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Optimal substrates for producing housefly larvae with high nutritional composition for sustainable poultry feed in Niger

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RESEARCH ARTICLE

Abstract

Poultry farming, because of its many potentialities (i.e. short duration of reproduction and production cycle, rapid return on investment), occupies a place of choice in development strategies and the fight against poverty in most African countries. In Niger, West Africa, poultry are fed specific protein-providing feed ingredients (such as fishmeal); however, these ingredients are very expensive and unsustainable. Larvae represent a potential alternative source of protein for poultry. Here, we investigated different substrates to optimise housefly (*Musca domestica* L. 1758) maggot production and nutritional composition. Eight dry substrates were tested. The highest larval biomass (larval biomass produced by 10 mg of house fly egg placed on 50 g dry substrate) and mean weight (individual house fly larvae 5 days after the incorporation of eggs on the substrate) were observed on millet and wheat bran (3,446.67±134.16 mg and 24.00±1.01 mg, respectively). However, larvae produced on Brewer's spent grains had the highest protein and lipid content (53.79±1.04% and 24.13±5.20%, respectively). Ash content was highest for larvae produced on cow dung and a mixture of 50% wheat bran and 50% cow dung (15.01±0.32% and 15.41±0.09%, respectively). Maggots produced on rumen contents had the highest water content (80.89±0.22%). The profile of produced larvae included palmitic acid (30.99±0.48% on grain), palmitoleic acid (30.26±2.84% on cow dung), oleic acid (27.93±0.31% on rice hulls), and linoleic acid (26.41±0.18% on millet bran + rumen contents). For all substrates, Maggots contained more unsaturated fatty acids (57.59-66.52%) than saturated fatty acids (26.54-46.34%). This study, offers to farmers a wide variety of substrates that could be used to produce maggots, providing a sustainable source of protein that has not been previously available in Niger. We recommend the farmers to use the cow dung to produce maggots without cost.

Keywords: Niger, *Musca domestica*, chicken

1. Introduction

In Niger, livestock farming is practiced by nearly 87% of the population (RECA, 2010). Most farms and households have poultry as a source of food (meat, eggs) and income (Zakara, 2016). Traditional poultry farming is key for food security and poverty reduction in rural populations (Alders, 2005; Ayissiwédé *et al.*, 2013; Ganahi *et al.*, 2016; Moussa, 2014; Youssao *et al.*, 2013). In 2007, chicken production represented 57.5% of poultry raised in Niger, with local breeds dominating flocks (54.7%). Local chicken farming is widely practiced in rural areas, and, to a lesser extent, in urban areas, mainly by people with limited resources (Vidogbena *et al.*, 2010). Although traditional poultry is highly prised in Africa because of the organoleptic qualities of the meat, it does not meet the demands of the population. Various constraints (e.g. lack of infrastructure, outbreaks of disease, and lack of feed sources) prevent small-scale poultry farmers from obtaining good zootechnical and financial performance on their farms (Ayssiwede *et al.*, 2013; Lwelamira, 2012). Feed quality represents a major constraint, partly due to the unavailability and price volatility of protein feed ingredients, such as fish meal and soybean meal (Ayssiwede *et al.*, 2013). Consequently, traditional poultry farmers must raise poultry by grazing them on natural rangeland to meet their own feed requirements (Ayssiwede *et al.*, 2013).

Insects have been widely identified as potential alternative environmentally sustainable food sources for use in animal feed (De Marco *et al.*, 2015; Kelemu *et al.*, 2015; Tchibozo *et al.*, 2005; Van Huis, 2003; Xiao *et al.*, 2010). For instance, Dipteran larvae (maggots) are being increasingly presented as a sustainable source of protein for animal feed globally (Makkar *et al.*, 2014; Pastor *et al.*, 2015; Van Huis *et al.*, 2013), particularly in Africa (Adenji, 2007; Bouafou *et al.*, 2006; Kenis *et al.*, 2014; Koné *et al.*, 2017; Pieterse and Pretorius, 2014). The species that are most frequently used include the black soldier fly (*Hermetia illucens* L. 1758) and housefly (*Musca domestica* L. 1758) (Pastor *et al.*, 2015). Houseflies are particularly suitable for smallholder farmers in Africa, because maggots develop on a wide range of wastes, such as animal droppings (e.g. chickens, cows, pigs, and rabbits), slaughter waste, and plant waste (e.g. crop and household waste) (Leyo *et al.*, 2021a), and can be harvested 3-4 days after oviposition (Koné *et al.*, 2017). Thus, *M. domestica* production as larvae are both a beneficial widely available protein source and a method for organic waste recycling (Leyo *et al.*, 2021b). The residue from fly larvae production on livestock manure could be used as high quality biofertilizer to improve soil quality, increase crop yield, and reduce the use of chemical fertilizers (Bloukounon-Goubalan *et al.*, 2017; Charlton *et al.*, 2015; Coulibaly *et al.*, 2020a,b; Wang *et al.*, 2016; Zhang *et al.*, 2012).

This study aimed to identify the optimal substrate for the mass production of maggots and maximum nutritional composition to improve poultry feed. The study region was the peri-urban area of Niamey, Niger. Larval productivity was compared on eight available local substrates, and the chemical composition of maggots was determined. Our results are expected to provide guidelines to farmers on how to produce larvae on local substrates to improve the nutritional content of poultry feed at low cost and with high sustainability.

2. Materials and methods

House fly colony

The insects used in this experiment were obtained from the mass breeding of *M. domestica* at the Faculty of Agronomy in Abdou Moumouni University (Niamey, Niger). Five breeding cages (75×75×115 cm BugDorm, Mega View Science, Taichung, Taiwan) were used to maintain the colony. Each cage contained 25,000 reared *M. domestica* pupae corresponding to a storage density of approximately 2.8 cm^3 per fly (Niu *et al.*, 2017). Food for adults included cotton soaked in a mixture of powdered milk and granulated sugar (ratio 1:1), and sponges soaked in sweet water, placed in plastic containers. The cages were placed in a room with photoperiod of 12 h light and 12 h dark (12:12 L:D), at 25±2 °C, and a relative humidity (RH) of 60-70% (Holmes *et al.*, 2012; Niu *et al.*, 2017).

Egg collection

Five days after adult emergence, plastic containers (83 mm diameter and 3 cm height) containing a mixture of water, wheat bran, and granulated sugar (2:1; 70% moisture) covered with filter paper (grade: 50, circular, porosity: 2.7 µm; Whatman, La Chapelle-sur-Erdre, France) were placed in the colony cages as spawning medium (Niu *et al.*, 2017). Flies were allowed to lay eggs for 8 h (08:00 to 16:00). Filter paper was used to prevent flies from laying eggs on the mixture of fermented wheat bran and granulated sugar as spawning medium, and to allow for the easy collection of eggs. The eggs were weighed on a balance (0.001 g, Sartorius, Goettingen, Germany) using a fine brush. This procedure was conducted in the breeding room, where humidity was kept relatively high (60-70% RH), to prevent eggs from desiccating and water loss from the larval medium (Keiding and Arevad,1964).

Experimental design

The substrates selected for use in this study were based on a combination of: (1) those that the maggots of houseflies develop on (Leyo *et al.*, 2021a); and (2) those that are accessible and easily available in the peri-urban area of Niamey. Eight types of dry substrates (in triplicate) were used to make feeding substrates for *M. domestica* maggots, namely: cow dung, rumen content, spent grain from traditional beer production, wheat bran, millet bran, rice husks, millet husks and agricultural residues of millet crops. Several mixtures were tested: three mixtures of millet bran and cow dung (25/75; 50/50; 75/25%) and three mixtures of millet bran and rumen content (25/75; 50/50; 75/25). Rice husks, millet husks, and agricultural residues were ground using a traditional mill. Fresh cow dung and rumen content were oven-dried (UL50 780301, Memmert; Germany) at 60 °C for 48 h, and was then ground with a porcelain mortar and pestle. Mixed substrates were homogenised manually with a wooden spatula.

For each feed substrate, 50 g substrate was measured with a precision balance (Sartorius, Goettingen, Germany), and was moistened to 70% by adding tap water. Then, 10 mg eggs (Leyo *et al.*, 2021b) were incorporated in each substrate type per replicate (three replicates). All maggots were reared in plastic containers (17.20×11.50×6.00 cm, AVA, Temse, Belgium) covered with a transparent thin cloth lid for ventilation. The containers were randomly arranged at half-height on a board in the rearing room. The experiment was implemented under the same environmental conditions as the adult rearing (26 °C±2 °C; 60-70% relative humidity and 12:12 light:dark).

Evaluation

Five days after incubating the eggs in the substrates, the larval biomass, number of larvae, and average weight of maggots were measured. Larval biomass was weighed on a balance (0.001 g, Sartorius), and the number of larvae was counted manually. The average larval weight was calculated by dividing the harvested weight (larval biomass) by the number of larvae harvested (Hussein *et al.*, 2017). Larvae from each substrate were cold-killed at -20 °C for 24 h. Then, the larvae were oven-dried (UL50 780301) at approximately 40 °C for 72 h (Sogbesan and Ugwumba, 2008).

Chemical composition of maggots

The chemical composition of maggots was analysed at the Laboratory of Functional and Evolutionary Entomology (Gembloux AgroBioTech – Uliège, Liège, Belgium). First, the moisture content of fresh larvae was determined following the procedure recommended by the Association of Official Analytical Chemists (AOAC, 2005). Then, the samples were frozen at -50 °C for 24 h (Barroso *et al.*, 2014) and then freeze-dried (Gamma 2-16 LSCPLUS, Martin Christ, Germany) for 72 h. Each sample was ground using a porcelain mortar and pestle, and was stored at -20 °C until analyses.

The protein content of maggots was determined using the Dumas method (Rapid N Cube Elementar, Hanau, Germany). Lipid content was quantified following the method of Folch *et al.* (1957). Ash content was determined according to AOAC (AOAC, 2005). Fatty acid composition was determined by converting 10 mg to fatty acid methyl esters using boron tri-fluoride (Sigma-Aldrich, Overijse, Belgium) and methanol (VWR, Oud-Heverlee, Belgium). Fatty acid methyl esters were diluted in 8 ml hexane (VWR) and were then analysed by gas chromatography-mass spectrometry (GCMS: Trace GC Ultra; Thermo Scientific Interscience; Asse, Belgium). The following parameters were used: column (Restek Stabilwax-DA (Bellefonte, PA, USA), 30 m, 0.25 mm, ID 0.25 µm df); gases (He: 1 ml/min, H2: 35 ml/min, air: 350 ml/min, N2: 30 ml/min); injection (splitless 0.85 min); Detector (FID 2,050 °C). The temperature program was as follows: hold at 50.0 °C for 1 min, increase to 150.0 °C at 30.0 °C/min, increase to 240.0 °C at 5.0 °C/min, and hold at 240.0 °C for 10 min

Fatty acid methyl esters were identified based on their retention data compared to a reference mixture of 37 key fatty acid methyl esters (Supelco 37 component FAME mixture, Sigma-Aldrich).

Statistical analyses

All data were processed with R software version 4.0.3. The Shapiro-Wilk test (Patrick, 1982) and Bartlett's test (Bartlett, 1937) were performed to check the normality of data and the homogeneity of variance, respectively. Data were submitted for analysis of variance (ANOVA) at the threshold of 5%, followed by Duncan's contrast for the comparison of means, to assess the lipid and moisture content of maggots and the probabilities of distributions being higher than 5%. Kruskal-Wallis test at the 5% threshold followed by Dunn's post-hoc test for comparison of means was used to assess the growth parameters of *M. domestica*, protein content, ash content, and fatty acids (with distribution probabilities lower than 5%).

3. Results

Table 1 presents information on the chemical composition of the substrates used in this study.

Table 1. Chemical composition of the substrates.[1]

Substrates	Crude protein (% DM[2])	Crude fat (% DM)	Ash (% DM)
Agricultural residue	2.86±0.11	7.58±2.12	26.25±8.46
Brewer's spent grains	27.72±0.78	9.11±2.22	10.43±0.63
Cow manure	6.68±0.38	5.58±0.07	46.78±20.26
Millet bran	13.26±0.27	9.95±4.51	9.84±0.60
Millet glumes	7.99±0.34	9.47±0.41	10.43±0.81
Rumen content	6.97±0.15	5.42±0.83	27.32±6.06
Rice glumes	6.16±0.23	11.39±2.16	21.06±0.96
Wheat bran	17.87±0.27	4.28±0.03	5.30±0.15

[1] Values are mean ± standard error.
[2] DM = dry matter.

Larval biomass of *Musca domestica* maggots

After five days of development, the biomass of maggots ranged from 1,218.33±19.21 mg (on glume millet) to 3,446.67±134.16 mg (on millet bran) (Table 2). The number of maggots ranged from 137.66±4.72 (on wheat bran) to 179.00±3.60 (on 50% wheat bran + 50% cow manure). The average weight of maggots ranged from 6.85±0.10 mg (on glume millet) to 19.58±0.68 mg and 24.46±0.57 mg (on millet bran and wheat bran, respectively) (Table 2).

Chemical composition of maggots fed on different substrates

The crude protein (53.79±1.04%) and crude fat (24.13±5.20%) content of maggots were highest on Brewer's spent grains, and were lowest on cow manure (33.99±0.25%) and the mixture of 25% millet bran + 25% rumen content (6.68±2.30). The ash content of maggots ranged from 5.88±0.01% (on wheat bran) to 14.93±0.50; 15.01±0.32 and 15.41±0.09 (on 25% wheat bran + 75% cow manure and 50% wheat bran + 50% cow manure, respectively). Maggot water content (humidity) ranged from 72.65±0.26 (on rice glumes) to 80.89±0.22 (on rumen content) (Table 3).

Fatty acid profile of maggots produced on different substrates

The substrate type affected the fatty acid profile of *M. domestica* maggots (Supplementary Table S1). The fatty acid profile was largely composed of C16:0; C16:1; C18:1n9, and C18:2n6. The C16:0 content of maggots ranged from 18.47±15.51% (on wheat bran) to 32.09±0.96% (on 50% millet bran + 50% rumen content). The C16:1 content of maggots ranged from 10.46±1.20% (on wheat bran) to 30.26±2.84% (on cow dung). The C18:1n9 content of maggots ranged from 18.73±2.04% (on 50% millet bran + 50% rumen content) to 27.93±0.31% (on rice glume).

Maggots had more unsaturated fatty acids (monounsaturated (MUFA) + polyunsaturated (PUFA)) than saturated fatty acids (Supplementary Table S1). Unsaturated fatty acids ranged from 57.59 to 66.52%, whereas saturated fatty acids ranged from 26.54 to 46.34%. There were more monounsaturated fatty acids (31.25-58.23%) compared to polyunsaturated fatty acids (5.29-29.91).

4. Discussion

Biomass of *Musca domestica* maggots

The maggot biomass obtained on the different substrates tested in the present study are comparable to those reported by Ganda *et al.* (2019) who compared similar substrates in a free oviposition system. The biomass of *M. domestica* larvae obtained in our study are lower than those obtained by Ganda *et al.* (2019) for all substrates. This difference can be explained by the system (egg incubation by housefly adult rearing vs free oviposition.) and the quality of the substrates as shown by Anene *et al.* (2013) and Koné *et al.* (2017). The maggot biomass we obtained is also lower than those obtained by Ganda *et al.* (2021) who used a much

Table 2. Growth parameters of maggots on different substrates.[1]

Growth substrate	Substrate type[2]	Biomass (mg)	Mean weight (mg)	Number of larvae
Agricultural residue	Veg	1,367.33±57.72[fg]	8.66±0.50[ef]	172.33±6.80[abc]
Brewer's spent grains	Veg	2,435.33±43.92[cd]	14.13±0.30[b]	172.33±1.52[abcde]
Cow manure	An	2,273.66±30.43[cd]	14.33±0.76[b]	158.66±10.21[def]
Millet bran	Veg	3,411.67±186.38[a]	19.58±0.68[a]	176.01±2.01[ab]
Millet glumes	Veg	1,218.33±19.21[g]	6.85±0.10[f]	177.00±2.51[ab]
Rumen content	An	2,245.66±29.95[de]	12.63±0.40[d]	174.00±6.08[ab]
Rice glumes	Veg	2,276.33±23.58[cd]	14.55±0.79[d]	157.00±7.01[ef]
Wheat bran	Veg	3,281.00±133.04[ab]	24.46±0.57[a]	137.66±4.72[f]
25% Millet bran + 75% rumen content	Veg + An	2,325.33±161.80[de]	14.10±1.51[bc]	166.00±15. 71[bcde]
50% Millet bran + 50% rumen content	Veg + An	2,502.66±102.02[ab]	14.31±0.41[b]	174.66±3.05[abc]
75% Millet bran + 25% rumen content	Veg + An	2,249.00±21.79[de]	14.06±1.23[bc]	160.66±14.01[cdef]
25% Wheat bran + 75% cow manure	Veg + An	1,369.33±54.84[fg]	8.30±0.15[ef]	165.00±3.46[bcdef]
50% Wheat bran + 50% cow manure	Veg + An	2,228.66±17.03[ef]	11.80±0.77[de]	179.00±3.60[a]
75% Wheat bran + 25% cow manure	Veg + An	2,254.00±5.00[de]	13.01±0.25[cd]	173.00±3.60[abcd]
Statistical analyses		Chi^2=36.531; Df=13	Chi^2=36.378; Df=13	Chi^2=26.901; Df=13
P-value		*P*<0.001	*P*<0.001	*P*=0.012

[1] Values are mean ± standard error. Similar letters in the same column indicate no significant difference at 0.05 level. Letters are from the post-hoc tests.
[2] An = animal-based; Veg = plant-based.

higher amount of egg and substrate (1 g of egg per 2 kg of each substrate) than those used in our study (10 mg of egg per 50 g of dry substrate).

Maggots that developed in millet bran had the highest biomass and average weight. This might be explained by the fine and loose texture of the feed, with low consistency and higher aeration, compared to the other substrates. Furthermore, the chemical composition might also enhance larval growth; millet bran (protein=13.26%; lipid=9.95%; ash=9.84%); wheat bran (protein=17.87%; lipid=4.28%; ash=5.30%) (Bouafou *et al.*, 2006; Čičková *et al.*, 2013; Ganda *et al.*, 2021; Hussein *et al.*, 2017; Koné *et al.*, 2017; Sanou *et al.*, 2019). Despite Niger being the second largest millet producing country in West Africa, where wheat production is low (FAO, 2018). Millet bran and wheat bran are typically used to feed small and large ruminants, despite their marketability (1 kilo costs less than one euro). These factors could hinder the use of these substrates in maggot production by smallholder farmers in Niger.

The poor performance of millet glume could be attributed to its coarse texture (even after grinding) and consequent low moisture retention capacity and chemical composition (protein=7.99%; lipid=9.47%; ash=10.43%), hindering maggot development. Despite the low performance of millet glume, it is a substrate with zero market value and represents a potential source of organic matter. It is readily available in most villages in Niger, as the world's second largest millet producer (IRD, 2009). Nevertheless, it requires processing (grinding) to be suitable for larval development. However, the processing of this substrate could induce a financial cost that would hinder its use in maggot production by poultry farmers. Apart from its use in larvae production, Millet glume could possibly be used to aerate dense animal manure such as cow or sheep manure.

In comparison, rice glume and rumen content were promising. These wastes could be well valorised for maggot production. Niger produces about 100,000 tons paddy rice per year, while the rice glume generated represents 21% of the total amount of this production (Ouedraogo, 2016). In addition, according to the Ministry of Agriculture and Livestock, annual beef production is estimated at 59,887 tons of meat. This meat production generates a non-negligible amount of rumen content that could be used in production.

Maggot yield varies greatly with the characteristics of the substrate used, including texture, moisture holding capacity, and chemical composition which can impact egg survival and the larval growth. (Bouafou *et al.*, 2006; Čičková *et al.*, 2013; Hussein *et al.*, 2017; Koné *et al.*, 2017; Sanou *et al.*, 2019). This variability in larval productivity was detected on the substrates used in the present study, and might be attributed to the ability of eggs to survive and develop on each substrate (Fitches *et al.*, 2019).

The housefly is receiving increasing attention in West African countries because she can decompose a large wide

Table 3. Chemical composition of *Musca domestica* maggots produced on different feeding substrates.[1,2]

Growth substrate	Crude protein (% DM)	Crude fat (% DM)	Ash (% DM)	Humidity (% FM)
Agricultural residue	41.47±0.13^{fg}	19.37±2.55^{ab}	13.16±1.14^{b}	72.65±0.26^{k}
Brewer's spent grains	53.79±1.04^{a}	24.13±5.20^{a}	6.27±0.03^{gh}	78.13±0.15^{d}
Cow manure	33.99±0.25^{h}	20.52±4.00^{abc}	15.01±0.32^{a}	80.43±0.37^{b}
Millet bran	43.32±0.64^{cd}	14.94±0.29^{abcdef}	9.75±0.01^{fgh}	75.20±0.20^{h}
Millet glume	43.22±0.47^{d}	21.83±5.91^{ab}	10.58±0.14^{d}	73.15±0.05^{j}
Rumen content	44.74±0.62^{bc}	12.65±1.62^{bcdef}	11.77±0.32^{c}	80.89±0.22^{a}
Rice glume	42.31±0.24^{e}	21.41±2.89^{ab}	9.575±0.04^{f}	73.55±0.24^{ij}
Wheat bran	46.56±0.16^{ab}	16.33±0.02^{abcde}	5.88±0.01^{h}	75.63±0.20^{h}
25% Millet bran + 75% rumen content	43.22±0.02^{d}	6.68±2.30^{cdef}	9.87±0.06^{e}	77.20±0.09^{f}
50% Millet bran + 50% rumen content	40.44±0.01^{gh}	11.60±2.87^{cdef}	9.89±0.02^{e}	76.23±0.19^{g}
75% Millet bran + 25% rumen content	41.79±0.42^{f}	10.16±1.24^{def}	11.68±0.01^{c}	73.91±0.20^{i}
25% Wheat bran + 75% cow manure	41.52±0.47^{f}	11.37±8.97^{cdef}	14.93±0.50^{a}	79.59±0.11^{c}
50% Wheat bran + 50% cow manure	42.43±0.10^{e}	7.70±0.64^{cdef}	15.41±0.09^{a}	77.71±0.05^{de}
75% Wheat bran + 25% cow manure	41.32±0.90^{fg}	15.38±2.39^{abcdef}	13.21±0.08^{b}	77.57±0.19^{ef}
Statistical analyses	Chi^2=39.086; Df=13	F=6.506; Df=13	Chi^2=40.214; Df=13	F=570.05; Df=13
P-value	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$

[1] Values are mean ± standard error. Similar letters in the same column indicate no significant difference at 0.05 level. Letters are from the comparison of means (Duncan and post hoc Kruskal-Wallis test).
[2] DM = dry matter; FM = fresh matter.

of substrates (animal residue, crop and agri-food wastes) for the production of fly larvae, increasingly considered for animal feed worldwide. Outside the maggot production by housefly adult rearing (Drew and Pieterse, 2015; Ganda *et al.*, 2021; Leyo *et al.*, 2021b; Pastor *et al.*, 2015), a simple way to produce fly larvae is to expose suitable substrates to attract adult flies that will lay eggs in the substrates from where larvae will be subsequently extracted (Koné *et al.*, 2017; Nyakeri *et al.*, 2017; Pomalégni *et al.*, 2017).

Chemical composition of maggots fed on different substrates

The highest crude protein and crude fat content of maggots were obtained on spent grain. This substrate type initially had higher protein and fat content comparted to the other substrates. This phenomenon reflects the nutritional quality of brewer's spent grain substrate, which had the highest protein and crude fat content of all substrates.

The nutritional composition of maggots mainly depends on their age at harvest (Aniebo *et al.*, 2008; Aniebo and Owen, 2010), drying method (Fasakin *et al.*, 2003), and larval feeding substrate (Newton *et al.*, 1977). Lipid content slightly increases with larval age (from 20.8 to 25.3%) (Aniebo and Owen, 2010). However, Itongwa *et al.* (2019) showed that the protein content of maggots increasingly varies from the first to fourth stage of maggot development. Therefore, we selected final stage maggots for the current study. The nutrient composition of *M. domestica* larvae found in the current study are in accordance with those reported for several protein sources used as animal feed (Adeboye, 2014; Adesina, 2012; Makkar *et al.*, 2014; Newton *et al.*, 2005; Rana, 2014; Spranghers *et al.*, 2017; Tschirner and Simon 2015; Yu *et al.*, 2009). The results confirmed that *M. domestica* larvae meal had all the qualities to be classified as high protein feed ingredient containing 46 to 51% crude protein.

Crude protein content was determined by the Dumas method, using the conversion factor of 4.76 recommended by Janssen *et al.* (2017). Crude protein content ranged between 33.99% and 53.79%, with previous studies recording ranges of 45-72.5% (Fitches *et al.*, 2019), 42.3-60.4% (Makkar *et al.*, 2014), 39-64% (Makinde, 2015) and 46-51% (Ganda *et al.*, 2021). In the current study, the highest crude protein content was obtained from maggots on Brewer's spent grain (53.79±1.04). This value was lower than that obtained on a mixture of cow dung, chicken droppings, and fresh fish remains (59.65%; Ouédraogo *et al.*, 2015), cattle manure (59%; Hussein *et al.*, 2017), or cow dung (61.52%; Itongwa *et al.*, 2019). This difference was attributed to substrate type and the protein determination method. In contrast to the current study, the other studies used the Kjeldah method and a factor of 6.25, which overestimates the crude protein content of maggots (Janssen *et al.*, 2017). The lowest maggot content obtained on cow manure (33.99±0.25%) in the present study was below that previously obtained on a mixture of bovine blood and wheat bran (47.1%; Aniebo *et al.*, 2008), poultry manure (48%; Odesanya *et al.*, 2011), or on a mixture of bovine blood, bovine manure, and vegetable waste (39.59%; Ferdousi *et al.*, 2020). All of these studies used the Kjeldah method and a factor of 6.25 to determine the protein content of maggots. Overall, the differences between our results and those reported by these researchers were probably caused by the differences of the quality and nature of growing substrate, age at harvest, the method of drying and the analytical procedures employed or the medium (Dillak *et al.*, 2019).

Larvae have high crude protein content can compete with fishmeal commonly used in monogastric feeds and which is not easily available in Africa and certainly not by farmers. However, while the protein content of maggots is lower than that reported for fishmeal (69-72% (protein content of international, high quality fish meal); Batal and Dale, 2010), it is higher than that reported for soybean meal (38-47%; Batal and Dale, 2010). Although protein levels are an essential component of feed, the amino acid content of the flours used in feed is also important. While amino acid content was not measured in this study, Zheng *et al.* (2010) reported that certain essential amino acids (threonine, valine, leucine, phenylalanine, methionine, and lysine) in maggots represent about 48.5% of total amino acids. Adesulu and Mustapha (2000) also reported that the levels of certain amino acids (such as cystine, histidine, phenylalanine, tryptophan, and tyrosine) in maggot meal are higher compared to those in fish meal and soybean meal. Maggot meal is also rich in phosphorus, trace elements, and B-complex vitamins (Teotia and Miller, 1973). Akpodiete and Ologhobo (1999) showed that maggot meal contains all 10 essential amino acids, and is comparable to fish meal (Fetuga, 1977). Ogunji *et al.* (2008b) also reported that maggot meal does not contain anti-nutritional or toxic factors that are sometimes found in alternative plant-based protein sources (sunflower oil) used to feed fish.

The crude fat content range of 6.68 to 24.13 obtained in the present study was comparable to 16-21% lower compared to that obtained by Fitches *et al.* (2019) (18.4-31.1%), but were within the range of those obtained by Makkar *et al.* (2014) (9-26%) and those obtained by Ganda *et al.* (2021) (16-21%). This range was higher than that of other existing studies (8.41-11%) (Cadag *et al.*, 1981; Sogbesan *et al.*, 2005; Ugwumba and Ugwumba, 2003). The crude fat content of larvae produced on brewer's spent grain was comparable to that obtained on poultry manure (24.2%; Fitches *et al.*, 2019) and slightly higher than that obtained for cattle manure (19.6%; Hussein *et al.*, 2017). Maggots have a lipid content that competes with conventional sources. Maggot meal has a fat content (19.10%) that is twice as high as fish meal (10.2%) and 22 times higher than that of soybean meal

(0.9%) (Odesanya *et al.*, 2011). The fat content of maggots is adequate for the required oil addition (of 5 to 7%) to poultry feed (Nigerian Industrial Standard, 2018).

The content of different minerals in maggot ash was not determined. However, maggot ash contained a calcium content (0.31-2.01%) that was equal to or higher than that of soybean (0.33%), but was lower than that of fish meal (5.55%). Similarly, the phosphorus content of maggots was 1.09-1.32% higher compared to that of soybean (0.73%), but was lower below that of fish meal. The potassium content of maggots (0.29-1.27%) is also lower compared to that of soybean meal (2.22%) and fish meal (0.71%). The magnesium content of maggots (0.23-0.25%) is lower compared to that of soybean meal (0.31%), but is higher than that of fish meal (0.17%). Maggot meal contains more iron (604-1,317.34 mg/kg) compared to soybean meal (90 mg/kg) and fish (478 mg/kg). The zinc content in maggot meal ash (48.87-1,039 mg/kg) is also higher compared to soybean meal (28 mg/kg) and fish meal (160 mg/kg). According to the National Research Council (NRC, 1994), calcium, phosphorus and sodium are essential minerals for the nutritional requirements of poultry. Poultry require 0.90-1% calcium depending on age and the amount of feed. Poultry require 0.45-0.48% phosphorus and 0.16-0.20% sodium. Thus, maggot meal meets the mineral requirements of poultry.

The moisture content obtained from maggot meal was comparable to that previously obtained (86%, Odesanya *et al.*, 2011; 83.3%, Sogbesan *et al.*, 2005), confirming the high moisture content of maggots.

Fatty acid profile of maggots

In the present study, the fatty acid profile of maggots was largely composed of C16:0, C16:1, C18:1n9, and C18:2n6. The C16:0 content of maggots ranged from 18.47% (on wheat bran) to 32.09% (on 50% millet bran + 50% rumen content). The C16:1 content of maggots ranged from 10.46% (on wheat bran) to 30.26% (on cow dung). The C18:1n9 content of maggots ranged from 18.73% (on 50% millet bran + 50% rumen content) to 27.93% (on rice glume). The C18:2n6 content of maggots ranged from 2.65 (on cow manure) to 26.41% (on 75% millet bran plus 25% rumen content).

The relative percentage of unsaturated fatty acids in housefly larvae from the present study was similar to existing publications (range: 56-64%), and mainly consisted of palmitoleic, oleic and linoleic acids (Makkar *et al.*, 2014). Fishery products rich in ω3 polyunsaturated fatty acids are widely used in animal feeds, but are expensive; thus, vegetable oils represent alternative cost-efficient (Lagarde, 2008) sources of fats in poultry feed. These oils are rich in the essential fatty acids (ω3 and ω6) required by poultry. Linoleic acid is the essential fatty acid required to meet the nutritional needs of poultry (Cobb, 2008; NRC, 1994). Linoleic acid is a fatty acid with 18 carbons. It is a precursor of long chain fatty acids, such as eicosapentaenoic acid (EPA), docosapentaenoic acid (DPA), and docosahexaenoic acid (DHA) (Kouba and Mourot, 2011; Leighton, 2002). In the present study, the linoleic acid of maggots ranged from 2.65 (on cow manure) to 26.41% (on 75% millet bran plus 25% rumen content). This largely covers the fatty acid requirement of poultry, which represents 1% of fatty acids in poultry diets (Cobb, 2008; NRC, 1994).

5. Conclusions

Larval yield (or biomass) in *M. domestica* varies greatly with the developmental environment of larvae (maggots). The highest larval biomass and average maggot weight were obtained on millet bran and wheat bran, respectively. However, the marketability of these two substrates and their use in animal feed could limit their use for maggot production by small-scale poultry producers. Therefore, animal dung (manures), would be more profitable, especially because livestock production is mainly practiced in rural areas in Niger (89.5% of households own livestock). Animal manures also has the advantage that its residues (after larvae production) are of better quality than those obtained with plant products such as bran.

The protein and lipid content of maggots was highest on Brewer's spent grain. Farmers and industrialists have access to a wide variety of substrates could be used to produce maggots, providing a sustainable source of protein that has not been previously available in Niger. The fatty acid profile of *M. domestica* larvae varied with substrate. The maggots in the present study were rich in linoleic acid (C18:2n6), which is an essential fatty acid used in poultry feed. This acid was higher in maggots produced on 75% millet bran + 25% rumen content.

In conclusion, this study showed that the nutritional profile of *M. domestica* larvae is comparable to that of other known conventional protein sources, including soybean meal, blood meal, and fish meal used in animal feed. *Musca domestica* larvae are an alternative protein source that can replace conventional protein sources used as feed. Its production by small farmers, or small and medium-sized production units using suitable substrates should be encouraged.

Supplementary material

Supplementary material can be found online at https://doi.org/10.3920/JIFF2022.0013

Table S1. Fatty acid profile of *Musca domestica* maggots produced on different feeding substrates.

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Conflict of interest

The authors declare no conflict of interest.

References

Adeboye, O.R, 2014. Effects of different feeding strategies on foraging ability and nutrient digestibility of a slow growing organic broiler genotype. Internship report, Faculty of Science and Technology, Aarhus University, Denmark. 33 pp. Available at: http://orgprints.org/27398

Adenji, A.A., 2007. Effect of replacing groundnut cake with maggot meal in the diet of broilers. International Journal of Poultry Science 6(11): 822-825. https://doi.org/10.3923/ijps.2007.822.825

Adesina, A.J., 2012. Comparability of the proximate and amino acids composition of maggot meal, earthworm meal and soybean meal for use as feedstuffs and feed formulations. Elixir Applied Biology 51: 10693-10699.

Adesulu, E.A. and Mustapha, A.K., 2000. Use of housefly maggots as a fishmeal replaces in tilapia culture: a recent vogue in Nigeria. In: Ftzimmons, K. and Filho, J.C. (ed.) Proceedings of the fifth international symposium on Tilapia Aquaculture. 3-7 September 2000. Rio de Janeiro, Brazil, pp. 138-143.

Akpodiete, O.J. and Ologhobo, A.D., 1999. Biological evaluation of maggot (larvae) meal on the growth and sexual maturity of replacement pullets. Tropical Journal of Animal Science 1(2): 45-51.

Alders, R., 2005. L'aviculture: source de profit et de plaisir. Food and Agriculture Organisation, Rome, Italy, 41 pp.

Anene, A., Afam-Anene, C.O., Ike, K. and Ekekwe, H.N., 2013. Preliminary investigations on quantity and proximate quality of maggots produced from four different sources of livestock wastes. Journal of Research in Biology 3: 1060-1065.

Aniebo, A.O., Erondu, E.S. and Owen, O.J., 2008. Proximate composition of housefly larvae (*Musca domestica*) meal generated from mixture of cattle blood and wheat bran. Livestock Research for Rural Developmen 20(15): 1-5.

Aniebo, A. and Owen, O., 2010. Effects of age and method of drying on the proximate composition of housefly larvae (*Musca domestica* Lineaus) meal. Pakistan Journal of Nutrition 9: 485-487.

Association of Official Analytical Chemists (AOAC), 2005. Official methods of chemical Analysis. 18th Edition. AOAC International, Rockville, MD, USA

Ayssiwede, S.B., Dieng, A., Houinato, M.R.B., Chrysostom, C.A.A.M., Hornick, J.L. and Missohou, A., 2013. Elevage des poulets traditionnels ou indigènes au Sénégal et en Afrique Subsaharienne: état des lieux et contraintes. Annales de Médecine Vétérinaire 158: 101-117.

Barroso, F.G., De Haro, C., Sánchez-Muros, M.J., Venegas, E., Martínez-Sánchez, A. and Pérez-Bañón, C., 2014. The potential of various insect species for use as food for fish. Aquaculture 422-423: 193-201. https://doi.org/10.1016/j.aquaculture.2013.12.024

Bartlett, M.S., 1937. Properties of sufficiency and statistical tests. Proceedings of the Royal Society of London Series A 160: 268-282. https://doi.org/10.1098/rspa.1937.0109.

Batal, A. and Dale, N., 2010. Ingredient analysis table: 2011. University of Georgia, Athens, GA, USA.

Bloukounon-Goubalan, A.Y., Saidou, A., Clottey, V., Chrysostom., C.A.A.M., Kenis, M. and Mensah, G.A., 2017. Typology of organic residues attracting flies and their utilization in the agricultural sector in southern Benin. International Journal of Biological Chemical Science 11(6): 2560-2572.

Bouafou, K.G.M., Kouame, K.G., Amoikon, K.E. and Offoumou, A.M., 2006. Potentiel pour la production d'asticots sur des sous-produits en Côte d'Ivoire. Tropicultura 24: 157-161.

Cadag, M.T., Lopez, P.L. and Mania, R.P., 1981. Production and evaluation of maggot meal from common housefly (*Musca domestica*) as animal feed. Philippine Journal of Veterinary and Animal Sciences 7(1): 40-41.

Charlton, A.J., Dickinson, M., Wakefield, M.E., Fitches, E., Kenis, M., Han, R., Zhu, F., Kone, N., Grant, M., Devic, E., Bruggeman, G., Prior, R. and Smith, R., 2015. Exploring the chemical safety of fly larvae as a source of protein for animal feed. Journal of Insects as Food and Feed 1(1): 7-16. https://doi.org/10.3920/JIFF2014.0020

Čičková, H., Kozánek, M. and Takáč, P., 2013. Improvement of survival of the house fly (*Musca domestica* L.) larvae under mass-rearing conditions. Bulletin of Entomological Research 103(01): 119-125. https://doi.org/10.1017/S000748531200065X

Cobb, 2008. Cobb 500 – performances et recommandations nutritionnelles. Available at: https://tinyurl.com/2bmueu2m

Coulibaly, K., Sankara, F., Pousga, S., Philippe, J.N., Marc, B.S. and Hassan, B., 2020a. Effects of poultry litter and the residues of maggot's production on chemical fertility of a lixisol and maize (*Zea mays* L.) yield in western of Burkina Faso. Nigerian Journal of Soil Science 30(2): 95-102. https://doi.org/10.36265/njss.2020.300212

Coulibaly, K., Sankara, F., Pousga, S., Nacoulma, P.J., Somé, M.B. and Nacro, H.B., 2020a. On station maggot production using poultry litter as substrate: assessment on the quantity and the chemical quality of the litter before and after maggot production in Burkina Faso. International Journal of Biological Chemical Science 14(5): 1689-1697. https://doi.org/10.4314/ijbcs.v14i5.16

De Marco, M., Martínez, S., Hernandez, F., Madrid, J., Gai, F., Rotolo, L., Belforti, M., Bergero, D., Katz, H., Dabbou, S., Kovitvadhi, A., Zoccarato, I., Gasco, L. and Schiavone, A., 2015. Nutritional value of two insect larval meals (*Tenebrio molitor* and *Hermetia illucens*) for broiler chickens: Apparent nutrient digestibility, apparent ileal amino acid digestibility and apparent metabolizable energy. Animal Feed Science and Technology 209: 211-218. https://doi.org/10.1016/j.anifeedsci.2015.08.006

Dillak, Y.F.G., Suryatni, N.P.F., Handayani, H.T., Temu, S.T., Nastiti, H.P., Osa, D.B., Ginting, R., Yunilas, and Henuk, Y.L., 2019. The effect of fed maggot meal as a supplement in the commercial diets on the performance of finisher broiler chickens. IOP Conference Series: Earth and Environmental Science. Vol. 260. International Conference on Agriculture, Environment, and Food Security 2018. 24-25 October 2018. Medan, Indonesia. Available at: https://doi.org/10.1088/1755-1315/260/1/012056

Drew, D.J.W. and Pieterse, E., 2015. Markets, money and maggots. Journal of Insects as Food and Feed 1: 227-231.

Fasakin, E.A., Balogun, A.M. and Ajayi, O.O., 2003. Evaluation of full-fat and defatted maggot meals in the feeding of clariid catfish *Clarias gariepinus* fingerlings. Aquaculture Research 34(9): 733-738.

Ferdousi, L., Bithi, U., Lisa, S., Momtaz, N., Rashid, M. and Islam, M., 2020. Nutritional composition of house fly larvae (*Musca domestica*) reared on different mixture ratio of cattle blood with organic wastes. International Journal of Biosciences 17: 518-527. https://doi.org/10.12692/ijb/17.6.518-527

Fetuga, B.I., 1977. Animal production in Nigeria and feed supplies. Nigerian Journal of Animal Production 418-421.

Fitches, E.C., Dickinson, M., De Marzo, D., Wakefield, M.E., Charlton, A.C. and Hall, H., 2019. 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. and Sloane Stanley, G.H., 1957. A simple method for the isolation and purification of total lipides from animal tissues. The Journal of Biological Chemistry, 226(1): 497-509.

Food and Agriculture Organisation (FAO), 2018. Classement des Etats d'Afrique par production de blé. Available at: https://tinyurl.com/hwnjf36m

Ganahi, A., Maizama, D.G., Assane, A., Boukari, M., Karimou, A., Salé, M., Hama, H., Mounkaila, M., Madougou, B. and Maimouna, N., 2016. Guide de l'aviculteur au Niger. Available at: https://reca-niger.org/IMG/pdf/Guide_Aviculture_Niger_VF.pdf

Ganda, H., Zannou-Boukari, E.T., Kenis, M., Chrysostome, C.A.A.M. and Mensah, G.A., 2019. Potentials of animal, crop and agri-food wastes for the production of fly larvae. Journal of Insects as Food and Feed 5(2): 59-60.

Ganda, H., Zannou, E.T., Kenis, M., Abihona, A.H., Houndonougbo, F.M., Chrysostome, C.A.A.M., Chougourou, C.D. and Mensah, G.A., 2021. Effect of four rearing substrates on the yield and the chemical composition of housefly larvae, *Musca domestica* L. 1758 (Diptera: Muscidae). International Journal of Tropical Insect Science 42: 1331-1339. https://doi.org/10.1007/s42690-021-00651-z

Holmes, L.A., Vanlaerhoven, S.L. and Tomberlin, J.K., 2012. Relative humidity effects on the life history of *Hermetia illucens* (Diptera: Stratiomyidae). Environmental Entomology 41(4): 971-978. https://doi.org/10.1603/EN12054

Hussein, M., Pillai, V.V., Goddard, J.M., Park, H.G., Kothapalli, K.S., Ross, D.A., Ketterings, Q.M., Brenna, J.T., Milstein, M.B., Marquis, H., Johnson, P.A., Nyrop, J.P. and Selvaraj, V., 2017. Sustainable production of housefly (*Musca domestica*) larvae as a protein-rich feed ingredient by utilizing cattle manure. PLoS ONE 12(2): e0171708. https://doi.org/10.1371/journal.pone.0171708

Institut de recherche pour le développement, 2009. Le mil, aliment du futur au Sahel. Available at: https://tinyurl.com/mt4u5md8

Itongwa, J.A., Wasso, D.S., Kazamwali, L.M., Bisimwa, N.P. and Jean-Pierre, B.B., 2019. Essai de production et composition chimique des asticots élevés sur des substrats locaux au Sud-Kivu (RDC). Journal of Applied Bioscience 142: 14529-14539.

Janssen, R.H., Vincken, J.P., Van den Broek, L.A.M., Fogliano, V. and Lakemond, C.M.M., 2017. Nitrogen-to-protein conversion factors for three edible insects: *Tenebrio molitor, Alphitobius diaperinus*, and *Hermetia illucens*. Journal of Agricultural and Food Chemistry 65(11): 2275-2278. https://doi.org/10.1021/acs.jafc.7b00471

Kelemu, S., Niassy, S., Torto, B., Fiaboe, K., Affognon, H., Tonnang, H., Maniania, N.K. and Ekesi, S., 2015. African edible insects for food and feed: inventory, diversity, commonalities and contribution to food security. Journal of Insects as Food and Feed 1(2): 103-119. https://doi.org/10.3920/JIFF2014.0016

Kenis, M., Koné, N., Chrysostome, C.A.A.M., Devic, E., Koko, G.K.D., Clottey, V.A., Nacambo, S. and Mensah, G.A., 2014. Insects used for animal feed in West Africa. Entomologia 2(2): 65. https://doi.org/10.4081/entomologia.2014.218

Keiding, J. and Arevad, K., 1964. Procedure and equipment for rearing a large number of housefly strains. Bulletin of the World Health Organization 31: 527-528.

Koné, N., Sylla, M., Nacambo, S. and Kenis, M., 2017. Production of house fly larvae for animal feed through natural oviposition. Journal of Insects as Food and Feed 3(3): 177-186. https://doi.org/10.3920/JIFF2016.0044

Kouba, M. and Mourot, J., 2011. A review of nutritional effects on fat composition of animal products with special emphasis on n-3 polyunsaturated fatty acids. Biochimie 93: 1317.

Lagarde, M., 2008. Docosahexaenoic acid: nutrient and precursor of bioactive lipids. European Journal of Lipid Science and Technology 110: 673-678.

Leighton, F., 2002. Dietas mediterraneas 6. Boletín Ciencia, Vino y Salud 1: 1-20.

Leyo, I.H., Ousman, Z.M., Francis, F. and Caparros Megido, R., 2021a. Techniques for the production of housefly (*Musca domestica* L. 1758) maggots for poultry feed, a literature review. Tropicultura 39(2): 2295-8010. https://doi.org/10.25518/2295-8010.1813.

Leyo, I.H., Ousmane, Z.M., Noël, G., Francis, F. and Caparros Megido, R., 2021b. Breeding enhancement of *Musca domestica* L. 1758: egg load as a measure of optimal larval density. Insects 12(11): 956. https://doi.org/10.3390/insects12110956

Lwelamira, J., 2012: Phenotypic and genetic parameters for body weights and antibody response against Newcastle disease virus (NDV) vaccine for kuchi chicken ecotype of Tanzania under extensive management. Tropical Animal Health and Production 44(7): 1529-34. https://doi.org/10.1007/s11250-012-0099-z

Makinde, O.J., 2015. Maggot meal: a sustainable protein source for livestock production – a review. Advances in Life Science and Technology 31: 34-41.

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

Moussa, H.O., 2014. Caractérisation zootechnique et morphologique des poulets 'Kolonto' dans la zone de Gaya. Mémoire de Master, Université Abdou Moumouni de Niamey, Niamey, Niger, 71 pp.

National Research Council, 1994. Nutrient requirement of poultry, 9th revised edition. The National Academic Press, Washington, DC, USA. https://doi.org/10.17226/2114

Newton, G.L., Booram, C.V., Barker, R.W. and Hale, O.M., 1977. Dried *Hermetia illucens* larvae meal as a supplement for swine. Journal of Animal Science 44(3): 395-400. https://doi.org/10.2527/jas1977.443395x

Newton, L., Sheppard, C., Watson, D.W., Burtle, G., Dove, R., 2005. Using the black soldier fly, *Hermetia illucens*, as a value-added tool for the management of swine manure Animal and Poultry Waste Management Center, North Carolina State University, Raleigh, NC, USA.

Nigerian Industrial Standard, 2018. Standard for poultry feeds. Nigerian Industrial Standard, Lagos, Nigeria, 47 pp.

Niu, Y., Zheng, D., Yao, B., Cai, Z., Zhao, Z., Wu, S., Cong, P. and Yang, D., 2017. A novel bioconversion for value-added products from food waste using *Musca domestica*. Waste Management 61: 455-460. https://doi.org/10.1016/j.wasman.2016.10.054

Nyakeri, E.M., Ogola, H.J., Ayieko, M.A. and Amimo, F.A., 2017. An open system for farming black soldier fly larvae as a source of proteins for small scale poultry and fish production. Journal of Insects as Food and Feed 5: 39-51

Odesanya, B.O., Ajayi, S.O., Agbaogun, B.K.O. and Okuneye, B., 2011. Comparative evaluation of nutritive value of maggots. International Journal of Scientific and Engineering Research 2(11).

Ogunji, J.O., Kloas, W., Wirth, M., Neumann, N. and Pietsch, C., 2008b. Effect of housefly maggot meal (magmeal) diet on the performance, concentration of plasma glucose, cortisol and blood characteristics of *Oreochromis niloticus* fingerlings. Journal of Animal Physiology and Animal Nutrition 92(4): 511-518.

Ouedraogo, W.M., 2016. Analyse socio-économique de l'utilisation des balles de riz comme source d'énergie innovante dans le centre d'étuvage de Bama au Burkina Faso. Mémoire de Master, 51 pp.

Ouédraogo, B., Gnanda, I.B., Sanfo, R., Zoundi, S.J. and Bayala, B., 2015. Etude comparative des performances réalisées avec l'incorporation de la farine de co-produits de volaille et la farine des asticots dans des rations de poulets de chair au Burkina Faso. Revue Ivoirienne des Sciences et Technologies 25: 148-161.

Pastor, B., Velasquez, Y., Gobbi, P. and Rojo, S., 2015. Conversion of organic wastes into fly larval biomass: bottlenecks and challenges. Journal of Insects as Food and Feed 1(3): 179-193. https://doi.org/10.3920/JIFF2014.0024

Patrick, R., 1982. An extension of Shapiro and Wilk's W test for normality to large samples. Applied Statistics 31: 115-124. https://doi.org/10.2307/2347973.

Pieterse, E. and Pretorius, Q., 2014. Nutritional evaluation of dried larvae and pupae meal of the housefly (*Musca domestica*) using chemical- and broiler-based biological assays. Animal Production Science 54(3): 347. https://doi.org/10.1071/AN12370

Pomalégni, S.C.B., Gbemavo, D.S.J.C., Kpadé, C.P., Kenis, M. and Mensah, G.A., 2017. Traditional use of fly larvae by small poultry farmers in Benin. Journal of Insects as Food and Feed 3(3): 187-192.

Rana, K., 2014. Development of black soldier fly larvae rearing technique to supplement fish feed. Réseau national des chambres d'agricultures du Niger (RECA), 2010. Revue du secteur del'élevage au Niger.115 pp.

Sanou, A.G., Sankara, F., Pousga, S., Coulibaly, K., Nacoulma, J.P., Ouedraogo, I., Nacro, S., Kenis, M., Sanon, A. and Somda, I., 2019. Production de masse de larves de *Musca domestica* L. (Diptera: Muscidae) pour l'aviculture au Burkina Faso: analyse des facteurs déterminants en oviposition naturelle. Journal of Applied Biosciences 134(1): 13689. https://doi.org/10.4314/jab.v134i1.6

Sogbesan, A.O. and Ugwumba, A.A.A., 2008. Nutritional values of some non-conventional animal protein feedstuffs used as fishmeal supplement in aquaculture practices in Nigeria. Turkish Journal of Fisheries and Aquatic Sciences 8: 159-164

Sogbesan, O.A., Ajuonu, N.D., Ugwumba, A.A.A. and Madu, C.T., 2005. Cost benefits of maggot meal as supplemented feed in the diets of *Heterobranchu slongifilis* × *Clarias gariepinus* (Pisces-Clariidae) hybrid fingerlings in outdoor concrete tanks. Journal of Industrial and Scientific Research 3(2): 51-55.

Spranghers, T., Ottoboni, M., Klootwijk, C., Ovyn, A., Deboosere, S., Meulenaer, B., Michiels, J., Eeckhout, M., De Clercq, P. and De Smet, S., 2017. Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. Journal of the Science of Food and Agriculture 97: 2594-2600. https://doi.org/10.1002/jsfa.8081

Tchibozo, S., Van Huis, A. and Paoletti, M.G., 2005. Notes on edible insects of South Benin: a source of protein. In: Paoletti, M.G. (ed.) Ecological implications of mini livestock. Role of rodents, frogs, snails and insects for sustainable development. Science Publishers, Enfield, USA, pp. 246-250.

Teotia, J.S. and Miller, B.F., 1973. Fly pupae as a dietary ingredient for starting chicks. Poultry Science 53: 1830-1835.

Tschirner, M., Simon, A., 2015. Influence of different growing substrates and processing on the nutrient composition of black soldier fly larvae destined for animal feed. Journal of Insects as Food and Feed 1: 249-259.

Ugwumba, A.A.A. and Ugwumba, A.O., 2003. Aquaculture options and future of fish supply in Nigeria. The Zoologist 2(2): 96-122.

Van Huis, A., 2003. Insects as food in sub-Saharan Africa. International Journal of Tropical Insect Science 23(3): 163-185. https://doi.org/10.1017/S1742758400023572

Van Huis, A., Van Itterbeeck, J., Klunder, H., Mertens, E., Halloran, A., Muir, G. and Vantomme, P., 2013. Edible insects: future prospects for food and feed security. FAO Forestry Paper No. 171. FAO, Rome, Italy. Available at: https://www.fao.org/3/i3253e/i3253e.pdf

Vidogbena, F., Adegbidi, A., Garnett, S.T., Koudande, D., Agbo, V. and Zander, K., 2010. Peace, health or fortune? Preferences for chicken traits in rural Benin. Ecological Economics 69(9): 1848-1857.

Wang, H., Wang, S., Li, H., Wang, B., Zhou, Q., Zhang, X., Li, J. and Zhang, Z., 2016. Decomposition and humification of dissolved organic matter in swine manure during housefly larvae composting. Waste Management and Research 34(5): 465-473. https://doi.org/10.1177/0734242X16636675

XiaoMing, C., Ying, F., Hong, Z. and ZhiYong, C., 2010. Review of the nutritive value of edible insects. In: Durst, P.B., Johnson, D.V., Leslie, R.N. and Shono, K. (eds.) Forest insects as food: humans bite back. Proceedings of a workshop on Asia-Pacific resources and their potential for development. 19-21 February 2008. Chiang Mai, Thailand, pp. 85-92.

Youssao, A.K.I., Tougan, U.P., Ahounou, S.G., Houessionon, B.F.J. and Koutinhouin, B., 2013. Typology of local poultry breeding of *Gallus gallus* species in family poultry in Benin. International Journal of Agronomy and Agricultural Research 4: 1-13

Yu, G., Chen, Y., Yu, Z. and Cheng, P., 2009. Research progress on the larvae and prepupae of black soldier fly *Hermetia illucens* used as animal feedstuff. Chinese Bulletin of Entomology 46: 41-45.

Zakara, T.A.L., 2016. Effet d'une substitution de la farine de poisson par la farine de criquet sur les performances de croissance du poulet de chair au Niger. Thèse de Doctorat en Médecine Vétérinaire, E.I.S.M.V. Université Cheikh Anta Diop de Dakar, Dakar, Senegal, 91 pp.

Zhang, Z., Wang, H., Zhu, J., Suneethi, S. and Zheng, J., 2012. Swine manure vermicomposting via housefly larvae (*Musca domestica*): the dynamics of biochemical and microbial features. Bioresource Technology 118: 563-571. https://doi.org/10.1016/j.biortech.2012.05.048

Zheng, W., Dong, Z., Wang X.Q., Cao, M., Yan, B.L. and Li, S.H., 2010. Effects of dietary fly maggot (*Musca domestica*) on growth and body compositions in Chinese shrimp *Fenneropenaeus chinensis* juveniles. Fisheries Science 29(4): 187-192.