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Differences in Life History Traits and Morphology in Wild vs. Domesticated Populations of Black Soldier Fly, *Hermetia illucens* (Diptera: Stratiomyidae)

Mbenoun Masse Paul Serge[1, *], Mbansie Gbetkom Loudh[1], Yede[1], Ngo Libong Sipora Glwadys[2], Mamno Totuom Clarette Sidoine[3], Bilong Bilong Charles Felix[4]

[1]Laboratory of Zoology, University of Yaoundé 1, Yaoundé, Cameroun

[2]Laboratory of Hydrobiology and Environment, University of Yaoundé 1, Yaoundé, Cameroun

[3]Laboratory of Biochemistry, University of Yaoundé 1, Yaoundé, Cameroun

[4]Laboratory of Parasitology and Ecology, University of Yaoundé 1, Yaoundé, Cameroun

Email address:

masseserge@yahoo.fr (Mbenoun Masse Paul Serge)

[*]Corresponding author

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Abstract: The Black Soldier Fly (BSF) *Hermetia illucens* is widely studied as a sustainable alternative source of protein. Herein, we evaluated the changes in life history and morphometric traits between wild (WP) and domesticated populations (DP) with implications for larval biomass production. Prepupa stages of both populations were maintained under the same rearing conditions from July 2020 to June 2021. Our results show that the pupation time was longer in WP (10.25 ± 2.66 days) than in DP (7.2 ± 1.1 days). In contrast, the emergence time of BSF adults was shorter in WP (8.3 ± 2.2 days) than in DP (9.7 ± 1.8 days). The courtship was nearly similar in both populations. Mounting and reverse coupling were the two different copulation models used by BSF adults in WP while reverse coupling dominated in DP. The BSF females laid more eggs in WP (1468.75 ± 593.09 eggs) than in DP (246.21 ± 96.23 eggs). The egg stage was similar in length and width in both populations while the morphometric traits in the larval, pupal and adult stages were consistently lower in domesticated than in wild population. The life span of adults (males and females) was longer in DP than in WP. Our findings indicate higher values of morphological traits in WP than in DP, and distinct mating and reproductive behaviours between both populations. Our results suggest ‘domestication syndrome hypothesis’ as the main cause of changes in reproductive behaviour and reduction of size in DP. Therefore, wild population of *H. illucens* seems be more suitable for maggot mass production as an alternative source of protein for animal feed production.

Keywords: Black Soldier Fly, Wild and Domesticated Populations, Life History Traits, Maggot Production, Animal Feed

1. Introduction

The Black soldier fly (BSF) *Hermetia illucens* is an insect belonging to the order of Diptera, family of Stratiomyidae, and sub-family of Hermetiinae. The Stratiomyidae encompasses 12 subfamilies, 375 genera and more than 2, 650 species described [1]. The transition from the larval to the adult stage of the BSF happens through a nymphal or pupal stage i.e it is a holometabolous insect. *Hermetia illucens* is native of tropical, subtropical and temperate regions of the American continent, but was accidentally introduced in other continents including Europe, Asia, Oceania, and Africa [2].

The BSF larvae are of great economic interest and used for several purposes. They are considered as good candidates for treating organic wastes or livestock manure. Many reports documented their ability to feed on a wide variety of organic matter [3-6]. The residue generated by BSF larvae during the processing of organic waste is used as soil amendment with fertilizing properties in agriculture [7-10]. The BSF larvae are rich in minerals, amino acid profile (Lysine, methionine, Alanine and Cystine) and macronutrients (crude protein range from between 15% to 32% and lipid from between 15% to 40%) [1-12]. Moreover, they can be used as alternative food resource for a variety of animals such as chickens [13, 14], pigs [15] and fish [16, 17]. At the same time, BSF larvae have been considered as an excellent mitigation measure against environmental pollutants. For instance, several studies have shown that BSF larvae can reduce populations of undesired human pathogens including *Escherichia coli*, *Salmonella enterica*, *Candida* spp. and viruses in organic waste [18-20].

The life cycle of BSF from the egg to the imago lasts approximately 55 days [21]. Females lay between 500 to 900 eggs in dry substrate and oviposition activities begin after two-day mating [22]. The eggs hatch between 4 to 5 days of incubation period. The development of the BSF encompasses six larval stages, one pupal stage and one imago stage. The larval development time is influenced by biotic (quality and quantity of available food) and abiotic factors (temperature, relative humidity, light intensity) [23]. Recent studies have documented and illustrated the reproductive behavior of adults [24] and morphological description of BSF eggs, larvae, and pupa of domesticated populations reared in artificial conditions [25, 26]. Few studies have investigated the influence of the origin of BSF population on its life history traits and larval mass production.

The present study aimed to compare sequences of mating and reproductive behaviour, and morphometric parameters between wild and domesticated populations of *H. illucens* reared in semi-natural conditions.

2. Materiel and Methods

2.1. Study Area

This work was carried out from July 2020 to June 2021 at the Laboratory of Zoology, University of Yaoundé 1 located in Yaoundé (3°56'N; 11°10'E; 750 a.s.l.), the political capital of Cameroon. The climate of the area is the equatorial Guinean type with four seasons: a long dry season (November to March), a short rainy season (March to June), a short dry season (July to August) and a long rainy season (September to November) [27]. The average annual rainfall is approximately 1540 mm; the mean annual relative humidity is 79.5% and the mean air temperature ranges from 19.2 to 28.6°C.

2.2. Sample Collection and Rearing Procedure

A total of 533 instar BSF larvae (L6 larval stage or pre-pupa) from each population (domesticated and wild) were collected and introduced into rectangular boxes (8 cm height x 12 cm width x 18 cm length) containing wood shavings as pupation substrate [31]. The domesticated population (DP) came from the University of Liege, Gembloux Agro-Tech (Belgium) and maintained in the laboratory since 2018 whereas the wild population (WP) was freshly collected from pig carrion at Foumbot town located about 304 km from the Yaoundé I university. Boxes containing larvae were separately placed inside two love cages (75x75x115cm) equipped with one tunnel (Ø 18 mm), then installed on a table (90 x 57 x 152 cm) near the grills of a window to receive sunlight. At night, a permanent lighting was maintained to simulate the emergences. All experiments were conducted at 28°C ± 4 and a relative humidity of 73 ± 6 %.

2.3. Emergence, Reproduction and Oviposition of BSF

From the post feeding larvae, the emergence time of BSF adults was registered as well as the first mating. Following [24], we selected 50 pairs of newly-emerged adults within each population to observe reproductive behaviour. Each selected group was placed into 60 x 60 x 60 cm cage. Around day fourteen during two months, observations of mating behaviour were conducted from 6 a.m to 6 p.m. Two days after mating, each rearing cage was equipped with a watering system made up of a sponge soaked in sugared water, pieces of cardboard and a small box containing fermented spent grains (oviposition substrate) to attract BSF females for oviposition.

2.4. Post Embryonic Development

After laying, 6 to 8 egg clusters were each incubated in a small transparent plastic box (3 x 5 x 10 cm) equipped with a pierced cover. After hatching, the larvae were transferred into medium containers (Ø18 mm, 15 cm), and fed on local diet [28]. Observations were made once a day to record the development time of each larval instar. Thirty individuals for each developmental stage (larval, pupa, and imago) were collected and stored in eppendorf tubes containing 70% ethanol for subsequent morphological studies. The remaining larvae were maintained in rearing cages at the laboratory for a new cycle of pupae production.

2.5. Morphological Study

The morphometric traits were measured under a stereomicroscope (Olympus X40); they included: - *larvae and pupa*: total body length (Tbl), total body width (Bw), total body weight (Tbw); - *adults*: the length of the cephalic capsule (Lcc) which is the distance between the vertex and the end of the mouth, the diameter of the cephalic capsule (Dcc), the length of the thorax (Ltx), the diameter of the thorax (Dtx), the length of the abdomen (Lab), the diameter of the abdomen (Dab), the total body length (Tbl), the total body weight (Tbw), the length of the antenna (Lat) i.e from the base of the scape to the apex of the flagellum, the number of articles of the flagellum (Naf), the length of the wings (Lw) i.e. from the base of the wing insertion to the apex, the diameter of the wings (Dw), the length of the pro, meso and metathoracic femur (Lf1, Lf2, Lf3 respectively), and the length of the pro, meso and metathoracic tibiae (Lti1, Lti2 and Lti3 respectively).

2.6. Statistical Analysis

For each population, the number of eggs was counted and the mass of egg clusters was weighed using a TN-SERIE electronic scale readable to 0.01g. The relative frequency of each behavioural act was calculated as followed: Rf= (f/n) x 100 where f is the number of times the behavior occurred in an observation and n = total number of observations. Behavioural acts described or calculated, included ovipositional behaviour of female, sequences of mating behavior, daily mating frequency, development time for each stage, and male and female lifespans (see Julita et al. 2020). The averages of the calculated or measured parameters were expressed as follows: means ± standard error (SE). The Student's t test or Z test, with respect to normality, was performed to compare the mean values of the morphological parameters studied in both populations. Statistical analyses were performed using software SPSS version 10. The significance threshold for the differences between values was set to 5% for all analyses.

3. Results

3.1. Emergence, Courtship and Mating

About 98% of males emerged earlier than females in both populations. In both populations, the wings of the new-emerged adults were still folded after emergence. Wings were unfolded after 7.16± 2.32 minutes in DP and 8.83±9.11 minutes in WP (t = 3.73; p < 0.05), and closed thereafter. This folding and unfolding of the wings were observed for 5.28± 0.89 minutes and 5.50±0.97 minutes (t = 1.35; p > 0.05) in DP and WP respectively. The first flight occurred after 33.95±7.06 minutes in DP and 32.72±8.326 minutes in WP (t = 0.97; p > 0.05).

The courtship rituals began 48 h after the emergence of adults or one day after a flight attempt. At this stage, females flew and landed on the grid or on the ground in the cage while opening their oviscapte. Males flew from one corner to another in the cage and aggregated when landing. They initiated either frontal or lateral approach to intercept the females. This attractiveness or pre-mating behavior lasted 35.84±12.81 minutes in DP and 35.74±8.34 minutes in WP (t = 1.09; p > 0.05).

The mating activities took place between 11:00 a.m and 1:00 p.m. In both populations, after acceptance, males and females flew away together; males carried out some mating attempts trying to capture females during flight, then they both landed. The male either climbed on the back and connected its aedeagus to the oviscapte of the females (mounting model) (Figure 1a) or its aedeagus being connected to the female oviscapte and rotated its body 180° in opposite direction (reverse coupling model) (Figure 1b). The first coupling model occurred in 40% of all mating pairs in WP and 2% in DP. Conversely, reverse coupling model represented 98% and 60% of all mating pairs in DP and WP respectively. This last copulation model lasted 33.7 ±5.26 minutes and 34 ±6.68 minutes in DP and in WP respectively (t = 1.64; p > 0.05).

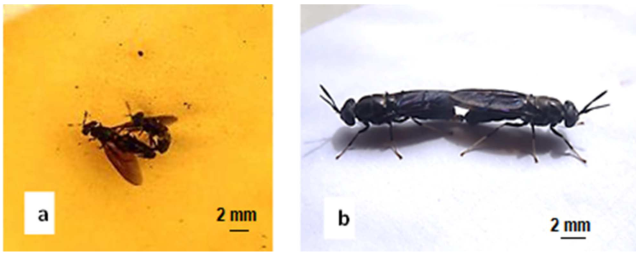

Figure 1. *Copulation models used by H. illucens during mating. a) mounting model; b) reverse coupling model.*

The sequences of mating behaviour and relative frequency of the different behavioural acts initiated by adults from DP (Figure 2a) and WP (Figure 2b) are summarized in different ethograms.

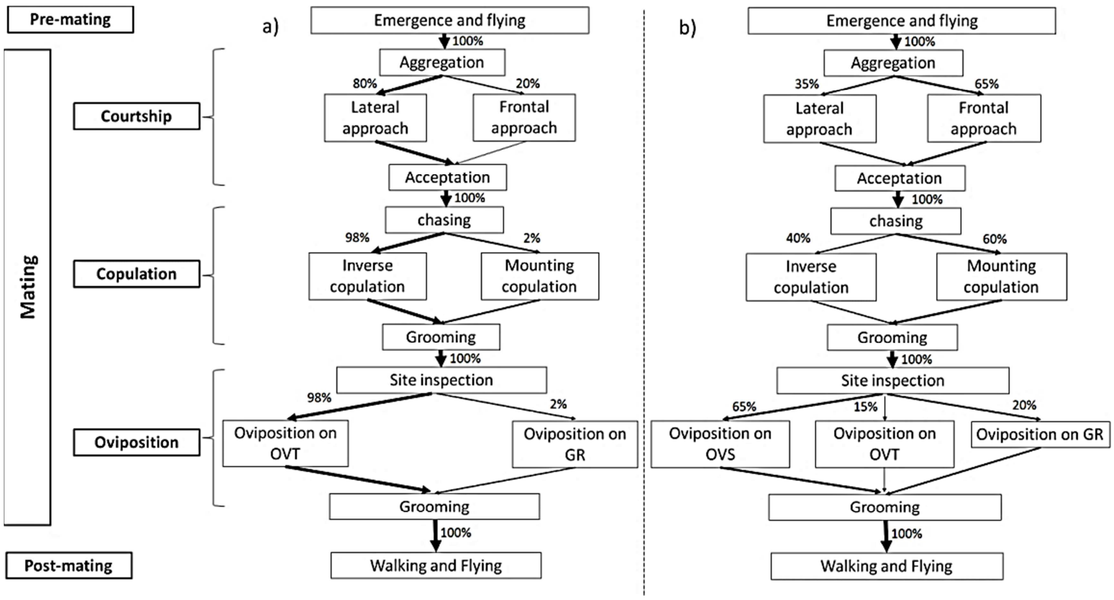

Figure 2. *Ethograms of the sequences of mating behaviour recorded in domesticated (a) and wild populations (b) of H. illucens. Nb: in the figure, OVT represent Ovitrap, OVS = oviposition substrate, GR =grill.*

3.2. Oviposition

The females found a suitable site for egg laying 3 to 4 days after mating. These eggs were laid either inside the gap of the cardboard (15%), on the oviposition substrate (65%), or on the grid (20%) in WP, whereas 98% of the eggs were laid in the ovitrap, 2% on the grid and none in oviposition substrate in DP. Egg clusters contained between 702 to 2048 eggs (1468.75±593.09 eggs) in WP and between 347 to 992 eggs (246.21±96.23 eggs) in DP (t = 3.33; p < 0.05). Egg laying time ranged from 30 to 35 minutes (18.71±3.02 minutes) in DP and from 25 to 32 minutes (12.04±1.12 minutes) in WP (t = 1.04; p > 0.05).

3.3. Post-Embryonic Development and Development Time

In both populations, post-embryonic development of BSF went through 8 stages: six larval, one pupal and one adult stages (Figure 3). Overall, the development time of all larval stages was longer in WP than in DP, except the prepupa stage. More specifically, the duration of the development time of the third (L3) and fifth (L5) larval stages differed significantly (p < 0.05) between both studied populations (Table 1). The same trend was observed in the pupal stage (p < 0.05). In contrast, the emergence time of BSF adults was relatively shorter (8.3 ± 2.2 days) in WP than in DP (p > 0.05).

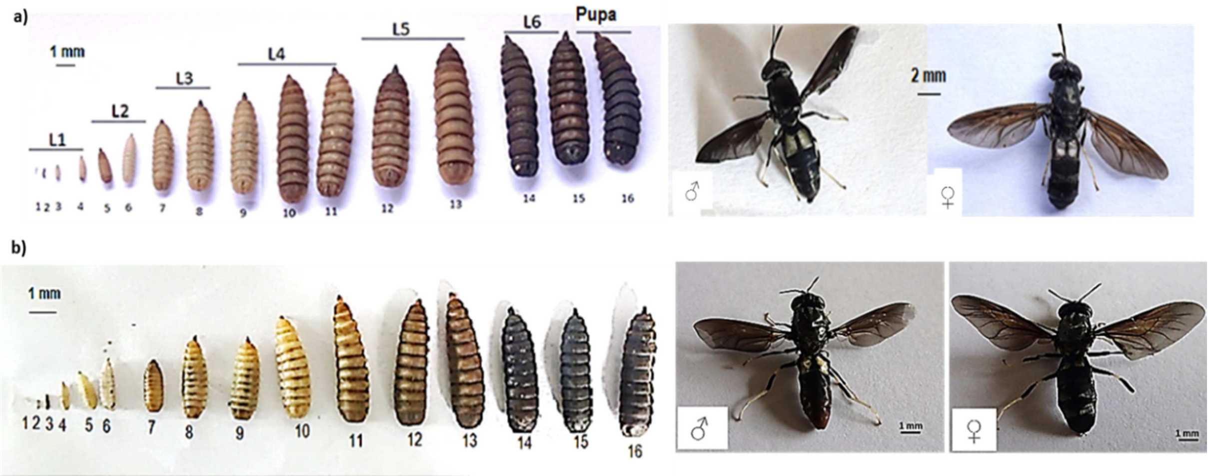

Figure 3. *Development stages from first larval stage to adult of BSF recorded in its wild (a) and domesticated populations (b).*

3.4. Adults' Lifespan

After mating, a few rare cases of sudden death of males were noticed in both populations. Overall, the male lifespan varied significantly between both populations (Z = 3.74; p < 0.05); it ranged between 5 to 13 days (10.14±2.95 days) in DP and between 3 to 10 days (5.25±2.49 days) in WP. The female lifespan appeared much longer than that of males in both populations. Indeed, it ranged between 6 to 14 days (10.53±2.67 days) in DP and between 3 to 13 days (7.94±3.72 days) in WP (Z = 4.10, p < 0.05).

3.5. Morphometric Traits Between Populations

Overall, morphometric parameters from larval to pupal stages appeared higher in WP than in DP except for egg stage. The two populations significant differed (p < 0.05) in their specimens' length (L3, L4 larval stages and pupae), width (L1, L2, L3, L5 and L6 larval stages) and weight (L4, L6 larval stages and pupae) (Table 2). A similar trend of higher values of the above traits was consistently observed when comparing males and females of WP and DP. Nevertheless, the total body length (Tbl), the length of cephalic capsule (Lcc), the length of abdomen (Lab), the length of the profemur (Lf1) and the length of pro and metathoracic tibiae (Lti1and Lti3 respectively) of males on the one hand and the length of cephalic capsule (Lcc) and that of pro, meso and metathoracic tibiae (Lt12, Lti2 and Lti3) of females on the other hand were relatively higher (p > 0.05) in DP than in WP (Table 3).

Table 1. *Development times comparison of different stages of H. illucens among the studied populations. (Nb: values in the table represent mean±SE; minimum and maximum values are indicated in the brackets).*

Population/test	Development time of BSF (days)							
	Larval stage						Pupae	Adults
	L1	L2	L3	L4	L5	L6		
DP	1.61±1.26 (1-4)	1.29±0.46 (1-2)	1.05±0.22 (1-2)	2.57±1.21 (1-3)	1.75±0.46 (1-2)	1.5±0.50 (1-2)	10.25±2.66 (6-14)	9.7±1.8 (5-13)
WP	2.36 ± 1.06 (1-4)	1.69 ± 0.45 (1-2)	1.70 ± 0.45 (1-2)	3.20 ± 1.36 (1-4)	3.84 ± 1.58 (1-2)	1.5 ± 0.5 (1-2)	7.2±1.1 (5-9)	8.3±2.2 (6-14)
Test	Z=1.453	Z=1.2637	t=4.9873	Z=1.2387	Z=8.3663	Z=1	Z= 3.53	Z=1.47
P	>0.05	>0.05	<0.001	>0.05	<0.05	>0.05	<0.05	>0.05

Table 2. *Egg, larval and pupal stage traits and comparison between wild and domesticated populations of H. illucens.*

Stages	origin	Length (mm)			Width (mm)			Weight (g)		
		Mean ± SE	test (t/z)	P	Mean ± SE	test (t/z)	P	Mean ± SE	Test z	P
Egg	WP	1.12 ± 0.07	1.256	0.542	0.25 ± 0.01	2.003	0.066	-	-	-
	DP	1.02±0.06			0.25±0.008					
L1	WP	2.28 ± 0.17	1.109	0.601	1.58± 2.36	2.025	<0.0001	-	-	-
	DP	1.57±1.22			0.40±0.25					
L2	WP	3.51 ± 0.57	1.559	0.214	1.49 ± 0.31	2.699	0.006	-	-	-
	DP	3.3±0.44			0.98±0.18					
L3	WP	5.4 ± 0.77	3.342	0.002	2.01 ± 22	8.179	<0.0001	-	-	-
	DP	4.60±0.53			1.35±0.25					
L4	WP	10.15 ± 2.10	1.760	0.005	3.72 ± 0.99	1.136	0.523	0.12 ± 0.03	2.411	<0.0001
	DP	4.60±0.53			3.04 ±0.80			0.04 ±0.02		
L5	WP	18.07 ± 2.35	1.280	0.169	5.70 ± 0.33	2.537	<0.0001	0.21 ± 0.03	1.625	0.064
	DP	10.79±2.29			4.66±0.50			0.15 ±0.08		
L6	WP	20.02 ± 1.68	1.832	0.223	4.88 ± 0.71	4.638	<0.0001	0.18 ± 0.03	1.855	0.013
	DP	19.35±1.24			5.11±0.33			0.20 ±0.02		
Pupae	WP	19.59 ± 0.50	4.87	<0.0001	5.31 ± 0.3	1.113	0.736	0.13± 0.01	4.87	<0.0001
	DP	19.24±1.16			4.83±0.26			0.16 ± 0.01		

Legend: WP = wild population; DP= domesticated population. NB: in the table, the egg and larval stage (L1, L2 and L3) weights were not measured because of the low sensitivity of the electronic balance readable to 0.01 g, *t* represent student test and Z the value of reduced difference, and P value.

Table 3. *Individual traits comparison of males and females among the studied population of H. illucens.*

Traits	Population	male			female		
		Mean ± SE	*t*	P	Mean ± SE	*t*	p
Tbl	DP	15.34±0.46	0.58009	0.569	15.78±0.76	3.7329	0.0008
	WP	14.41±3.63			16.66±0.54		
Bw	DP	0.06±0.01	2.3755	0.029	0.07±0.01	1.283	0.210
	WP	0.072±0.013			0.127±0.18		
Tbw	DP	3.69±0.27	2.8012	0.012	3.68±0.26	5.2722	<0.0001
	WP	3.95 ± 0.20			4.12 ± 0.18		
Ltx	DP	4.34±0.33	4.1229	0.880	4.21±0.27	9.6	<0.0001
	WP	4.86 ± 0.37			5.06 ± 0.31		
Lcc	DP	3.2±021	0.8	0.434	3.58±1.75	0.94639	0.352
	WP	3.08 ± 0.24			3.27 ± 0.18		
Dcc	DP	3.82±017	3.8645	0.001	4.10±0.21	2.9324	0.006
	WP	4.08 ± 0.19			4.38 ± 0.30		
Lab	DP	8.01±0.33	0.381	0.708	8.33±0.43	4.6328	<0.0001
	WP	7.98 ± 0.31			8.97 ±0.46		
Dab	DP	3.14±0.22	8.3799	<0.0001	3.52±0.24	8.6876	<0.0001
	WP	3.74 ± 0.15			4.08 ± 0.17		
Lat	DP	3.75±0.32	2.1746	0.043	4.27±0.22	3.2703	0.003
	WP	4.0 ± 0.11			4.56 ± 0.30		
Naf	DP	7.86±0.34	1.750	0.076	7.90±0.30	1.923	0.085
	WP	8.01±0.14			7.98±0.15		
Lw	DP	10.53±1.35	5.6772	<0.0001	12.33±0.54	1.8246	0.079
	WP	11.59 ± 0.44			12.65±0.56		
Dw	DP	3.98±1.46	5.6293	<0.0001	4.43±0.27	8.9306	<0.0001
	WP	4.4 ± 033			5.18 ±0.26		
Lf1	DP	2.10±0.22	0.55253	0.587	2.18±0.23	0.83425	0.411
	WP	2.08 ± 0.15			2.30 ±0.24		
Lf2	DP	2.87±0.29	1.2165	0.240	2.95±0.14	4.6024	<0.0001
	WP	3.02 ± 0.22			3.29 ± 0.24		
Lf3	DP	3.16±0.24	1.4459	0.165	3.19±0.17	4.7469	<0.0001
	WP	3.33 ± 0.28			3.62 ±0.29		
Lti1	DP	1.92±0.15	0.14907	0.883	2±0.10	0.85078	0.403
	WP	1.88 ± 0.15			1.93 ± 0.09		
Lti2	DP	2.45±0.20	0.44563	0.661	2.64±0.24	0.90198	0.375
	WP	2.46 ± 0.22			2.56 ±0.20		
Lti3	DP	2.87±0.14	1.61	0.125	2.96±0.13	1.0325	0.311
	WP	2.76 ± 0.19			2.88 ±0.36		

4. Discussion

4.1. Mating Activities and Reproductive Behaviour

Our study provides evidence that the BSF males emerged earlier than the BSF females as shown by the recorded adults' emergence rates of both studied populations. This is consistent with previous studies carried out in other tropical and sub-tropical areas invaded by this fly [22-29]. Several works have demonstrated that the emergence time of adults depends on ambient temperature and pupation substrate [30, 31]. Moreover, a recent study showed that the sex-ratio of adults is strongly influenced by diets formulation and composition [28]. After the emergence, the first flight attempt occurs after few minutes followed by the courtship rituals. During mating, we found that reverse coupling as a copulation model dominated in the domesticated population whereas both mounting and reverse coupling are almost equally represented in the wild population. So far mounting copulation model is not largely reported in BSF because this form is rare and occurs most often in small numbers [24]. This might be due to the fact that all the experiments were mostly performed with domesticated populations, which were reared and maintained in artificial conditions for many years. Furthermore, these conditions might also be responsible for the reduction of the number of eggs laid by the BSF females in domesticated populations in comparison to wild populations. In fact, the wild BSF females laid eggs preferentially in fermented spent grains while domesticated females laid eggs in the small spaces of the ovitrap (cardboard). The latter ovipositional behaviour has been previously reported in domesticated population of BSF reared in artificial conditions [32-24]. This could be an adaptation or a learning behaviour in response to artificial conditions. Unlike domesticated BSF females, the ovipositional behaviour of wild BSF females did not alter under semi outdoor conditions; they remained naturally attracted by decaying organic matter that released various volatile attractive substances such as aldehydes, organic acids and alcohol [33, 34]. In accordance with previous studies [22], the current study demonstrates that the life span of the male is shorter than that of the female. This likely depends on body size, energy reserve (carbohydrates, lipids and proteins) and on access to water [21].

4.2. Morphological Traits' Differences Between the Wild and Domesticated Populations

Our results indicate that larval, pupal and adult stages of BSF of both studied populations have distinct morphological traits, exception to eggs, which were similar in two traits (length and width). Eggs were laid in clusters (702 -2048 eggs) and covered with a mucus substance allowing the clusters to adhere to the substrate. The larval, pupal and adult stages of the domesticated population were smaller than the wild one in three traits (length, width and weight). We speculate that the growth performance of the wild population may be due to the rearing time in artificial conditions. This assumption is supported by the fact that the wild population was freshly collected in a natural environment (pig carrion) before the experimentation. When bred in captivity for a shorter time, their behavioural and morphological traits might have not altered; they remained wild having similar traits as their wild counterparts.

In contrast, the reduction of size in BSF domesticated population may be due to rearing conditions, during which desirable traits are selected and evolved over thousands of generations. This phenomenon is known as ''domestication syndrome' [35]. Domesticated species typically display 'domestication syndrome', exhibiting similar patterns of simultaneous alterations in physiological, behavioural and morphological traits compared to their wild forebears [36]. For example, studies in mammals (e.g rats, pig, sheep and foxes) revealed that domestication is commonly associated with increased coat color changes, reductions in tooth size, changes in craniofacial morphology, docility and tameness, alterations in ear changed concentrations of several neurotransmitters, prolongations in juvenile behavior, and reductions in brain size [37-39]. Domestication is the result of a separation of a species from its natural ecological context and its development under artificial selection pressure and under artificial environments [40]. This process involves phenotypic and genetic changes in domesticated populations compared to their wild ancestors as a result of artificial selection [41]. In this regard, genetic changes occurring over generations, in domesticated population, might lead to reproductive isolation which is the evolutionary process by which populations evolve to become distinct species (speciation). This phenomenon is well described in other dipterans like *Drosophila* spp. [42].

4.3. Maggot Production and Sustainable Animal Production

The world's population has doubled (100% increase) in 40 years from 1959 (3 billion) to 1999 (6 billon). The latest projections indicate that world population will reach 10 billon persons in the year 2057. About two-thirds of the predicted population growth between 2020 and 2050 will occur in less developed regions of the world including Africa [43]. In Africa, around 282 million people are undernourished [44]. This situation is now getting worse with the reduction of soybean meal and fishmeal importation for animal production due to the current Covid-19 pandemic and Ukraine war. Looking for alternative sources of food and protein becomes therefore an obvious necessity for the rearing of chickens, pigs and fish for human consumption. The insect larvae in general, and BSF fly larvae in particular, are protein-rich and thus, a desirable feed alternative for animal production [14-17].

In this regard, the selection of populations exhibiting better life history traits and growth performance, as found in this study with the BSF wild population, will enable the optimization of the maggot biomass production and subsequently contribute to food security in Africa.

5. Conclusion

This study indicates differences in mating behaviour and distinct morphological traits between wild and domesticated populations of the BSF *H. illucens*. The domesticated population exhibits reverse coupling as copulation model, oviposition preferentially in the ovitrap, smaller number of eggs, and smaller size of some morphological traits compared to wild population. Although other factors might affect the behavioural, physiological and morphological traits in animals living in captivity over time, our findings support the domestication syndrome hypothesis in the studied domesticated population. As a whole, this study demonstrates that the morphological traits of larval and prepupal stages (maggot) were higher in the wild population compared to the domesticated one. These different stages could be used for many purposes, including protein sources for animal feed productions. Further studies should be performed to investigate the relationship between behavioural traits, morphological traits and genetic variation between the BSF african populations and the BSF populations from its original distribution areas, as North America.

Conflict of Interest

The authors declare that they have no competing interests.

Author Contribution

Mbenoun Masse Paul Serge, Mbansie Gbetkom Loudh, Ngo Libong Sipora Glwadys, Mamno Totuom Clarette Sidoine, and Bilong Bilong Charles Félix: conceptualization. Mbenoun MASSE Paul Serge and Bilong Bilong Charles Félix: formal analysis, visualization and writing-original draft preparation. Mbansie Gbetkom Loudh, Yede, Ngo Libong Sipora Glwadys, and Mamno Totuom Clarette Sidoine: methodology. Mbenoun Masse Paul Serge and Bilong Bilong Charles Félix: writing-review and editing. All authors contributed to the article and approved the submitted version.

Data Availability Statement

All data used in this research are available on request from the corresponding author.

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