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Influence of adult diet on biological parameters of the housefly, *Musca domestica* L. (Diptera: Muscidae)

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Abstract

Background: Housefly (*Musca domestica* L. 1758) larvae are used in various parts of the world for animal feeding either by exposing substrates for natural oviposition or in industrial systems involving an adult rearing unit to produce eggs that are then placed in a substrate suitable for larval development. In order to develop *M. domestica* rearing system in Benin, effects of five types of food (pineapple, papaya, banana, honey, and a mixture of milk + sugar) on some biological parameters (female fecundity, adult mortality, egg hatching, pupation, and emergence time and rates) have been evaluated.

Results: Flies fed with pineapple and milk + sugar showed the highest fecundity (respectively 321 and 325 eggs per female within 10 days). Adult mortality rates decreased significantly with flies fed with honey (27% in 10 days) and milk + sugar (37%) compared to flies fed on local fruits (57 to 62%). Only minor differences were observed between the five foods in egg hatching, pupation and emergence rates.

Conclusion: This study showed that pineapple can be used to feed *M. domestica* instead of the conventional and more expensive milk + sugar mixture without major impact on the efficiency of *M. domestica* rearing.

Keywords: *Musca domestica*, Local fruits, Fecundity, Mortality, Animal protein

Introduction

The housefly (*Musca domestica* L. 1758) is mainly known for its nuisances as a disease vector. This fly species is characterized by large populations and a high fecundity, which makes it a human and animal health problem (Hogsette et al. 2001; Scott et al. 2000). However, the ability of *M. domestica* to reproduce quickly can also be used to produce larvae for the feeding of poultry and fish. Indeed, the high costs of dietary protein are a hindrance to livestock development in Africa, particularly fish and poultry (Kenis et al. 2014). This leads

to the search for other cheap sources of protein that are available and accessible to all. In comparison with other insect species, larvae of *M. domestica* (maggots) have been widely studied as a potential source of protein for animals (Aniebo et al. 2008; Fasakin et al. 2003; Kenis et al. 2018; Newton et al. 2005; Pastor et al. 2015).

Animal wastes, agri-food wastes, and decaying fruits are the main food sources for flies in nature (Newton et al. 2005; Pomalégny et al. 2016; Sanou et al. 2018). These substrates can therefore be used for the production of fly larvae in free oviposition systems as described in Koné et al. (2017). In Benin, almost 6% of the farmers feed their poultry with fly larvae, at least occasionally, mostly by exposing substrates to naturally occurring flies (Pomalégny et al. 2016; Pomalégny et al. 2017). However, fly larvae can also be obtained using an adult rearing unit to produce eggs that are then inoculated in a

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substrate suitable for larval development (Čičková et al. 2015; Drew and Pieterse, 2015; Pastor et al. 2015; Wang et al. 2013). The rearing systems of adult flies in cages for the production of larvae have the advantage of reducing the risk of increasing fly populations in the nature and therefore their impact on human health. Systems for breeding *M. domestica* in wire cages with several food sources (sugar-milk mixture in the same proportions, honey and meat broth) are described in Čičková et al. (2015), Čičková et al. (2012), Ortiz et al. (2016), and Kenis et al. (2018).

Food quality greatly influences life history traits such as survival, development, and fecundity of an insect in nature (Bong et al. 2014). Carbohydrates are generally the main source of energy for insects, while proteins play a major role in their reproduction and fecundity (Lardies et al. 2004). In fly rearing, the quality of adult food is essential to ensure that females are capable of producing large amounts of eggs and vigorous larvae (Pastor et al. 2015). However, the different types of food used for breeding *M. domestica* (sugar, powder milk, honey, sometimes yeast, and meat) are expensive and often not accessible to small farmers and small- and medium-sized production units; hence, the need to look for new sources of locally available and accessible foods.

The aim of this study was to test different types of food that are locally available and applicable to *M. domestica* under breeding conditions and analyze their effect on the biological parameters that are essential for setting up an efficient *M. domestica* adult rearing system for larvae production in Benin.

Materials and methods

Material

The tests were conducted at the farm of the Faculty of Agro-nomic Sciences, Abomey-Calavi University in Benin (latitude 6°24'54.6912'' N and longitude 2°20'40.1892'' E) from January to September 2017. The different fly colonies used were obtained in January by exposing fermented corn bran and soybean bran outdoors to naturally occurring flies. In the following days, the substrates containing larvae were placed in wire netting cages until fly emergence. Emerged *M. domestica* adults were identified with a stereomicroscope using identification keys (Delvare and Aberlenc, 1986), isolated in 60 × 60 × 80 cm wire netting cages and fed with a powder milk and sugar mixture. Maize bran was placed in the cages as laying substrate in order to obtain a new generation of larvae, pupae, and adults. Flies of third generation were used for experimentation.

Musca domestica rearing and assessment of biological parameters

Adults of *M. domestica* were reared in gauze cages (about 100 adults per cage of 60 × 60 × 80 cm). They

were provided with water and fed with different foods to assess the food influence on biological parameters of adult of *M. domestica*. The oviposition substrate consisted of fermented poultry manure covered by yellow fabric (Charlton et al. 2015). The cages were placed outdoors under a roof to avoid the effects of rain and direct sun. Temperatures during tests varied between 24 and 32 °C when relative humidity varied from 60 to 70%.

The tests consisted in a comparison between biological parameters of flies fed on two conventional types of food (honey and mixture of 50% dry milk and 50% sugar) and that of flies fed on three local fruits: banana (local variety), pineapple (variety "Pain de Sucre"), and papaya (variety Sunrise). The approximate nutritional composition of the foods used in the experiments is presented in Table 1 (Stadlmayr et al. 2010). Honey and mixture of dry milk and sugar were renewed weekly while fruits were renewed every 3 days. The pulps of the three fruits were mixed in an electric mixer to obtain a pasty substrate easily consumable by adult flies. Fifty grams of each type of food were used per treatment and replication.

Biological parameters' collection

To assess fecundity, hundreds of freshly emerged adults (sex ratio 1:1) were placed in cages, and eggs were collected and counted daily from the yellow fabric that covered poultry manure for 10 days. Adult mortality was recorded daily, as well as the sex of the dead flies. Fifty eggs per replicate were incubated on a substrate (humid maize bran) in a Petri dish for monitoring the development time. Eggs hatched, and larvae and pupae were monitored until the emergence of adults. All tests were conducted according to a completely randomized design with six repetitions and five types of food as treatment (honey, mixture of dry milk and sugar, banana, pineapple, and papaya) during the period October 2016 to March 2017 at the farm of the Faculty of Agricultural Sciences of the University of Abomey-Calavi in Southern Benin. For each replicate, observations were done in parallel for the five rearing systems to avoid a potential influence of climatic conditions on the biological parameters.

Data collected during this study included fecundity (number of eggs laid per female), adult mortality, the number of eggs hatched after incubation, the number of pupae obtained, and the number of flies that emerged by type of food. Data collection for female fecundity and adult mortality started 24 h after adult emergence and were measured daily during 10 days. The fecundity per female was estimated by dividing the total number of eggs collected by the number of live females in the cage, taking into account the daily mortality and the sex of dead flies. The rate of hatched eggs was estimated by

Table 1 Nutrients content of food used to feed housefly adults

Nutrients	Pineapple	Banana	Powder milk + white sugar	Honey	Papaya
Energy (Kcal/100 g)	56	100	430.5	322	38
Protein (g/100 g)	0.4	1.3	12.65	0.3	0.5
Carbohydrate available (g/100 g)	12.1	22.2	64.9	80.2	7.7
Fat (g/100 g)	0.3	0.3	13.4	0	0.1
Fibre (g/100 g)	1.4	1.9	0	0	1.9

Source: Stadlmayr et al. 2010

counting the number of larvae 3 days after incubation. Pupation and adult emergence rates estimation started respectively the 5th day after egg incubation and the 4th day after pupation and lasted 5 days for each parameter. Daily pupation rate was calculated by dividing the number of pupae by the initial number of larvae introduced. Adult emergence rate was determined by dividing the number of emerged adults by the total number of pupae formed. Daily mortality of *M. domestica* adults was estimated by dividing the cumulative number of dead adults each day by the number of initial adults in the cage.

Data analysis

Female fecundity (number of eggs per female) and adult mortality were statistically analyzed by two-way (food and time (day of measurement) for fecundity; food and sex for mortality) analysis of variance (ANOVA), using the general linear model (GLM) procedure of SAS ($\alpha = 0.05$). Hatching, pupation, and emergence rates were analyzed by one-way (food) analysis of variance. Previously, normalities and homogeneity of the variances were tested using Levene test (Zar, 1999). Student Newman

and Keuls test was used for comparison of means among treatment ($P \leq 0.05$ level of significance). All statistical analyses were carried out using SAS (version 9.2).

Results

Fecundity of *M. domestica* females

The number of eggs laid by female varied with the type of food ($DF = 4$; $F = 126.90$; $P < 0.0001$) and time (number of days after emergence) ($DF = 7$; $F = 256.13$; $P < 0.0001$) with a significant type of food/time interaction ($DF = 28$; $F = 34.27$; $P < 0.0001$). Oviposition started the 3rd day after emergence, and the highest daily fecundity rates were reached between 6 and 8 days after emergence, with a peak at 98 eggs per female on average for flies fed with pineapple on day 8 (Table 2). Females of *M. domestica* fed with milk + sugar mixture laid on average 325 eggs/female during the first 10 days after emergence. This is statically superior ($DF = 4$, $F = 38.91$, $P < 0.0001$) to fecundities obtained with flies fed with honey (179), papaya (210), and banana (151). However, there was no significant difference with the number of eggs (321) produced by female fed with pineapple (Table 2).

Table 2 Evolution of fecundity (means $\pm$ standard deviation) of *M. domestica* females according to type of food and time

Number of eggs laid per female											
Diets	Day 1–2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Fisher F probability	Total fecundity
Pineapple	0	0.65 $\pm$ 0.05Dd	10.42 $\pm$ 0.16Cd	11.27 $\pm$ 0.53Cd	64.08 $\pm$ 7.04Bb	40.81 $\pm$ 4.58Ac	97.93.20 $\pm$ 4.30Aa	44.41 $\pm$ 1.55Bc	37.00 $\pm$ 3.12Ac	81.03 $P < 0.0001$	320.82 $\pm$ 25.39 A
Banana	0	7.42 $\pm$ 0.20Bd	15.09 $\pm$ 0.75Bc	16.62 $\pm$ 1.14Bc	19.13 $\pm$ 0.90Cbc	15.21 $\pm$ 0.81Cc	36.86 $\pm$ 3.93Ca	23.56 $\pm$ 1.56Da	17.32 $\pm$ 1.59Cc	24.64 $P < 0.0001$	151.21 $\pm$ 4.93 C
Milk + sugar	0	9.65 $\pm$ 0.47Ae	22.62 $\pm$ 1.09Acd	18.06 $\pm$ 0.91Bd	84.64 $\pm$ 5.82Aa	31.66 $\pm$ 2.67Bc	62.84 $\pm$ 3.35Bb	68.01 $\pm$ 2.70Ab	27.34 $\pm$ 2.02Bcd	90.82 $P < 0.0001$	324.81 $\pm$ 16.71 A
Honey	0	5.19 $\pm$ 0.34Ce	9.37 $\pm$ 0.26Ce	24.72 $\pm$ 1.00Ac	64.63 $\pm$ 3.60Ba	22.29 $\pm$ 0.93Cc	29.52 $\pm$ 0.82Cb	8.62 $\pm$ 0.47Ee	14.66 $\pm$ 0.22Cd	183.24 $P < 0.0001$	178.99 $\pm$ 5.29 BC
Papaya	0	4.91 $\pm$ 0.21Cf	14.36 $\pm$ 1.18Ae	15.26 $\pm$ 1.28Be	25.73 $\pm$ 7.7Cd	31.13 $\pm$ 0.78Bcd	43.66 $\pm$ 2.77Ca	39.28 $\pm$ 1.69Cab	35.85 $\pm$ 3.43Abc	51.40 $P < 0.0001$	210.18 $\pm$ 7.78 B
Fisher F Probability	–	131.92 $P < 0.0001$	42.31 $P < 0.0001$	23.88 $P < 0.0001$	39.11 $P < 0.0001$	15.87 $P < 0.0001$	44.58 $P < 0.0001$	165.34 $P < 0.0001$	18.81 $P < 0.0001$		31.57 $P < 0.0001$

Similar capital case letters in the same column indicate no significant difference between foods at 0.05 level Similar lower letters in the same row indicate no difference between days at 0.05 level

Mortality of *M. domestica* adults

Cumulative mortality during the 10 days of observation is shown in Fig. 1. Sex (DF = 4; $F = 0.24$ to 2.21 ; $P = 0.08$ to 0.91) did not affect the mortality rate of housefly adults, in contrast to the food type, which significantly affected mortality every day of observation (DF = 4; $F = 3.41$ to 28.29 ; $P = 0.0154$ to $P < 0.0001$) except the third (DF = 4; $F = 1.49$; $P = 0.22$) and fourth (DF = 4; $F = 1.81$; $P = 0.14$) days. On the 1st day, no mortality was registered. Mortality started to increase extensively on the 5th day. On the last day (10th), flies fed on local fruits (pineapple, papaya, and banana) statistically recorded higher mortality (> 50%) than those fed on conventional foods (milk + sugar and honey). Flies fed with pineapple registered the highest cumulative mortality (63%) after 10 days and those fed with honey the lowest (27%) (Fig. 1).

Hatching rate of eggs

The hatching of housefly eggs was not affected by the quality of food with which females were fed (DF = 4; $F = 1.67$; $P = 0.1895$). The highest hatching rate was obtained with eggs from females fed with milk + sugar (89%) while the lowest (80%) was recorded with eggs from flies fed with banana (Fig. 2).

Pupation rate of *M. domestica* larvae

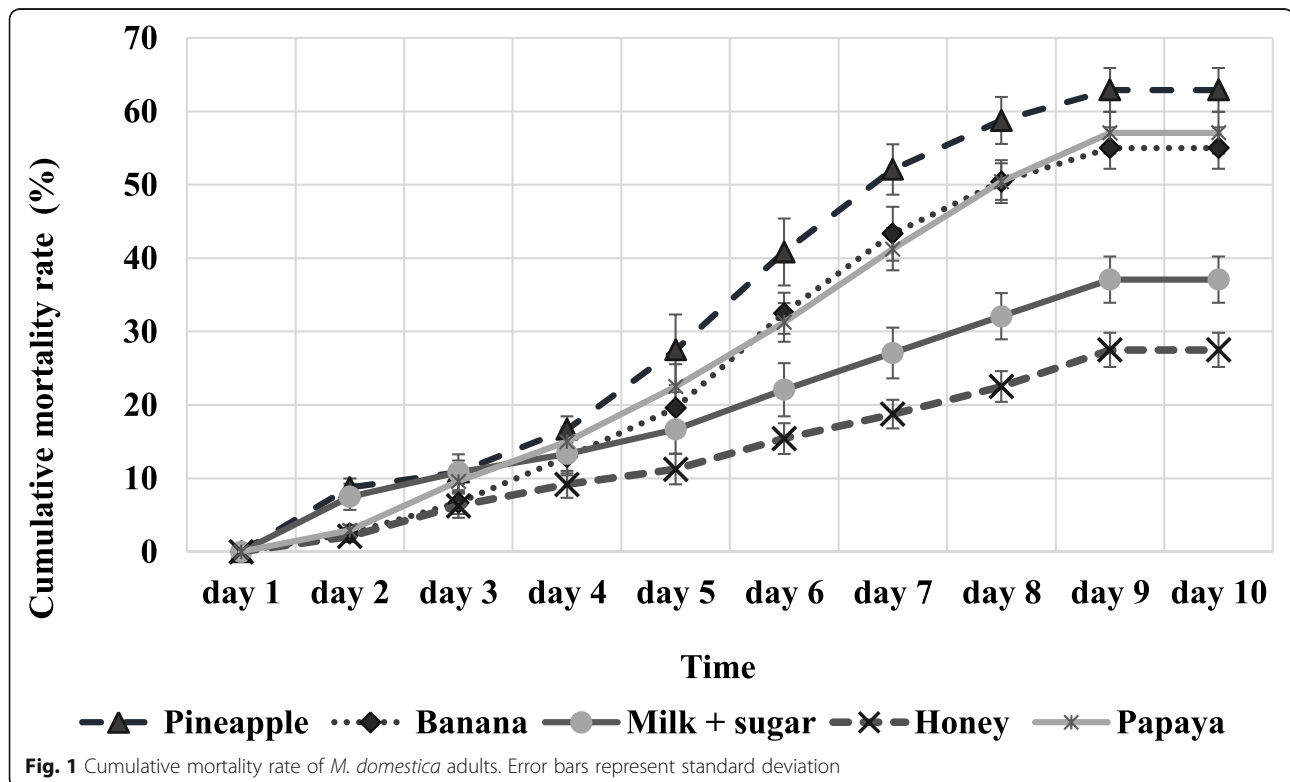
Figure 3 shows the cumulative pupation rate of house fly larvae after egg incubation. Pupation started the 5th day after egg incubation. The pupation rate of larvae from different rearing systems was significantly influenced by the type of food (DF = 4; $F = 3.81$ to 10.77 ; $P = 0.0149$ to $P < 0.0001$) all observation days except the 9th day (DF = 4; $F = 0.88$; $P = 0.4903$) when over 95% of the larvae had pupated in all food rearing systems. Pupation was faster in larvae fed with milk + sugar than in the other rearing systems (e.g., for the 7th day: DF = 4; $F = 7.09$; $P = 0.0006$).

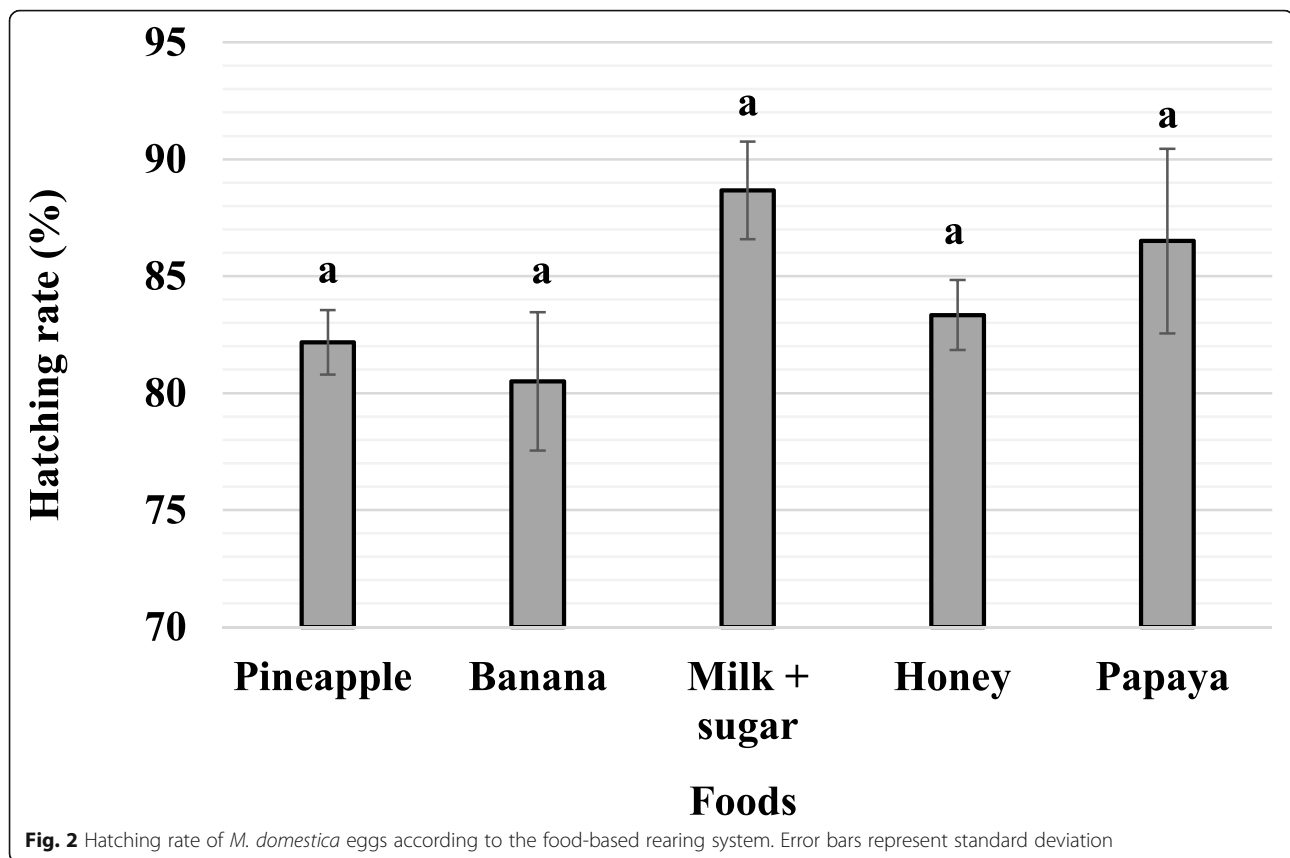
Emergence rate of *M. domestica* adults

The cumulative emergence rate of *M. domestica* adults is shown in Fig. 4. Emergence of adults started 4 days after pupation. There were strong statistical differences in the emergence rate of *M. domestica* adults among food types (DF = 4; $F = 2.61$ to 32.00 ; $P = 0.0600$ to $P < 0.0001$) all days except the last day (8th day: DF = 4; $F = 0.81$; $P = 0.5298$) when the emergence rate was over 94% for all rearing systems. The shortest pupation time was observed in flies fed with milk + sugar and pineapple.

Discussion

Feeding is an important parameter in conventional insect breeding systems and has a significant influence on





the productivity of insects, as shown by our results on *M. domestica*. The mixture of milk + sugar and pineapple induced the highest daily fecundity rates. Pastor et al. (2011) demonstrated that a well-balanced diet is necessary for successful reproduction. Also, according to Strangways-Dixon (1961), *M. domestica* needs both sugar and protein for egg production and the ratio sugar/protein changes with the stage of development. The number of eggs obtained per female of *M. domestica* fed on milk + sugar mixture in this study (40.60 egg/female/day) is somewhat different from that reported by other authors for the same diet. Lysyk (1991) reported a maximum laying rate in a field experiment of 11.4 eggs per female per day. (Fletcher et al. 1990) estimated the lifetime fecundity of *M. domestica* female at 433.1 eggs at 25 °C when fed with a dilute solution of evaporated milk and granular sugar (324.81 eggs/female during 10 days in our study). Several factors can explain the difference between our results obtained and those of these authors: differences in fly strains, rearing techniques and conditions, quality and quantity of milk powder used, etc. In addition, these authors report a different number of flies (more than 100) in experimental cages, which may also have influenced their results. Pastor et al. (2011) observed that fly density is negatively correlated with fecundity; nevertheless, they recommend rearing at high density (14.2 cm³ per fly) to increase the efficiency and productivity of

the fly production system. More generally, the number of eggs a fly female can oviposit is influenced by environmental temperature and humidity, quantity and quality of larval diet, quantity and quality of adult diet, mating, adult population density, age of flies, oviposition substrate, photoperiod, and genetic factors (see a discussion of these factors in Pastor et al. (2015)).

Although, in our study, the best results were obtained with the conventional milk and sugar diet; the different local fruits used in our experiments showed very satisfactory results. Especially, flies fed on pineapple showed similar egg-laying performances with those fed on the milk and sugar mixture. These results are particularly important since they meet the objective pursued by this study, i.e., finding alternatives to replace expensive conventional food with a local food, easily accessible and cheaper. As the variety of pineapple used in our experiments is naturally high in sugar, we could think that the sugar level in the fly diet plays an important role in the fecundity of *M. domestica* females. For Sun et al. (2002) and Pastor et al. (2011), oviposition of *M. domestica* is strongly influenced by several factors such as the quality of protein source that determines the volume of eggs produced. The work by Beard and Sands (1973) on the comparison of the non-protein diet with diets enriched in protein supplements revealed that the addition of

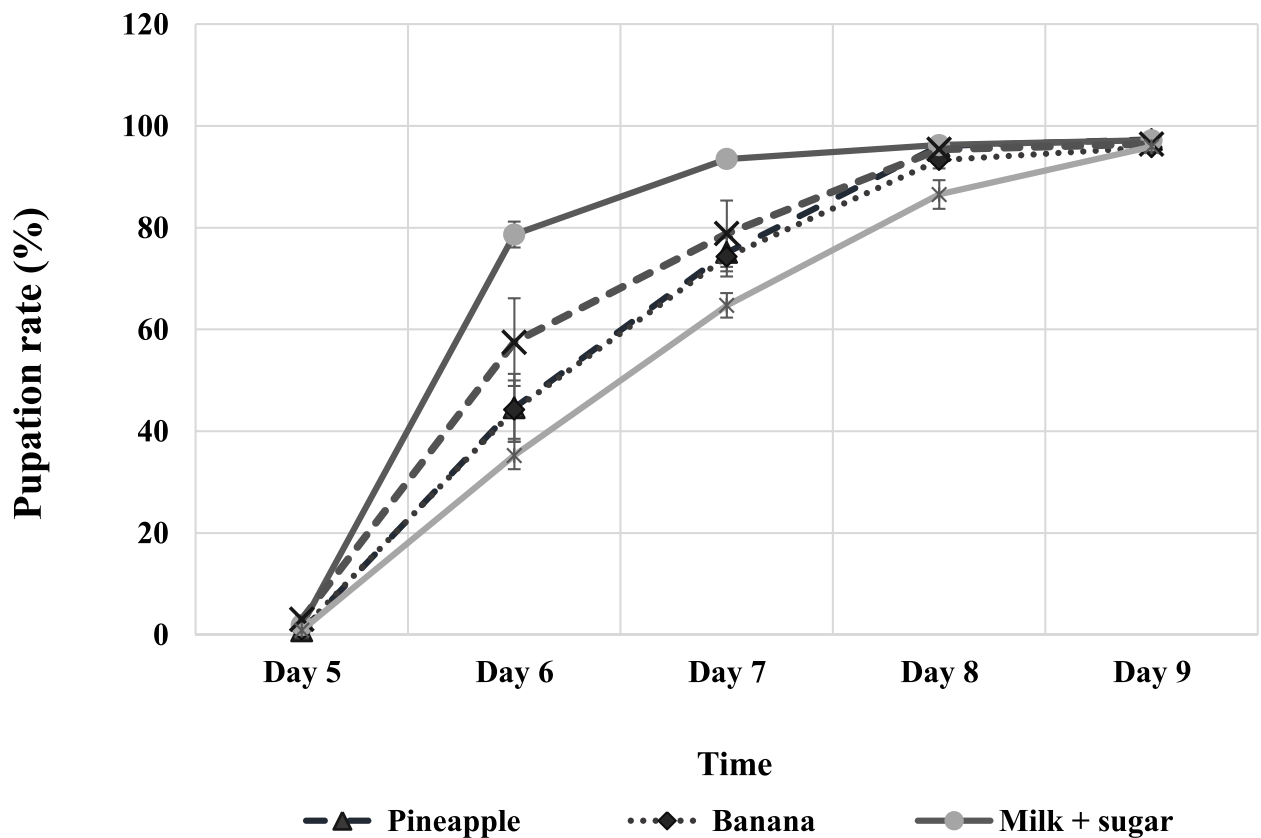


Fig. 3 Cumulative pupation rate of *M. domestica* larvae from different food-based rearing systems. Error bars represent standard deviation

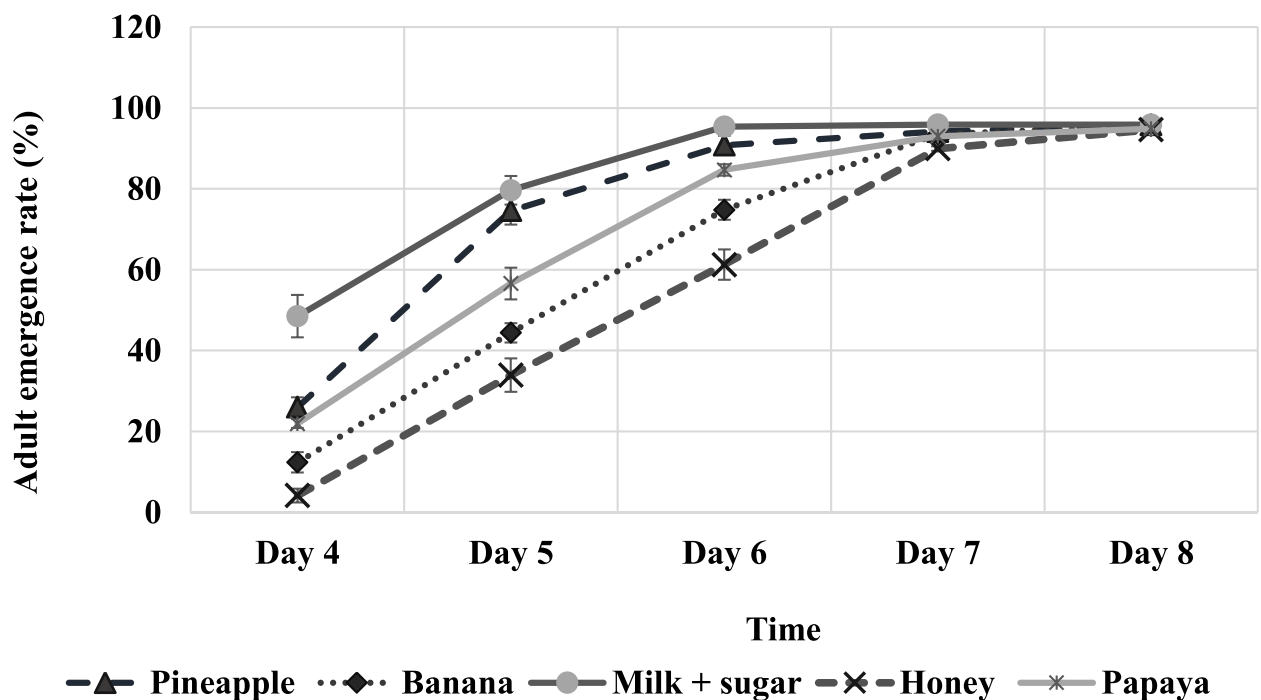


Fig. 4 Evolution of the cumulative emergence rate of *M. domestica* adults according to the food-based rearing system. Error bars represent standard deviation

protein to the diet of *M. domestica* adults resulted in a substantial increase in the production of eggs. This explains the high fertility of flies fed on the milk + sugar mixture. Indeed, this food has the highest levels of carbohydrates and proteins. However, the high potential of pineapple is surprising because in terms of energy and protein content, it is only fourth behind banana and honey. As the protein content plays an important role in female fecundity (Lardies et al. 2004), it is difficult to conceive that pineapple showed a high potential compared to bananas, which are richer in protein. However, the nature of the proteins present in these different fruits could explain the differences observed in fly fecundity. Furthermore, Shipp and Osborn (1967) showed that the physical state in which food is offered to adult flies is also important. In our case, the gelatinous nature of the mixed banana diet was different from the pineapple diet, which forms a homogeneous paw, and may be less suitable for flies. Another potential replacement of milk in fly production systems is smashed fly larvae, which also contain a high level of proteins and are very efficient in rural fly production systems, as shown by Maciel-Vergara (2014).

The study of the effect of the different types of adult food on the pupation rate and time of the progeny reveals that more than 50% of the larvae have pupated the 7th day after egg incubation. Several authors have reported that pupation is time-dependent and the nature of larvae development substrate can influence the pupation rate of *M. domestica* larvae (Loa 2000; Pastor et al. 2011). Their conclusions thus confirm our results, which highlighted that the pupation of larvae and the emergence of adults increased with time depending the type of food until the last day where there is no food influence on pupation and emergence rates. Robertson (2015) claimed on their side that the pupal stage usually lasts about 6–7 days and is influenced not only by substrate temperature but also by ambient temperature.

The results also showed that the mortality rate of adults reached 50% the 8th day except for flies fed on milk + sugar and honey which mortality rate remained lower. Indeed, these two foods are characterized by a high sugar content, thus promoting the longevity of flies. Pastor et al. (2011) report that adult houseflies fed with the milk + sugar mixture were still able to lay at 34 days and have a low mortality rate. However, for Berberian et al. (1971) and Golubeva (1984), fly mortality may be related to the number of eggs laid, which depends on their diet and the availability of suitable substrate for laying and eventually on local climatic factors. Flies fed on pineapple showed the highest mortality rates on the 8th day of observation. This high mortality of flies fed on pineapple, combined with their high fecundity and low protein and carbohydrate content, seems to corroborate the observations of for Berberian et al. (1971) and Golubeva (1984).

Finally, it must be noted that these results were carried out under quasi natural conditions to mimic potential fly larvae production systems that could be set up in rural areas in Benin. We do not think that the variable climatic conditions experienced during the trials influenced the comparison between the adult food treatments because these were carried out in parallel. However, it is clear that climatic conditions influence fecundity, egg hatching mortality, and development (Fletcher et al. 1990; Kenis et al. 2018; Pastor et al. 2015; Zhemchuzhina and Zvereva, 1985) and, thus, the absolute data of our studies on these biological parameters have to be considered with caution. Similar trials should be repeated in other agroecological zones to better understand the effect of natural climatic factors on house fly rearing systems in West Africa.

Conclusions

The establishment of a controlled rearing system of *M. domestica* in a perspective of maggot production in Benin motivated this experiment which led to quite satisfactory conclusions. Thus, the evaluation of the nutritional potential of five types of food revealed that flies fed with pineapple and milk + sugar showed the highest fecundity of *M. domestica* females. This study showed that pineapple can be used to feed *M. domestica* instead of the conventional and more expensive foods (honey and milk + sugar mixture) without major impact on the fecundity of females.

Abbreviations

ANOVA: Analysis of variance; GLM: General linear model; *P*: Probability; DF: Degree of Freedom; *F*: Fisher value

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Authors' contributions

HG conceived and designed the experiments, performed the bioassay, analyzed and interpreted the data, and wrote the manuscript. HAA performed the bioassay, collected and interpreted the data. ETZB suggested, planned, and designed the study and contributed to manuscript correction. MK suggested the study and contributed to manuscript correction. CAAMC suggested the study and contributed to manuscript correction. GAM contributed to the manuscript correction. All authors read and approved the final manuscript.

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Availability of data and materials

Data will not be shared, only by request from the corresponding author.

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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