International Journal of Zoology and Applied Biosciences **ISSN: 2455-9571**
Volume 6, Issue 2, pp: 76-83, 2021
https://doi.org/10.5281/zenodo
http://www.ijzab.com

Research Article

EFFECTS OF DIFFERENT SUBSTRATES (FRUITS AND VEGETABLES) ON THE PRODUCTION AND EVOLUTION OF BLACK SOLDIER FLY (*Hermetia illucens*) LARVAE

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Article History: Received 27th March 2021; Accepted 22nd April 2021; Published 30th April 2021

ABSTRACT

The high cost of poultry feed requires the search of alternative solutions for feeding poultry. The objective of this study is to identify the substrate that offers an optimal production of larvae of the black soldier fly which can be used as source of protein in poultry feed. To do this, different substrates made up of fruits and vegetables were used for the production of larvae. Six types of substrates (papaya, avocado, cucumber, sweet banana, watermelon and orange) were tested. Fifty grams (50 g) of black soldier fly larvae (*Hermetia illucens*) were placed in six containers each containing 350 g of specific substrate. In order to assess the effect of these substrates, fruits and vegetables were first chemically characterized. Then the weight, the length and the rate of converted larvae were determined weekly. The results showed that the substrates had a different chemical profile. At the end of the study, larvae with sweet banana and watermelon as substrate had the highest total weights (96 g ± 4.00 and 94 g ± 3.2) compared to avocado, cucumber, papaya and orange (88 g ± 3.01; 84 g ± 3.01; 77 g ± 2.04; 72 g ± 3.02). Regarding the length, it has evolved according to the weight. Thus, the length of the larvae was significantly ($p < 0.05$) higher with sweet banana substrates (29.1 ± 0.03 mm) and watermelon (27.3 mm ± 0.01). Regarding the rate of converted larvae, it was significantly ($P<0.05$) higher with sweet banana (94.43% ± 7.01), watermelon (93.16% ± 5.00) and papaya (83.75% ± 4.02).This study has shown that sweet bananas and watermelons are excellent feed substrates for optimizing the development of black soldier fly larvae and allowing larval production on a large scale.

Keywords: Black soldier fly, Conversion rate, Larvae, Physical characteristics.

INTRODUCTION

Protein nutrients such as soybeans and fish are the most widely used products in the diets of farm animals (Hardouin & Mahoux, 2003). However, their high cost is most often a limiting factor for a balanced ration. This situation creates a handicap in the food balance and, consequently, limits the zootechnical and economic performances of the animals. So it is necessary to develop sources of protein that are cheap and can enrich the diet of farm animals. In this perspective, the use of insects is considered as an alternative source for soybeans and fish. They provide proteins of high biological value with a relatively low cost. Among these insects, the larvae of the black soldier fly prove to be more advantageous because of their high nutritional value for animals (Newton *et al*., 2005a). The production of black soldier flies is one of the emerging technologies that can help alleviate this animal feeding problem (De Smet *et al*., 2018). Indeed, the large quantity production of black soldier fly larvae can facilitate the obtaining of alternative and eco-responsible feeds (Barragan *et al*., 2017) for monogastric animals (poultry, pork and fish). In addition, the mass production of black soldier flies larvae could improve the soil through the production of quality fertilizer (Xiao *et al*., 2018). Generally, the larvae of the black soldier fly are produced with organic matter. Several bioconversion studies have demonstrated the ability of larvae to biologically convert several types of organic matter, including municipal waste (Diener & Tockner, 2011), food waste (Cheng *et al*., 2017), septic tank sludge

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(Banks *et al*., 2014; Nyakeri *et al*., 2017b), animal waste (poultry, pig, cow) (Gobbi *et al*., 2013; Newton *et al*., 2005b; ur Rehman *et al*., 2017) and fruit and vegetables (Jucker *et al*., 2017; Nyakeri *et al*., 2017a). The results of these various studies concluded that the growth and the physico-chemical composition of the larvae of the black soldier fly depended on the substrate used (St-Hilaire *et al*., 2007). However, for each category of substrates, these studies do not indicate what is the best substrate may promote production of larvae on a large scale.

In Côte d'Ivoire, fruits and vegetables are an asset for the large-scale production of black soldier fly larvae. Indeed, they constitute a considerable part of waste and losses (FAO, 2002).These is the sweet banana, watermelon, avocado, cucumber, papaya, and orange. In addition, they are easily accessible. The objective of this study is to identify the substrate (fruits and vegetables) which offers an optimal production of black soldier fly and which could be used as a source of protein in animal feed. This is specifically to determine the physical characteristics of black soldier fly larvae (weight, size, and the conversion rate) obtained after feeding with different fruits and vegetables.

MATERIAL AND METHODS

Study site

The study took place in the district of Abidjan precisely in the locality of Bingerville (Côte d'Ivoire). This locality is characterized by a humid tropical climate which has a very high temperature and humidity respectively 33 ° C and 68%.

Organic substrates

The organic substrates used for the study are fruits and vegetables. This is precisely the rejection of papaya, cucumber, avocado, sweet banana, watermelon and orange all ripe and collected from the fruit and vegetable markets of the district of Plateau (Abidjan).

Larvae

The larvae used for the study were the larvae of the black soldier fly. The larvae were 2 days old at the start of the study and had a mean weight of 97 mg ± 4.00. They are white in color and have an average size of 1.2 mm ± 0.00. To obtain the larvae, it was used an incubator for hatching the eggs. Each egg was approximately 1 mm of long and had a creamy white color. The incubator is in the form of a straight paving stone with a length of 3 m, a width of 2.5 m and a height of 2.1 m. Plastic containers with a capacity of 5 liters were used to serve as a deposit for the incubator eggs and for the growth of the larvae.

Technical material

Bins of 15 liters and plastic drums of 50 liters were used for collecting larvae and for transporting fruits and vegetables respectively. An electronic spoon of precision of 0.1 g was used for individual larval weighing. A 1 kg capacity scale was used for mass weighing of the larvae. Fine, medium and large mesh sieves with a diameter respectively of 0.5 mm; 1 mm and 2 mm were used to separate the larvae from the different substrates. An iron press machine was used to wring out the various substrates. A metal shelf with 4 levels placed under an open-air shed allowed aeration of the substrates and good growth of the larvae. A moisture meter and a 20 cm ruler were respectively used to measure the humidity of the substrates and to determine the length of the larvae.

Collection of substrates

The substrates were collected from fruit and vegetable sellers in the district of Plateau (Abidjan).These are fruits and vegetables ripe unusable for marketing and stored in bags ready to be discarded. They were put in drums with a capacity of 50 liters, sealed and transported by a van to the site of the experiment.

Technical monitoring

The study was conducted over a period of three weeks. The eggs were obtained from the breeding of the black soldier fly previously done upstream. They were then placed in the incubator at a temperature of 37.80 ° C and a humidity of 60%. After four days, the eggs hatched to give larvae. These larvae are left two days in the incubator for a pre-fattening. Upon leaving the incubator, 50 g of larvae were weighed and placed in containers each containing a substrate. Six batches of substrates were made. These are the papaya, avocado, cucumber, sweet banana, watermelon and orange batches. Beforehand, each substrate has been wrung out to reduce humidity to 60%. This value constitutes the ideal humidity for the good growth of the larvae. The humidity of the various media is maintained at 60% by the action of the spinning. For some substrates, the spinning is done on the 1st day only for others. It is done over 2 days or 3 days depending on the water content in the substrate. From the first week, it was made visual observations to differentiate the white larvae and black larvae. On day 14 and day 21, a sort was made to separate in each container, the black larvae and the white larvae.

Experimental disposition

During the experiment the larvae received different substrates. Each batch of larvae received a specific type of substrate. The substrates used are papaya, avocado, cucumber, sweet banana, watermelon and orange. The larvae were fed once a week. It was 350 g of substrate per week in each container. The weights of the larvae at different ages were recorded weekly from day one up to three weeks. On the first day of the experiment each substrate received 50 g of larvae. After a week, the total weight, the average weight and height were determined. For the conversion rate of white larvae to black larvae, the determination started from the 2nd and 3rd week of the study. It consisted in sorting each batch in order to separate the black larvae to the white larvae and then determine the rate of each type of larvae.

Technical separation of larvae

To separate the larvae to the production substrates, the method of Alauzen and Malivel (2020), was used. It consisted of pouring the mixture of larvae and substrate on a plastic sieve resting on a tray for a while having taken care beforehand to mix well. Sieve with a diameter of 0.5 mm, 1 mm and 2 mm were used respectively at the 1st, 2nd and 3rd week. This technical uses the lucifuge character of the larvae (fears light). Indeed, as the larvae do not like light, they give up the top layer of substrates; they migrate through the sieve and fall into the tray. The collection is therefore done through the control of the contents of the tank under the sieve and a systematic search of the substrate is made to extract the remaining larvae.

Chemical analysis of substrates

The substrates were analyzed to determine the values of metabolizable energy, the level of protein, crude fiber, fat, carbohydrate, ash and minerals. The chemical analyzes were carried out at the Central Analysis Laboratory of the Nangui Abrogoua University.

Moisture content

Moisture was determined using the method of AOAC (2005).

Metabolizable energy

The value of the metabolizable energy (ME) is obtained by calculation from the fat, cellulose and ash levels of the sample. This value is determined from AOAC (2005).

Protein

The total nitrogen content is determined by KJEDAHL according to the method of AOAC (2005). The nitrogen content obtained affected by the conversion coefficient 6.25 made it possible to estimate the total protein content.

Crude fiber

The dosage of the cellulose is carried out according to the method of Van Soest *et al*. (1991).

Fat

The determination of fat was done using soxhlet according to AOAC (2005).

Ash

Ash content is determined by subtracting from the dry matter (DM) rate, the organic matter (OM) content.

Carbohydrate content

Carbohydrate content is determined using the method of AOAC (2005).

Minerals

The quantification of the minerals was done by Atomic Absorption Spectrometry in accordance with the instructions of AFNOR (1991).

Determination of the physical characteristics of the larvae

The total weight, mean weight, length and conversion rate of white lava to black larvae were determined according to the method of Ma *et al*. (2018). Determining the total weight of each batch consists of weighing all the larvae in each container to determine their mass. For the average weight, a given mass of larvae was taken. Then the number of larvae has been counted and the formula for average weight is applied.

$$\text{Average weight} = \frac{\text{Total weight}}{\text{Nomber of individuals}}$$

As for the rate of converted larvae, it represents the ratio between the number of black larvae and the total number of larvae multiplied by 100.

$$\text{Rate of black larvae (\%)} = \frac{\text{number of black larvae x 100}}{\text{total numbers}}$$

The rate of white larvae is determined by subtracting from 100 the rate of black larvae. For the average length, it was determined by averaging the lengths of the larvae measured.

Statistical analysis

The data collected was entered using the Excel® 2007 computer spreadsheet, Microsoft Corporation. Statistical analysis was performed using STATISTICA software, Stat Soft, version 7.0 (2009). The average values were subjected to an analysis of variance (ANOVA) and compared to a factor according to the multiple range test of Duncan at the 5% threshold. It was used to calculate the average and make a ranking based on performance. The mean value is accompanied by the standard error on the mean (Mean ± SEM).

RESULTS AND DISCUSSION

Table 1 shows the nutritional profile of the different substrates. This nutritional profile shows significant differences ($p<0.05$). It emerges from this table that the sweet banana and the watermelon are rich in proteins respectively 3.20% and 1.99%. Sweet bananas are also rich in carbohydrates (20.5%), ash (4.80%) and mineral elements (sodium and magnesium). Avocado is energetic (161 kcal). It is rich in fat (43.5%) and potassium (339 mg). As for the orange, it is rich in carbohydrates (15%).

Table 2 shows the weekly evolution of the total weight of the larvae. Total weights change over time. These weights vary from one substrate to another. At week 1, the larvae that had sweet banana and avocado as substrate recorded the highest weight (respectively 68 g ± 3.00 g and 64 ± 2.00). From week 2 to week 3 the larvae fed with sweet banana recorded the best weight (81 g ± 2.03 and 96 g ± 4.00), followed by those fed with watermelon (77 g ± 1.2 and 94 g ± 3.2). Low total weights were recorded with orange (53 g ± 2.00).

Table1. Nutritional profile of the different substrates.

Constituents	Sweet banana	Watermelon	Avocado	Cucumber	Papaya	Orange
Humidity (%)	73.8 ± 0.50	93.91 ± 1.00	70.8 ± 1.00	91.4 ±1.01	87.1± 0.10	85 ±1.00
Metabolizable Energy (kcal/kg)	93.6^{b} ± 1.00	29^{d} ± 0.05	161^{a} ± 1.02	3^{e}± 0.00	32^{d} ± 0.05	62^{c} ±1.00
Crude Protein (%)	3.20^{a} ± 0.00	1.99^{b} ± 0.00	1.32^{c}± 0.00	1.27^{c}±0.00	0.5^{e} ± 0.00	1^{d} ± 0.00
Fat (%)	0.10^{b} ± 0.00	0.18^{b} ± 0.00	43.5^{a}± 0.01	0.11^{b}±0.00	0.1^{b} ± 0.00	0.19^{b} ± 0.00
Carbohydrate (%)	20.5^{a} ± 0.1	1.80^{e} ± 0.00	4.8^{d} ± 0.00	4.06^{d}±0.00	7.8^{c} ± 0.00	15^{b} ±0.05
Cellulose (%)	9.10^{a} ± 0.00	11.41^{a} ± 0.01	6.9^{b} ± 0.00	11.1^{a}±0.01	10.2^{a}±0.01	12.3^{a} ±0.02
Ash (%)	4.80^{a} ± 0.00	0.81^{e} ± 0.00	1.77^{c} ±0.00	3.17^{b}±0.00	0.5^{e}± 0.00	1.2^{d} ±0.00
K (mg/100g)	318.95^{a} ± 8.20	143.91^{c}±7.40	339^{a} ± 2.3	38^{d} ± 1.01	214^{b} ±7.00	237^{b} ±5.01
P (mg/100g)	21.7^{b} ± 2.40	17.4^{c} ±0 .01	52^{a} ± 3.02	6^{e}±0.01	11^{d} ±1.02	18^{c} ±0.05
Ca (mg/100g)	4.9^{d} ± 1.00	10.43^{c} ± 0.01	12^{c} ± 0.05	4^{d}±0.00	20^{b} ± 0.05	52^{a} ±1.00
Na (mg/100g)	17.35^{a} ± 3.68	1.25^{d} ± 0.00	7^{b} ± 0.02	1^{d} ± 0.00	3^{c} ± 0.00	0.01^{e} ± 0.00
Mg (mg/100g)	30.8^{a} ± 4.40	11.31^{b} ± 0.05	29^{a} ± 2.01	3^{c}± 0.00	13^{b} ± 0.03	13^{b} ± 0.05

The different letters a, b, c, d, e, f on the same line means that there is a significant difference at the 5% threshold between the values.

Table 2. Weekly evolution of total larval weights (g).

Weeks	Larvae fed with papaya	Larvae fed with avocado	Larvae fed with sweet banana	Larvae fed with watermelon	Larvae fed with cucumber	Larvae fed with orange
0	50^{a} ± 2.01	50^{a} ± 2.01	50^{a} ± 2.01	50^{a} ± 2.01	50^{a} ± 2.01	50^{a} ± 2.01
1	58^{d} ± 1.02	64^{b} ± 2.00	68^{a} ± 3.00	61^{c} ± 1.00	56^{e} ± 1.00	53^{f} ± 2.00
2	66^{e} ± 3.00	73^{c} ± 2.01	81^{a} ± 2.03	77^{b} ± 1.2	70^{d} ± 1.01	63^{f} ± 1.00
3	77^{d} ± 2.04	88^{b} ± 3.01	96^{a} ± 4.00	94^{a} ± 3.2	84^{c} ± 3.01	72^{e} ± 3.02

The different letters a, b, c, d, e, f on the same line means that there is a significant difference at the 5% threshold between the values.

Table 3 shows the change in average weight per week. The analysis shows that all the average weights change over time. From week 1 to the end, the different average weights were significantly different ($p<0.05$). At the first week, the larvae fed sweet bananas have a higher average weight (235 ± 10.2 mg). They are followed by larvae fed with avocado (220 mg ± 12.1). At weeks 2 and 3, larvae fed with sweet banana recorded the best average weights (290 mg ± 17.0 and 371 mg ± 13.01) followed by those fed with watermelon (268 mg ± 15.01 and 368 mg ± 18.02). In general the low average weights were recorded with the larvae having orange as a substrate and that every week (175 mg ± 13.01, 209 mg ± 14.02 and 317 mg ± 15.02). However at week 3 there was no significant difference between sweet banana and watermelon.

Table 4 shows the evolution of the length of the larvae over time. This length presents significant differences ($p<0.05$). At the 1st week the larvae having used the sweet banana, the avocado and the watermelon recorded the best sizes respectively 13.4 mm ± 0.02; 12.2 mm ± 0.01 and 11.2 mm ± 0.02. At the end of the study, the larvae which used the

sweet banana and the watermelon presented the best lengths with respectively 29.1 mm ± 0.03 and 27.3 mm ± 0.01.The short lengths were generally obtained with the larvae which had for substrates orange (8.1 mm ± 0.01; 13.3 mm ± 0.02 and 21.6 mm ± 0.02), papaya (10 mm ± 0.01; 15 mm ± 0.01 and 23.6 mm ± 0.02) and cucumber (9.5 mm ± 0.02; 16.7 mm ± 0.02 and 25.4 mm ± 0.01).

Table 5 shows the evolution of the conversion rate of white larvae to black larvae. The rates of conversion of white larvae to black larvae are different from one substrate to another from the 2nd to the 3rd week. From the start of the experiment to the end of the 1st week, the rate of conversion of the white larvae to black is zero. At the 2nd week, papaya recorded the highest rate of white larvae to black larvae (73.89% ± 6.01).Then follow the watermelon and the sweet banana respectively 49.29% ± 3.00 and 38.25% ± 2.01. At the 3rd week, the best conversion rates of white larvae into black larvae were obtained respectively with sweet banana (94.43% ± 7.01), watermelon (93.16% ± 5.00) and papaya. (80.75% ± 4.02). Low conversion ratesof white larvae to black larvae were recorded with avocado (4.89% ± 6.00 and 15.75% ± 5.00). The differences in the weight and size of black soldier fly larvae with different fruits and vegetables are due to differences in the nutritional profile of these fruits and vegetables. The better physical performance (weight and size) attributed to larvae fed with sweet banana and watermelon would be due to the high nutritional value in protein compared to other fruits and vegetables. Indeed, proteins are the key elements of the structural constructions of the majority of feeds. The proteins provided by the diet ensure growth, the construction of living matter and the repair of the body (Kone, 2013). In these two substrates, the high level of proteins certainly led to a faster larval development compared to the other larvae fed with the other substrates. This hypothesis is in agreement with the work of Carvalho & Mirth (2017) and Gold *et al*. (2018). According to these authors, the low protein level in the diet (substrate) negatively influences larval growth and prolongs larval development time. The results of this study are also supported by Oonincx *et al.*, (2015). According to these authors, it is the high protein diets that cause the lowest rates of feed conversion (thus revealing a greater efficiency). They also found that nitrogen is the most efficient element converted to body mass by larvae. Indeed, if the value of the feed conversion index is low the larvae are more efficient in converting plant organic matter into larval biomass (Banks *et al*., 2014; Nyakeri *et al*., 2017b).

Table 3. Weekly evolution of mean larval weights (mg).

Weeks	Larvae fed with papaya	Larvae fed with avocado	Larvae fed with sweet banana	Larvae fed with watermelon	Larvae fed with cucumber	Larvae fed with orange
0	97 ± 4.00	97 ± 4.00	97 ± 4.00	97 ± 4.00	97 ± 4.00	97 ± 4.00
1	210^{d}±3.01	220^{b} ±12.1	235^{a}± 10.2	215^{c}±4.00	190^{e}±13.02	175^{f}±13.01
2	234^{e}±16.00	257^{c}±9.02	290^{a}±17.00	268^{b}±15.01	252^{d}±4.01	209^{f}±14.02
3	350^{d}±9.01	365^{b}±10.00	371^{a}±13.01	368^{a}±18.02	360^{c}±11.00	317^{e}±15.02

The different letters a, b, c, d, e, f on the same line means that there is a significant difference at the 5% threshold between the values.

Table 4. Weekly evolution of the length of the larvae (mm).

Weeks	Larvae fed with papaya	Larvae fed with avocado	Larvae fed with sweet banana	Larvae fed with watermelon	Larvae fed with cucumber	Larvae fed with orange
0	1.2 ± 00	1.2 ± 00	1.2 ± 00	1.2 ± 00	1.2 ± 00	1.2 ± 00
1	10^{d} ± 0.01	12.2^{b} ± 0.01	13.4^{a} ±0.02	11.2^{c} ± 0.02	9.5^{e} ± 0.02	8.1^{f} ±0.01
2	15^{e} ± 0.01	18^{c} ± 0.02	21.8^{a} ± 0.01	19.7^{b} ± 0.01	16.7^{d}± 0.02	13.3^{f} ± 0.02
3	23.6^{e} ± 0.02	26.1^{c} ± 0.02	29.1^{a} ± 0.03	27.3^{b} ± 0.01	25.4^{d} ± 0.01	21^{f} ± 0.02

The different letters a, b, c, d, e, f on the same line means that there is a significant difference at the 5% threshold between the values.

Table 5. Weekly evolution of the conversion rate of white larvae to black larvae (%).

Weeks	Larvae fed with papaya	Larvae fed with avocado	Larvae fed with sweet banana	Larvae fed with watermelon	Larvae fed with cucumber	Larvae fed with orange
0	0	0	0	0	0	0
1	0	0	0	0	0	0
2	73.89^{a} ± 6.01	4.89^{f} ± 6.00	38.25^{c} ± 2.01	49.29^{b} ± 3.00	26.22^{e} ± 2.01	29.51^{d} ± 3.00
3	83.75^{b} ± 4.02	15.75^{e} ± 5.00	94.43^{a} ± 7.01	93.16^{a} ± 5.00	63.58^{c} ± 3.01	52.61^{d} ± 5.01

The different letters a, b, c, d, e, f on the same line means that there is a significant difference at the 5% threshold between the values.

At the week 3, there was no significant difference between the conversion rates of larvae fed with sweet banana and watermelon. This could be explained by the achievement of the prepupal phase of larvae fed with sweet bananas. Indeed, at this stage, the larvae of the black soldier fly stop feeding and therefore their growth is stopped. They empty their digestive tract, develop fat that serves as energy for migration and pupation to the adult stage (Burtle *et al*., 2012). The low weights and sizes obtained by the larvae fed with avocado, cucumber, papaya and orange would be linked to the nutritional composition of each substrate. Indeed, the larval evolution depends on the nutrients of the different substrates. Their very low protein content certainly justifies the low weight and small size. According to Tinder *et al*. (2017), the nutritional composition of the diets supplied to the larvae has a great influence on the growth performance and nutritional composition of the larvae. As regards the orange, the last place occupied, would undoubtedly be related to the orange peel. Indeed, the orange peel contains a bitter pungent liquid which must have made the environment toxic, slowing the growth of the larvae. This remark is also supported by Diener *et al*., (2011). For these authors, under unfavorable conditions (high temperature, toxic conditions), the larvae try to abandon the feed source. Thus, for a good larval treatment system, it is therefore extremely important to determine the conditions that trigger the cessation of feed intake or mass migration of immature larvae (Diener *et al*., 2011). By comparing our results for weight and height with other authors, we see that our results obtained in 3 weeks are clearly superior to those obtained by Diclaro & Kaufman (2009) and Makkar *et al*. (2014). The studies of these authors indicated that the larvae can reach in the last instar a length of up to 27 mm and an average mass of up to 220 mg. As for Jucker *et al*. (2017), they obtained an average weight of 154-184 mg from fruits and vegetables at three weeks.

Regarding the conversion of white larvae to black larvae, she referred to the life cycle of the larvae. In this study, larval stages were determined based on a visual approach. From the 2nd week, the phenomenon of melanization was observed in all the batches. This is because the larva's exoskeleton was starting to change from a white color to a dark brown color. This made it possible to determine the rate of black larvae from the 2nd week of the larval stage. These results are comparable to those obtained by Sheppard *et al*. (2002) who explains that under appropriate conditions, the larva can reach the pre-pupa stage after two or three weeks of production. These results are also similar to those of Newton *et al*. (2005b) who obtained larvae on a Gainesville diet. According to Li *et al*. (2011), the fly life cycle is done in 4 stages and the pre-pupa stage is the most used in animal feed because of their nutritional composition. This point of view is contrary to the studies of some authors. For Barros et al. (2014), under optimal conditions, fly larvae pass through six stages in 14 days including the pre-pupa stage and the pupal stage. In the present study, the larval time was relatively long compared to the last authors. Because, for the determination of the rates of black larvae, it took up to 3 weeks. This would certainly be attributable to the nature of the different substrates. Studies have shown that the macronutrients (proteins, carbohydrates, fibers and fats) contained in the diets provided to the larvae have a great influence on the growth performance and nutritional quality of the larvae (Nguyen *et al*., 2013; Oonincx *et al*., 2015; Tinder *et al*., 2017). Larvae fed with fruits and vegetables reach maturity with a longer time than larvae fed with food residues and liver (Nguyen *et al*., 2013).The low protein content of fruits and vegetables would probably be the cause (Jucker *et al*., 2017; Nguyen *et al*., 2013). According to Carvalho & Mirth (2017) and Gold *et al*. (2018), protein deficiency prolongs larval development time.

The larvae which were fed with the avocado had the low conversion rates (passage from white larvae to black larvae). This could be explained by the amount of fat in avocado. Indeed, avocado is one of the fruits with high lipid content. This high quantity of lipids would have favored the delay in the time of conversion of the white larvae into black larvae. These results are in agreement with the studies of Oonincx *et al*. (2015). According to these authors, larval development is slowed down by excess lipids. However, for diets low in fat and protein, but high in carbohydrate, carbohydrates are converted to fat by the larvae and stored in adipose tissue as fatty bodies (Handke *et al*., 2013; Pimentel *et al*., 2017). On the other hand, the high levels of black larvae obtained with the use of sweet bananas, watermelon and papaya respectively at the 2nd and 3rd week would be attributable to the carbohydrates and fibers contained in these fruits and vegetables. Indeed, the carbohydrates and fibers present in these substrates would have accelerated the larval development more compared to the avocado.

CONCLUSION

This study revealed that the substrate (fruits and vegetables) used has an impact on the production of black soldier fly larvae. Of the six fruits and vegetables used only the sweet banana and watermelon resulted in the best total weights, good body weights, good sizes and a good conversion rate of white larvae to black larvae in a short time. Avocado, papaya, cucumber and orange gave low efficiency. Thus, the use of sweet bananas and watermelon could allow the production of black soldier fly larvae on a large scale (even industrial) which can be used as a source of protein in chicken feed.

ACKNOWLEDGMENT

We would like to thank the company Labograin Africa for facilitating the incubation of the eggs of the flies.

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