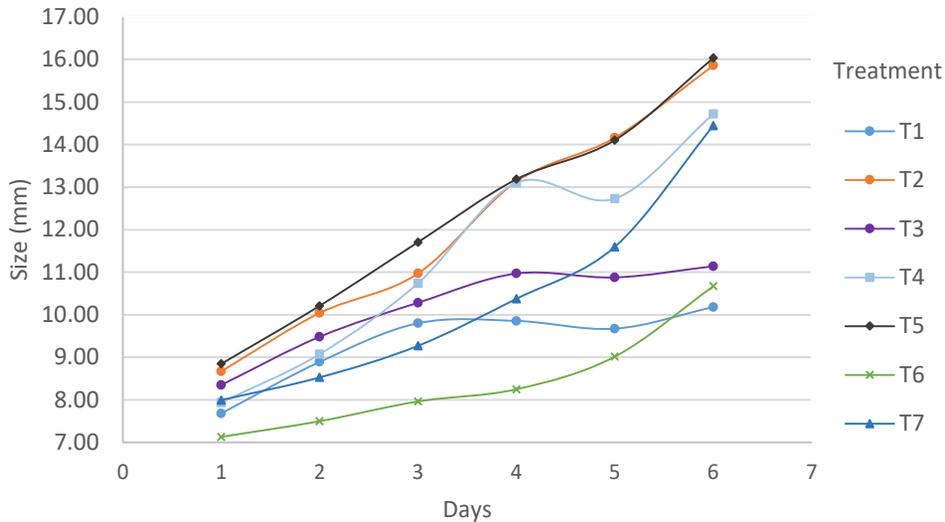


Fig. 2: Size of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera).

Table 3: ANOVA *Hermetia illucens* larvae size at day 5

Source	Sum of Squares	Gl	Half-square	F	P
Substrate	273.49	1	273.49	248.95	0.0000
Cooking	68.037	1	68.037	61.93	0.0000
Interaction	232.012	1	232.012	211.19	0.0000
Residue	171.377	156	1.09857		
Total (correct)	697.911	159			

T7 (1.06 ± 0.07 g), and finally T1 (0.49 ± 0.04 g), T3 (0.65 ± 0.05 g), T6 (0.64 ± 0.05 g). Gold *et al.* (2020) presented data about low-weight larvae in the same stage fed with substrates like Mill by-products (0.17 g), Cow manure (0.06 g), Human feces (0.24 g), and Poultry slaughterhouse waste (0.16 g). Similar results, Zhou *et al.* (2013) tried with Poultry manure (0.15 – 0.26 g), Cow manure (0.07 – 0.15 g) and Human faeces (0.07 - 0.30 g). In addition, Tinder *et al.* (2017) studied millings and brewery side streams (0.08 – 0.29 g).

In Table 2 can be observed the type of substrate used having an influence on weight ($F = 825.62$, $P < 0.0001$), but not on whether the substrate was raw or cooked ($F = 2.70$, $P > 0.0001$). On the other hand, there was an interaction between the type of substrate and the cooking process ($F = 200.45$, $P < 0.0001$).

Fig. 2 shows evolution profiles of BSF size, T2 (15.86 ± 0.22 mm) remains very close to T5 (16.03 ± 0.34 mm) with little difference, the next profile is

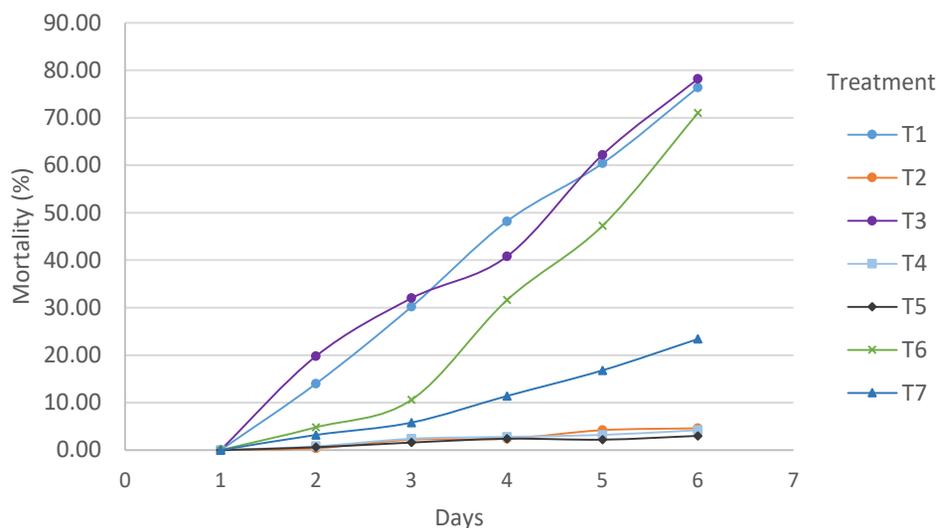


Fig. 3: Mortality of *Hermetia illucens* larvae for each treatment over time. Larval growth system (T1: raw beef blood, T2: raw beef viscera, T3: cooked beef blood, T4: cooked beef viscera, T5: control (balanced feed), T6: raw chicken viscera, and T7: cooked chicken viscera)

Table 4: ANOVA *Hermetia illucens* larvae mortality at day 5

Source	Sum of squares	Gl	Half-square	F	P
Substrate	67522.0	1	67522.0	917.81	0.0000
Cooking	19895.0	1	19895.0	270.43	0.0000
Interaction	19210.0	1	19210.0	261.12	0.0000
Residue	11476.7	156	73.5684	-	-
Total (correct)	110284.0	159	-	-	-

T4 (14.72 ± 0.35 mm) with small stagnation due to the digestibility of the larvae. T7 (14.51 ± 0.40 mm) has a very slow growth below the rest in the first 4 days. Finally, T1 (9.98 ± 0.12 mm), T3 (11.14 ± 0.35 mm) and T6 (10.67 ± 0.40 mm). In addition, it was shown in Table 3 that substrate type ($F = 248.95$, $P < 0.0001$), cooking ($F = 61.93$, $P < 0.0001$) and the interaction between the two ($F = 211.19$, $P < 0.0001$) did influence BSF size and growth.

As shown in Fig. 3, T1 and T3 have the highest mortality, reaching $76.40 \pm 2.86\%$, followed by T6 with $69.67 \pm 4.55\%$. Likewise, T7 with $24.00 \pm 3.48\%$. T2 with $4.60 \pm 1.92\%$, T4, and T5 with $4.20 \pm 2.00\%$. Some authors indicate this result in % survival units (% complementary to mortality), Gold et al. (2020) use as biomass mill by-products, human feces, cow manure, and poultry slaughterhouse waste, with results from 1% to 10% and were not significantly different between the types of biowaste. Similar

found by Rehman et al. (2017) with M% less than 20%. Lalander et al. (2018) reported a range of 0 - 19%, except for wastewater. In Table 4, it was possible to identify the type of substrate used for larval production ($F = 917.81$, $P < 0.0001$), cooking ($F = 270.43$, $P < 0.0001$) and the interaction between both ($F = 261.12$, $P < 0.0001$) significantly influenced the %BSF mortality. The apparent digestibility analysis was carried out for the treatments with the lowest % mortality, obtaining 20.39% in T5, 12.66% in T2, 10.61% in T4, and 5.97% in T7.

In treatments T1 and T3, which had cooked and raw cattle blood respectively, as they were liquid in consistency, they were thickened by adding dry feed; the cooked blood being more digestible and assimilable by the soldier fly larvae than the raw blood. These two treatments, together with T6, presented the highest mortality % over time since they initiated a decomposition natural process which

Table 5: Comparison of meal nutritional parameters according to four viable treatments

Meal nutritional parameters	T2	T4	T5	T7
TDM (%)	26.82	91.93	93.65	97.89
H (%)	73.18	8.07	6.35	2.11
CP (%DM)	50.81	53.90	41.11	42.63
EE (%DM)	21.88	15.04	19.55	32.03
A (%DM)	5.04	5.75	8.09	6.08
CF (%DM)	5.47	4.87	5.91	5.00
NFE (%DM)	16.79	20.44	25.34	14.27
VOM (%DM)	94.96	93.92	91.91	93.92

makes the humidity and temperature not ideal for larval survival, as indicated by Tomberlin (Tomberlin and Sheppard, 2002), while T3, being cooked, its decomposition is slower, here, dry and hard complexes are formed. These three substrates have the lowest growth and weight, and the highest mortality, confirming that blood is not a viable substrate for BSF larval development. In raw chicken viscera substrate, the pH is acidified, which is not suitable for larval development, several studies indicate that a pH above 6 to 10 is more appropriate (Meneguz et al., 2018), since BSF is capable of regulating the pH of liquid alkaline substrate but not strongly acidic medium (Singh and Kumari, 2019). Factors like organic matter, protein, non-fibrous carbohydrates (NFC), and lipids are important to determine quality nutrition (Barragán-Fonseca et al., 2018, Gold et al., 2018, Gold et al., 2020, Tinder et al., 2017); thus viscera wastes are rich in organic matter, protein (50–63%) and lipids (Kazemi-Bonchenari et al., 2017), it had almost no NFC (Gold et al., 2020), with controlled density (humidity), proportion-based in balanced feed, instead, blood wastes do not have necessary nutritional requirements (liquid consistency, low protein, and fat). Considering the previous results, treatments T2, T4, and T7 were selected as the most viable, discarding T1, T3, and T6 due to their mortality percent higher than 50%. Table 5 shows the comparison of the 3 meals and the control, where T4 has the highest level of crude protein of 53.90 % and low fat of 15.04%, the T2 treatment with 50.81% crude protein and fat of 21.88 %, both T2 and T4 have a notably higher percentage than the control treatment T5 of 41.11% protein, which indicates that the residual substrates have been assimilated.

The T4 treatment of cooked beef viscera was the substrate with maximum protein amount obtained,

but not the most viable due to the weight, size, and mortality of larvae. Being T2 treatment of raw beef viscera was the optimum for obtaining high protein content *Hermetia Illucens* meal, with a crude protein value of 50.81 %, being above the range reported by other authors that goes from 42.00% to 45.00% CP (Hopkins et al., 2021); exceeding by more than 10.00% the content of soybeans, 41.10%, Beetles, 42.20%, *Eristalis tenax*, 40.90%, *Tenebrio molitor*, 38.30% to Crickets, 32.60%, fruits and vegetables, 12.90% to 18.40% (Adámková et al., 2017; Barbi et al., 2020; Cashion et al., 2017; Hu et al., 2020; Kuntadi et al., 2018; Nestic and Zagon, 2019; Nyakeri et al., 2017; Sogari et al., 2019; Zielińska et al., 2015). Compared to other organic wastes, such as fruit and vegetable wastes, 48.00%, distillers' grains and cellulose wastes, 47.00 %, being lower values; wheat and barley grain wastes, 41.00 % to 54.00 % (Barragán-Fonseca et al., 2018; Bava et al., 2019; Chia et al., 2020; Salomone et al., 2017), with values like the one obtained. The highest protein content was found in BSF fed with *S. aurita* fish waste, 77.40% a 78.80 % (Barroso et al., 2019). Likewise, the ethereal extract of T2, with 21.88%, is within the range reported between 18.10% and 35.00% (Nyakeri et al., 2017; Weththasinghe et al., 2021), this parameter varies depending on the substrate on which the crop is grown (Nyakeri et al., 2017). Soldier fly meal exhibits a good amino acid and fatty acid profile suitable for inclusion in feed, with high levels of monounsaturated and polyunsaturated fatty acids such as lauric acid (59%), linoleic acid (98%), α -linolenic acid (0.79%) (Renna et al., 2017), palmitic acid (15,23 %) and myristic acid (14,34%) (Abduh et al., 2022). In recent years, insect species have received increasing attention as ingredients for animal feed production .Makkar et al., 2014; Nestic

and Zagon, 2019); such as *Tenebrio molitor*, which is being studied in the feeding of *Hyplus* rabbits, proving its additional efficiency in digestibility and nitrogen parameters (Kowalska *et al.*, 2021); and *Hermetia illucens*, in guinea pig feed at 16.00% improving feed conversion to 2.50 ± 0.04 and with no detrimental effects (Reátegui *et al.*, 2020), and in aquaculture feeds, using zebrafish as an animal model, replacing 100.00% of its protein source and tripling its body weight (Fronte *et al.*, 2021), replacing fish meal in *Totoaba macdonaldi* (Villanueva-Gutiérrez *et al.*, 2022), also several studies that support BSFL meal can improve the disease resistance of aquatic animals against pathogens (Mohan *et al.*, 2022). Although the mass production of insects is still under review (Sogari *et al.*, 2019), the production of BSF larval meal is increasing, due to its high protein content, its form of consumption and sustainability must be optimized (Addeo *et al.*, 2021; Weththasinghe *et al.*, 2021). Hence, waste management with insect larvae is considered one of the most efficient techniques for resource recovery.

CONCLUSIONS

The increase in the human population has generated a massive demand for animal protein and has created the need to seek protein alternatives in a climate emergency context. Currently, insects are cultivated to produce protein-rich foods and replace more polluting productions. *Hermetia illucens* is a saprophytic species, which colonizes and bioprocesses poultry and cattle slaughterhouse waste to convert it into its body mass; raw beef viscera was the most viable substrate generating more crude protein (50,81% - 53,90%) than the standard balanced feed (41,11%), being a valuable experimental data to scale and use this residual to finally obtain high protein meal as food substrate. The treatments with BSF meal represent a valid alternative; due to its low carbon footprint in production and its high nutritional value, it is a promising sustainable innovation, which can be applied as a supplement or added to animal feed. BSF meal is being recognized as a feed ingredient in animals for its protein-rich content. An additional factor is that this process represents a complete management of residues; frass can be recovered and used as fertilizers for its multiple plant nutrients, larval fats can be extracted to obtain

bio diesel, and chitin from adulthood. The BSF rearing system can be implemented at all levels of society and technology, this approach, which also incorporates cost considerations, is applied for feed formulation in commercial livestock production. Future research should investigate whether these results are transferable to treatment plants with higher larval densities and feeding temperatures. Various balanced formulations of biowaste should be investigated with additional analytical resources and new technologies.

AUTHORS' CONTRIBUTIONS

A. Luperdi Puentes de la Vega conceived the study and processed data, S. Flores Calla analyzed data and wrote the manuscript, X. Barriga processed and analyzed data, V. Rivera Valdez wrote and translated the manuscript, P. Manrique conducted experiments and statistical analyses, I. Salazar Churata conducted experiments, J. Reátegui Ordoñez conducted experiments. All authors read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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ABBREVIATIONS

°C	Degrees Celsius
° ' "	Degrees, latitude, altitude
%	Percent
%DM	Percentage of dry matter
%M	Percentage of mortality
A	Ash
AD	Apparent digestibility
AOAC	Association of official analytical chemists
ANOVA	Analysis of variance
BID	Banco Interamericano de Desarrollo
BM	Banco mundial
BOD	Biochemical oxygen demand
BSF	Black soldier fly
CF	Crude fiber
CP	Crude protein
EE	Ethereal extract
F	Statistical value F
g	Gram
GHG	Greenhouse gases
GI	???
h	Hours
H	Humidity

INIA	Instituto Nacional de Innovación Agraria
kg	Kilograms
MPL	Maximum permissible limit
m.a.s.l.	Meters above sea level
mg/L	Milligram per liter
mm	Milimeters
M	Moisture
NFE	Nitrogen free extract
NFC	Non-fibrous carbohydrates
P	Probability value
PNIA	Programa Nacional de Innovación Agropecuaria
T1	Treatment 1, raw beef blood
T2	Treatment 2, raw beef viscera
T3	Treatment 3, cooked beef blood
T4	Treatment 4, cooked beef viscera
T5	Treatment 5, standard balanced feed
T6	Treatment 6, raw chicken viscera
T7	Treatment 7, cooked chicken viscera

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