Journal of
Fisheries and Aquatic Science

ISSN 1816-4927

Academic Journals Inc.

www.academicjournals.com

OPEN ACCESS Journal of Fisheries and Aquatic Science

ISSN 1816-4927
DOI: 10.3923/jfas.2026.1.10

Research Article

Valorization of Defatted Black Soldier Fly (*Hermetia illucens*) Larvae Meal and Papaya (*Carica papaya*) Seeds in *Clarias gariepinus* Feed

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Abstract

Background and Objective: Increased aquaculture production is essential to reduce the animal protein deficit in Sub-Saharan Africa, which requires efficient and cost-effective fish feed management. This study was therefore conducted to evaluate the effects of black soldier fly (*Hermetia illucens*) meal supplemented with papaya (*Carica papaya*) seed powder on the survival, growth performance, flesh quality and production cost of *Clarias gariepinus*. **Materials and Methods:** Four experimental diets were formulated: R0 (control diet); R1 (75% fish meal, 25% fly meal, 0.25% papaya seed powder); R2 (50% fish meal, 50% fly meal, 0.50% papaya seed powder); and R3 (25% fish meal, 75% fly meal, 0.75% papaya seed powder). A total of 360 *C. gariepinus* fry (mean weight: 8.83±2.00 g; mean total length: 10.4±1.14 cm) were randomly assigned to treatments in triplicate and fed twice daily for 84 days. At the end of the trial, 24 fish per ration were sacrificed for bromatological and biochemical analyses. Data were analyzed using one-way ANOVA followed by Duncan's test (5%) in SPSS 21.0, with results expressed as Mean±SD, while graphs and weight–length regressions were generated using Excel 2010. **Results:** Survival rates were significantly higher ($p<0.05$) in fish fed diets R1, R2 and R3 compared to the control. The highest values for final live weight (101.00±1.01 g), weight gain (60.3±9.41 g), specific growth rate (6.64±1.79%/day), condition factor (1.85±0.48) and feed conversion ratio (3.54±0.34) were observed in fish fed R3. Bromatological and biochemical analyses showed that the highest crude and total protein contents were obtained with R0 (60.81±0.19% DM and 0.66±0.03% DM), while the highest fat content (26.61±0.17% DM) was recorded with R2. Production costs were comparable among diets, with the highest cost in R0 (1135.93±172.82 FCFA) and the lowest in R3 (1014.20±198.68 FCFA). **Conclusion:** Overall, diet R3, containing 25% fish meal, 75% black soldier fly meal and 0.75% papaya seed powder, provided the best production performance and economic efficiency in *Clarias gariepinus* juveniles.

Key words: Valorization, *Hermetia illucens*, *Carica papaya*, *Clarias gariepinus*, growth

Citation: Songmo, B.L., H.K. Mube, A.T. Nana, D.P.Z. Tagning and R.N. Komguep *et al.* 2026. Valorization of defatted black soldier fly (*Hermetia illucens*) larvae meal and papaya (*Carica papaya*) seeds in *Clarias gariepinus* feed. J. Fish. Aquat. Sci., 21: 1-10.

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Fish feed is an essential factor for their growth, health and well-being. Whether in their natural or artificial environment, nutritional intake must be balanced and adapted to the specific needs of each species. Among the most commonly used sources of nutrients, fishmeal is one of the major components in aquaculture feed formulation. However, its high cost and competition with human and animal feed remains a real challenge[1]. In view of this situation, it makes sense to promote the development of aquaculture based primarily on the use of alternative sources of animal and/or plant protein to fishmeal[2]. Several research studies have identified insects (black soldier flies) as an alternative to fishmeal[3,4]. Black soldier flies have a crude protein content ranging from 40 to 75% of dry matter, with an interesting amino acid profile and variable fat content[5]. They have a high digestibility rate and contain bioactive substances that improve the health of fish, particularly tilapia and increase producers' profits while reducing environmental pollution[6-8], black soldier flies also play a role in the immune system by producing antibodies to defend against disease in carp.

However, their use in aquaculture is still hampered by certain obstacles, including the presence of fat. In response to this situation, methods such as degreasing and toasting have been tested, with the advantages of improving digestibility, reducing lipid content, increasing nutritional value and reducing production costs[6,7]. In addition to the high protein requirements in fish feed, in order to improve the growth of aquatic animals, it is becoming necessary to focus on the use of local, available and low-cost ingredients in the formulation of fish feed, combining them with phytobiotics[9]. Phytobiotics and/or plant-based dietary supplements such as *Carica papaya* are potential candidates for this purpose.

Carica papaya, commonly known as papaya seed, is locally available, natural, inexpensive and safe for animals, humans and the environment. *Carica papaya* has the ability to strengthen the immune system, stimulate growth and improve the quality of fish flesh thanks to its antioxidant properties[10]. These seeds have anti-parasitic qualities, reducing harmful microorganisms in the intestinal tract and bacteria that can cause digestive problems[11]. Research has shown that papaya seed contains papain, a synthetic enzyme that improves growth and combats sterility in Nile tilapia. Therefore, combining papaya seeds with black soldier fly larvae is necessary to better assess their potential as fish feed, particularly for *Clarias gariepinus,* which has established zootechnical advantages, with many benefits (rapid growth, highly prized flesh and strong disease resistance) compared to other fish species[12]. Hence, the interest of this work is to minimize fish production costs while ensuring the sustainability of the farming system with alternative resources to fishmeal and synthetic additives. The objective of this study was to evaluate the effects of dietary inclusion of black soldier fly (*Hermetia illucens*) meal supplemented with papaya (*Carica papaya*) seed powder on survival, growth performance, flesh quality and production cost of *Clarias gariepinus*.

MATERIALS AND METHODS

Study period, area and site: The study was conducted from 1 March to 1 June 2025 at the University of Dschang's Application and Research Farm (FAR), located in the Dschang District, Menoua Department, West Region of Cameroon, between 5°44'-5°36' and 5°44'-5°37' North Latitude; 10°06'-9°94' and 10°06'-9°85' East Longitude. The climate is of the high-altitude Sudano-Guinean type, characterised by a short dry season (mid-November to mid-March) and a long rainy season (mid-March to mid-November). Rainfall varies between 1,500 and 2,000 mm per year. The average temperature is 20°C.

Animal materials

Juvenile *Clarias gariepinus*: A total of three hundred and sixty (360) juveniles of *Clarias gariepinus* with an average weight of 8.83$\pm$2.00 g and an average total length of 10.4$\pm$1.14 cm was used. These juveniles were obtained following artificial reproduction carried out within the same facility and the broodstock therefore came from the city of Douala. For two weeks, the juveniles were acclimatized in a 0.28 m^3 (0.7$\times$0.4$\times$1 m) fast tank and fed twice a day with a local feed (control ration) in powder form containing 40% crude protein.

Black soldier fly larvae: The black soldier fly larvae used were obtained from a producer based in Bekoko, in Cameroon's Littoral Region. They were then cleaned and processed (20% fat removed) using a locally manufactured machine with the following specifications: Capacity (10 kg), voltage (220V, 50Hz), power (1250W), dimensions (560$\times$255$\times$350 mm) and weight (14.5 kg) to reduce the lipid content of the larvae, thereby increasing the protein concentration and improving the digestibility of the final product. Finally, the defatted black soldier fly larvae were analyzed (Table 1) at the Animal Nutrition and Feeding Laboratory of the University of Dschang[13].

Table 1: Composition and bromatological values of defatted black soldier fly larvae

Characteristics	Values
Dry matter (%)	94.34
Moisture (%)	5.67
Ash (%MS)	10.41
Organic matter	89.59
Lipids (%MS)	18.71
Proteins (%MS)	35.8
Crude fibre (%MS)	0.00
Gross energy (Kcal/kg)	5176.81
Metabolisable energy (Kcal/kg)	4543.67

Table 2: Composition and bromatological values of papaya seed powder

Characteristics	Bromatological values
Dry matter (%)	93.92
Moisture (%)	6.09
Ash (%)	5.64
Matter organic (%)	94.37
Lipids (%)	25.88
Proteins (%)	25.00
Crude fibre (%)	8.03
Gross energy (Kcal/kg)	5680.65
Metabolizable energy (Kcal/kg)	4416.46

Table 3: Composition and biochemical values of papaya seed powder

Bioactive compounds	Present (+)	Amounts present (mg/L)
Phénols	+	19.23
Tannins	+	2.94
Flavonoids	+	16.20
Alkaloids	+	/
Saponins	+	/

Plant material: The papaya seeds (*Carica papaya*) of the 'SOLO' variety incorporated into the ration were purchased on loan from a trader selling peeled papaya at the Dschang market. They were soaked in clean water, dried to a constant weight at a temperature of 40°C in an oven at the Renewable Energy Laboratory of the Department of Rural Engineering at the University of Dschang and ground using a Unitech Germany blender with a capacity of 1.5 litres, voltage (220-240 V), power (300-350 W), dimensions (40×20×20 cm) and weight of 3.5 kg to obtain the powder. The papaya seed powder obtained (Table 2 and 3) was analysed at the Animal Nutrition and Feeding Laboratory and the Biochemistry Laboratory at the University of Dschang[14].

Farming structure: The trial was conducted in 12 plastic containers with a surface area of 0.28 m^3 (0.7×0.4×1 m) attached on all four sides to a wooden support. The fastank was equipped with a water supply and drainage system consisting of a 25 mm diameter pressure pipe supplied with water from a borehole. Each tank was equipped with a 10 cm diameter circular floating frame placed on the surface to serve as a feeder and labelled according to the different treatments.

Experimental rations: Four experimental rations were produced from the basic ration. The choice of these different rations was inspired by the nutritional needs of *Clarias gariepipnus*. Each ration was produced from ingredients purchased from the same feed store in the town of Dschang, for the purpose of traceability. The ingredients were first ground into fine particles. The mixture was prepared as follows: The ingredients with the smallest mass were mixed with those with the largest mass, gradually until a homogeneous mixture was obtained. Then, water (2 litres per 10 kg of feed) was added to obtain a paste. The formulated and moistened rations were granulated using a manual granulator with 2 mm diameter mesh, then dried in the sun until their weight remained constant before use. Each ration was stored in labelled, hermetically sealed plastic bottles to prevent rancidity. The crude protein and metabolisable energy contents of the different rations (Table 4) were obtained at the Animal Nutrition and Feeding Laboratory of the University of Dschang[14].

Conducting the trial and collecting data: To carry out this trial, 360 juvenile *Clarias gariepinus* previously described were randomly divided into four batches comparable in terms of size and weight, with three replicates per batch in twelve

Table 4: Experimental ratio of ingredients used

	Rations			
Ingredients	R0	R1	R2	R3
Fish meal	26.00	19.50	13.00	6.50
Black soldier fly meal	0.00	6.50	13.00	19.50
Wheat bran	5.00	2.50	2.50	3.00
Soybean meal	23.50	35.00	42.00	48.00
Peanut meal	15.00	12.50	10.00	15.00
Maize	21.00	21.00	10.00	17.00
Cassava	2.00	2.00	2.00	2.00
Oil	2.00	2.00	2.00	3.00
5% meat concentrate	5.00	5.00	5.00	5.00
Salt	0.50	0.50	0.50	0.50
Papaya seed meal	0.00	0.25	0.50	0.75
Total (kg)	100.00	100.00	100.00	100.00
Calculated chemical composition				
Crude protein (%)	41.74	40.00	40.02	39.51
Calcium (%)	2.88	2.17	2.05	1.35
Lipids (%)	9.49	7.21	5.00	4.98
Crude fibre (%)	6.23	5.65	4.98	5.85
Metabolisable energy (kcal/kgMS)	3174.09	3005.49	2770.50	3058.33
Analyzed chemical composition by weight				
Dry matter (%)	88.88	88.26	88.68	86.35
Moisture (%)	11.12	11.74	11.32	13.65
Ash (%)	8.38	7.11	8.27	6.14
Organic matter (%)	91.89	92.89	91.72	93.86
Crude protein (%)	31.58	28.06	31.90	29.32
Lipids (%)	15.28	15.26	15.94	15.14
Crude fibre (%)	3.45	4.32	8.13	6.41
Crude energy (kcal/kgMS)	5077.90	5069.91	5145.04	5144.52

R0: Basic ration (control), R1: Ration containing 75% fish meal, 25% fly meal and 0.25% papaya seed powder, R2: Ration of 50% fish meal, 50% fly meal and 0.50% papaya seed powder, R3: Ration of 25% fish meal, 75% fly meal and 0.75% papaya seed powder

plastic containers. Each plastic container was randomly assigned one of the experimental rations R0, R1, R2 and R3 previously formulated, as illustrated by the experimental design. Each tank was stocked with 30 individuals. Two-thirds (2/3) of the water was changed every three days. The animals were fed twice a day at regular times (8-9 a.m. and 4-5 p.m.) at 8% of their fish biomass[15]. A control catch was carried out every 14 days on the total number of fish in each tank. These fish were weighed individually using an SF-400 electronic scale with a capacity of 10 kg and an accuracy of 1 g and measured (total and standard length) using a 1 mm precision ichthyometer to assess growth characteristics. The amount of feed was readjusted after each control fishing operation. In parallel with data collection, the physical and chemical characteristics of the water were measured *in situ* between 6 and 7 a.m.[16]. This involved measuring the temperature, pH and dissolved oxygen using a GAIN EXPRESS and DO-66 multi-parameter meter, respectively.

Ethical consideration: The experimental protocols used in this study were approved by the Ethical Committee of the Department of Animal Science of the University of Dschang (ECDAS-UDs 12/03/2025/UDs/FASA/DSAES) and conformed with the internationally accepted standard ethical guidelines for laboratory animal use and care as described in the European Community guidelines.

Characteristics studied

Survival rate and growth characteristics

Survival rate: This was assessed by the number of fish alive at the end of the experiment relative to the number at the start of the experiment, using the following formula[17]:

$$SR = \frac{N_f}{N_i} \times 100$$

where, N_f is the final number of fish and N_i is the initial number of fish.

Growth characteristics

Weight gain (g): This allows the weight gain of fish during farming to be assessed. It is calculated using the following formula[17]:

$$WG = W_f - W_i$$

Where:
W_i = Initial average weight (g)
W_f = Final average weight (g)

Average daily gain (g/day): This represents the growth rate of fish in farming and is determined using the following formula[18]:

$$ADG = \frac{W_f}{W_i} \times 100$$

where, W_f: Average final weight, W_i: Average initial weight t: Time (number of days) and is expressed in g/day.

Specific growth rate: The specific growth rate is used to assess the weight gained by fish each day as a percentage of their live weight. It is calculated using the following formula[17]:

$$SGR = \frac{\text{Ln } W_f - \text{Ln } W_i}{t} \times 100$$

where:
W_f = Average final weight of individuals during the trial (g)
W_i = Average initial weight of individuals during the trial (g)
t = Rime or duration of the growth trial period (days)

Condition factor K: The condition factor K gives a good idea of the fish's body condition, i.e. the relative importance of body mass in relation to its length. It is calculated using the following formula[19]:

$$K = \frac{W}{LT^3} \times 100$$

where:
W = Total weight (g)
LT = Total length (cm)

Total length gain (GLT): Total length gain is used to assess the linear growth of fish during farming. It is calculated using the following formula[17]:

$$GTL = TL_f - TL_i$$

Where:
TL_f = Final total length
TL_i = Final total length

Consumption index (CI): This is a criterion used in animal husbandry to measure the efficiency of feed conversion into a given production. Its formula is[20]:

$$CI = \frac{\text{Amount of feed served}}{\text{Weight gain}}$$

Characteristics of *Clarias gariepinus* flesh: At the end of the trial, 12 individuals weighing 50 g or more per treatment were sampled, weighed and measured, then sacrificed using a knife in order to assess the bromatological and biochemical characteristics of the flesh.

Bromatological characteristics of *Clarias gariepinus* flesh: For the bromatological analyses, samples of flesh from the dorso-ventral muscles were taken (50 g) from 12 fish of both sexes, weighed and dried in a ventilated oven at 40°C until a constant weight was reached, then ground in a Moulinex (ROYALTY LINE). The bromatological analyses were carried out accordingly[21], consisting of determining the water content, dry matter, crude protein, fat, ash and organic matter.

Biochemical characteristics of *Clarias gariepinus* flesh: For the biochemical analyses, dorso-ventral muscle samples were taken[22] from 12 fish of both sexes and used to determine the concentrations of total protein and cholesterol, high-density lipoproteins, albumin, globulin and triglycerides according to the Chronolab kit instructions (Barcelona, Spain). These samples were ground in a mortar placed on a block of ice, then Tris buffer (pH 7.4) was added to obtain 15% homogenates[23]. These were then centrifuged at 3,000 rpm for 30 min and the supernatant was collected and stored at -20°C in labelled microtubes for the determination of the above biochemical characteristics.

Statistical analysis: The data collected were subjected to One-way Analysis of Variance (ANOVA) to compare the growth, bromatological and biochemical characteristics of *Clarias gariepinus* flesh according to the different experimental rations. Duncan's test at a 5% threshold was used to separate the means in cases of significant differences between ratios. The results were expressed as Mean±Standard Deviation. The SPSS 21.0 statistical software was used for these analyses. Graphs and regressions between weight and length were also produced using Excel 2010 software.

RESULTS

Effects of replacing fish meal with defatted black soldier fly larvae meal supplemented with papaya seed powder on the survival rate and growth of *Clarias gariepinus* juveniles.

Survival rate of *Clarias gariepinus* juveniles: Replacing fish meal with defatted black soldier fly larvae meal supplemented with papaya seed powder in the diet significantly ($p<0.05$) increased the survival rate of *C. gariepinus* juveniles (Fig. 1).

Effect of the incorporation rate of defatted black soldier fly larvae supplemented with papaya seed powder on the growth characteristics of *Clarias gariepinus* juveniles: The effect of incorporating defatted black soldier fly larvae meal supplemented with papaya seed powder into the diet on the growth characteristics of juvenile *C. gariepinus* is summarized in Table 5. It shows that, except total length gain, specific growth rate and condition factor K, growth performance was significantly ($p<0.05$) affected by the increasing rate of substitution of defatted black soldier fly larvae meal supplemented with papaya seed powder in the rations.

The live weight of *C. gariepinus* juveniles receiving ration R3 (101.00±1.01 g) was significantly ($p<0.05$) higher than that of the other rations. The R0 ration (56.76±1.56 g) was significantly ($p<0.05$) lower than that of the other rations. The values for weight gain and average daily gain for ration R3 (60.35±9.41 and 4.31±0.67 g, respectively) were significantly ($p<0.05$) higher than those for the other rations. The values for weight gain and average daily gain for rations R0, R1 and R2 were comparable. The weight gain and average daily gain values for rations R0, R1 and R2 were comparable. The weight gain and average daily gain values (33.01±11.87 g and 2.36±0.84 g) respectively were significantly ($p<0.05$) lower with ration R0. The condition factor K of *Clarias gariepinus* juveniles receiving rations R0, R1, R2 and R3 were comparable throughout the trial. The values for total length and specific growth rate of *Clarias gariepinus* juveniles receiving rations R0, R1, R2 and R3 were comparable throughout the trial. The feed conversion ratio of *C. gariepinus* juveniles receiving ration R2 (1.96±0.11) was significantly ($p<0.05$) higher compared to the other rations. However, those of rations R2 (1.96±0.11), R1 (1.63±0.17) and R0 (1.79±0.27); as well as those of rations R0 (1.79±0.27), R1 (1.63±0.17) and R3 (1.40±0.27) were comparable.

Bromatological and biochemical characteristics of the flesh of juvenile *Clarias gariepinus*: The bromatological and biochemical characteristics of the flesh of juvenile *Clarias gariepinus*, except total protein (Table 6), were significantly ($p<0.05$) influenced by the incorporation rate of defatted black soldier fly larvae meal and papaya seed powder in the diet. The dry matter content of rations R3 (97.50±0.29%) and R0 (96.91±0.30%) was comparable and significantly ($p<0.05$) higher than that of the other rations. The crude protein content was significantly ($p<0.05$) higher (60.81±0.19% DM) in ration R0 compared to the other rations. However, the crude protein content of rations R1 (57.92±0.36% DM) and R3 (58.33±0.18% DM) were comparable. The fat content of rations R2 (26.61±0.17 % DM) and R3 (23.87±0.07 % DM) were comparable and significantly ($p<0.05$) higher than the other rations. The ash content was significantly ($p<0.05$) higher in ration R0 (14.06±0.56% DM) compared to the other rations. However, the ash content values of rations R2 (10.92±0.89% DM) and R3 (10.98±0.33% DM) were comparable. The organic matter content of rations R2 (89.08±0.89% DM) and R3 (89.01±0.33% DM) was comparable and significantly ($p<0.05$) higher than in the other rations. Moisture was significantly ($p<0.05$) higher in ration R2 (5.74±0.60%) compared to the other rations. However, the moisture content of rations R0 (3.08±0.30%) and R3 (2.49±0.29%) was comparable. The lipid (26.61±0.17% DM) and gross energy (5865.18±25.37 Kcal/kg DM) values were significantly ($p<0.05$) higher in ration R2 compared to the other rations.

The total protein content in the different rations was comparable. The albumin values of rations R0 (0.30±0.02 g/dL), R2 (0.29±0.00 g/dL) and R3 (0.28±0.01 g/dL) were comparable and significantly ($p<0.05$) higher than ration R1 (0.23±0.01 g/dL). The globulin concentration in rations R0 (0.36±0.00 g/dL), R1 (0.37±0.01 g/dL) and R2 (0.37±0.01 g/dL) were comparable and significantly ($p<0.05$) higher than in ration R3

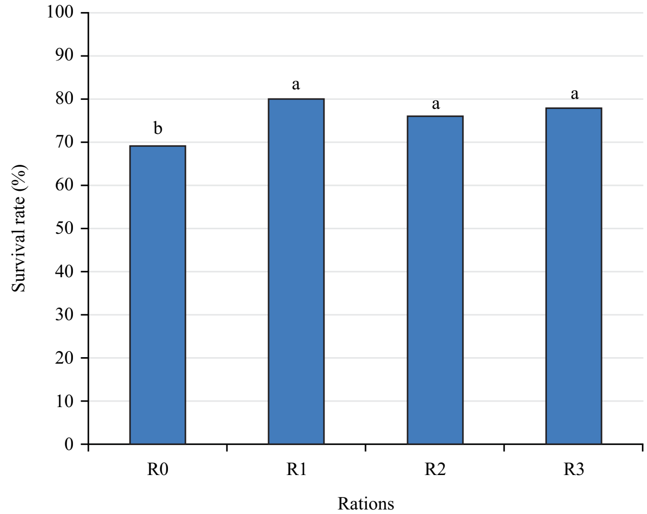

Fig. 1: Variation in survival rate according to the incorporation rate of defatted black soldier fly larvae meal and papaya seeds in the diet of *Clarias gariepinus* juveniles

R0: Ration with 100% fish meal, R1: Ration with 75% fish meal, 25% MSN meal and 0.25% papaya seed powder, R2: Ration with 50% fish meal, 50% MSN meal and 0.50% papaya seed powder, R3: Ration with 25% fish meal, 75% MSN meal and 0.75% papaya seed powder

Table 5: Growth characteristics according to the incorporation rate of defatted black soldier fly larvae meal supplemented with papaya seed powder in the diet of *Clarias gariepinus* juveniles

	Rations				
Growth of characteristics	R0	R1	R2	R3	p value
W (g)	56.76±1.56^{d}	62.20±1.22^{c}	80.88±1.74^{b}	101.00±1.01^{a}	0.00
WG (g)	33.51±4.68^{b}	36.46±3.61^{b}	33.01±11.87^{b}	60.35±9.41^{a}	0.00
ADG (g/j)	2.39±0.33^{b}	2.61±0.25^{b}	2.36±0.84^{b}	4.31±0.67^{a}	0.00
TL (cm)	16.73±1.61^{a}	15.9±1.00^{a}	18.86±2.28^{a}	17.8±1.68^{a}	0.19
SGR	6.49±1.48^{a}	6.37±1.15^{a}	3.96±2.09^{a}	6.64±1.79^{a}	0.18
K	1.26±0.42^{a}	1.55±0.3^{a}	1.27±0.46^{a}	1.85±0.48^{a}	0.66
IC	1.79±0.27^{ab}	1.63±0.17^{ab}	1.96±0.11^{a}	1.40±0.27^{b}	0.05

^{a,b,c,d}Means with the same letter in the same row are not significantly different (p<0.05). R0: Ration with 100% fish meal, R1= ration with 75% fish meal, 25% MSN meal and 0.25% papaya seed powder, R2: Ration with 50% fish meal, 50% MSN meal and 0.50% papaya seed powder, R3: Ration with 25% fish meal, 75% MSN meal and 0.75% papaya seed powder. W: Weight, TL: Total length, WG: Weight gain, ADG: Average daily gain, SCR: Specific growth rate, CI: Conversion index, K: Condition factor and p: Probability

Table 6: Bromatological and biochemical characteristics of *C. gariepinus* flesh

Characteristics bromatological and biochemical	Rations				
	R0	R1	R2	R3	p value
Bromatological characteristics					
DM (%)	96.91±0.30^{a}	95.44±0.00^{b}	94.25±0.60^{c}	97.50±0.29^{a}	0.00
Prot B (%DM)	60.81±0.19^{a}	57.92±0.36^{b}	55.92±0.36^{c}	58.33±0.18^{b}	0.00
M G (%DM)	17.45±0.05^{c}	19.57±0.02^{b}	26.61±0.17^{a}	23.87±0.07^{a}	0.00
Ash (%DM)	14.06±0.56^{a}	12.85±0.02^{b}	10.92±0.89^{c}	10.98±0.33^{c}	0.00
M O (%DM)	85.93±0.56^{c}	87.14±0.02^{b}	89.08±0.89^{a}	89.01±0.33^{a}	0.00
Moisture (%)	3.08±0.30^{c}	4.55±0.00^{b}	5.74±0.60^{a}	2.49±0.29^{c}	0.00
Raw energy (kcal/kgDM)	5316.92±30.74^{d}	5439.62±0.59^{c}	5865.18±25.37^{a}	5753.76±8.57^{b}	0.00
Biochemical characteristics					
T Prot (g/dL)	0.66±0.03^{a}	0.60±0.04^{a}	0.66±0.05^{a}	0.60±0.00^{a}	0.11
Albumine (g/dL)	0.30±0.02^{a}	0.23±0.01^{b}	0.29±0.00^{a}	0.28±0.01^{a}	0.00
Globuline (g/dL)	0.36±0.00^{a}	0.37±0.01^{a}	0.37±0.01^{a}	0.32±0.01^{b}	0.01
TGS (mg/dL)	27.50±0.10^{c}	45.00±2.64^{a}	40.00±1.00^{b}	19.16±0.14^{d}	0.00
T Chol (mg/dL)	5.53±0.53^{a}	4.15±0.17^{b}	4.14±0.13^{b}	4.49±0.42^{b}	0.00
HDLC (mg/dL)	0.92±0.00^{b}	0.92±0.00^{b}	0.74±0.02^{c}	1.11±0.05^{a}	0.00

^{a,b,c,d}Averages with the same letter on the same line are not significantly different (p>0.05), R0: Ration with 100% fish meal, R1: Ration with 75% fish meal, 25% MSN meal and 0.25% papaya seed powder, R2: Ration with 50% fish meal, 50% MSN meal and 0.50% papaya seed powder, R3: Ration with 25% fish meal, 75% MSN meal and 0.75% papaya seed powder, DM: Dry matter, CP: Crude protein, FM: Fat, OM: Organic matter, TP: Total protein, TC: Total cholesterol, HDLC: High-density lipoprotein cholesterol, TGS: Triglycerides and p: Probability

(0.32±0.01 g/dL). Triglycerides in ration R1 (45.00±2.64 g/dL) were significantly ($p<0.05$) higher than in the other rations. Total cholesterol was significantly ($p<0.05$) higher in ration R0 (5.53±0.53 g/dL) compared to the other rations. However, it was comparable between rations R1 (4.15±0.17 g/dL), R2 (4.14±0.13 g/dL) and R3 (4.49±0.42 g/dL). The concentration of High-Density Lipoprotein Cholesterol (HDLC) was significantly ($p<0.05$) higher (1.11±0.05mg/dL) with ration R3 compared to the other rations. The concentrations for rations R0 (0.92±0.00 g/dL) and R1 (0.92±0.00 g/dL) were comparable.

DISCUSSION

At the end of the experiment, the survival rate represents the percentage of fish still present in the tanks at the end of the experimental period compared to the total number of fish present at the beginning. In this study, the survival rate was higher with ration R1 (75% fish meal, 25% fly meal and 0.25% papaya seed powder). The improvement in survival rate values is thought to be due to the presence of bioactive properties such as saponins, which may protect the animal against many diseases[24]. These results are lower than the 99% obtained with a survival rate of 85% for defatted black soldier fly larvae meal supplemented with 1% ginger powder[25] after 70 days of testing. They are comparable to the 80%[26] in *Clarias gariepinus* fingerlings fed 75% black soldier fly larvae meal for 60 days.

The results obtained show that all growth characteristics were significantly affected with increasing levels of black soldier fly larvae meal supplemented with papaya seed powder in the ration. Live weight values increased significantly throughout the trial regardless of the ration considered. The highest value (101.00±1.01 g) obtained at ration R3 was due to better utilization of the proteins present in black soldier fly larvae meal with the help of the bioactive properties present in papaya seeds. This result corroborates with studies by Fawole *et al.*[25] and Adeoye *et al.*[27] when black soldier fly larvae meal supplemented with ginger was used in the diet of *Clarias gariepinus*.

The weight gain values obtained during the trial are increasing. The differences between the values could be related to the difference in initial fish sizes and climatic conditions, the pre-treatment of the larvae, which could cancel out any adverse effects and the presence of bioactive compounds in the feed.

In terms of average daily gain, which represents the daily increase in weight and allows the growth rate to be assessed over a given period, the value obtained (4.31±0.67 g/day) with the R3 ration, which had the best result, is higher than that (6.2±0.1 g/day) obtained[25] obtained in *C. gariepinus* when using defatted black soldier fly larvae meal supplemented with 1% ginger; and 0.21±0.90 g/day obtained[20] with feed supplemented with 1% ginger. This is thought to be due to the ability of the fish in this treatment to adapt quickly and make better use of the defatted black soldier fly meal thanks to the presence of bioactive compounds such as phenols and flavonoids. Regarding the specific growth rate, the values show that the daily weight gain in the treatments was almost similar at the end of the rearing period. Ration R3 (6.64±1.79%) had the highest value, which was higher than that (5.48±1.34%) reported by Byrd *et al.*[21] in *C. gariepinus* fingerlings fed 75% black soldier fly meal for 60 days in aquariums. This high value may be due to the action of papaya seeds in the feed, which promoted better assimilation of the nutrients contained in the ration.

Furthermore, the condition factor K values recorded were above 1, showing that the fish were in good condition during the rearing period. The highest value (1.85) recorded with ration R3 is thought to be linked to variations in physicochemical parameters, the nature of the species, the combined effect of the nutrients contained in black soldier fly larvae meal and papaya seed powder and the duration of rearing. This result is higher than that (0.9) obtained[25] in *C. gariepinus* when using defatted black soldier fly larvae supplemented with 1% ginger and higher than the 0.72±0.08 reported[11] in *C. gariepinus* juveniles fed with feed supplemented with 1% *Zingiber officinale* powder. This could be due to the difference in the additives used, which influenced the nutritional composition of the feed for each trial, as well as the rearing environment.

The best feed conversion ratio (1.40±0.27) recorded with ration R3 proves that *C. gariepinus* juveniles assimilate nutrients in the feed better than with other rations. This result is higher than that (1.00±0.10) recorded[25] for *C. gariepinus* when using defatted black soldier fly larvae supplemented with 1% ginger, as well as the 1.36 recorded[28] recorded in *Oreochromis niloticus* with 1% garlic inclusion for 60 days in aquariums. This could be due to differences in species, nutritional composition of the feed for each trial and the rearing environment.

Black soldier fly larvae meal supplemented with papaya seed powder in the feed significantly influenced the bromatological and biochemical characteristics of *Clarias gariepinus* flesh, with the exception of total protein. However, the values remain within the normative range for fish flesh. This could be explained by the ability of *C. gariepinus* juveniles to better convert the nutrients contained in the feed into high-quality protein, with an excellent ash and fat profile. The higher crude protein value (58.33%) obtained in treatment R3 is thought to be due to the presence of black soldier fly larvae. The protein value (58.33%) remains higher than that (52.20%) reported[25] in *C. gariepinus* when using black soldier fly larvae supplemented with 0.75% ginger. About lipids and centers 10.98 and 23.87% respectively, the values obtained with R3 are higher than[25] (3.65 and 4.13%, respectively) in *C. gariepinus* when using black soldier fly larvae supplemented with 0.75% ginger. These differences can be explained by the level of feed utilization, which confirms the action of bioactive compounds capable of stimulating digestion and the level of conversion or storage of fat in the fish's body. These results justify the ability of black soldier fly larvae meal supplemented with papaya seed powder to replace fish meal in the feed of *C. gariepinus* juveniles without affecting the flesh.

Furthermore, about biochemical characteristics, the total protein values for each treatment are comparable to each other, with the highest values obtained with rations R0 and R2 (0.66 ± 0.03 and 0.66 ± 0.05), respectively. These values are lower than those reported[29] 3.54 ± 0.26 when fish meal was replaced by beans in carp. The differences observed in their work may be due to the protein sources and species studied. The total cholesterol level varied between treatments, with the highest level obtained with ration R0 (5.53 ± 0.53) and the lowest with ration R2 (4.14 ± 0.13). This result could be explained by the presence of fishmeal in the control ration, which was not treated at the outset, thus reducing the lipid content.

CONCLUSION

Survival rate and growth characteristics, except total length and specific growth rate of the condition factor K, increased significantly with the substitution rate of black soldier fly meal supplemented with papaya seed powder. Thus, the best values for these characteristics were recorded with ration R3 (25% fish meal, 75% MSN meal and 0.75% papaya seed powder).

Bromatological analysis shows that partial substitution of fish meal with *Hermetia illucens* meal, with the addition of papaya seed powder, can be an effective nutritional alternative without compromising the quality of the fish flesh.

These results highlight the zootechnical benefits of partially replacing fishmeal with black soldier fly larvae meal supplemented with papaya seed powder without altering the quality of the product.

A ration containing 25% fish meal, 75% black soldier fly larvae meal and 0.75% papaya seed powder in the feed is recommended during the pre-fattening phase.

SIGNIFICANCE STATEMENT

This study demonstrates a sustainable and cost-effective alternative to conventional fishmeal by integrating defatted *Hermetia illucens* larvae meal with *Carica papaya* seed powder in the diet of *Clarias gariepinus*. The findings show that a higher substitution level (R3: 75% insect meal+0.75% papaya seed) significantly improves growth performance, survival rate and feed utilization while reducing production costs. Importantly, the nutritional quality of fish flesh is maintained within acceptable ranges, confirming the suitability of this formulation for aquaculture systems. This approach supports circular bio-economy principles by valorizing locally available resources, reducing dependency on expensive fishmeal and promoting environmentally sustainable aquaculture practices, particularly in resource-limited regions.

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