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Performance of Two Food Substrates in the Mass Rearing of *Bactrocera dorsalis* Hendel (Diptera: Tephritidae)

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Abstract

The fruit fly *Bactrocera dorsalis* Hendel is a major constraint to mango production in Burkina Faso. The objective of this study was to evaluate the performance of two types of food substrates in optimizing the mass rearing of *B. dorsalis* larvae. For this purpose, 200 eggs of *B. dorsalis* were divided into four batches of 50 eggs and incubated in Petri dishes containing the different food substrates (Diet 1 and Diet 2). This method was used to evaluate the rate and duration of egg hatching, as well as the development time of the different larval stages. In addition, 1200 pupae divided into four batches of 300 pupae, contained in PVC tubes, were placed inside the rearing cages to monitor the emergence of *B. dorsalis*. Ten pairs of *B. dorsalis* were placed in rearing cages and fed with Enzymatic Yeast Hydrolysate and sugar to evaluate the fecundity of female flies and the survival of both sexes. The developmental cycle length in Diet 1 and Diet 2 was 23.03 days and 23.24 days, respectively. Fecundity duration ranged from 57.75 ± 2.29 to 109.81 ± 3.81 days for females from Diet 1 and Diet 2, respectively. The pupal hatching rate varied significantly ($P < 0.0001$) from 89.12% ± 1.47% to 97.93% ± 0.34% depending on the type of food substrate. Males lived longer than females regardless of food substrate type (60.36 ± 1.84 to 107.10 ± 4.08 days for Diet 1 versus 42.02 ± 1.65 to 87.79 ± 2.27 days for Diet 2). Both food substrates tested were favorable to the good development of *B. dorsalis*, but the spawning index was 4 times higher with Diet 1. Most of the components of Diet 1 are available on the local market and are cheaper. Thus, we recommend the use of Diet 1 for *B. dorsalis* larvae mass rearing.

Keywords

Fruit Fly, *Diachasmimorpha longicaudata*, Biology, Food Substrates, Mass Rearing

1. Introduction

Fruit production, including banana, guava, citrus fruits, papaya and mango, is an important component of agricultural production in Africa. The mango tree is one of the most important fruit trees in West Africa. Mango production is of great importance in Burkina Faso and is considered one of the six promising sectors given the strong potential for export diversification [1]. Nearly 20,000 farmers are involved in mango production, with orchards covering close to 33,000 hectares of land, mainly in the southwest and centre-west of the country [2]. Mango production in Burkina Faso has increased over the past three years. It increased from 90,000 tonnes in 2017 to 200,000 tonnes in 2018, and in 2019, the production of 243,000 tonnes of mango was recorded according to the Association of Producers of Mango of Burkina Faso [3]. Unfortunately, the expansion of this sector is hampered by pests, including fruit and vegetable flies of the family Tephritidae [4]. Approximately 30 species of fruit flies have been inventoried in mango and citrus orchards, agroforestry parks and natural formations in the country [5] [6] [7]. These insect pests reproduce by laying their eggs in the fruit. The eggs hatch, giving rise to the larvae that feed on the fruit flesh by creating galleries. Average attack rates of 0% to 0.43% at the start of the mango season (early April) can reach 20.55% to 86.67% at the end (early July) depending on the mango variety [8]. The economic consequences include not only direct yield losses and high control costs, but also the loss of export markets due to the high cost of quarantine treatments imposed by importing countries [9]. Losses related to interceptions amount to several hundred tons of mangoes from West Africa, which are destroyed at the exporters' expense. In 2017, 163,228 tons of mangoes from Burkina Faso were intercepted in Europe, causing an estimated economic loss of 175,000 USD. Fruit flies have become a scourge for the fruit and vegetable sector in Burkina Faso. Faced with this situation, several control methods have been developed and disseminated to producers. These are mainly sanitation, mass trapping using sexual attractants and the use of protein baits. Biological control by the use of parasitoids and the sterile insect technique is being studied to reinforce the existing means of control. The implementation of these two control methods depends on the quality mass production of the fruit fly *Bactrocera dorsalis*. For this purpose, two types of food substrate are used in the laboratory for the mass rearing of *B. dorsalis* larvae. However, the performance of these substrates in optimizing the mass rearing of *B. dorsalis* larvae is not yet well known. The aim of this study was to evaluate some biological parameters of *B. dorsalis* reared on two types of diet. This specifically involved 1)

determining the duration of each developmental stage of *B. dorsalis*, 2) evaluating the survival rate of the different larval stages, 3) assessing the fecundity of female flies and 4) determining the longevity of male and female flies.

2. Methods

2.1. Laboratory Facilities

The study was conducted over a period of 10 months (from August 2019 to May 2020) in the laboratory. During this period, the average daily temperature varied from 23.05˚C (May) to 27.42˚C (December), and the relative humidity varied from 45.24% (February) to 76.48% (August). The photoperiod was maintained at 12 hours of light a day.

2.2. Diet Preparation

The first diet (local Diet 1) consisted of several protein sources namely soybean meal, rice bran, corn flour and yeast waste. According to [10], soybean meal and rice bran contain respectively 44.46% and 13.25% of protein. Corn flour contains 6.05% of protein [11]. Yeast waste was boiled for 30 minutes before mixing with other components. The diet obtained had a pasty appearance. The second diet (Diet 2) was obtained by mixing different components in water. This diet was liquid and contains two types of yeast: LBI2240 and FNILS65. LBI2240 is a debittered brewer's yeast without the use of chemicals and is deactivated by being heated and roller dried. LBI2240 is a whole-cell yeast while FNILS65 is hydrolysed yeast. LBI2240 and FNILS65 contain respectively 45.40% and 65% of protein [12]. **Table 1** presents the composition of the two diets used to rear *B. dorsalis* larvae.

2.3. Rearing of *B. dorsalis* on the Two Types of Diet

The *B. dorsalis* larvae were reared in the laboratory under the same temperature and relative humidity conditions of the experiment room. Eggs were first collected by placing artificial nests in rearing cages containing a population of sexually mature *B. dorsalis*. This population was derived from a strain of *B. dorsalis* bred since 2018. Each artificial nest consisted of a yellow funnel perforated with small equidistant 1-mm-diameter holes and containing black muslin cloth moistened with mango juice. After 24 hours of exposure, the nests were removed and rinsed with tap water. This water was then filtered through a very-fine-mesh muslin cloth to collect the eggs.

The collected eggs were then placed using a brush in plastic pots containing the diets. For Diet 1, eggs incubation was carried out on blotting paper previously placed on the diet. For Diet 2, the eggs were spread on vegetable sponges previously placed in the substrate. Observations were made daily to monitor the hatching of the eggs and the progression of the different larval stages (L1, L2, L3) that feed on diets. First-instar larvae (L1) are recognizable by their egg-like whitish colour and poorly developed mouth stylets. Second-instar larvae (L2) are

Table 1. Composition of diets used to rear *B. dorsalis* larvae in this study.

Ingredients	Diet 1		Diet 2	
	%	G	%	G
Corn flour	5.51	60		-
Soybean meal powder	10.47	114		-
Sugar	10.11	110	8.70	18.27
Rice bran	6.43	70		-
Rice litter	2.75	30		-
Nipagen	0.09	1		-
Citric acid		-	4.28	9
LBI2240		-	10.91	22.95
FNILS65		-	3.64	7.65
Sodium benzoate		-	0.14	0.3
Methyl-p-Hydrobenzoate		-	0.14	0.3
Streptomycin		-	0.10	0.225
Hydrochloric acid	0.27	3 ml		-
Yeast wastes from bear processing	36.76	400 ml		-
Distilled water	27.57	300 ml	71.37	150 ml
Wheat germ oil		-	0.71	1.5 ml

intermediate larvae. They begin to take on the colour of the nutrient medium and are slightly larger in size than the first-stage larvae. The segments become increasingly visible. Third-instar larvae (L3) are well developed, are able to jump, and the segments are clearly visible. At each observation, Diet 1 was soaked in distilled water to prevent it from drying out. These third-stage larvae were recovered 6 to 7 days after incubation and then placed in jars containing sand sterilized at 100˚C for 12 hours. These jars were covered with a muslin canvas held by elastic bands.

The pupae formed at the end of the larval cycle were finally collected by sieving the sand. They were placed in Petri dishes and transferred to rearing cages for the emergence of adult flies.

2.4. Biological Parameters of *B. dorsalis*

2.4.1. Assessment of Egg Hatching Time and Rate

For the evaluation of these parameters, 200 eggs were incubated in four Petri dishes (50 eggs/dish) containing 25 g of Diet 1 or 25 ml of Diet 2. For Diet 1, the eggs were placed on blotting paper previously deposited on the 25 g of substrate (**Figure 1(a)**). For Diet 2, the eggs were placed on a vegetable sponge immersed in 5 ml of Diet (**Figure 1(b)**). The remaining quantity (20 ml) was added at a

(a) (b)

Figure 1. (a) Egg incubation device on Diet 1; (b) Egg incubation device on Diet 2.

rate of 5 ml every 48 hours to avoid drowning of newly hatched larvae. Observations were made every 24 hours with a binocular magnifying glass to count the hatched eggs. The hatched eggs were recognizable by the tear in the shell when the first instar larvae emerged. After each observation, a few drops of distilled water were sprinkled on Diet 1 to prevent it from drying out. The experiment was repeated four times. Egg hatching time and rate were calculated by applying the following formulas:

$$\text{Hatch duration} = \left(\sum \text{ai.ei} / \sum \text{ei}\right) \quad [13]$$

ai: Time required for the first instar larva to emerge from the egg;
ei: Number of eggs hatched for the duration ai.

$$\text{Hatch rate} = \frac{\text{Number of eggs hatched}}{\text{Total number of incubated eggs}} * 100$$

2.4.2. Evaluation of the Duration and Survival of Different Larval Stages

The experiment continued after the eggs hatched to assess the duration and survival of the different larval development stages. This involved counting every 24 hours the larvae of the different developmental stages that were able to continue growing after hatching. For this purpose, the number of L1, L2, and L3 larvae and the time taken to pass from one stage of development to another were noted after each observation session. The duration of development and the survival rate of first-instar larvae were calculated using the following formulas:

$$\text{Development time}\left(\text{L1 larvae}\right) = \left(\sum \text{xi1.ni1} / \sum \text{ni1}\right) \quad [10]$$

$$\text{Survival rate of L1 larvae} = \left[\text{Number of L2 larvae}\left(\text{obtained}\right) / \text{number of L1 larvae}\right] * 100$$

xi1: Evolution time of larvae from Stage 1 to Stage 2;
ni1: Number of first instar larvae having reached into second instar at time xi1.
The same formulas were applied for the other developmental stages.

2.4.3. Assessment of Pupal Development Time

The third-instar larvae obtained at the end of egg incubation were used to assess

this parameter. The pupal development time, *i.e.* the time between pupation and adult emergence, was determined by carrying out daily observations to note the date of pupation of third-instar larvae. These larvae were previously transferred to sterilized sand. The pupae were collected by sieving the sand. Then, they were transferred to rearing cages to observe the emergence of adult flies. The date of emergence and the number of emerged adult flies were recorded according to each diet through observations that made every 24 hours. The development time was determined using the following formula:

$$\text{Duration of pupal development} = \left(\sum \text{xip.nia} / \sum \text{nia}\right)$$

xip: Time taken by the pupa to hatch;
nie: Number of emerged adults.

2.4.4. Evaluation of Emergence Time

The determination of this parameter consisted of diving 1200 pupae of the same age reared on the same diet among four Petri dishes (300 pupae/dish). The Petri dishes were individually placed in rearing cages to observe the emergence of flies every 24 hours. The number of emerged adults was recorded by sex at each observation session according to the type diet. At the end of these observations, the following formulas were applied to calculate the rate of emergence of the flies and the sex ratio.

$$\text{Emergence rate} = \frac{\text{Number of emerged flies}}{\text{Total number of pupae}} * 100$$

$$\text{Sex ratio} = \frac{\text{Number of female flies emerged}}{\text{Number of male flies emerged}}$$

2.4.5. Evaluation of Flight Ability

For each diet, the flight ability of emerged flies was evaluated in four PVC tubes, each containing 100 pupae. The inner surface of each tube was brushed with wheat powder to prevent flightless flies from escaping. The tubes were placed individually in rearing cages to observe the emergence of flies every 24 hours. All of the emerged flies able to fly out of the PVC tube were counted. Flight ability was calculated by applying the following formula:

$$\text{Flight ability} = \frac{\text{Number of emerged flies exiting the tube}}{\text{Total number of emerged flies}} * 100$$

2.4.6. Evaluation of Fecundity and Longevity

The fecundity of *B. dorsalis* was assessed by using pairs of flies that emerged on the same day. These flies were transferred to rearing cages with a mouth aspirator. Flies weakened during the transfer were replaced after 24 hours. For each diet, four rearing cages were used, each containing 10 couples. A drinker containing cotton wool soaked in tap water and a Petri dish containing a mixture of sugar (50%) and yeast enzymatic hydrolysate (50%) were also placed in each cage to feed the flies.

Artificial nest boxes containing black cloth moistened with mango juice were

then placed inside the cages to collect the eggs laid. Nest boxes were removed and replaced with new ones every 24 hours. Each nest box was rinsed with tap water, and eggs were collected by sieving using a black muslin cloth. Eggs were counted per cage and per diet. Egg collection continued every 24 hours until all female flies were dead. At each collection session, the number of dead flies (male and/or female) was recorded per cage and per diet. These observations were made until total death of the flies.

2.5. Data Analysis

Microsoft Office Excel was used for data entry and processing. Data processing consisted of applying the above formulas before performing the statistical analyses. Statistical analysis was conducted using R software 3.6.0. The Kruskal-Wallis and Wilcox comparison tests were used to compare the means in case of significant difference at the probability threshold of 5%.

3. Results

3.1. Duration of the Different Developmental Stages

Table 2 presents the effect of diet on the duration of each developmental stage of *B. dorsalis*. Egg hatching lasted an average of 1.95 days on Diet 1 and 2.15 days on Diet 2. No significant difference (W = 0.84; P = 0.61) was observed between these two diets for this stage. Similar results were recorded for the duration of development of the different larval stages. First-instar larvae reached the second instar after 2.94 days on Diet 1 and 3.30 days on Diet 2. Second-instar larvae reached the third instar after 1.85 days on Diet 1 and 2.03 days on Diet 2. Third-instar larvae pupated after 1.97 days and 2.23 days on Diet 1 and Diet 2, respectively. The duration of pupal development was significantly influenced (W = 0.97; P = 0.003) by the diet. The pupae started to hatch after 8.51 days for Diet 1 and 10.28 days for Diet 2.

3.2. Survival Rate of the Different Developmental Stages

Table 3 presents the survival rate of the different developmental stages. After incubation, 32.12% of the eggs hatched on Diet 1, while 74.87% of the eggs hatched on Diet 2. The survival rate of the larvae in the different developmental stages varied significantly as a function of diet. From the first-instar larvae obtained after egg hatching, 98.75% and 85.52% were able to reach the second instar on Diet 1 and Diet 2, respectively. The survival rate of second-instar larvae was 97.75% on Diet 1 and 82.61% on Diet 2. No significant difference (P = 0.7) was observed between the two diets with regard to the survival rate of third-instar larvae. In total, 98.24% and 97.82% of third-instar larvae on Diet 1 and Diet 2, respectively, were able to become pupae. Adult flies emerged from these pupae with an emergence rate of 88.33% on Diet 1 and 95.36% on Diet 2. Statistical analysis revealed a highly significant difference (P = 0.001) between the two food substrates for this developmental stage.

Table 2. Average duration (days) of each *Bactrocera dorsalis* developmental stage as a function to diets

Type of diet	Development time (days) ± SD				
	Egg-L1	L1-L2	L2-L3	L3-Pupae	Pupae-Adult
Diet 1	1.95 ± 0.33[a]	2.94 ± 0.16[a]	1.85 ± 0.09[a]	1.97 ± 0.38[a]	8.51 ± 0.22[a]
Diet 2	2.15 ± 0.14[a]	3.30 ± 0.13[a]	2.03 ± 0.07[a]	2.23 ± 0.11[a]	10.28 ± 0.30[b]
Probability	0.61[NS]	0.13[NS]	0.16[NS]	0.88[NS]	0.003**

In the same column, the means followed by the same letter are not statistically different at the 5% probability threshold. NS: Not Significant; **: Highly Significant.

Table 3. Survival rates of the different developmental stages of *Bactrocera dorsalis*.

Type of diet	Survival rate (%) ± SD				
	Egg-L1	L1-L2	L2-L3	L3-Pupe	Pupe-Adult
Diet 1	32.12 ± 2.01[a]	98.75 ± 0.69[a]	97.75 ± 1.32[a]	98.24 ± 1.1[a]	88.33 ± 1.52[a]
Diet 2	74.87 ± 1.15[b]	85.52 ± 4.07[b]	82.61 ± 4.09[b]	97.82 ± 1.1[a]	95.36 ± 1.19[b]
Probability	<0.0001***	0.003**	0.001**	0.7[NS]	0.001**

In the same column, the means followed by the same letter are not significantly different at the 5% probability threshold. NS: Not Significant; **: Highly Significant; ***: Very Highly Significant.

3.3. Emergence Duration, Flight Ability and Sex Ratio

The emergence of adult flies was spread over 3.12 days for Diet 1 and over 3.56 days for Diet 2 (Table 4). For these two respective diets, average pupal hatching rates of 89.12% and 97.93% were recorded. The flight ability rates were 98.59% and 97.63% for Diet 1 and Diet 2, respectively. No significant difference (W = 83.5; P = 0.095) was observed between the two diets for this parameter. The sex ratio was 1 male to 0.92 females for Diet 1 versus 1 male to 1.10 females for Diet 2. Emergence duration, emergence rate and sex ratio were significantly influenced ($P < 0.05$) by the type of diet.

3.4. Females Fertility

The female *B. dorsalis* experienced a preoviposition period of 3.25 days and 5.81 days after emergence for Diet 2 and Diet 1, respectively (Table 5). The average laying time was 57.75 days for females from Diet 1 and 109.81 days for those from Diet 2. The average daily spawning indices were 4.76 eggs/female/day for Diet 2 and 20.54 eggs/female/day for Diet 1. All these parameters were significantly influenced ($P < 0.05$) by the type of diet.

3.5. Laying Dynamics

Figure 2 illustrates the progression in the number of eggs laid by females of *B.*

dorsalis from Diet 1. The first eggs laid were observed 72 hours after the emergence of the females. The maximum number of eggs laid was recorded between the 8th and 28th days. The peak of laying was observed on the 15th day, with an average of 40 eggs laid per female on that day. No eggs were laid from the 78th day onwards after emergence of the females.

Table 4. Pupal hatching time, pupal hatching rate, sex ratio and flight ability of *Bactrocera dorsalis* as a function of diet.

Type of diet	Hatch duration (days) ± SD	Hatch rate (%) ± SD	Sex-ratio (M:F) ± SD	Fligth ability (%) ± SD
Diet 1	3.12 ± 0.09[a]	89.12 ± 1.48[a]	1:0.92 ± 0.04[a]	98.59 ± 0.24[a]
Diet 2	3.56 ± 0.13[b]	97.93 ± 0.35[b]	1:1.10 ± 0.04[b]	97.63 ± 0.52[a]
Probability	0.011*	<0.0001***	0.014*	0.095[NS]

In the same column, the means followed by the same letter are not significantly different at the 5% probability threshold. NS: Not Significant; *: Significant; ***: Very Highly Significant; M: Male; F: Female.

Table 5. Average duration of preoviposition and oviposition and average number of eggs laid by *Bactrocera dorsalis* as a function of diet.

Type of diet	Pre-oviposition duration (days) ± SD	Oviposition duration (days)	Number of eggs laid/day/female
Diet 1	5.81 ± 0.29[a]	57.75 ± 2.29[b]	20.54 ± 0.49[a]
Diet 2	3.25 ± 0.49[b]	109.81 ± 3.81[a]	4.76 ± 0.10[b]
Probability	0.0001***	<0.0001***	<0.0001***

In the same column, the means followed by the same letter are not significantly different at the 5% probability threshold. ***: Very Highly Significant.

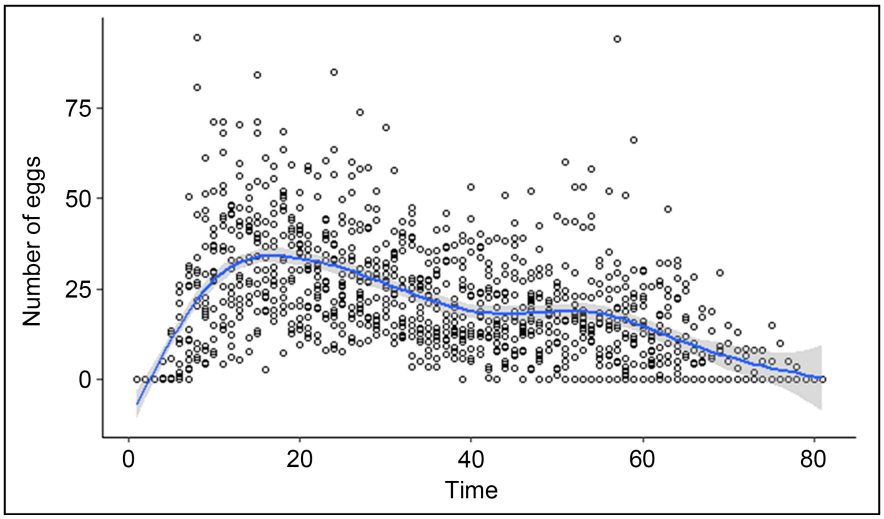

Figure 2. Progression curve of egg laying by *Bactrocera dorsalis* females from larvae fed Diet 1.

Figure 3 shows the progression in the number of eggs laid by female *B. dorsalis* from Diet 2. The females started to lay 24 hours after their emergence. The maximum number of eggs laid was observed between the 15th and 40th days. The peak of laying was recorded on the 28th day after emergence, with an average of 14 eggs laid per female on that day. No eggs were laid after the 157th day.

3.6. Lifespan

The lifespan varied on average from 42.02 days to 107.18 days depending on the sex and diet (Table 6). Flies from larvae fed Diet 2 lived longer than those from larvae fed Diet 1. In addition, males lived longer than females regardless of the type of diet. The multiple comparison test showed a very highly significant difference (X_3^2 = 91.74; P < 0.0001) between the two diets.

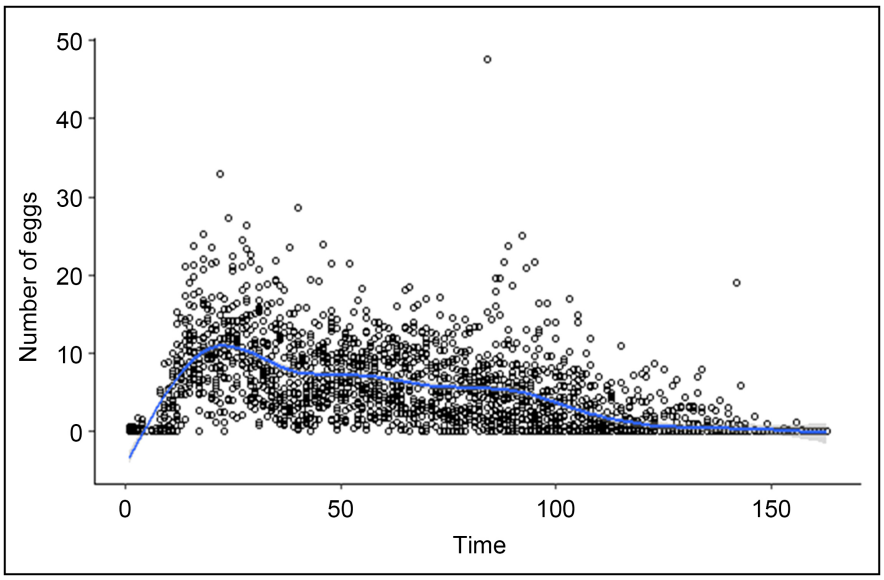

Figure 3. Progression curve of egg laying by female *Bactrocera dorsalis* from larvae fed Diet 2.

Table 6. Average lifespan of *Bactrocera dorsalis* as a function of sex and diet.

Type of diet	Sex	Lifespan (days) ± SD
Diet 1	Male	60.36 ± 1.84[c]
	Female	42.02 ± 1.65[d]
Diet 2	Male	107.18 ± 4.08[a]
	Female	87.79 ± 4.27[b]
χ^2		165.15
Probability		<0.0001***

In the same column, the means followed by the same letter are not significantly different at the 5% probability threshold according to Kruskal-Wallis multiple comparison test. ***: Very Highly Significant.

3.7. Survival Rate of Males and Females

Figure 4 shows the progression of the survival rate of adult males and adult females of *B. dorsalis* according to the two larval diets. In males that emerged from larvae fed Diet 1, approximately 50% of the flies died 60 days after emergence. This survival rate was observed 45 days after the emergence of female flies obtained from Diet 1. For the males and females that emerged from the larvae fed Diet 2, survival rates of 50% were observed 83 days and 63 days after emergence, respectively. The last female and male mortalities were observed 140 days and 145 days after their emergence for Diet 2, respectively. For Diet 1, the last female and male mortalities were observed 81 days and 100 days after their emergence, respectively.

4. Discussion

4.1. Life Cycle of *Bactrocera dorsalis*

The two food substrates were all favourable to the development of the different stages of *B. dorsalis*. The type of food substrate did not significantly influence the egg incubation time or the development time of the L1, L2 and L3 larval stages, which varied from 1.85 to 3.30 days. Previous studies have highlighted the life cycle of *B. dorsalis*. [14] reported a duration of 1.61 to 4.5 days for the development time of *B. dorsalis* eggs and larvae on three varieties of mangoes. [15] reported an egg incubation time ranging from 2.68 to 3.12 days on fruits of four host plants, including mango. [13] reported egg incubation times of 2.60 and 3.33 days on mango and orange, respectively. On these two respective host fruits, the total duration of development of the L1, L2 and L3 larval stages was 7.97 and 8.73 days, respectively. Conversely, the egg incubation time noted on our two food substrates is similar to that reported by [16] for the same species reared with mango pulp. Pupation duration was significantly influenced by the type of food substrate. It was 8.51 days for food substrate 1 and 10.28 days for food substrate 2. These results are similar to those reported by [14] for mango and [13] for orange. According to [15], the duration of pupal development varies from 7 to 7.80 days on the following host fruits: guava, banana, mango and sapota. For this parameter, the difference observed between food substrates 1 and 2

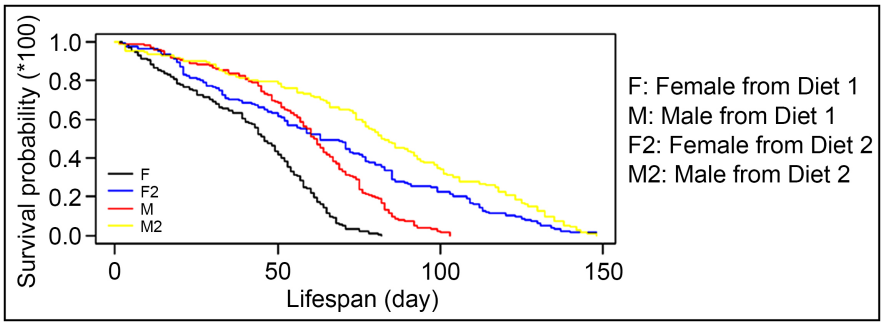

Figure 4. Progression curves of the survival rate of *Bactrocera dorsalis* as a function of diet and sex.

is likely be related to the chemical composition of the substrates or to the content of a chemical element that plays a major role in the development of *B. dorsalis* pupae. [17] showed that a yeast concentration of 20 g/L water results in a shorter development time from egg to pupa in *B. dorsalis* (11.77 days) than concentrations of 10 g/L, 60 g/L and 100 g/L. In our study, this development time was 8.71 days on food substrate 1 and 9.71 days on food substrate 2. The developmental time of immature stages of *B. invadens* is also affected by temperature with the duration of each stage decreasing as temperature increased [18]. The daily temperatures (23˚C - 27.5˚C) recorded during our study are included the optimal range of 20˚C - 30˚C reported by these authors.

4.2. Survival Rates of the Different Developmental Stages

The survival rate of the different developmental stages of *B. dorsalis* was significantly influenced by the food substrate. The egg-hatching rate was lower on food substrate 1 (32.12%) than on food substrate 2 (74.87%). When food substrate 2 was liquid, it probably maintained a relative moisture level that favoured egg hatching. Food substrate 1 was in a pasty state, so distilled water was sprinkled on it during the observations to prevent it from drying out. Conversely, the survival rate of larvae and pupae (82 to 99%) was higher on food substrate 1 than on food substrate 2. Under the same rearing conditions, [19] reported larval survival rates of 49% to 85.4% depending on the mass of food substrate 1 (30 g/100 larvae, 50 g/100 larvae, 70 g/100 larvae, 90 g/100 larvae, 110 g/100 larvae) used to feed *B. dorsalis* larvae. [17] highlighted the role of yeast in the development of *B. dorsalis*. These authors reported that *B. dorsalis* cannot survive until the adult stage when the artificial food substrate fed to the larvae does not contain yeast. As part of their study, yeast concentrations of 10 g/L water and 20 g/L water in the food substrate of the larvae made it possible to obtain pupation rates of 82% and 88%, respectively. With these two respective concentrations, 78.71% and 78.17% of the pupae hatched. Beyond these concentrations, the pupation rate and the adult emergence rate decreased significantly. The pupation rates recorded on food substrate 1 and food substrate 2 were 98.24% and 97.82%, respectively. This performance would be linked to a good concentration of yeast used in the two food substrates. These pupation rates are well above those reported on mango (74.17%) and orange (35%) by [13].

4.3. Emergence Dynamics and Flight Ability

The emergence rate of *B. dorsalis* adults was 89.12% for food substrate 1 and 97.93% for food substrate 2. This significant difference between the two food substrates lies in the content of certain chemical elements, such as proteins, which mainly make up the two types of yeast used. [17] reported a decrease in the emergence rate of *B. dorsalis* when the amount of yeast increases in the food substrate fed to larvae. [20] indicated that the emergence rate of adult flies is not influenced by the type of yeast or the structure of the food substrate. In this

study, the sex ratio was 1 male to 0.92 female for substrate 1 and almost identical for substrate 2. According to [13], the sex ratio of *B. dorsalis* is 0.74 on mango and 0.87 on orange. The flight ability of *B. dorsalis* was not influenced by the larval food substrates. The result was similar to those obtained by [12] who observed 98.80% of adult fliers in *B. dorsalis* by rearing the larvae with a mixture of LBI2240, FNILS65 and Wheat germ oil.

4.4. Fertility and Longevity of *B. dorsalis*

4.4.1. Female Fertility

Preoviposition corresponds to the period of sexual maturation of *B. dorsalis* females. This period was short on food substrate 2 (3.21 days) versus food substrate 1 (5.81 days). Similar results were reported by [15] for the same species whose larvae were fed on four host fruits. The adult flies from our two food substrates were placed under the same conditions and fed enzymatic yeast hydrolysate and sugar at a ratio of 1:1. Females from larvae fed from substrate 1 laid more eggs in a short time (57.75 days), with an average of 20.54 eggs laid per female/day. Fertility was low in females from larvae fed on food substrate 2, with a daily average of 4.76 eggs laid per female/day over a period of 109.81 days. Egg-laying peaks were observed between the 8th and 28th day in females from food substrate 1 and between the 15th and 40th day in females from food substrate 2. The higher yeast content in food substrate 1 probably allowed adult flies to have more additional protein reserves for ovarian development. The lack of proteins in the food of adult flies can have a negative impact on the number of eggs laid by females and the duration of laying. Indeed, *B. dorsalis* females fed water plus sugar laid eggs on mango for 21.46 days with a daily egg-laying index of 14.32 eggs/female/day [14]. However, females from larvae fed mango and orange laid an average of 269.13 eggs and 58.97 eggs, respectively, for 75.96 days and 54.7 days when fed 5% honey diluted in water [13]. [17] suggested that yeast:sugar ratios of 1:1 and 1:3 are favourable to the fecundity of *B. dorsalis* females.

4.4.2. Longevity

The lifespan of *B. dorsalis* differed depending on sex and food substrate. Adult flies from larvae fed food substrate 2 had a longer lifespan than those from larvae fed food substrate 1. The chemical composition of the different larval food substrates and the content of certain major elements remain factors that significantly influenced the longevity of adult flies. Food substrate 2, which is richer in protein, allowed adult flies to live longer. Furthermore, males lived longer than females regardless of the type of larval food substrate. These results confirm those obtained by [21] and [13], who studied the biology of *B. dorsalis* on different food media. The cost of reproduction in females, described by [22], is likely the cause of the shorter lifespan of female *B. dorsalis* compared to males of the same species. Moreover, our results confirm those of [16], who found an average lifespan of 55.03 days for males and 51.94 days for females during. In addi-

tion, the survival rate was lower in females than in males regardless of the type of food substrate. In fact, 50% of females from larvae fed food substrate 1 and that fed food substrate 2 died 45 days and 63 days after emergence, respectively. Conversely, in males, this rate was observed at 60 days and 83 days on food substrate 1 and food substrate 2, respectively.

5. Conclusion

The results of the study on the influence of food media on the biological parameters of *B. dorsalis* revealed that larval nutrition can influence the longevity and fertility of the resulting adults. The duration of larval and pupal development varied significantly depending on the food substrate. There was no variation in flight ability or hatching time of the pupae according to sex, regardless of the food substrate consumed by the larvae. However, the emergence dynamics and sex ratio did vary with food substrate. The study was conducted with the aim of identifying the most suitable food substrate to optimize the mass rearing of *B. dorsalis*. In general, the results revealed significant differences in female fecundity between the two food substrates. Food substrate 1 was more favourable to egg laying. Conversely, food substrate 2 led to a better egg-hatching rate. Food substrate 1, which was mainly composed of products available locally and at a lower level of yeast, can be retained for the mass rearing of *B. dorsalis*. We recommend that its structure be improved to obtain an increase in the hatching rate.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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