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Effects of Pretreatment of Black Soldier Fly Larvae (BSFL, *Hermetia illucens*) on Feed Intake and *in Vivo* Digestibility of Rations in Rabbits (*Oryctolagus cuniculus*)

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Abstract

In the context of sustainable agriculture, identifying accessible, low-carbon feed resources is crucial. Black soldier fly (*Hermetia illucens*) larvae represent a promising option due to their ability to bioconvert organic waste and their nutritional value. This study evaluated the effects of blanching black soldier fly larvae on their chemical composition, feed intake, and digestibility in local adult rabbits (3.5 - 4 kg). Thirty-six rabbits were housed individually with ad libitum water and fed six rations: a control ration without larvae, a ration with untreated larvae, and four rations with larvae blanched for 2, 4, 6, and 8 minutes at 100˚C. Larva samples were oven-dried and analyzed for their chemical and mineral composition. The digestibility test lasted 15 days. The main results showed that the highest Crude Protein content (33.78% DM) and the lowest Fat content (9.46% DM) were recorded with the larvae boiled for 8 minutes. Conversely, the highest calcium (1934.28 mg/100g) and phosphorus (781.56 mg/100g) levels were obtained with larvae boiled for 4 minutes. The lowest digestibility coefficients for DM, organic matter, crude protein, and fiber were obtained with group R3. This study demonstrated that larvae blanched for 8 minutes are a valuable source of protein, minerals, and micronutrients in rabbit diets, as they promote better ingestion and digestibility. Pretreatment with black soldier fly larvae provides a well-tolerated and readily assimilated source of nutrients without disrupting normal ingestion and digestion processes.

Keywords

Rabbit, Black Soldier Fly Larvae, Pretreatment, Ingestion and Digestibility

1. Introduction

Faced with the growing challenges of food security and the sustainability of livestock systems, the use of insects as an alternative source of protein in animal feed is generating increasing interest. Among them, the black soldier fly (*Hermetia illucens*) has shown promise due to its richness in protein, lipids, and minerals, as well as its ability to utilize various organic substrates [1] [2]. However, the chitinous structure of its cuticle, its high lipid content, and its potential microbial load limit its ingestion and digestibility in monogastric animals such as rabbits [3] [4]. To improve the sanitary and nutritional quality of these larvae, technological pretreatments are often carried out during the process (roasting, boiling). Thus, the research results obtained by [5] showed that roasted larvae had the highest protein content (42.74%). Furthermore, high-temperature cooking can lead to a loss of water-holding capacity, which concentrates the proteins in the product [6] [7]. Thermal blanching is a technique that is increasingly being studied. This process, which involves briefly subjecting the larvae to a high temperature (generally 90˚C - 100˚C for a few minutes), significantly reduces the microbial load [8] and inactivates certain oxidative enzymes, while also modifying the structure of proteins and lipids [9]. However, the effects of this treatment on zootechnical performance, particularly voluntary intake and *in vivo* digestibility in rabbits, remain poorly documented. Some studies suggest an improvement in microbiological safety without a major negative impact on digestibility. while others observe a decrease in nutrient bioavailability depending on the processing conditions [10]. It is therefore essential to better understand the impact of blanching on the effective nutritional value of black soldier fly larvae in lagomorph diets. In this context, the present study aimed to evaluate the effects of blanching black soldier fly larvae on feed intake and *in vivo* digestibility of rations in rabbits, in order to optimize their incorporation into rabbit diets.

2. Materials and Methods

Study area

This study was conducted in the Ndé division, at the multipurpose station of the Bangangte Institute of Agricultural Research for Development. The division is located between 10˚21' and 10˚51' East longitude and between 4˚52' and 5˚16' North latitude. It covers an area of approximately 1524 km^2. It has a population of over 200,000 [11]. Its tropical climate is classified as Aw (dry winter savannah climate) according to the Köppen climate classification, with an average annual temperature of 20.4˚C and rainfall of approximately 1950 mm per year [12].

Pet facilities and accommodations

A sample of 36 adult rabbits of local breed was used to evaluate the *in vivo* ingestion and digestibility of a diet based on Black Soldier Fly (BSFL) larvae. These animals were on average 4 to 5 months old and weighed on average between 3.5 and 4 kg. For this test, they were placed individually in wire cages measuring 75 mm^3 (0.5 cm × 0.5 cm × 0.3 cm). Each cage was equipped with a 200 g aluminum feeder and a 250 ml plastic waterer (bottle with an aluminum nipple). The cages were covered with wire mesh for the animals' safety (**Figure 1**).

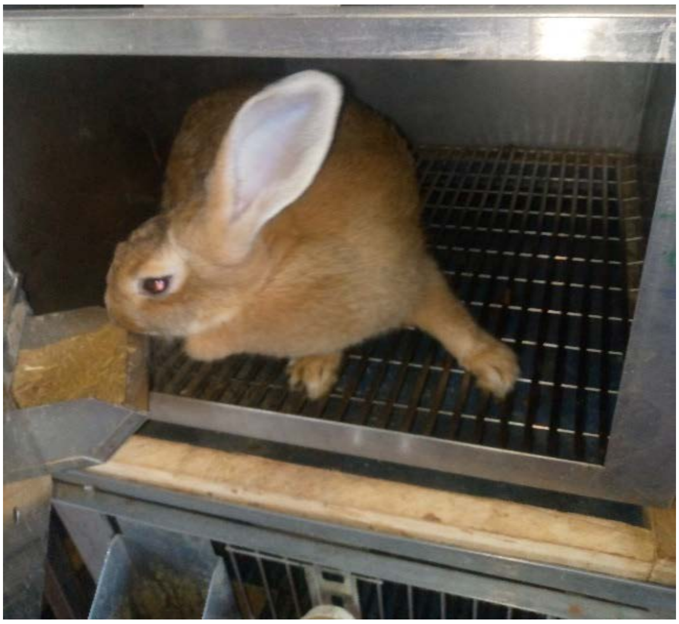

Figure 1. Burgundy fawn hybrid in a digestibility cage.

Production and processing of larvae Black Soldier Fly

In this study, larval production was carried out on a substrate composed of laying hen manure, with ambient humidity maintained between 45% and 60%. Under aerobic fermentation conditions, larval production began on the fifth day following the establishment of the rearing system. The total larval production period lasted up to 15 days, with harvesting taking place 20 days after the start of incubation. The larvae were harvested at the pre-pupal stage using 3 × 3 mm mesh sieves. After production, samples of fresh larvae (**Figure 2(a)**) were blanched in boiling water for 2, 4, 6, and 8 minutes. After blanching, the larvae were drained using a plastic sieve, then spread evenly on tarpaulins and air-dried at room temperature for three days (**Figure 2(b)**). A 100 g sample was taken from each treatment for bromatological and mineral analyses prior to the formulation of the experimental diets. The iso-nitrogenous and isocaloric diets were formulated to provide 2200 kcal of digestible energy/kg and 160 g/kg of crude protein (**Table 1**). The diet ingredients were purchased from a local market.

(a) (b)

Figure 2. Fresh (a) and dried (b) treated larvae.

Food intake or consumption was calculated using the following formula:

Food intake = Amount of food served – Amount not consumed or refused

The apparent digestive utilization coefficients for dry matter (CUDaMS), organic matter (CUDaMO), crude protein (CUDaPB), and crude cellulose (CUDaCB) were determined using the formula developed by Roberge and Toutain (1999):

$$\text{CUDaMS}(\%) = \frac{\text{MS ingérée} - \text{MS fécale}}{\text{MS ingérée}} \times 100$$

$$\text{CUDaMO}(\%) = \frac{\text{MO ingérée} - \text{MO fécale}}{\text{MO ingérée}} \times 100$$

$$\text{CUDaPB}(\%) = \frac{\text{PB ingérée} - \text{PB fécale}}{\text{PB ingérée}} \times 100$$

$$\text{CUDaCB}(\%) = \frac{\text{CB ingérée} - \text{CB fécale}}{\text{CB ingérée}} \times 100$$

Evaluation of the chemical and mineral composition of bleached black soldier fly larvae meal and preparation of experimental diets

The chemical composition of BSF larvae was analyzed to determine the dry matter, ash, organic matter, crude fiber, crude protein, and lipid content, according to the methods of [13] Analyses of mineral composition, particularly calcium (Ca), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na) and iron (Fe), were carried out according to the protocol described by [14]. Starting with a basic control diet without BSFL (R_0) and a diet containing untreated BSFL (R_0^+), four additional experimental diets (R_1, R_2, R_3, R_4) were formulated using BSFL that had been blanched in boiling water for 2, 4, 6, and 8 minutes, respectively (**Table 1**). To replace conventional protein sources, primarily fishmeal and soybean meal, in the control diet (**R_{0-}**), BSF larvae were introduced into four rations. After formulation, a 100 g sample of each diet was taken for immediate compositional analysis according to the protocol described by [15]. **Table 1** shows the percentage composition of the different rations. The table shows the percentage composition of the different rations.

Table 1. Percentage composition of the different rations.

Ingredients (%)	Rations					
	R_0^-	R_0^+	R_1	R_2	R_3	R_4
Maize	21	21	21	21	21	21
Cassava	4	4	4	4	4	4
wheat bran						
Palm bean cake	8	8	8	8	8	8
Pennisetum sp	20	20	20	20	20	20
Bone meal						
Oil	4	4	4	4	4	4
Soyabean cake	6	3.5	3.5	3.5	3.5	3.5
Fish	5	4	4	4	4	4
BSFL	0	5	5	5	5	5
Total	100	100	10	100	100	100
Calculated bromatological characteristics of the rations						
Crude protein (% DM)	15.70	15.00	14.96	14.96	14.95	15.43
Digestible energy (kcal/kg DM)						
Dry matter	2205.9	2101.5	2101.5	2101.5	2101.56	2101.5
Organic matter	92.45	92.03	91.92	92.21	92.13	92.54
Fat	88.61	92.03	90.93	92.21	92.13	92.54
Crude fiber (% MS)	12.37	12.10	12.10	12.10	12.10	12.10
Calcium (% MS)	0.77	0.45	0.45	0.45	0.45	0.45
Phosphore (% MS)	0.82	0.64	0.64	0.64	0.64	0.64
DE/CP ratio	140.47	140.07	140.44	140.44	140.44	140.44
Ca/P ratio	0.94	0.81	0.81	0.81	0.81	0.81

MS: Dry matter; **BSF:** Black Soldier Fly; **R_0^-:** Larva-free ration; **R_0^+ R_1:** Ration with untreated larvae; **R_2:** Ration with larvae treated at 2 minutes; **R_3:** Ration with larvae treated at 6 minutes; **R_4:** Ration with larvae treated at 8 minutes.

***In vivo* ingestion and digestibility of experimental diets**

For each treatment, six rabbits were randomly assigned to individual cages according to a completely randomized design. Water and food were available ad libitum every day between 8:00 and 9:00 AM throughout the trial. To assess feed intake, the amount of feed dispensed was recorded, and uneaten feed was collected daily and weighed using a digital balance with a capacity of 7 kg and an accuracy of 1 g before each feeding. Feed intake was calculated using the following formula:

Food consumption = Quantity of food offered − Quantity of food refused.

The digestibility trial was preceded by a 10-day adaptation period during which the animals acclimated to the digestibility cages and experimental diets. The amount of feed distributed during this period was adjusted according to each animal's daily consumption. The digestibility measurement period lasted five days, during which urine and feces were collected each morning before feed distribution. The feces were weighed and dried at 60˚C in a ventilated oven to determine their dry matter (DM), organic matter (OM), crude protein (CP), and crude fiber (CF) content according to the methods of [reference missing]. [13] After urine collection and analysis each morning, the cages were cleaned and scrubbed with a 10% solution. Urinary nitrogen was fixed using dilute sulfuric acid. The urine samples were stored in a refrigerator for nitrogen analysis.

The apparent digestibility coefficients of dry matter (CUDaDM), organic matter (CUDaOM), crude protein (CUDaCP) and crude fiber (CUDaCF) were calculated according to the formula of Roberge and Toutain (1999).

$$\text{CUDaDM}(\%) = \frac{\text{Ingested DM} - \text{fecal DM}}{\text{ingested DM}} \times 100$$

$$\text{CUDaOM}(\%) = \frac{\text{Ingested OM-fecal OM}}{\text{ingested OM}} \times 100$$

$$\text{CUDeCP}(\%) = \frac{\text{Ingested CP} - \text{fecal CP}}{\text{ingested CP}} \times 100$$

$$\text{CUDaCF}(\%) = \frac{\text{Ingested CF} - \text{fecal CF}}{\text{Ingested CF}} \times 100$$

Statistical analyses

Data on the chemical and mineral composition of the larval meal, as well as the ingestion and digestibility of the feed components, were analyzed using a factorial analysis of variance (ANOVA) with the feed ration as the primary factor, employing the general linear model (GLM). When significant differences were observed between treatments, means were compared using Duncan's test at a significance level of 5% [16]. All statistical analyses were performed using SPSS version 21.0.

3. Results

Effect of different treatments on the chemical and mineral composition of BSF larvae

Table 2 shows that the dry matter (DM), organic matter (OM), crude protein (CP), lipid, and ash content of BSF larvae were significantly affected ($p < 0.05$) by boiling time (2, 4, 6, and 8 minutes). The DM content of larvae from treatments T_0, T_1, and T_4 did not differ significantly ($p > 0.05$) and was significantly lower ($p < 0.05$) than that of larvae from treatments T_2 and T_3. Furthermore, larvae from treatment T_2 had a significantly higher DM content ($p < 0.05$) than those from treatment T_3. The highest OM and CP content were observed in larvae from treatment T_4 ($p < 0.05$). The lipid content was significantly lower ($p < 0.05$) in larvae from treatment T_4. The ash content of the larvae in treatments T_0 and T_3 was comparable ($p > 0.05$), significantly lower than that of treatments T_1 and T_2 ($p < 0.05$) and significantly higher than that of treatment T_4 ($p < 0.05$). Table 2 shows the macronutrient content of BSF larvae.

Table 2. Macronutrient content of BSF larvae.

Macronutrients	**BSFL**					**MEB**	**p**
	T_0	**T_1**	**T_2**	**T_3**	**T_4**		
DM (%)	90.82[c]	90.21[c]	9238[a]	91.64[b]	89.2[c]	0.94	<0.001
OM (%DM)	80.22[b]	79.87[c]	77.43[d]	80.18[b]	87.10[a]	0.86	<0.001
CP (%DM)	29.63[b]	25.10[c]	24.35[d]	24.19[d]	33.78[a]	1.01	<0.001
Matières grasses (%MS)	19.15[b]	18.92[c]	19.41[a]	15.53[d]	9.46[e]	1.01	<0.001
Cendres (% MS)	19.77[c]	20.12[b]	22.68[a]	19.82[c]	12.89[d]	0.87	<0.001

[a, b, c, d, and e]**:** Means followed by the same letter on the same line are not significantly different at the 5% level; DM**:** Dry matter; **SEM:** Standard error of the mean; **p:** Probability; **BSFL:** Larva Black Soldier Fly; **T_0:** Untreated larvae; **T_1:** Larvae treated for 2 minutes; **T_2:** Larvae treated for 4 minutes; **T_3:** Larvae treated for 6 minutes; **T_4:** Larvae treated for 8 minutes; OM: Organic matter; PB: Crude protein; MG: Fat.

The analysis of variance of the mineral composition of the treated larvae is summarized in Table 3. Overall, the highest mineral composition ($p < 0.05$) was obtained with the larvae from treatment T_2 containing Boiled larvae for 4 minutes. Table 3 presents the mineral composition of BSF larvae.

Table 3. Mineral composition of BSF larvae.

Mineralogical composition (mg/100 g)	**BSF larvae**					**MEB**	**p**
	T_0	**T_1**	**T_2**	**T_3**	**T_4**		
Calcium	238.28[d]	1681.56[b]	1934.28[a]	478.71[c]	479.68[c]	187.19	<0.001
Mg	7.67[d]	32.00[a]	16.00[b]	12.00[c]	10.40[c]	2.31	<0.001
K	788.18[d]	1974.65[b]	2030.69[a]	1296.60[c]	1014.15[c]	134.06	<0.001
N/A	194.08[d]	467.09[b]	506.15[a]	467.14[b]	233.09[c]	35.25	<0.001
P	430.69[e]	705.93[b]	781.56[a]	673.46[c]	553.77[d]	32.98	<0.001
Cl	0.04[e]	21.16[a]	8.88[c]	10.65[b]	0.07[d]	2.09	<0.001

[a, b, c, d and e]**:** Means followed by the same letter on the same line are not significantly different at the 5% level; MS**:** Dry matter; **SEM:** Standard error of the mean; **p:** Probability; **BSF:** Black Soldier Fly; **T_0:** Untreated larvae; **T_1:** Larvae treated for 2 minutes; **T_2:** Larvae treated for 4 minutes; **T_3:** Larvae treated for 6 minutes; **T_4:** Larvae treated for 8 minutes; Ca: Calcium; Mg: Magnesium; K: Potassium; Na: Sodium; P: Phosphorus and Cl: Chlorine.

Effect of incorporating treated BSF larvae into rations on feed intake in rabbits

Table 4 summarizes the effect of larval treatments on nutrient intake by rabbits. Overall, the intake of the control rations (R_0^- and R_0^+) was statistically comparable ($p > 0.05$) and significantly higher ($p < 0.05$) than that observed for rations R_2 and R_3, regardless of the nutrient considered. Table 4 shows the nutrient intake from rations containing treated MSN larvae.

Table 4. Nutrient intake from rations containing treated MSN larvae.

Ingestion (gMS/day/animal)	MSN larvae						ESM	p
	R_0^-	R_0^+	R_1	R_2	R_3	R_4		
MS	110.7^{a}	106.1^{a}	100.34^{abc}	87.91^{a}	85.98^{a}	101.49^{ab}	1.93	0.001
MO	98.11^{a}	98.14^{a}	$92.59^{bC.}$	$80.99^{abc.}$	79.47^{c}	94.08^{ab}	2.13	0.02
PB	17.37^{a}	15.91^{ab}	15.01^{ab}	13.16^{c}	12.85^{C}	15.66^{ab}	0.44	0.001
CB	13.69^{a}	12.89^{a}	12.21^{ab}	$10.72^{abc.}$	10.38^{C}	12.32^{ab}	0.33	0.001

$^{a, b\ and\ c}$: Means followed by the same letter on the same line are not significantly different at the 5% level; **SEM:** Standard error of the mean; **p:** Probability; **BSF:** Black Soldier Fly; **R_0^-:** Ration without larvae; **R_0^+:** Ration with untreated larvae; **R_1:** Ration with larvae treated for 2 minutes; **R_2:** Ration with larvae treated for 4 minutes; **R_3:** Ration with larvae treated for 6 minutes; **R_4:** Ration with larvae treated for 8 minutes; **DM:** Dry matter. **MO:** Organic matter; PB: Crude protein and CB: Crude fiber.

Table 5. Digestibility of different rations containing treated BSFL.

CUDe (%)	Treatments							
	R_0^-	R_0^+	R_1	R_2	R_3	R_4	ESM	p
DM	52.32^{a}	56.64^{a}	50.86^{a}	52.98^{a}	38.21^{b}	48.24^{ab}	2.54	0.04
OM	64.29^{a}	63.67^{a}	58.47^{a}	61.69^{a}	48.01^{b}	56.19^{ab}	2.33	0.03
CP	74.19^{a}	73.01^{a}	74.04^{a}	72.35^{a}	64.13^{b}	74.27^{a}	2.30	0.01
Fibre	61.60^{a}	61.59^{a}	52.85^{b}	51.24^{b}	28.03^{C}	47.04^{b}	4.12	0.001

$^{a, b\ and\ c}$: Means followed by the same letter on the same line are not significantly different at the 5% level; **SEM:** Standard error of the mean; **p:** Probability; **BSF:** Black Soldier Fly; **R_0^-:** Ration without larvae; **R_0^+:** Ration with untreated larvae; **R_1:** Ration with larvae treated for 2 minutes; **R_2:** Ration with larvae treated for 4 minutes; **R_3:** Ration with larvae treated for 6 minutes; **R_4:** Ration with larvae treated for 8 minutes; **DM:** Dry matter. **MO:** Organic matter; PB: Crude protein and CB: Crude fiber.

Effect of incorporating treated BSF larvae into rations on digestibility in rabbits Table 5 shows that the digestibility coefficients were significantly affected ($p < 0.05$) by the inclusion of blanched BSF larvae in the rabbit rations. Indeed, the apparent digestibility of dry matter of the rations without larvae (R_0^-) and with unblanched BSF larvae (R_0^+), as well as that of the rations containing larvae blanched for 2 and 4 minutes (R_1 and R_2), was comparable ($p > 0.05$). However, the lowest dry matter digestibility value was obtained with the ration containing larvae BSF blanched for 64 minutes (R_3). Similar trends were observed for the apparent digestibility coefficient of organic matter. The digestibility coefficients of crude protein for rations R_0^-, R_0^+, R_1, R_2, and R_4 were comparable ($p > 0.05$) and significantly higher than that of ration R_3 ($p < 0.05$). However, we observed a reduction in food consumption with intermediate bleaching treatments (R_2 and R_3) compared to the control ration. These results are similar to those obtained in a palatability test in which rabbits had access to several diets of their choice. The rabbits significantly preferred a control ration based on soybean meal (82.03% of choices), while rations containing BSF larvae did not always affect the overall significance when offered alone; their texture and sensory appeal may influence voluntary consumption in a context of choice. Since heat treatments (bleaching) alter texture and aroma, these changes may reduce the rabbits' acceptance of the food. Regarding the digestibility of crude fiber, rations R_1, R_2 and R_4 were comparable ($p > 0.05$), but significantly lower than those of rations R_0^- and R_0^+ ($p < 0.05$) and significantly higher than that of the ration containing larvae blanched for 6 minutes (R_3) ($p < 0.05$). **Table 5** shows the digestibility of different rations containing processed BSFL.

4. Discussion

The experimental study investigated the effect of incorporating bleached BSF larvae meal at different times as a protein source in rabbit feed. The use of bleached BSF larvae, thus guaranteeing their safety and nutritional quality, will not only reduce reliance on conventional protein sources but also offer an environmentally friendly and economical feed alternative for farmers, with extended storage times. Indeed, it promotes better feed intake and digestibility without significantly affecting nutrient intake and digestibility parameters. In this study, the mineral composition after 8 minutes was significant in reducing the calcium and phosphorus concentrations observed in $_{T4}$ compared to the other treatments. This is mainly explained by the chemical and physico-structural phenomena induced by the heat treatment. Indeed, bleaching causes an increase in the permeability of larval tissues and a denaturation of proteins capable of binding minerals, thus promoting the leaching of Ca^{2+} and PO_4^{3-} ions into the aqueous environment. Similar results have been reported for BSF larvae subjected to pre-drying bleaching, where changes in overall mineral composition were observed, indicating a loss of inorganic elements [17] [18]. The chemical composition of the larvae was significantly affected by the different treatments applied to the BSF larvae. The organic matter content of the BSF larvae samples ranged from 77.43% to 87.10%. These results are higher than the organic matter content (36.933% DM) obtained by [19] [20]. This high organic matter content is likely due to the use of laying hen manure as a substrate for BSF larvae production. The highest protein content was obtained with BSF larvae blanched for 8 minutes. This high protein concentration is due to the significant reduction in fat content. Indeed, the protein content of the larvae increases as their fat content decreases. [5] This value is comparable to that reported by [21] (32%). However, the result of the present study is lower than that [19] [20] obtained, in BSF larvae samples, a crude protein content of 39.513% dry matter. Furthermore, the lowest fat content was obtained with larvae from the same treatment. In this study, the highest calcium content was obtained with treatment T_2. This value is comparable to that obtained by those who used the same substrates (laying hen manure). According to [22] [23], phosphorus is the second most important inorganic compound in the body's metabolic reactions after calcium and represents 1% of body weight. In this test, the highest content was obtained with rations prepared from larvae treated for 4 minutes at 100˚C. This value is similar to that obtained by [24].

Rabbits fed a ration based on BSF larvae boiled at 100˚C for 8 minutes ingested a quantity of protein comparable to that ingested by rabbits receiving the control rations. These values are higher than those obtained by [25]. 14.75 g and 11.45 g, respectively for the control ration based on *Panicum maximum* and the test ration based on *Mucuna purians.* The best crude fiber intake was obtained with rations R_0^+ and R_4, containing untreated larvae and larvae boiled for 8 minutes at 100˚C, respectively. These results are lower (19.06 g) than those of [26].

Analysis of variance revealed that the digestibility of the proteins contained in rations R_1, R_2 and R_4 were comparable to the control rations R_0^- and R_0^+. This means that boiling BSF larvae does not affect the digestibility of crude protein in rabbits; however, these results demonstrate the palatability and efficient utilization of the protein present in these rations by rabbits. These results are lower than those obtained [27] in a comparative study on the digestibility of certain protein crops (peas, beans) as an alternative protein source to soy in rabbits.

The digestibility of crude fiber (CF) for rations R_1, R_2, and R_3 was comparable and significantly lower than that of the control ration R_0. The results of this study indicate that larval bleaching negatively affects CF ingestion. Similarly, Lounaouci *et al.* [28] reported a crude fiber utilization coefficient (CUDa) of 58.14% in rabbits fed rations containing high levels of raw kapotier seeds, attributing this low value to the high incorporation of fiber sources in the feed. Indeed, cellulose serves as a ballast feed in rabbits, with very low digestion occurring primarily in the caecum and closely linked to its dietary content. Additionally, pretreatments to enhance feed preservation or palatability along with added ingredients (e.g., vitamins, minerals), feed quality, and plant types with low cellulose levels can further reduce fiber content and digestibility.

5. Conclusion

This study demonstrated that processing BSF larvae significantly increased their protein, crude fiber, and organic matter content. Larvae boiled for 8 minutes had the highest protein and lowest fat content, while those boiled for 4 minutes had the highest calcium and phosphorus levels. Rabbits fed the diet of larvae blanched for 8 minutes (R_4) showed better intake and digestibility than those fed the diet of larvae blanched for 6 minutes (R_3). Incorporating these larvae into rabbit diets is feasible without adverse effects on nutrient utilization. However, this study was limited to short-term feeding trials and did not assess long-term impacts on reproduction, immunity, or economic viability. Further research is needed to evaluate these aspects and confirm the practical applicability of this method in tropical farming systems.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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