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Effects of the fresh and dried housefly (*Musca domestica*) larvae in the diets of Nile tilapia *Oreochromis niloticus* (Linnaeus, 1758): growth, feed utilization efficiency, body composition and biological indices

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ABSTRACT

A 56-day feeding trial was undertaken to assess the effects of housefly maggots (HM) forms (dried and fresh) as protein sources on growth, feed efficiency, and body indices of *Oreochromis niloticus* fingerlings. A control diet (T0) contained 300 g/kg of fishmeal (without HM). Two practical diets with the same formula were prepared with dried HM (T1) and fresh HM (T2) where 66 % of the fishmeal was replaced. Diets were fed to triplicate groups of tilapia (mean initial weight: 10.26 ±0.12 g). There was no difference in survival, condition factor, feed conversion ratio, and protein efficiency ratio. Fish fed diets T0 and T1 had significantly increased ($P < 0.05$) mean final weight (50.25 ±1.39 - 52.24 ±1.03 g), specific growth rate (2.84 ±0.03 - 2.88 ±0.03 %/day) and weight gain (389.70 ±7.63 - 402.78 ±8.16 %) compared to T2 diet ones (46.30 ±2.03 g; 2.67 ±0.07 %/day and 356.70 ±7.76 % respectively). Viscerosomatic and hepatosomatic index in fish fed T1 and T2 diets were significantly higher than those fed T0. The present findings indicate that the dried form of housefly maggot has given the best results in terms of growth compared to the live form. However, housefly forms did not affect feed efficiency parameters.

Keywords: Maggot meal, Fresh maggot, Forms, Carcass composition, Tilapia

Introduction

The continued decline in capture fisheries and the increasing demands for livestock and aquaculture have ensued in a quick decrease in the supply of fish meal (FM) coupled with its price increasing (Henry *et al.,* 2015). The current global human consumption of fish is estimated at 20 kg of fish per year per capita, nearly half of which is provided by aquaculture (FAO, 2018). To satisfy the increasing demand for fish facing a growing number of population, there is an urgent need to improve the efficiency of aquaculture production. The necessity for more ecologically and durable aquafeed materials has previously been examined for fish farming to replace a pricey and unsustainable fish meal (Gasco *et al.,* 2018). Among alternative sources of protein for the aquafeed formulation, insects are greatly promising as sustainable ingredients for future commercial eco-friendly aquafeed production (Henry *et al.,* 2015; Tran *et al.,* 2015).

Generally, the amino acids profiles of insects are taxon-dependent, with Diptera profiles thought to be close to those of fish meal (Henry *et al.,* 2015). Insects larvae are very good for its high protein content and easy digestibility and amino acid profile comparable to fish meal (Fitches *et al.,* 2018). Moreover, their production can be examined as environmental-friendly animal farming and they do not rival along with human nutrition (van Huis *et al.,* 2013). One species that has saved more attention than others is the housefly *Musca domestica* (Diptera: Muscidae), whose larvae are recognized to develop on a various types of substrates, such as poultry droppings (Ogunji *et al.,* 2008), chicken manure (Fitches *et al.* 2018), chicken viscera (Djissou *et al.,* 2016; Alofa *et al.,* 2020; Alofa & Abou, 2020) and wheat bran wet (Wang *et al.,* 2017). The successful use of housefly larvae as a fish meal substitution has been documented in these different investigations.

Tilapias are the most commonly aquacultured fish in the world, as classified second only to carp in world fish production (Caï *et al.,* 2018). Nile tilapia *Oreochromis niloticus* is one of both major species, most reared in Benin (Rurangwa *et al.,* 2014). This species grows fast, tolerates a large range of environmental factors, is resistant to stress and diseases, has a low trophic level and accepts dry feeds just after absorption of the yolk sac, and is highly appreciated for its tasty flesh (El-Sayed, 2006; Bhujel, 2014). The potential of housefly maggot as a fish meal replacement has been assessed in several species, such as *O. niloticus* (Alofa *et al.,* 2020; Alofa and Abou, 2020; Wang *et al.,* 2017), *Carassius gibelio* (Dong *et al.,* 2013), *Clarias gariepinus* (Aniebo *et al.,* 2011; Oyelese, 2007; Fasakin *et al.,* 2003) and *Heterobranchus longifilis* (Ossey *et al.,* 2012). The feasibility of incorporating housefly larvae in the diet of tilapia has been successfully tested in several previous investigations. Feeding Nile tilapia with 27 % of maggots meal was also shown not to affect the growth compared to a commercial feed (Wang *et al.,* 2017). Partial replacement of FM with maggot meal may be more effective. This was verified in the aquaculture recirculation system in our previous study, where *O. niloticus* was fed successfully with live housefly larvae (25 % of maggots) (Alofa *et al.,* 2020). We have demonstrated that *O. niloticus* fed live maggots has a higher growth performance and feed efficiency than those fed spirulina waste, probably because the diet containing maggots was more balanced and matched to the requirements of this species. In addition, the housefly maggot meal has been used in combination with chicken viscera to substitute substantially the fish meal in the diet of the same species (Alofa and Abou, 2021).

On the other hand, the use of fresh maggots directly in the diet of fish would be very beneficial for them. Thus, feeding *C. gariepinus* with live maggots mixed with an artificial diet (3.5 % FM) resulted in higher growth performances than an artificial feed alone (Oyelese, 2007). The development of good quality and less expensive feeds for aquaculture is very important in underdeveloped countries such as Benin. In these countries, the efficient use of simple materials in the production of diets can define the success of aquaculture exploitation (Ekpo and Bender, 1989). The use of fresh maggots directly in fish feeds could allow not only a better valorization of the nutritional elements by fish but also a reduction of the energetic costs linked to its processing. Indeed, the direct use of fly larvae in fresh form in fish diets is the easiest method but it could generate the presence of pathogens if the treatment is not correctly carried out. Oven drying, however, could generate supplementary expenses in fish production. However, research on the different forms in which maggots can be successfully used in the diet is still limited and no investigation has not been reported in Nile tilapia. Moreover, there are no investigations assessing the efficiency of the use of a different form of housefly maggots for tilapia aquaculture in single-growth experiments. Therefore, the current study could contribute to filling this gap of information by examining for the first time, the effects of the use of fresh and dried *Musca domestica* larvae on biological indices of *Oreochromis niloticus*. In this investigation, we examined the effects of using a dried and fresh HM to replace 66.6 % of the fishmeal in a diet for Nile tilapia juveniles. Specifically, we analyze feed utilization, growth performance, and carcass quality and identify the most appropriate form of HM for diet formulation in this species.

Material and Methods

Experimental Design

The experiment was conducted in a Recirculating Aquaculture System at the Aquaculture Research Center (ARC) of the Laboratory of Ecology and Aquatic Ecosystem Management, University of Abomey-Calavi, Benin (06°24'49.4''N Latitude and 002°20'17.1''E Longitude). Nine circular cement tanks (diameter: 1.2 m with a volume of 1 m^3) were used. All tanks were connected to a mechanical and biological filter and water pump to maintain optimal water quality. The water was continuously aerated using a compressed air pump (Axair 300). The water flow rate was 4 L/min per tank. During the experiment, the photoperiod was 12 hours dark and 12 hours light (7:30 - 19:30 h) cycle, and tanks were covered two-thirds of their surface by racks to prevent algal development. The feeding trial lasted 8 weeks.

Fish and Feeding Management

A total of four hundred and fifty *O. niloticus* juveniles were purchased from the fish farm ''Dieu Exauce'' situated in Tori Avamey (Benin), and transported to ARC in closed oxygenated plastic bags. All male Nile tilapia with an average weight of 10.26 ±0.12 g (n = 30) was used in this trial. They were distributed randomly into tanks with a density of 50 fish per tank. Prior to the start of the experiment, all fish were fed with an equal mixture of the test diet (1:1:1) at a rate of 3 % of biomass twice daily for one week to acclimate with the experimental condition. Fish were weighed using a digital scale every 2 weeks to determine gain in weight and each tank was cleaned.

Fish were fed manually to apparent visual satiation thrice daily (at 09:00 h, 13:00, and 17:00 h) for a period of 56 days. Test diets were randomly distributed over nine tanks, with three replicates per treatment. Feed distributed each days was noted, and the uneaten diet was collected one hour after distribution. The collected feed has been dried and weighed to evaluate the real feed consumption.

Ingredients, Experimental Diets, and Preparation

Housefly (*Musca domestica*) maggots and fish meal (sun-dried *Sardinella* sp) were obtained as described by Alofa *et al.* (2020) and blood meal, following the method described by Alofa *et al.* (2016). The other ingredients were purchased from commercial sources.

Table 1. Biochemical composition (as % dry matter) of feeds ingredients used in the experimental diets

Ingredients	Dry matter	Crude protein	Crude lipid	Ash
Fish meal	92.2	66.7	6.8	14.7
Housefly maggot	92.7	48.8	21.0	6.3
Soybean meal	93.3	38.0	12.7	4.2
Cottonseed meal	91.1	39.8	8.2	8.5
Blood meal	91.2	72.2	1.5	6.7

All values are mean of triplicate samples

Table 2. Ingredients and proximate composition of the experimental diets: T0 (control diet), T1 (dried housefly maggots diet) and T2 (fresh housefly maggots diet)

	Experimental diets		
Ingredients (g/kg)	T0	T1	T2
Fish meal	300	100	100
Maggot	–	250	X[a]
Blood meal	70	70	70
Corn bran	340	265	265
Soybean meal	160	170	170
Cottonseed meal	100	105	105
Palm oil	20	20	20
Vitamins premix[b]	10	10	10
Minerals premix[c]	10	10	10
Total	1000	1000	750 + X[a]
Chemical composition			
Dry matter (%)	90.16	90.54	90.54
Crude protein (%)	35.36	35.13	35.13
Crude lipid (%)	8.19	11.88	11.88
NFE[d] (%)	36.48	31.35	31.35
Ash (%)	7.98	6.45	6.45
Gross energy[e] (kJ/g)	17.92	18.58	18.58

a. X represents the quantity of fresh maggots. Based on the dry matter, inclusion level, and used as a complement in the diet. Thus, 25 % of fresh maggots correspond to 935 g/kg basis live weight, because the water content of fresh maggots is 77% (Alofa *et al.,* 2020).
b. Vitamin premix contains (mg or IU/kg diet) : Vitamin B1, 15 mg; Vitamin B2, 15 mg; Vitamin B3, 30 mg; Vitamin B5, 35 mg; Vitamin B6, 6 mg; Vitamin B12, 0.03 mg; Vitamin C, 200 mg; Vitamin D3, 2.000 IU; Vitamin E, 50 mg; Vitamin K3, 5 mg; Inositol, 200 mg; Folic acid, 3 mg; Biotin, 0.2 mg.
c. Mineral premix contains (mg/kg diet): I, 0.4 mg; Co, 0.1 mg; Cu, 4 mg; Fe, 150 mg; Zn,80 mg ; Mn, 20 mg; Se, 0.1 mg; Mg, 100 mg.
d. Nitrogen-Free-Extract (NFE) = 100 - (moisture + crude protein + crude fat + ash + crude fibre).
e. Gross energy was estimated using the following values: 23.7 kJ/g for protein, 39.5 kJ/g for fat, and 17.2 kJ/g for carbohydrates (Guillaume *et al.,* 1999).

Three experimental isoproteic (35 % crude protein) and isocaloric (18 kJ/g gross energy) diets were formulated to fill the nutrient requirements of *O. niloticus* fingerlings (FAO, 2020). Before the formulation, the proximate composition of the experimental ingredients was analyzed (Table 1). Ingredients and formulation of the practical diets are shown in Table 2. A control diet (T0) contains a high level of fishmeal (300 g/kg). The other diets were formulated by replacing 200 g/kg with dried and fresh maggots designed as T1 and T2 respectively.

The ingredients were finely ground and blend in a food mixer. During mixing, vitamins and minerals mixtures were added. Then, oil was added and mixed for another 5 minutes. For the preparation of control and dried maggot diets, warm water (60 °C) was added (40 % of the dry ingredients) (Wang *et al.,* 2017). The fresh maggot diet was processed following the procedures described by Alofa *et al.* (2020). Then, the dough was passed through a kitchen meat grinder (Bosh MFW). The diets had a diameter of 3.0 mm, and were oven-dried for 24 hours at 60°C and stored at -4°C until use. Tables 1 and 2 summarize the formulation and composition of ingredients and the test diets.

Somatic Indices and Body Composition

At the end of the trial, the fish were fasted for 24 h to drain the stomach contents. All fish were weighed individually and counted to assess the survival rate and mean weight. Fish from each treatment (six fish per treatment) were randomly selected and dissected to assess the viscero somatic index (VSI, %). The liver was separated from the viscera and weighed to calculate the hepato somatic index (HSI, %).

To determine the whole-body composition, six other fish (two specimens per tank) were randomly selected by treatment and put in a freezer at -20°C.

- VSI = (viscera weight [g] / fish weight [g]) × 100 (Guroy and Karadal, 2019)
- HSI = (liver weight / body weight) × 100 (Guroy and Karadal, 2019)
- Fulton's Condition factor (CF) = [body weight (g)/length^3 (cm)] × 100 (Nash *et al.,* 2006)

Sample Collection and Analyses

The proximate composition of ingredients, diets, and fish from each treatment were determined following procedures of the Association of Official Analytical Chemists Statistical analysis (AOAC, 2005). Before chemical analysis, samples were finely cut, homogenized by grinding in a mincing machine. Dry matter was determined by oven-drying the samples at 105°C for 24 h. Ash content was measured by incinerating the sample at 550°C for 12 h in furnace. Crude proteins was determined using the Kjeldahl method. Crude fat was extracted according to Folch *et al.* (1957) method.

Water Quality

The water temperature, pH, dissolved oxygen and conductivity were measured *in situ* with a multiparameter (HANNA HI-9828). The weekly water samples were collected at 10 cm depth from tanks to determine nitrate and nitrite. These parameters were analyzed by cadmium reduction and phenate methods respectively using a spectrophotometer (Hach Lange DR6000). During the feeding trials, nitrite (NO_2–N, mg/L) concentration was lower than 0.5 mg/L.

Calculations

Growth parameters and feed utilization indices were calculated as followed :

- Survival rate (SR, %) = (Nf/Ni) × 100], where Nf and Ni refer to the final number of fish and the initial number of fish respectively.
- Specific growth rate (SGR, %/day) = 100 × [ln(Final body weight) − ln(Initial body weight)]/days.
- Daily weight gain (DWG) = (Wf - Wi)/T), where Wf is the mean final body weight and Wi, the mean initial body weight, and T is the duration in days.
- Percent weight gain (PWG) = (Final body weight - Initial body weight/Initial body weight × 100
- Total feed intake per fish (FI) = [total feed consumed (g)/number of fish].
- Yield = [final biomass per tank (kg)−initial biomass per tank (kg)]/ Volume (m^3)
- Production (P) = Yield × 365 days/ rearing period (days)
- Feed conversion ratio (FCR) = dry feed consumed/weight gain.
- Protein efficiency ratio = weight gain/crude protein consumed.

Statistical Analysis

All data are expressed as means ± standard deviation. Data were analyzed for homogeneity of variance by Levene's test. Differences were regarded as significant when $P<0.05$. Data were analyzed using a one-way analysis of variance (ANOVA I) and Tukey test. All statistical analyses were executed using the SPSS v20.0 software and graphs were executed with Microsoft Excel 2016.

Results and Discussion

During the study, the levels of pH, dissolved oxygen, temperature and nitrite did not differ significantly by treatment (Table 3). Values of physicochemical parameters of water measured in the tanks during the test are as follows: pH ranged between 7.14 to 7.19, temperature from 29.88 to 30.08 °C, dissolved oxygen from 5.34 to 5.47 mg.L^{-1}, nitrate from 0.24 to 0.26 mg.L^{-1} and nitrite from 3.2 to 3.31 mg.L^{-1}. These physical and chemical water parameters were preserved within the tolerable range for tropical fish (Delong *et al.,* 2009; Bhujel, 2014), signifying that the environmental conditions of *O. niloticus* during the trial were appropriate. This result is in agreement with the study of Alofa *et al.* (2020) with the same species reared in the tank.

Table 3. Water quality parameters measured during the feeding trial

Parameters	T0	T1	T2	$F_{\text{-value}}$	$p_{\text{-value}}$
pH	7.14 ±0.22	7.19 ±0.10	7.17 ±0.11	1.2	0.303
Temperature (°C)	29.88 ±0.68	30.08 ±0.72	29.88 ±0.78	1.25	0.29
Dissolved oxygen (mg/L)	5.47 ±0.43	5.39 ±0.39	5.34 ±0.65	0.81	0.447
Nitrite (mg/L)	0.24 ±0.09	0.26 ±0.07	0.25 ±0.06	1.7	0.186
Nitrate (mg/L)	3.20 ±0.55	3.30 ±0.32	3.31 ±0.28	1.13	0.325

Values represent the mean and standard deviation. T0: a control diet ; T1: a diet containing dried maggot and T2: a diet containing fresh maggot.

No lesions were observed with any treatment and no dead fish were recorded during the trial, suggested that the rearing facilities and quality of experimental ingredients were in adequate conditions. Growth performance after the 8-week feeding trial is given in Table 4. The initial weight of the *O. niloticus* ranged from 10.26-10.39 g and did not significantly (P>0.05) between all treatments. However, the mean final weight (FW) for some of the groups was significantly different (P < 0.05). The mean FW, weight gain, SGR, and DWG of *O. niloticus* of T1 groups did not significantly differ from T0 group. However, all these growth parameters significantly decreased in T2 (P < 0.05). Changes in weight during 56 days of rearing are shown in Fig 1. In the first 4 weeks, weights did not vary significantly between the T1 and T2 groups. On weeks 4-8, T0 and T1 individuals weighed more than T2 individuals. Thus, body weight was significantly greater in the fish fed T0 and T1 than in fish fed T2 (P < 0.05).

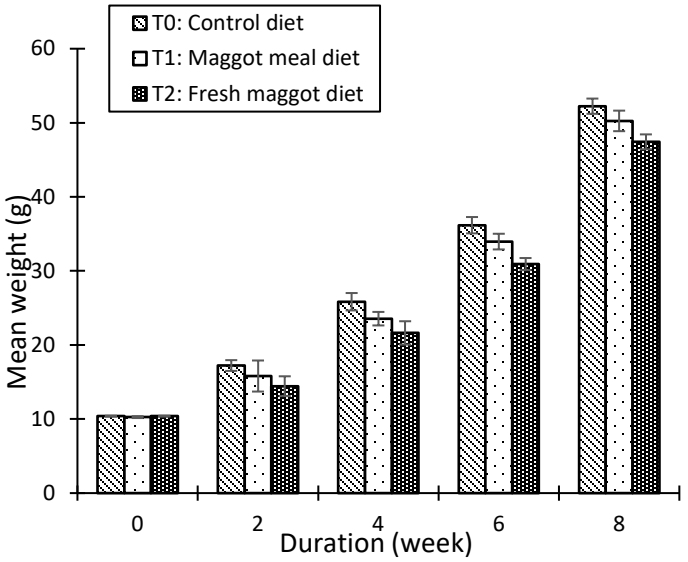

Figure 1. Average weight (g) of *Oreochromis niloticus* during 56-day experimental period.

Table 4. Growth parameters of *Oreochromis niloticus* fed with each practical diet

	Experimental diets			ANOVA	
Parameters	T0	T1	T2	p-value	F-value
Mean initial weight (g)	10.39 ±0.06	10.26 ±0.12	10.38 ±0.06	0.192	2.2
Mean final weight (g)	52.24 ±1.03^{a}	50.25 ±1.39^{a}	46.30 ±2.03^{b}	0.009	11.59
PWG (%)	402.78 ±8.16^{a}	389.70 ±7.63^{a}	356.70 ±7.76^{b}	0.001	27.43
SGR (%.day^{-1})	2.88 ±0.03^{a}	2.84 ±0.03^{a}	2.67 ±0.07^{b}	0.003	18.25
DWG (g.day^{-1})	0.75 ±0.02^{a}	0.71 ±0.02^{a}	0.64 ±0.04^{b}	0.007	12.79
Yield (kg.m^{-3})	1.94 ±0.08^{a}	1.82 ±0.08^{ab}	1.63 ±0.09^{b}	0.009	11.42
P (kg.m^{-3}.year^{-1})	12.62 ±0.50^{a}	11.83 ±0.50^{ab}	10.94 ±0.23^{b}	0.009	11.4

PWG: Percent weight gain, **SGR:** Specific Growth Rate, **DWG:** Daily Weight Gain, **T0:** a control diet; **T1:** a diet containing dried maggot and **T2:** a diet containing fresh maggot. Values represent the mean and standard deviation. In each line, different superscript letters indicate the significant differences between the treatments (P<0.05).

The present study provides important knowledge on the different forms of housefly larvae that can be used in the Nile tilapia diet. Housefly larvae have been found as a durable alternative source of protein for fish feeds (Henry *et al.,* 2015; Makkar *et al.,* 2014). It's been shown that maggots efficiency in the fish diet depends on the species and/or stage, the feed substrate and the process (Fasakin *et al.,* 2003). Diets containing maggots were easily acceptable by the *O. niloticus* used in this experiment, suggesting that this ingredient could contain free amino acids, which could improve feed intake. The specific growth rate of Nile tilapia (weighing 10.23 g) fed with the fishmeal based-diet (T0) was around 2.88 %/day, which is higher than those (1.12-2.26 %/day) recorded for the same species (weighing 25-68.89 g) (Wang *et al.,* 2017; Obirikorang *et al.,* 2015), probably because of the size of the fishes. Generally, the smaller fish get a higher growth rate than the bigger fish (Dong *et al.,* 2013). This experiment shows that the ingredient form of housefly maggots affects significantly the growth performance ($P<0.05$). Fish fed the diets T0 and T1 performed significantly better ($P<0.05$) than that fed fresh based diet. This is consistent with the results of Awom and Eyo (2016), where the weight gain, PER, and specific growth rate for *Clarias gariepinus* after 70 days were lower in fish fed 100% of live maggots. But, on the other hand, maggots were used alone in their investigation. The highest Specific Growth Rate (2.84 ±0.03 %/days) and final body weight (50.25 ±1.39 g) are obtained with the dried form of maggots diet (T1), indicating that the omnivorous Nile tilapia can well utilize dried maggots based diet. For these parameters, the values (2.67 ±0.07 %/days and 46.30 ±2.03 g respectively) recorded with fish fed with fresh form are lower. The findings of this research suggest that the cheaper dried housefly maggots can partially substitute fish meal as a dietary protein source in *O. niloticus* diets. This is in accordance with other investigations where fish meal was replaced by maggots, producing good growth performance in Nile tilapia. (Ogunji *et al.,* 2008; Wang *et al.,* 2017). Nile tilapia fed 25 % of live maggots showed a better growth performance, and specific growth rate, than fish fed spirulina waste (Alofa *et al.,* 2020), probably because the diets were better adapted to the needs of the fish and palatable. The growth reduction observed by Awom and Eyo (2016) in African catfish fed live maggots may be due to the fact that it does not provide all the nutrients necessary for optimal growth of this fish. In their study, maggots were used solely.

Table 4 shows that there was no significant difference in body weights at the beginning of the experiment and that the final body weight of fish fed the fresh maggot diet was significantly lower than that of the other diets throughout the experiment ($P< 0.05$). The poor growth of fish fed the diets containing fresh maggots could be due to the presence of chitin in the exoskeleton of housefly (Cummins Jr *et al.,* 2017), imbalance of fatty acid profile (Lin and Mui, 2017), and lower lipid digestibility (Shiau and Yu, 1999; Diener *et al.,* 2009). These factors could decrease palatability and nutrient absorption resulting in reduced growth. Furthermore, the processing (different forms) of maggots are worthy to consider. Therefore, the decrease in growth performance observed in the fish fed diet containing fresh maggots could be associated with the processing conditions of the maggots used.

The effects of different forms of maggots on the feed utilization parameters of *O. niloticus* are shown in Figure 2. Palatability is an important factor in fish nutrition that influences feed consumption and digestibility by returning the diet to a greater or lesser extent acceptable (Bowker, 2013). Feed conversion ratio (FCR) and protein efficiency ratio (PER) did not differ between the three groups ($P > 0.05$). In this study, the highest feed intake (FI) was observed in fish fed with T0, while the lowest was observed in fish fed with T2 (Fig. 2.c). However, feed intake did not differ significantly in fish fed maggot-based-diets. A similar finding was found by substituting the maggot meal for fish meal in the *O. niloticus* diet (Wang *et al.,* 2017). These authors reported that this ingredient was widely palatable and attractive for Nile tilapia.

The findings of biological indices and whole body composition are presented in Table 5. Hepatosomatic index (HSI) and viscerosomatic index (VSI) were significantly increased in fish fed maggots ($P < 0.05$) but condition factor (CF) did not significantly differ between treatments. VSI of fish fed with T0 was significantly decreased than that of fish fed with the other experimental diets. This could be explained by the increased lipid content of the maggot diet. Studies have revealed a positive relationship between HIS and liver metabolism and usually, increased lipids content generates higher HSI (Liu *et al.,* 2010). This is in accordance with the research on Japanese sea bass *Lateolabrax japonicus*, which showed hepatic steatosis and higher HSI and liver lipid values when high levels of animal protein blend were utilized as a substitute for fish meal (Hu *et al.,* 2013). Nevertheless, the effects of dietary incorporation of animal protein and high-fat sources on the liver forms of fish are contrasted. For example, the histopathology of the liver of Atlantic cod and sea bream showed no changes when these fish are fed high-fat diets (Caballero *et al.,* 1999; Hansen *et al.,* 2006). However, no significant difference was observed for the hepatosomatic index between experimental treatments, indicating that the presentation form of maggots has no adverse effect on the hepatopancreas.

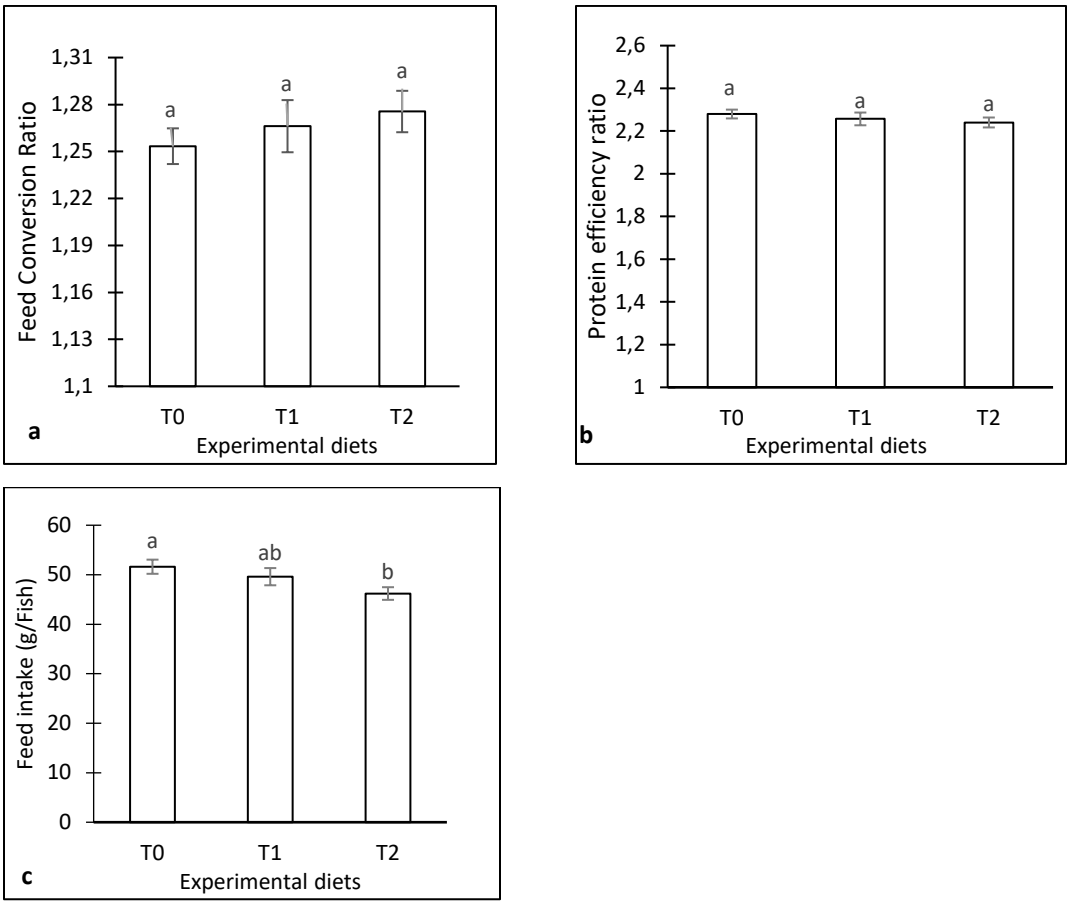

Figure 2. Histogram of the mean of food conversion ratio (a), protein efficiency ratio (b), feed intake (c) with standard deviations of Nile tilapia fed experimental diets (T0: a control diet ; T1: a diet containing dried maggot and T2: a diet containing fresh maggot). Different letters indicate a significant difference among treatments ($P < 0.05$).

Table 5. Morphological and organosomatic indices and carcass composition of Nile tilapia fed the test diets

Parameters		T0	T1	T2	*p-value*
Biological indices (%)					
VI		8.88 ±0.54[b]	10.61 ±0.38[a]	10.41 ±0.79[a]	0.005
HI		3.07 ±0.36[b]	4.95 ±0.21[a]	4.71 ±0.14[a]	0.000
CF		1.90 ±0.02[a]	1.89 ±0.02[a]	1.88 ±0.02[a]	0.83
Proximate composition (%)					
	Initial body				
Dry matter	89.92 ±0.16	90.06 ±1.02	89.95 ±1.24	90.64 ±1.23	0.68
Crude protein	62.11 ±0.21	61.30 ±0.61	60.97 ±0.33	60.68 ±1.00	0.493
Crude lipid	12.76 ±0.59	19.38 ±0.74[b]	26.36 ±0.60[a]	26.45 ±0.49[a]	0.000
Ash	16.22 ±0.39	15.53 ±0.78[a]	13.80 ±0.51[b]	13.84 ±0.29[b]	0.003

Values are means ± standard deviation and values within the same row with different superscript letters are significantly different ($P < 0.05$). **HI** (Hepatosomatic index), **VI** (Viscerosomatic index), **CF** (Condition factor). **T0:** control diet; **T1:** diet containing dried maggot and **T2:** diet containing fresh maggot.

Dietary housefly maggots replacement did not modify body proximate composition, which was also observed in studies with maggots substitution in fish feeds (Ogunji *et al.,* 2008; Wang *et al.,* 2017). Nevertheless, in the present investigation, the fat content of the whole-body increased by maggots supplementation, indicating that the lipid metabolism in Nile tilapia may be affected by the inclusion of insects larvae, which was consistent with our previous findings (Alofa *et al.,* 2020). The dry matter and crude protein contents of the whole body were not affected by any treatment. However, the ash content decreased significantly with the incorporation of maggots (Table 5). This might be associated with the increase of VSI in T1 and T2 groups and the effect of the high-fat content of MM used in the diet formulation, resulting in increased fat content in a substrate (chicken viscera) used for their production.

Conclusion

Findings from this investigation showed that better growth performance in Nile tilapia, *O. niloticus* could be achieved by the using of dried maggot meal in the formulated fish diet compared to live maggots. The beneficial effects of dried maggots supplementation for FM substitution were demonstrated at growth performance and feed efficiency. However, the use of the fresh maggot, significantly decreased growth performance. Nutrient utilization efficiencies were not affected by the inclusion of both forms of maggots.

Compliance with Ethical Standards

Conflict of interests: The authors declare that for this article they have no actual, potential, or perceived conflict of interest.

Ethics committee approval: This research was conducted in accordance with the framework law N° 2014-19 of August 07, 2014 on fisheries and aquaculture in the Republic of Benin and the Directive 2010/63/EU of the European Parliament on the protection of animals used for scientific purposes

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References

Alofa, C.S., Oke, V., Abou, Y. (2016). Effect of replacement of fish meal with broiler chicken viscera on growth, feed utilization and production of African catfish *Clarias gariepinus* (Burchell, 1822). *International Journal of Fisheries and Aquatic Studies,* 4(6), 182-186.

Alofa, C.S., Abou, Y. (2020). A comparison between chicken viscera and housefly maggot cultured from this by-products for Nile tilapia Diets : growth performance, feed utilization and whole body composition. *Asian Journal of Fisheries and Aquatic Research,* 5(3), 1-12. https://doi.org/10.9734/ajfar/2019/v5i330075

Alofa, C.S., Adite, A., Abou, Y. (2020). Evaluation of Spirulina (*Spirulina platensis*) wastes and live housefly (*Musca domestica*) larvae as dietary protein sources in diets of *Oreochromis niloticus* (Linnaeus 1758) fingerlings. *Aquatic Research,* 3(1), 24-35. https://doi.org/10.3153/ar20003

Alofa, C.S., Abou, Y. (2021). A mixture of chicken viscera, housefly larvae and spirulina waste as replacement of fishmeal in Nile tilapia (*Oreochromis niloticus*) diets. *Aquaculture Studies,* 21(1), 11-21. https://doi.org/10.4194/2618-6381-v21_1_02

Aniebo, A.O., Odukwe, C.A., Ebenebe, C.I., Ajuogu, P.K., Owen, O.J., Onu, P.N. (2011). Effect of housefly larvae (*Musca domestica*) Meal on the carcass and sensory qualities of the mud catfish (*Clarias gariepinus*). *Advances in Food and Energy Security,* 1, 24-28.

AOAC (Association of Official Agricultural Chemists) (2005). Official Methods of Analysis (18th ed.) Gaithersburg, MD : Association of Official Analytical Chemists. https://doi.org/10.1002/0471740039.vec0284

Awom, I.E., Eyo, O.V. (2016). Comparative Study of Growth Performance, Food Utilization and Survival of the African Catfish *Clarias gariepinus* (Burchell, 1822) Fingerlings Fed Live Maggot (*Musca domestica*) and Coppens Commercial Feed. *International Journal of Scientific Research in Science Engineering and Technology,* 2(2), 379-386.

Bhujel, R.C. (2014). A manual for tilapia business. CABI Nosworthy Way Wallingford Oxfordshire OX10 8DE UK, 199 p. ISBN 978-1-78064-136-2. https://doi.org/10.1079/9781780641362.0000

Bowker, J. (2013). Attractant Properties of Chemical Constituents of the Green Macroalga Ulva and Their Response Effects on the Commercially Important Sea Urchin *Tripneustes gratilla*. Department of Biological Sciences, Honours Project 2. University of Cape Town, pp. 1-29. http://hdl.handle.net/11427/14098

Caballero, M.J., López-Calero, G., Socorro, J., Roo F.J., Izquierdo, M.S., Férnandez, A.J. (1999). Combined effect of lipid level and fish meal quality on liver histology of gilthead sea bream *Sparus aurata*. *Aquaculture,* 179, 277-290. https://doi.org/10.1016/S0044-8486(99)00165-9

Cai, J.N., Leung, P.S., Luo, Y.J., Yuan, X.H., Yuan, Y.M. (2018). Improving the performance of tilapia farming under climate variation: perspective from bioeconomic modelling. *In* Food and Agriculture Organization of the United Nations (FAO). Fisheries and Aquaculture Technical Paper No. 608. Rome, FAO.

Cummins Jr, V.C., Rawles, S.D., Thompson, K.R., Velasquez, A., Kobayashia, K., Hagera, J., Webster, C.D. (2017). Evaluation of black soldier fly (*Hermetia illucens*) larvae meal as partial or total replacement of marine fish meal in practical diets for Pacific white shrimp (*Litopenaeus vannamei*). *Aquaculture,* 473, 337-344. https://doi.org/10.1016/j.aquaculture.2017.02.022

DeLong, D., Losordo, T.M., Rakocy, J. (2009). Tank culture of tilapia. United States Department of Agriculture, Cooperative State Research, Education and Extension Services: 1-8.

Diener, S, Zurbrügg, C, Tockner, K. (2009). Conversion of organic material by black soldier fly larvae: Establishing optimal feeding rates. *Waste Management Resssource,* 27, 603-610. https://doi.org/10.1177/0734242X09103838

Djissou, A.S.M., Adjahouinou, D.C., Koshio, S., Fiogbe, E.D. (2016). Complete replacement of fish meal by other animal protein sources on growth performance of *Clarias gariepinus* fingerlings. *International Aquaculture Research,* 8, 333-341. https://doi.org/10.1007/s40071-016-0146-x

Dong, G.F., Yang, Y.O., Song, X.M., Yu, L., Zhao, T.T., Huang, G.L., Hu, Z.J., Zhang, J.L. (2013). Comparative effects of dietary supplementation with maggot meal and soybean meal in gibel carp (*Carassius auratus gibelio*) and dark-barbel catfish (*Pelteobagrus vachelli*): Growth performance and antioxidant responses. *Aquaculture Nutrition,* 19, 543-554. https://doi.org/10.1111/anu.12006

Ekpo, I. Bender, J. (1989). Digestibility of a commercial fish feed, wet algae, and dried algae by *Tilapia nilotica* and silver carp. *Progressive Fish-Culturist,* 5(1), 83-86. https://doi.org/10.1577/1548-8640(1989)051<0083:DOA-CFF>2.3.CO;2

El-Sayed, A.F.M. (2006). Tilapia culture. CABI Publishing, Cambridge, Massachusetts. https://doi.org/10.1079/9780851990149.0000

FAO (Food and Agriculture Organisation) (2018). The State of World Fisheries and Aquaculture : Meeting the Sustainable Development Goals ; FAO : Rome, Italy.

FAO (Food and Agriculture Organisation) (2020). Nile tilapia: nutritional requirements. http://www.fao.org/fishery/affris/species profiles/nile-tilapia/nutritional-requirements/en/ (assessed 28/4/2020)

Fasakin, E.A., Balogun, A.M., Ajayi, O.O. (2003). Evaluation of full-fat and defatted maggot meals in the feeding of clariid catfish *Clarias gariepinus* fingerlings. *Aquaculture Research,* 34, 733-738. https://doi.org/10.1046/j.1365-2109.2003.00876.x

Fitches E.C., Dickinson M., De Marzo D., Wakefield M.E., Charlton A.C. (2018). Alternative protein production for animal feed: *Musca domestica* productivity on poultry litter and nutritional quality of processed larval meals. *Journal of Insects as Food and Feed,* 5(2), 77-88. https://doi.org/10.3920/JIFF2017.0061

Folch, J., Lees, M., Stanley, G.H.S. (1957). A simple method for the isolation and purification of total lipides from animal tissues. *Journal of Biological Chemistry,* 226, 497-509. https://doi.org/10.1016/S0021-9258(18)64849-5

Gasco, L., Gai F., Maricchiolo, G., Genovese, L., Ragonese, S., Bottari, T., Caruso, G. (2018). Fishmeal alternative protein sources for aquaculture feeds: current situation and alternative sources. In: Feeds for the Aquaculture Sector. Springer International Publishing, Cham, pp. 1-28. https://doi.org/10.1007/978-3-319-77941-6_1

Guillaume, J., Kaushik, S.J., Bergot, P., Metailler, R. (1999). Nutrition et alimentation des poissons et crustacés. INRA-IFREMER éditions, Paris, 489 p.

Guroy, D., Karadal, O. (2019). Impacts of cycled dietary protein ratios on the growth performance and somatic indices of meagre (*Argyrosomus regius*). *Aquatic Sciences and Engineering*, 34(2), 61-66. https://doi.org/10.26650/ASE540928

Hansen, A.C., Rosenlund, G., Karlsen, O., Olsvik, P.A., Hemre, G.I. (2006). The inclusion of plant protein in cod diets, its effects on macronutrient digestibility, gut and liver histology and heat shock protein transcription. *Aquaculture Research,* 37, 773-784. https://doi.org/10.1111/j.1365-2109.2006.01490.x

Henry, M., Gasco, L., Piccolo, G., Fountoulaki, E. (2015). Review on the use of insects in the diet of farmed fish: Past and future. *Animal Feed Science and Technology,* 203, 1-22. https://doi.org/10.1016/j.anifeedsci.2015.03.001

Hu, L., Yun, B., Xue, M., Wang, J., Wu, X., Zheng, Y., Han, F. (2013). Effects of fish mealquality and fish meal substitution by animal protein blend on growth performance, flesh quality and liver histology of Japanese seabass (*Lateolabrax japonicus*). *Aquaculture*, 372-375, 52-61. https://doi.org/10.1016/j.aquaculture.2012.10.025

Lin, Y.H., Mui, J.J. (2017). Evaluation of dietary inclusion of housefly maggot (*Musca domestica*) meal on growth, fillet composition and physiological responses for barramundi, *Lates calcarifer*. *Aquaculture Research,* 48(5), 2478-2485. https://doi.org/10.1111/are.13085

Liu, X.J., Luo, Z., Xiong, B.X., Liu, X., Zhao, Y.H., Hu, G.F., Lv, G.J. (2010). Effect of water borne copper exposure on growth, hepatic enzymatic activities and histology in *Synechogobius hasta*. *Ecotoxicology and Environmental Safety,* 73, 1286-1291. https://doi.org/10.1016/j.ecoenv.2010.06.019

Makkar, H.P.S., Tran, G., Heuze, V., Ankers, P. (2014). State-of-the-art on use of insects as animal feed. *Animal Feed Science Technology,* 197, 1-33. https://doi.org/10.1016/j.anifeedsci.2014.07.008

Nash, R.D.M., Valencia, A.H., Geffen, A.J. (2006). The origin of Fulton's condition factor-setting the record straight. *Fisheries*, 31, 236-238.

Obirikorang, K.A., Amisah, S., Agbo, N.W., Adjei-Boateng, D., Adjei, N.G., Skov, P.V. (2015). Evaluation of locally-available agro-industrial byproducts as partial replacements to fishmeal in diets for Nile Tilapia (*Oreochromis niloticus*) production in Ghana. *Journal of Animal Research and Nutrition*, 1(1), 1-9. https://doi.org/10.21767/2572-5459.100002

Ogunji, J.O., Summan Toor, R.U.A., Schulz, C., Kloas, W. (2008). Growth performance, nutrient utilization of Nile tilapia *Oreochromis niloticus* fed housefly maggot meal (magmeal) diets. *Turkish Journal of Fisheies and Aquatic Science,* 8, 141-147.

Ossey, Y.B., Koumi, A.R., Koffi, K.M., Atse, B.C., Kouame, L.P. (2012). Utilisation du soja, de la cervelle bovine et de l'asticot comme sources de protéines alimentaires chez les larves de *Heterobranchus longifilis* (Valenciennes, 1840). *Journal of Animal and Plant Sciences,* 15, 2099-2108.

Oyelese, O.A. (2007). Utilization of compounded ration and maggot in the diet of *Clarias gariepinus. Research Journal of Applied Sciences,* 2, 301-306.

Rurangwa, E., Van den Berg, J., Laleye, P.A., van Duijn, A.P., Rothuis, A. (2014). Mission exploratoire Pêche, Pisciculture et Aquaculture au Bénin: Un quick scan du secteur pour des possibilités d'interventions. IMARES report C072/14, 70p.

Shiau, S.Y., Yu, Y.P. (1999). Dietary supplementation of chitin and chitosan depresses growth in tilapia, *Oreochromis niloticus* × *O. aureus*. *Aquaculture,* 179, 439-446. https://doi.org/10.1016/s0044-8486(99)00177-5

Tran, G., Heuzé, V., Makkar, H.P.S. (2015). Insects in fish diets. *Animal frontiers,* 5(2), 37-44.

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G., Vantomme, P. (2013). Edible Insects: Future prospects for food and feed security (No. 171). Rome: FAO.

Wang, L., Li, J., Jin, J., Zhu, F., Roffeis, M., Zhang, X. (2017). A comprehensive evaluation of replacing fishmeal with housefly (*Musca domestica*) maggot meal in the diet of Nile tilapia (*Oreochromis niloticus*): Growth performance, flesh quality, innate immunity and water environment. *Aquaculture Nutrition,* 23(5), 983-993. https://doi.org/10.1111/anu.12466