International Journal of Tropical Insect Science
https://doi.org/10.1007/s42690-021-00651-z

ORIGINAL RESEARCH ARTICLE

Effect of four rearing substrates on the yield and the chemical composition of housefly larvae, *Musca domestica* L. 1758 (Diptera: Muscidae)

H. Ganda[1,3] · E. T. Zannou[1] · M. Kenis[2] · H. A. Abihona[1] · F. M. Houndonougbo[3] · C. A. A. M. Chrysostome[3] · D. C. Chougourou[4] · G. A. Mensah[5]

Received: 12 May 2020 / Accepted: 10 September 2021
© African Association of Insect Scientists 2021

Abstract

The use of insects such as black soldier fly (*Hermetia illucens*) and common housefly (*Musca domestica*) as an alternative source of protein in animal feed has gained interest in recent years. This study investigated the effect of four growing substrates on the biomass, crude nutrient and mineral composition of *M. domestica* larvae. After a 5-day growing period, the total dry matter (DM) of maggot yield was 69.70; 59.33; 43.58 and 41.04 g/kg for soybean bran + maize pericarp, pig manure, maize bran and chicken manure, respectively. The chemical composition of maggot was significantly influenced by the type of substrate. The highest contents in crude ash (124.90 g/kg DM), crude fibre (167.65 g/kg DM) and sodium (53.47 g/kg DM) were obtained from maggots produced with pig manure. Maggots produced with the mixture of soybean bran and maize pericarp showed the highest fat (218.40 g/kg DM), crude protein (517.10 g/kg DM), potassium (89.05 g/kg DM) and metabolizable energy (4198.52 kcal/kg DM) contents. Maggots from maize bran had more calcium (51.84 g/kg DM) and phosphorus (104.55 g/kg DM) than those from others substrates. This study showed that soybean bran + maize pericarp and pig manure are the most suitable substrates for maggots' production to provide high yields of larvae with a good nutrient content.

Keywords Animal feed · Maggot yield · *Musca domestica* · Nutrients content · Protein

Introduction

The use of insects as an alternative source of protein in animal feed has gained interest in recent years. Insect production can potentially enhance food and feed security because they grow and reproduce easily, have high feed conversion efficiency and can be reared on bio-waste streams (Makkar et al. 2014). The most promising insect species are the Black soldier fly (*Hermetia illucens* (L.) 1758) and Common housefly (*Musca domestica* L. 1758). These species receive increasing attention because they can valorize organic waste, contain between 30 and 70% of protein on a dry matter basis and are also rich in lipids, minerals and amino acids (Veldkamp et al. 2012). *Musca domestica* is the most common fly (Diptera) species on earth. Both the larvae (maggots) and the adult flies feed on manure and decaying organic matters. House fly maggots can be fed alive, dried and ground to livestock and fish (Odesanya et al. 2011; van Zanten et al. 2014; Vodounnou et al. 2015).

Many studies have shown that maggot production is possible by using different substrates like manures, food wastes, market wastes, fish offal, viscera, bran, spent grain etc. (Boire et al. 1988; Bouafou et al. 2006; Mpoame et al. 2004; Ossey et al. 2012). Anene et al. (2013) evaluated the quantity of maggots harvested from various substrates such as cow blood, chicken, pig and cow manures and concluded that maggot production depended on the nature of the substrate.

✉ H. Ganda
gandahaffiz@gmail.com

1 Laboratory of Agricultural Entomology (LEAg), Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Republic of Benin

2 CABI, Rue des Grillons 1, 2800 Delémont, Switzerland

3 Laboratory of Aviculture and Zoo-Economy Research, Faculty of Agronomic Sciences, University of Abomey-Calavi, Abomey-Calavi, Republic of Benin

4 Département Génie de L'Environnement, Ecole Polytechnique d'Abomey-Calavi, Université d'Abomey-Calavi, Abomey-Calavi, Republic of Benin

5 Laboratory of Zootechny, Veterinary and Fishery Research, CRA Agonkanmey, National Institute of Agricultural Researches (INRAB), Abomey-Calavi, Republic of Benin

Published online: 25 September 2021

The most productive substrate was chicken manure followed by cow blood. Similarly, Larraín and Salas (2008) showed that composted swine manure did not allow the development of the house fly larvae because of the reduced moisture and the low nutritive value of the compost. Moon et al. (2001) and Wortman et al. (2006) established that moisture levels of substrates below 30–40% do not permit the development of the house fly larvae; the optimum moisture being in the range of 50 to 80% during the production cycle. It has also been shown that the average weight and size of house fly larvae and pupae varied according to the nature of the rearing substrate (Agbeko et al. 2014; Djissou et al. 2015; Larraín and Salas 2008). Furthermore, maggot quality depends to the nutritional composition of the substrate. Thus, protein, lipid, minerals, fibre and amino acids contents of maggots are known to vary from one substrate to the other (Akpodiete et al. 1998; Anene et al. 2013). Many investigations have been done on the maggot productivity of some substrates and their quality. The substrate which has been most studied is chicken manure. But other substrates have to be evaluated to assess their production potential and the chemical composition of maggots' yield. In a previous study, Ganda et al. (2019) had evaluated, in natural oviposition systems, the potential of several animal manures and agri-food wastes for maggot production. They identified soybean bran, maize bran, pig manure and chicken manure as the best substrates for maggot production. They also showed that house flies, black soldier flies and blow flies are the fly species that develop in these substrates. But they did not investigate the potential of these substrates using housefly eggs through an adult fly rearing system, i.e. a system where eggs are produced in cages and added to the substrate to obtain larvae. Nor did they investigate the quality of the maggots produced on these substrates.

This work is a comparative evaluation of the quantity and the quality of *M. domestica* larvae produced on chicken manure, pig manure, soybean bran and maize bran.

Material and methods

Musca domestica rearing

The tests were conducted at the farm of the Faculty of Agronomic Sciences, Abomey-Calavi University in Benin (latitude: 6°24'54.6912''N and longitude: 2°20'40.1892''E) from February to June 2018. The different fly colonies used in the study were obtained from fermented corn bran exposed to natural fly populations during the same period. Adults of *M. domestica* were reared in gauze cages (60 × 60x80 cm). They were provided with water and fed with pineapple pulp. The oviposition substrate consisted of fermented chicken manure covered by yellow fabric on which the females laid their eggs (Charlton et al. 2015). The harvested eggs were placed on different substrates (Devic 2014; Lomas 2012) for larvae production. All the tests were conducted outdoors under a roof to avoid the effects of rain and direct sun. Temperatures during the tests varied between 24 and 32 °C and relative humidity varied from 60 to 70%.

Production of fly larvae

Four different substrates (maize bran, soybean bran + maize pericarp, chicken manure and pig manure) were tested using a completely randomized design with six replicates. The manures used in our study were obtained in farms specialized in the production of chicken and pig in the township of Abomey-Calavi and were collected the day before the tests. Chicken manure came from laying hens. Maize and soybean brans came respectively from the processing of maize to starch and soybean to tofu. Brans were collected three days before the trials. Maize pericarp was added to soybean bran (proportion 1:3) to reduce the moisture of this substrate and improve its texture (Ganda et al. 2019).

To carry out the tests, 1 g of egg was placed on 2 kg of each substrate in 500 cm^3 plastic containers. Then, the containers were covered with a mesh (diameter of 1.2 mm) to avoid the oviposition of other flies. *Musca domestica* larvae were harvested on the fifth day after incubation, using a 5 mm sieve (Ganda et al. 2019) and weighed. A part of the harvested maggots was incubated on the different substrates to obtain pupae of which sizes were measured. The second part was cleaned with water and killed by plunging them during 20 min in hot water. Killed maggots were then sun dried during five days and further dried in an oven at 60 °C for 72 h to determine the dry matter.

Yield and length measurements

Killed maggots were then taken to the laboratory and weighted before being dried to determine the dry matter. The average lengths of the larvae and pupae was determined from a sample of 50 larvae and 50 pupae per substrate and replicated six times.

Sample preparation for chemical analysis

Three samples of 200 g of each substrate were taken before egg incubation, to determine their dry matter, protein, fat, total ash, fibre, phosphorus, potassium, calcium, sodium and metabolize energy contents. Fresh maggots were weighed and mixed. Then, three samples of 300 g were dried in open air during five days and then dried in an oven at 60 °C for

72 h. Dry maggots were used for chemical analyses to determine their dry matter, protein, fat, total ash, fibre, phosphorus, potassium, calcium, sodium and metabolizable energy.

Determination of chemical composition of maggots

The proximal physico-chemical composition of fly larvae and substrates were determined to evaluate the nutritional quality of fly larvae according to substrate quality. Standard methods as described in Chemists (2004) were used. Dry matter was determined by drying larvae in an oven at 105 °C. Crude protein content was obtained using the Kjeldahl method while fat was extracted by the soxhlet method using hexane. Crude fibre contents were determined by the Filter Bag Technique using sulfuric acid and sodium hydroxide. Phosphorus was determined as the phosphate using molybdovanandate method with a Spectrophotomer (DR 6000, 880 nm). Metabolisable energy was calculated according to the Sibbald equation in Leclercq and Pérez (1989).

$$ME = 3951 + 54.4Fat - 88.7CFi - 40.8CA$$

ME = Metabolisable energy (Kcal / kg MS); Fat = Fat (%); CFi = Crud Fiber (%); CA = Crud Ash (%). 3951; 54.4; 88.7 and 40.8 are constants.

The determination of potassium and sodium ions was carried out by potentiometry with an ion selected electrod. For validation, the reference material used was BIOLABO multicalibrator REF 95,015/SRM 909b. Calcium was determined by complexometry with ethylenediaminetetraacetic acid (EDTA). The crud ash content was obtained after calcination at 550 °C of the dry sample during six hours. All analyses were conducted at the «Laboratoire d'Etude et de Recherche en Chimie Appliquée of Ecole Polytechnique d'Abomey-Calavi» at University of Abomey-Calavi, Benin.

Data analysis

The statistical analyses were performed using R 3.5.1 software (R Core Team 2018). An analysis of variance following the GLM procedure with the substrate as factor was performed to compare larvae productivity and size, dry matter, protein, fat, total ash, fibre, phosphorus, potassium, calcium, sodium and metabolizable energy contents in substrates and maggots. The Student Newman and Keuls test was used for comparison of means among treatment ($P \leq 0.05$ level of significance).

To determine the best substrates considering the larval yield and their quality, a Principal Component Analysis (PCA) was carried out. This PCA considered the four substrates and the fourteen variables linked to the productivity of the substrates and the physicochemical characteristics of the larvae. It allows to group together all four substrates and the fourteen variables linked to the productivity of the substrates and to merge the physicochemical characteristics of the larvae into two (02) or three (3) macro variables (main components). Principal components analyses were performed using the function PCA of package FactoMineR (Lê et al. 2008).

Results

Substrates' chemical composition

The nutrient content varied among substrates ($P < 0.0001$) as shown in Table 1. Pig manure showed the highest content (g/kg DM) in crude ash (357.35), crude fibre (229.70), phosphorus (10.97) and sodium (5.83). The lowest contents in crud ash (31.90), crude fibre (74.45) and

Table 1 Chemical composition of the four substrates evaluated (means ± standard deviation)

Parameters	Substrates			
	Maize bran	Soybean bran + maize pericarp	Chicken manure	Pig manure
DM (%)	30.65 ± 0.89b	20.59 ± 0.72c	29.89 ± 0.32b	32.12 ± 0.54a
Ash (g/kg DM)	31.90 ± 7.60d	59.15 ± 8.75c	298.57 ± 8.73b	357.35 ± 8.05a
Lipid (g/kg DM)	41.95 ± 11.15b	79.75 ± 8.15a	4.75 ± 0.35c	08.00 ± 2.90c
Protein (g/kg DM)	166.00 ± 10.30b	196.00 ± 12.60a	136.1 ± 9.0c	84.85 ± 3.35d
Fibre (g/kg DM)	185.10 ± 13.3b	74.45 ± 10.75c	219.70 ± 7.1a	229.70 ± 4.0a
Ca (g/kg DM)	3.75 ± 0.14a	2.47 ± 0.20b	3.44 ± 0.25a	2.46 ± 0.11b
P (g/kg DM)	9.20 ± 0.24b	8.13 ± 0.11c	7.94 ± 0.21c	10.97 ± 0.38a
Na (g/kg DM)	4.35 ± 0.23c	4.77 ± 0.08b	4.33 ± 0.23c	5.83 ± 0.08a
K (g/kg DM)	7.56 ± 0.19b	11.72 ± 1.22a	7.20 ± 0.21b	7.05 ± 0.30b
Energy Kcal/kg DM	2407.2 ± 208.9b	3483,1 ± 122.6a	810.0 ± 36c	499.1 ± 122.7d

Similar letters in the same row indicate no significant difference between substrates at p = 0.05 level

Table 2 Maggot yield, larval and pupal size of *M. domestica* (means ± standard deviation)

Parameters	Substrates			
	Maize bran	Soybean bran + maize pericarp	Chicken manure	Pig manure
Yield maggot (g /kg of substrate in dry matter)	43.58 ± 4.25c	69.70 ± 1.84a	41.04 ± 3.28c	59.33 ± 3.13b
Larvae length (cm)	1.02 ± 0.01b	1.06 ± 0.02a	0.98 ± 0.02c	1.03 ± 0.01b
Pupae length (cm)	0.52 ± 0.01a	0.52 ± 0.01a	0.46 ± 0.01b	0.51 ± 0.01a

Similar letters in the same row indicate no significant difference between substrates at p = 0.05 level

phosphorus (7.935) were registered in maize bran, soybean bran + maize pericarp and chicken manure, respectively. The mixture of soybean bran and maize pericarp presented the highest content (g/kg DM) in fat (79.75), protein (196.00) and potassium (11.72). Maize bran contained more calcium (3.749 g/kg DM) than others substrates but there was no statistical difference with chicken manure.

Effect of substrates on maggot yield and size

Maggot yield (DF = 3; F = 104.76; P < 0.0001), larvae length (DF = 3; F = 28.29; P < 0.001) and pupae length (DF = 3; F = 63.62; P < 0.001) of *M. domestica* were significantly influenced by the type of substrate (Table 2). The more productive substrate was the mixture of soybean bran and maize pericarp (69.70 g of maggot/kg of substrate DM) whereas chicken manure showed the lowest productivity (41.04 g/kg DM). The mixture of soybean bran and maize pericarp also presented the longest larvae (1.06 cm) and pupae (0.52 cm) but there was no statistical difference between this substrate, maize bran and pig manure for larvae length. The shortest larvae (0.98 cm) and pupa (0.46 cm) were registered in chicken manure.

Effect of substrates on chemical composition of *M. domestica* larvae

The dry matter content of *M. domestica* larvae was not affected by the type of substrate (DF = 3; F = 1.376; P = 0.318) (Table 3). The DM content of substrates was comparable for the four substrates with values between 25.23 and 26.83% (Table 3). However, there were strong statistical differences in the chemical composition of larvae among substrates (DF = 3; F = 4.976 to 273.2; P = 0.031 to P < 0.0001) (Table 3). The highest content in total ash (124.90 g/kg DM), crude fibre (167.65 g/kg DM) and sodium (5.35 g/kg DM) where obtained in larvae from pig manure. Larvae produced in the mixture of soybean bran and maize pericarp had a high content of fat (218.40 g/kg DM), protein (517.10 g/kg DM), potassium (8.91 g/kg DM) and metabolizable energy (4198.52 kcal/kg DM). Larvae from maize bran contained more calcium (5.18 g/kg DM) and phosphorus (10.46 g/kg DM) than those from others substrates.

Table 3 Chemical composition (means ± standard deviation) of *M. domestica* larvae produced from different substrates

Parameters	Substrates			
	Maize bran	Soybean bran + maize pericarp	Chicken manure	Pig manure
DM (%)	26.06 ± 1.34a	25.23 ± 0.38a	26.07 ± 0.63a	26.83 ± 1.17a
Ash (g/kg DM)	61.20 ± 9.60c	55.20 ± 2.90c	97.15 ± 7.05b	124.90 ± 7.20a
Lipid (g/kg DM)	212.35 ± 10.03a	218.40 ± 8.40a	181.20 ± 4.80b	160.80 ± 18.40b
Protein (g/kg DM)	470.95 ± 6.45b	517.10 ± 22.00a	466.15 ± 7.75b	508.55 ± 2.05a
Fibre (g/kg DM)	127.70 ± 9.80c	80.65 ± 6.45d	150.10 ± 5.10b	167.65 ± 6.45a
Ca (g/kg DM)	5.18 ± 0.19a	2.69 ± 0.11c	4.28 ± 0.13b	2.80 ± 0.03c
P (g/kg DM)	10.46 ± 0.24a	9.29 ± 0.23b	8.87 ± 0.17c	10.38 ± 0.09a
Na (g/kg DM)	5.07 ± 0.45ab	4.54 ± 0.08b	4.96 ± 0.25ab	5.35 ± 0.02a
K (g/kg DM)	8.68 ± 0.28a	8.91 ± 0.01a	7.81 ± 0.10b	6.51 ± 0.34c
Energy Kcal/kg DM	3723.79 ± 181.85b	4198.52 ± 23.35a	3208.97 ± 9.64c	2829.10 ± 127.93d
P/Ca	2.02 ± 0.12	3.467 ± 0.222	2.072 ± 0.022	3.697 ± 0.002

Similar letters in the same row indicate no significant difference between substrates at p = 0.05 level

Characterization of substrates according to their productivity and the chemical composition of *M. domestica* larvae

The Principal Component Analysis applied to data on productivity and chemical composition of *M. domestica* larvae showed that the first two components account for 85.9% of the initial information, which validates the analysis (Fig. 1). The correlation coefficients between the two main components and the initial variables are shown in the Table 4. Figure 1 shows the distribution of variables and substrates on the two axes. The combined analysis of Table 4 and Fig. 1 reveals that:

- The mixture of soybean bran + maize grain pericarp allowed a good yield in larvae rich in protein, fat, potassium and metabolizable energy.
- Pig manure also produced a high quantity of larvae rich in protein, ash, fibre, sodium and with a high potassium / calcium ratio.
- Corn bran and chicken manure gave larvae with high calcium content.

Discussion

In this study, the effect of four substrates (chicken manure, pig manure, maize bran and mixture of soybean bran and maize pericarp) on the biomass, organic and mineral component of *M. domestica* larvae using housefly eggs through an adult fly rearing system was investigated. The crop and animal wastes' substrates used were commonly available in the study area. The total *M. domestica* larvae biomass was highest for the mixture of soybean bran and maize pericarp,

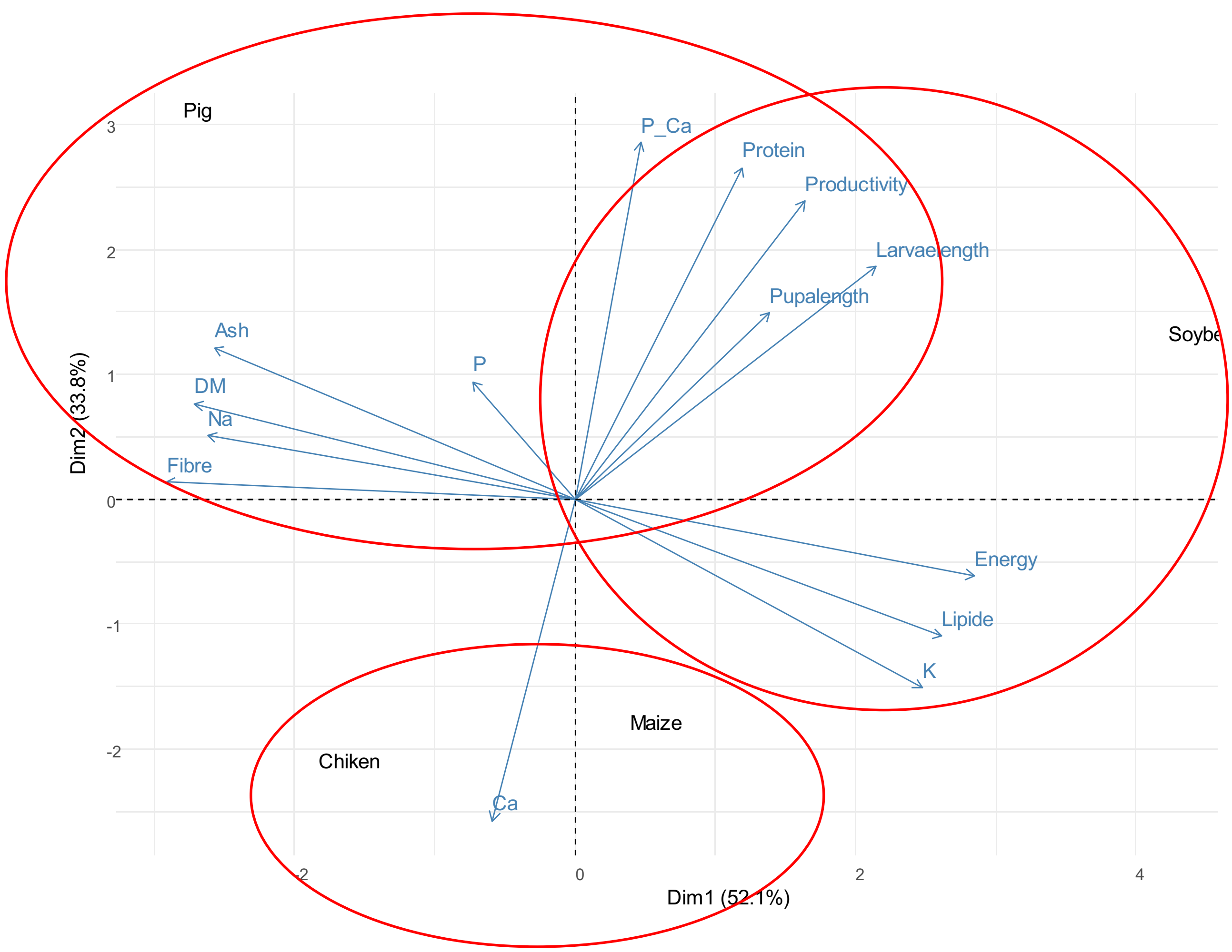

Fig. 1 Representation of the four substrates and the parameters of productivity and *M. domestica* larvae chemical composition following the two first axes

Table 4 Correlations between principal components and initial variables and between principal components and substrates

Variables	PC1	PC2	Substrates	PC1	PC2
Dry Matter	-0.929	0.262	Maize bran	0.393	-1.925
Ash	-0.882	0.416	Soybean bran + maize pericarp	4.226	1.182
Lipid	0.895	-0.376	Chicken manure	-1.825	-2.23
Protein	0.408	0.908	Pig manure	-2.794	2.973
Fibre	-0.998	0.047			
Calcium	-0.202	-0.882			
Phosphorus	-0.249	0.323			
Sodium	-0.898	0.174			
Potassium	0.848	-0.518			
Energy	0.974	-0.211			
Phosphorus/Calcium	0.16	0.979			
Productivity	0.561	0.817			
Larvae length	0.735	0.638			
Pupae length	0.474	0.511			

PC1 First Principal Component, *PC2* Second Principal Component

and lowest for chicken manure. Our results on these substrates are comparable to those reported by Ganda et al. (2019) who compared the same substrates in a free oviposition system. The biomass of *M. domestica* larvae obtained in our study were substantially higher than those obtained by Ganda et al. (2019) for all substrates. This difference can be explained by the system (free oviposition vs. egg incubation) and the quality of substrates as shown by Anene et al. (2013) and Koné et al. (2017). Larvae from the mixture of soybean bran and maize pericarp were bigger and weightier than those from the other three substrates. Larvae from this substrate were respectively followed by those from pig manure, maize bran and chicken manure. These results (larval biomass, size and weight) imply that the soybean bran and maize pericarp mixture was the richest substrate in nitrogen and energy. The determination of substrates nutrient composition showed that the soybean bran and maize pericarp mixture was the richest substrate in protein, lipid and energy whereas chicken and pig manures showed the lowest amounts of content of these nutrients. Results registered with the soybean bran and maize pericarp mixture and chicken manure were positively correlated with their nutrient content because these substrates showed respectively the highest and lowest larval biomass, size and weight. This corroborates the results obtained by Tschirner and Simon (2015) who evaluated the effect of rearing substrate on larval biomass, weight and chemical composition. These authors observed that the total larval yield depended on protein and carbohydrates content of the rearing substrate. In our study, although maize bran was richer in protein and energy than pig manure, larval biomass registered with pig manure was equal to 1.36 times that obtained with maize bran. Tschirner and Simon (2015) observed similar results and explained it by the excessive fungal growth on the substrate. Indeed, maize bran and chicken manure developed mycelium during larval development. Describing the impact of mycelium growth from *Mucor* spp., *Penicillium* spp. and *Aspergillus* spp. on the development of *Drosophila melanogaster*, Wertheim et al. (2002) stated that the development and survival rate of the younger larvae was negatively affected by the degree of mycelium coverage. These observations suggested that substrate's fungal activity had to be controlled during larval production.

The values for the protein content of *M. domestica* larvae (46–51%) in this study were within the range of those reported in the literature (28.63–78.17%). Lipid (16–21%), ash (6–12%) and fibres (8–16%) contents were also variable and ranged within those reported in earlier reports (Lipid: 4 to 28%, ash: 0.9 to 23% and fibres: 1 to 18%) by Aniebo et al. (2008), Olele (2011), Pretorius (2011), Moreki et al. (2012), Okah and Onwujiariri (2012), Olaniyi and Salau (2013), Ukanwoko and Olalekan (2015) and Dillak et al. (2019). 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). Protein (46%), ash (9%), lipid (18%) and energy (3209 kcal/kg) contents registered in our study with chiken manure are similar with those obtained by Odesanya et al. (2011) with the same substrate (48%, 10%, 16% and 3755 kcal/kg respectively for these parameters). The mineral composition (P: 1%, Ca: 0.51%, K: 0.87%, Na: 0.52%) are also comparable to the values obtained by these authors (P: 0.9%, Ca: 0.34%, K: 0.72%, Na: 0.86%). Ukanwoko and Olalekan (2015) reported protein (39%) and ash (5%) contents of *M. domestica* larvae produced with chicken manure lower than those found in our study. However, when they used raw broken eggs as fly attractant, the protein content increased by 6%, demonstrating the importance of substrate quality on the chemical composition of larvae. Regarding the mineral content in the housefly larvae, the Ca:P ratio (1:3.7 to 1:2.01) indicates a severe deficiency of calcium. For fish species, the optimal Ca:P ratio varies between 1:2 and 1.5:1, while, for other animals like poultry, a Ca:P ratio close to 2.5:1 is recommended (Tschirner and Simon 2015). Therefore, maggot meal will not be able to compensate the high calcium contents available in fishmeal (Table 5), hence the need to enrich calcium in food based on house fly larvae to meet the needs of poultry.

In this study, larvae reared on the mixture of soybean bran and maize pericarp showed the highest content in protein, lipid, potassium and energy. This mixture was itself richer in these chemical parameters than the three

Table 5 Comparison of chemical composition of some protein sources used in animal feed

Parameters	Housefly larvae (this study)	Earthworms	Termites	Black soldier fly larvae	Fish meal	Soybean meal
Crude protein % DM	46–51	15–46	20–46	35–57	65–70	46–50
Crude Lipid % DM	16–21	3–8	30–35	15–48	4–10	2–8
Ash % DM	6–12	6–24	4–8	11–28	12–24	6
Fiber % DM	8–16	1–2	6–8	7	1.2	4–6
Phosphorus % DM	0.8–1	0.3–0.5	1.5	0.6–1.5	1.8	0.73
Calcium % DM	0.3–0.5	0.8–1	2	2–6	1.34	0.33
Potassium % DM	0.7–0.9	0.5–0.8	4	0.8–2	0,4	2.25
Energy (Kcal/g) DM	2.83–4.20	2–3	4.40	5.28	4.92	3–4

Source: Newton et al. (2005), Yu et al. (2009), Igwe et al. (2011), Lourdumary and Uma (2013), Rana (2014), Adeboye (2014), Makkar et al. (2014), Bahadori et al. (2015), Tschirner and Simon (2015), Spranghers et al. (2017)

others substrates. The contents in ash, fibre, phosphorus and sodium were higher in pig manure and larvae produced with this substrate. Maize bran and mixture of soybean bran and maize pericarp as well as larvae from these substrates showed the lowest content in ash. The high phosphorus content of larvae reared on the maize bran and pig manure (10 g/kg DM) compared to those reared on other substrates was surely due to the high level of this nutrient in these substrates (9 and 10 g/kg DM). These results revealed a positive correlation between chemical composition of the substrates and those of the larvae. These results are comparable with those of other researchers who obtained variable chemical compositions of larvae with different rearing substrates (Spranghers et al. 2017; Tschirner and Simon 2015). Tschirner and Simon (2015), testing the effect of three growing substrates (mixture of middling, dried distillers' grains with soluble and dried sugar beet pulp) on the chemical composition of black soldier fly larvae (*Hermetia illucens*), observed a great variability in the nutrients' contents of larvae in relation to the growing substrates.

The nutrient composition of *M. domestica* larvae found in this study was closed to those reported for several protein sources used as animal feed (Table 5) (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. The crude protein content is higher than those contained in soymeal, earthworm (15–46%) and termites (20–46%) but is slightly lower than those reported for fishmeal (65%). The lipid content of earthworm, soybean and fish meal is lower than that of *M. domestica* larvae. In contrast, earthworm and black soldier fly larvae are richer in ash than housefly larvae. Calcium and phosphorus values are important for poultry production. Housefly larvae meal is rich in calcium and its supplementation is not required when used in animal feed (Makkar et al. 2014). All of the invertebrates' meals discussed in this paper have low phosphorus content compared to fishmeal. Insects, particularly *M. domestica* larvae, contain significantly higher amounts of fibre compared to fishmeal, soybean and earthworm as reported by (Anankware et al. 2015). The total metabolizable energy for housefly larvae meal (2830 to 4200 kcal/kg) was identical to values reported for others meals but lower than those reported for black soldier fly larvae (5280 kcal/kg) (Makkar et al. 2014). Considering the analysed values for crude protein, lipid and total metabolizable energy, we conclude that housefly larvae meal can be an improved substitute for soybean meal and is very comparable to fishmeal as a feed ingredient.

Conclusion

This study has confirmed that *M. domestica* larvae is a very good source of proteins, fibres and minerals but the nutrient composition of substrates has an important effect on the larvae yield and nutrient composition of larvae. The mixture of soybean bran and maize pericarp and pig manure appear to be the best substrates when considering larval productivity and chemical composition. These substrates recorded the highest *M. domestica* larvae yield and protein content. Maggot meal of *M. domestica* can be produced with these substrates and incorporated into poultry, fish, pig feeds. *Musca domestica* larvae are therefore 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.

Acknowledgements This study was carried out as part of the project IFWA—Sustainable use of insects to improve livestock production and food security in smallholder farms in West Africa.

Authors' contributions HG conceived and designed the experiments, performed the bioassay, analysed and interpreted the data, wrote the manuscript. HAA performed the bioassay, collected and interpreted the data. ETZB suggested, planned, and designed the study; contributed to manuscript correction. MK, CAAMC and HFM suggested the study; contributed to manuscript correction. GAM and DCC contributed to manuscript correction. All authors read and approved the final manuscript.

Funding This study was funded by the Swiss Agency for Development and Cooperation and the Swiss National Science Foundation, in the framework of the Swiss Programme for Research on Global Issues for Development (R4D).

Availability of data and material Data will not be shared, only by request from the corresponding author.

Code availability Not applicable.

Declarations

Conflicts of interest The authors declare that they have no competing interests.

References

Adeboye OR (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. 33p. Archived at http://orgprints.org/27398

Adesina AJ (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 Appl Biol 51:10693–10699

Agbeko E, Sakyi P, Obeng A, Quainoo AK (2014) A sustainable production of Maggots (squatts) as live food for Nile tilapia (*Oreochromis niloticus*). Int J Multidiscip Res Dev 1(1):51–55

Akpodiete O, Ologhobo A, Onifade A (1998) Maggot meal as a substitute for fish meal in laying chicken diet Ghana. J Agric Sci 31:137–142

Anankware P, Fening KO, Osekre E, Obeng-Ofori D (2015) Insects as food and feed: A review. Int J Agric Res 3:143–151

Anene A, Afam-Anene O, Ike K, Ekekwe N (2013) Preliminary investigations on quantity of maggots produced from four different sources of livestock wastes. JRB 3:1060–1065

Aniebo A, Erondu E, Owen O (2008) Proximate composition of housefly larvae (*Musca domestica*) meal generated from mixture of cattle blood and wheat bran. Livest Res Rural Dev 20(12):1–5

Bahadori Z, Esmaylzadeh L, Torshizi MAK (2015) The effect of earthworm (*Eisenia fetida*) and vermihumus meal in diet on broilers chicken efficiency and carcass components. BFIJ 7(1):998–1005

Boire S, Bay D, Olson J (1988) An evaluation of various types of manure and vegetative material as larval breeding media for the stable fly. Southwest Entomol 13:247–249

Bouafou K, Kouame K, Amoikon E, Offoumou A (2006) Potentiels pour la production d'asticots sur des sous-produits en Côte d'Ivoire. Tropicultura 24:157–161

Charlton AJ, Dickinson M, Wakefield ME, Fitches E, Kenis M, Han R, Zhu F, Kone N, Grant M, Devic E, Bruggeman G, Prior R, Smith R (2015) Exploring the chemical safety of fly larvae as a source of protein for animal feed. J Insects Food Feed 1(1):7–16

Chemists AOA (2004) Association of Official Analytical Chemists (AOAC) Official methods of analysis. AOAC Washington, DC, USA

Devic E (2014) Breeding flies in Ghana. PROteINSECT Project Progress. March 2014. Institute of Aquaculture, University of Stirling. 24p

Dillak YFG, Suryatni NPF, Handayani HT, Temu ST, Nastiti HP, Osa DB, Ginting R, Yunilas, Henuk YL (2019) The effect of fed maggot meal as a supplement in the commercial diets on the performance of finisher broiler chickens. In: IOP Conference Series: Earth and Environmental Science. IOP Publishing, p 012056. https://doi.org/10.1088/1755-1315/260/1/012056

Djissou AS, Tossavi EC, Vodounnou JD, Toguyeni A, Fiogbe ED (2015) Valorization of agro-alimentary waste for a production of maggots like source of proteins in the animal feeds. Int J Agron Agric Res 7:42–46

Ganda H, Zannou-Boukari ET, Kenis M, Chrysostome AAMC, Mensah GA (2019) Potentials of animal, crop and agri-food wastes for the production of fly larvae. J Insects Food Feed 5:59–67

Igwe CU, Ujowundu CO, Nwaogu LA, Okwu GN (2011) Chemical Analysis of an Edible African Termite, *Macrotermes nigeriensis*; a potential antidote to food security problem. Biochem & Anal Biochem 1:105. https://doi.org/10.4172/2161-1009.1000105

Koné N, Sylla M, Nacambo S, Kenis M (2017) Production of house fly larvae for animal feed through natural oviposition. J Insects Food Feed 3:177–186

Larraín P, Salas C (2008) House fly (*Musca domestica* L.) (Diptera: Muscidae) development in different types of manure. Chil J Agric Res 68:192–197

Lê S, Josse J, Husson F (2008) FactoMineR: an R package for multivariate analysis. J Stat Softw 25:1–18

Leclercq B, Henry Y, Pérez JM (1989) Données générales sur l'alimentation des monogastriques. In: INRA (ed) L'alimentation des animaux monogastriques : Porc, lapin, volailles., vol 2. INRA, Paris France., pp 10–14

Lomas N (2012) Comparison and selection of saprophagous diptera species for poultry manure conversion. A Thesis presented to the University of Guelph in partial fulfilment of requirements for the degree of Master of Science in Environmental Biology. Guelph, Ontario, Canada. 137p

Lourdumary BAJ, Uma K (2013) Nutritional Evaluation of Earthworm Powder (*Lampito mauritii*). J Appl Pharm Sci 3(03):082–084

Makkar HP, Tran G, Heuzé V, Ankers P (2014) State-of-the-art on use of insects as animal feed. Anim Feed Sci Technol 197:1–33

Moon RD, Hinton J, O'Rourke SD (2001) Nutritional value of fresh and composted poultry manure for house fly (Diptera: Muscidae) larvae. J Econ Entomol 94(5):1308–1317

Moreki J, Tiroesele B, Chiripasi S (2012) Prospects of utilizing insects as alternative sources of protein in poultry diets in Botswana: A review. Journal of Animal Science. Advances 2:649–658

Mpoame M, Téguia A, Nguemfo EL (2004) Essai comparé de production d'asticots dans les fientes de poule et dans la bouse de vache. Tropicultura 22:84–87

Newton L, Sheppard C, Watson DW, 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, p 17

Odesanya B, Ajayi S, Agbaogun B, Okuneye B (2011) Comparative evaluation of nutritive value of maggots. Int J Sci Eng Res 2:1–5

Okah U, Onwujiariri E (2012) Performance of finisher broiler chickens fed maggot meal as a replacement for fish meal. J Agric Technol 8:471–477

Olaniyi C, Salau B (2013) Utilization of maggot meal in the nutrition of African cat fish. Afr J Agric Res 8:4604–4607

Olele N (2011) Comparative study on the use of natural and artificial based feeds for the culture of *Clarias gariepinus* fingerlings. J Agric Biol Sci 6:9–13

Ossey Y, Koumi A, Koffi K, Atse B, Kouame L (2012) Use of soybean, bovine brain and maggot as sources of dietary protein in larval *Heterobranchus longifilis* (Valenciennes, 1840). J Anim Plant Sci 15:2099–2108

Pretorius Q (2011) The evaluation of larvae of *Musca domestica* (common house fly) as protein source for broiler production. Stellenbosch University, Stellenbosch

Rana K (2014) Development of black soldier fly larvae rearing technique to supplement fish feed

R Core Team (2018) R: A language and environment for statistical computing. R Fondation for Statistical Computing, Vienna, Austria. https://www.R-project.org/10.1515/cjf-2016-0006

Spranghers T, Ottoboni M, Klootwijk C, Ovyn A, Deboosere S, De Meulenaer B, Michiels J, Eeckhout M, De Clercq P (2017) de Smet S (2017) Nutritional composition of black soldier fly (*Hermetia illucens*) prepupae reared on different organic waste substrates. IJARR 97:2594–2600

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. J Insects Food Feed 1:249–259

Ukanwoko A, Olalekan O (2015) Effects of source and time of harvest on the proximate composition of maggot (*Musca domestica*) larva meal. Int J Livest Res 5:84–90

van Zanten BT, Verburg PH, Koetse MJ, van Beukering PJ (2014) Preferences for European agrarian landscapes: A meta-analysis of case studies. Landsc Urban Plan 132:89–101

Veldkamp T, Van Duinkerken G, van Huis A, Lakemond C, Ottevanger E, Bosch G, Van Boekel T (2012) Insects as a Sustainable Feed Ingredient in Pig and Poultry Diets: a Feasibility Study= Insecten als duurzame diervoedergrondstof in varkens-en pluimveevoeders: een haalbaarheidsstudie. Wageningen UR Livestock Research

Vodounnou D, Kpogue A, Dakpogan H, Mensah G, Fiogbe E (2015) Review about the use of the Invertebrates in Pisciculture: Termites Earthworms and Maggot. Int J Multidiscip Curr Res 3:620–628

Wertheim B, Marchais J, Vet LEM, Dicke M (2002) Allee effect in larval resource exploitation in Drosophila: an interaction among density of adults, larvae, and micro-organisms. Ecol Entomol 27:608–617

Wortman Ch, Shapiro Ch, Tarkalson D (2006) Composting manure and other organic residues. University of Nebraska-Lincoln Extension, Institute of Agriculture and Natural Resources, Lincoln, Nebraska, USA, p 4p

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

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.