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Insect floral visitors of *Solanum melongena* var. Black Beauty (Solanaceae) and impact of the foraging activities on the pollination, fruit and seed yields at Dourga (Far North, Cameroon)

Saliou Saidou [1,*], Joseph Blaise Pando [1], Auguste Pharaon Mbianda [2], Nadine Esther Otiobo Atibita [2], Cyril Roméo Heumou [3], Olivier Balti Moudelsia [1], Fernand-Nestor Tchuenguem Fohouo [4] and Joseph Lebel Tamesse [5]

[1] *Department of Laboratory of Life and Earth Sciences, Higher Teachers' Training College, University of Maroua, Maroua, Cameroon.*
[2] *Department of Animal Biology and Physiology, Faculty of Sciences, University of Douala, Douala, Cameroon.*
[3] *Department of Laboratory of Biological Sciences, Higher Teachers' Training College, University of Bamenda, Bambili-Bamenda, Cameroon.*
[4] *Department of Sciences Biology, Faculty of Sciences, University of Ngaoundéré, Ngaoundéré, Cameroon.*
[5] *Department Sciences Biology, Higher Teachers' Training College, University of Yaoundé I, Yaoundé, Cameroon.*

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Abstract

At Dourga, from july to december 2022 and june to november 2023, the investigations were made on *Solanum melongena* (Solanaceae) to determine the activities of the insects, the floral products required, the relative frequency and to evaluate the impact of these insects on the fruit and seed yields of this plant. For that purpose, two treatments were formed each year starting from the marking of 240 floral buttons by the absence or the presence of protection of insects visit on flowers. The observations were made on the flowers of *S. melongena* in free pollination from 12th to 20th October 2022 and from 22th September to 1st October 2023. The insects harvested the eggplant flowers between 6 am and 3 pm, with the peak of activity situated between 8-9 am. They collected pollen exclusively on the flowers of *S. melongena*. 3153 visits of 13 insects' species were inventoried and belong to two orders (Hymenoptera, Diptera) and seven families. *Seladonia* sp. was the most frequent species with 38.98% of visits, followed by *Amegilla calens* (14.05%) and *Apis mellifera* (12.37%). The comparison of the yields of the treatments showed that the flowering insects increased the fruiting rate, the number of seeds per fruit and the percentage of normal seeds of 35.65%, 12.67% and 11.72% respectively. This study provided some knowledge on the diversity of the pollinating insects of this plant, which can be exploited to improve the fruiting production. Thus, for the period of flowering of eggplant, the treatments with chemical pesticides are to be avoided to be able to benefit from the service of pollination ensured by the flowering insects.

Keywords: *Solanum melongena*; Insects; Flowers; Pollination; Yields

1. Introduction

In Cameroon, economic development is essentially based on the agriculture growth [1]. It is the backbone of overall growth for the majority of countries and indispensable for reducing poverty as well as strengthening food security [2]. Thus, agriculture occupies a major place in the fight against poverty and malnutrition [1]. The low productivity observed results from the lack of information surrounding second-generation agriculture and food insecurity by Cameroonian farmers [3,4]. For them, high yields depend exclusively on the mastery of various cultivation techniques, the supply of fertilizing elements and/or the control of infestations [5]. They are unaware that in the absence of pollinating insects, or in the presence of an insufficient number of them during the flowering of several crops, yields can fall considerably

* Corresponding author: Saliou Saidou

or even be nul [6,7]. Over the past thirty years, scientific production on insect pollinators in Cameroon has grown steadily [8,9,10,6,11,12]. Eggplant *Solanum melongena* (Solanaceae) is an annual herbaceous plant native to India that is cultivated for its leaves and fruits, which are consumed by humans [13]. Very low in calories, this vegetable is an important source of vitamins, minerals, trace elements, antioxidant compounds and fibre [14]. Its cultivation is linked to constraints of high temperatures, sunshine and permanent water availability [14]. Today, it is highly prized by almost everyone, and its cultivation is spreading in almost every region of the world [13]. In Cameroon, although it is grown in almost every region, production is insufficient to meet local demand [1]. There are no data on the contribution of insect pollinators to the production of this plant in this country. Whereas in some parts of the world, insect pollinators have been shown to increase fruiting of this Solanaceae [15,16]. Thus, *Amegilla calens* and *Xylocopa flavorufa* in Kenya [17], *Apis mellifera* and *Apis cerana* in Nepal [18] and *Hoplonomia westwoodi* and *Pachynomia* in Sri Lanka [16] have shown their efficiency and/or ability to pollinate the *S. melongena* flowers. According to Roubik [19], since the entomofauna of a plant can vary spatially, it would be very important to carry out investigations in Cameroon in order to identify the potential insect pollinators of this plant in this country. The general objective of the present work is to contribute to the understanding of the relationships between insect pollinators and *S. melongena*, in order to optimizing its yield management in Cameroon. This work has four specific objectives: (a) to identify the flowering insects of *S. melongena*; (b) to study the activities of insetcs on *S. melongena* flowers; (c) to assess the impact of these insect pollinators on yields.

2. Materials and methods

2.1. Site, study station and biological materials

Fieldwork was carried out from June to December 2022 and from May to November 2023 at Dourga-Maroua in Diamaré division, Far North Region of Cameroon. The climate is Sudano-Sahelian, characterized by a long dry season (November to June) and a short rainy season (July to October) [20]. The weather or month of August is the wettest of the year, with annual rainfall ranging is 1209 mm [21]. The mean annual temperature is 39°C [22]. The study station is a rectangular area measuring 325m^2, centred on a point with the following geographical coordinates: Latitude 10°35.375'N, Longitude 14°12.214'E and Altitude 942m above the sea level (Figure 1). These geographical coordinates were recorded with a "Global Positioning System" brand Garmin GPS II+.

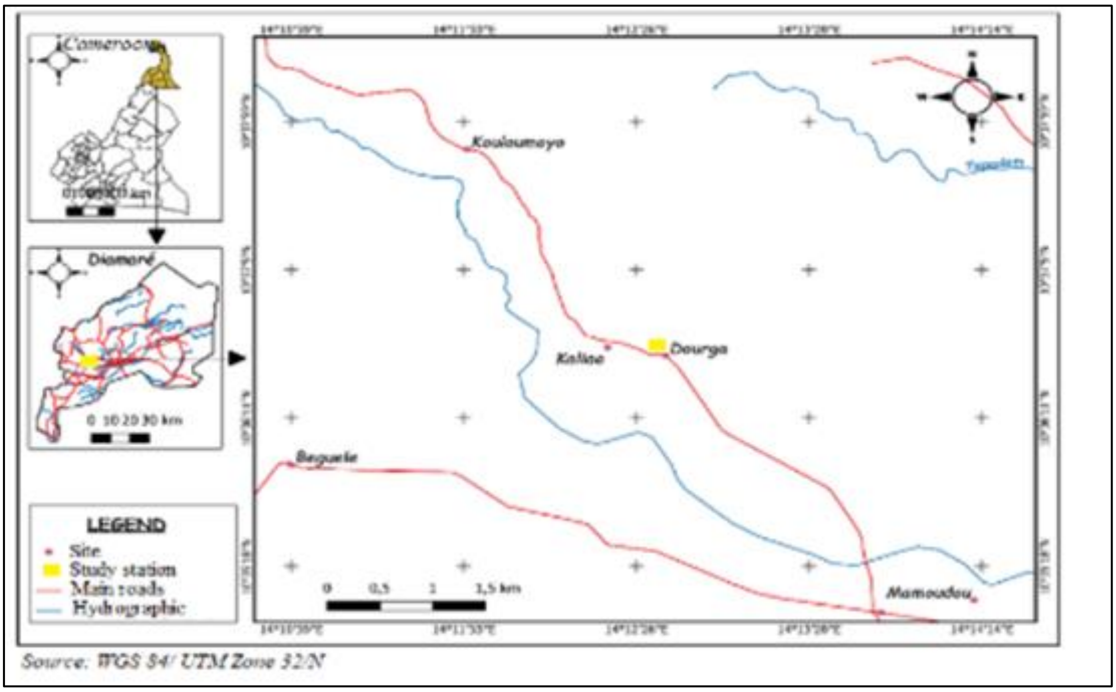

Figure 1 Location map of the investigation site (Dourga) in Diamaré, Far North (Cameroon)

The choice of this observation site was justified by the existence of other peasant crops and the guaranteed safety of the experimental plot and the observer. The biological material was made up of : (a) seeds of *S. melongena* L. 1753 var. Black Beauty purchased at the Abattoir market in Maroua from an approved agricultural seed sales outlet ; (b) various plant species (*Pennisetum pedicellatum, Chamacerista nictitans, Guiera senegalensis, Merremia umbellata, Stachytarpheta caryennensis, Solanum lycorpicum, Zea mays, Hisbicus cannabis, Gossypisum hirsutum, Cucumis melo*) located near the experimental plot and flowering at the same time as *S. melongena*; (c) All the insects present at the investigation site and visiting the flowers of *S. melongena.*

2.2. Methods

2.2.1. Preparation, sowing and maintenance of the Solanum melongena experimental plot

A nursery made up of 8m long and 2m wide was first set up. On this plot, *S. melongena* seeds were scattered, covered with straw and then covered with gauze to protect the seedling from pest attacks. From 21th June 2022 and from 08th june 2023, the experimental plots were formed after clearing, ploughing and the formation of eight (08) square sub-plots, each 5m square and 10cm high (Figure 2). The area of the experimental plot was 325 m^2 (Area =13m x 25m).

Figure 2 General view of the eight experimental subplots after ploughing (325m^2 of area in 2022)

These plots were separated from each other by 1 m paths. The distance between them and the field boundary was also 1 m. Forty days later, from 24th August 2022 and from 29th July 2023, vigorous seedlings from the nursery were transplanted in rows onto the subplots, with ten rows per subplot and one seedling per stake. Spacing between and within rows was 50cm and 80cm respectively. One week after transplanting, dead plants were replaced and weeding was carried out regularly every two weeks until flowering began (Figure 3). From the start of the flowering period to fruit ripening, weeding was carried out regularly by hand following the recommendations of Pando *et al.* [23].

Figure 3 Partial view of a sub-plot of *Solanum melongena* before the start of flowering

2.2.2. Determining the mode of reproduction of Solanum melongena

On the 11th of october 2022 at Dourga, 240 flowers at flower bud stage were tagged and two treatments formed, namely : (a) treatment A consisting of 120 tagged flowers left to pollinate freely and on which no insects were caught (Figure 4) ; (b) treatment B consisting of 120 tagged flowers protected from insects by gauze bags (Figure 5). On the 21th of September 2023, the same treatments were used (treatment A' and treatment B').

Figure 4 *Solanum melongena* flower labeled and left to freely pollinate

Figure 5 *Solanum melongena* flower labeled and isolated from insect visits using gauze bag

To determine the reproductive system, five (05) days after fanning of the last labeled flower, the number of fruits formed in each treatment was counted and the fruiting index was calculated using the following formula : $Ifr = (F_b / F_a)$ [6], where *Ifr* is the fruiting index, F_b is the number of fruits formed and F_a the number of viable flowers initially borne. Allogamy (*TC*) and autogamy (*TA*) rates are determined according to the formulas of [6]: $TC = \{[(Ifr_X - Ifr_Y) / Ifr_X] * 100\}$ and [24]: $TA = [100 - TC]$.

2.2.3. Determining the diversity and relative frequency of floricultural insects of Solanum melongena

To assess the diversity of flowering insects on *S. melongena*, insects were captured during the flowering period on open, unlabelled flowers using entomological net and/or by hand. The captured insects were kept in vials containing 70% ethanol. On the labelled specimen, the place, the date and the time of capture and the floral products sought were noted. Species not precisely identified in the field were given a code and description to facilitate observations. Specimens were identified at the Laboratory of Biological Sciences of Higher Teachers' Training College of the university of Maroua, using references collections and identification keys by [25, 26,27,28].

To determine the frequency of visits by the various insects, observations were made every day during the flowering period on flowers from treatments A and A' (unprotected), according to the following time slots: 6-7 am, 8-9 am, 10-11 am, 12-1 pm and 2-3 pm. At each pass, the various insects were counted on the flowers in full bloom. As these were not marked, the cumulative results were expressed by the number of visits according to Tchuenguem *et al.* [6]. The data obtained were used to determine the frequency of each insect species (*Fi*) on *S. melongena* flowers, according to the following formula : $Fi = \{[Vi/VT] * 100\}$ [6], where *Vi* is the number of visits by insect *i* to flowers in treatment A or A' and *VT* is the number of visits by all insects to the same flowers. To assess the specific richness of the floricultural insect diversity of this Solanaceae, the Shannon diversity index (H') was calculated using the formula:

$$H' = -\sum_{i=1}^{S} Pi \ln Pi$$ [29],

where $pi = ni/N$; *ni* is the number of individuals of *i* (corresponding to the number of visits to *i*); *N* is the total number of individuals (corresponding to the total number of visits) and *S* is the total number of species observed.

2.2.4. Determining the impact of floricultural insects on Solanum melongena pollination

The impact of insects on the pollination of *S. melongena* was assessed by recording the frequency of visits. This involved recording the number of times an insect came into contact with the stigma of the flower visited. This made it possible to assess the possibility of insect involvement in self-pollination and cross-pollination of visited flowers according to Delaplane *et al.* [30]. The regularity index (*R*) was used to categorize the different pollinators according to Tchuenguem [8]: $R = [(P/100) * (f/100)]$, where *P* is the percentage of insect visits and *f* is the relative frequency of insect visits.

2.2.5. Determining the impact of floricultural insects on Solanum melongena yields

Determination of the impact of flower-feeding insects on *S. melongena* yields was based on a comparison of fruit and seed yields in treatments A (flowers open to pollination) and B (flowers protected from insect visits). At maturity, the number of fruits, the number of seeds per fruit and the number of normal seeds were determined. The percentage (*Pf*) of fruiting rate attributable to floricultural insects was calculated using the formula of Tchuenguem *et al.* [6]: $Pf = \{[(f_A - f_B) / f_A] * 100\}$, where f_A and f_B are the fruiting rates in treatments A and B respectively. The percentage (*Pg*) of the average number of seeds per fruit attributable to floricultural insects is calculated using the formula of Tchuenguem *et al.* [6]: $Pg = \{[(g_A - g_B) / g_A] * 100\}$, where g_A and g_B are the average numbers of seeds per fruit in treatments A and B respectively. The percentage (*Pn*) of normal seeds due to floricultural insects is calculated using the formula of Tchuenguem *et al.* [6]: $Pn = \{[(g_{nA} - g_{nB}) / g_{nA}] * 100\}$, where g_{nA} and g_{nB} are the percentages of normal seeds in treatments A and B respectively.

2.2.6. Statistical analysis

Data were analysed using descriptive statistics, Student's t-test for the comparison of means of two samples, Chisquare (χ^2) for comparison of percentages using SPSS statistical software and Pearson's correlation coefficient (r) for evaluate two linear variables.

3. Results and discussion

3.1. Mode of reproduction of *Solanum melongena*

Fruiting indices were 0.95 (n = 120, s = 0.20), 0.62 (n = 120, s = 0.49), 0.88 (n = 120, s = 0.33) and 0.53 (n = 120, s = 0.50) for treatments A, B, A' and B' respectively. Thus, for 2022, *TC* = 34.74% and *TA* = 65.26% ; for 2023, the corresponding figures were 39.77% and 60.23% respectively. The cumulative values for the two years of investigation are 37.26% and 62.74% for *TC* and *TA* respectively. It appears that *S. melongena* has an allogamous-autogamous mode of reproduction, with autogamy predominating. In Pakistan, in Brazil and in Sri Lanka respectively [15,31,16] obtained similar results with the predominance of autogamy over allogamy in this Solanaceae.

3.2. Diversity and frequency of *Solanum melongena* flowering insects

Table 1 presents the diversity and frequency of insect visits to *S. melongena* flowers at Dourga. In 2022 and 2023, 1564 visits of 11 insects species and 1589 visits of 9 insects species were recorded respectively on 120 flowers each. The species richness of *S. melongena* flowering insects was 13 during these studies. This specific richness is higher than the 7 obtained in Nepal by Mainali *et al.* [18] in the same plant. This difference would be due to the fact that the specific diversity of floricultural insects of a plant can vary from one region to another according to Roubik [19]. This can be explained either by the absence or low presence of insects due to the floral composition of the study area. In fact, Dourga is an agricultural zone, unlike Lalitpur (City in Népal), which is an urban environment. According to Chagnon [32], urbanization could cause fragmentation and loss of habitat for many pollinators, leading to serious imbalances with detrimental ecological effects that result in the disappearance of many biotopes specific to certain floral species and a disruption of the balance between plants and their pollinators. In the same vein, [33] points out that urbanization can cause habitat destruction and subdivision, which remains one of the major causes of species extinction. In fact, for a long time, cities have developed without taking into consideration nearby natural environments.

Table 1 Diversity and frequency of insect visits to *Solanum melongena* flowers at Dourga in 2022 and 2023

Insects			**2022**		**2023**		**Total**	
Orders	Families	Genus, species	n_1	p_1 (%)	n_2	p_2 (%)	n_T	p_T (%)
Diptera	Muscidae	*Musca domestica*	-	-	14	0.88	14	0.44
	Syrphidae	*Sphaerophora scripta*	34	2.17	47	2.96	81	2.57
	Calliphoridae	*Chrysomya* sp.	28	1.79	17	1.07	45	1.43
Total	**03**	**03**	**62**	**3.96**	**78**	**4.91**	**140**	**4.44**
Hymenoptera	Apidae	*Apis mellifera*	159	10.17	231	14.54	390	12.37
		Xylocopa olivacea	139	8.89	-	-	139	4.41
		Xylocopa sp.	179	11.45	-	-	179	5.68
		Amegilla calens	186	11.89	257	16.17	443	14.05
	Formicidae	gn. sp.	24	1.53	-	-	24	0.76
	Halictidae	*Seladonia* sp.	531	33.95	698	43.93	1229	38.98

		Lasioglossum costulatum	123	7.89	128	8.06	251	7.96
		Nomiapis bipinosa	76	4.86	122	7.68	198	6.28
		Lipotriches sp.	85	5.43	-	-	85	2.69
	Megachilidae	*Megachile* sp.	-	-	75	4.72	75	2.38
Total	**04**	**10**	**1502**	**96.04**	**1511**	**95.09**	**3013**	**95.56**
Total	**07**	**13**	**1564**	**100**	**1589**	**100**	**3153**	**100**

n_1 : number of visits to 120 flowers in 9 days ; n_2 : number of visits to 120 flowers in 10 days; n_T : total number of visits for both years ; $\mathbf{p_1}$, p_2, p_T : visits percentages ; $p_1 = (n_1 / 1564) \times 100$; $p_2 = (n_2 / 1589) \times 100$; $p_T = (n_T / 3153) \times 100$; *P* : pollen harvest.

The Shannon-Weaver diversity indices were 3.99 and 2.80 in 2022 and 2023 respectively. In 2022, diversity was moderately diversified (H' > 3), whereas in 2023, the Dourga site was poorly diversified (H'< 3). This low observed diversity could be due to the fact that in 2022, neighboring plant species were absent, whereas in 2023, insects were attracted by the surrounding flowering plants, to the detriment of the eggplant. This table shows that only order Hymenoptera was the majority on Solanaceae flowers with a frequency of visits of 95.56%. In Pakistan, [15] found that the majority of insects on eggplant flowers also belonged to the order Hymenoptera. At Dourga, the order Hymenoptera is represented by four families (Halictidae, Apidae, Fomicidae, Megachilidae) and the one to which the most frequent insects on eggplant flowers belong is Halictidae with 55.92%. *Seladonia* sp. is by far the most frequent, accounting for 38.98 % of all recorded visits (Figure 6). The frequency of Halictes on eggplant flowers is higher at Dourga than at Rawalpindi (Pakistan), where the percentage of visits was 9.94% according to Bodlah & Waqar [15]. This difference would be linked to the abundance and diversity of these insects in each of these regions. The Diptera are represented by three families : Syrphidae, Calliphoridae and Muscidae.

Figure 6 *Seladonia* sp. foraging on *Solanum melongena* flower

3.3. Floral products collected

All floricultural insects of *S. melongena* in Dourga, exclusively collect the pollen (Table 2) of this Solanaceae. The collection of nectar is not observe during our investigation because this plant only produces pollen. This result corroborate with [34] who find te same results. Among eggplant pollen harvesters, a distinction was made between:

- (a)"in situ" pollen consumers represented by *Sphaerophora scripta*, *Musca domestica*, *Chrysomya* sp. and Formicidae (gn. sp.) (Figure 7). In this group of pollinivorous insects, all lack organs for transporting this food (baskets or ventral brush:[35]).

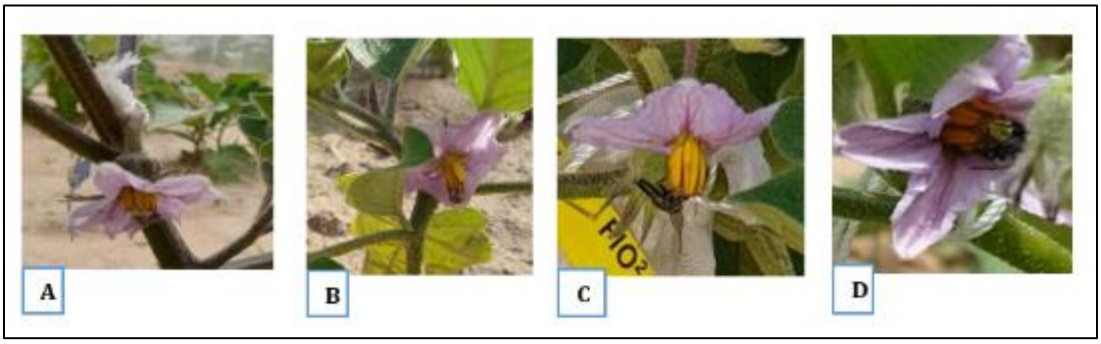

Figure 7 Some insects consuming pollen "in situ" on *Solanum melongena* flowers (A : *Sphaerophora scripta*, B : *Musca domestica*, C : *Chrysomya* sp., D : *Formicidae* (gn. sp.)

- (b) those that collect and carry pollen back to their nest or hive, represented by *Amegilla calens*, *Apis mellifera, Lasioglossum costulatum*, *Lipotriches* sp., *Megachille* sp., *Nomiapis bispinosa*, *Seladonia* sp., *Xylocopa olivacea* and *Xylocopa* sp., are equipped with pollen-carrying organs (Figure 8). These results are the same with those obtained at Lalitpur (Népal) by Mainali *et al.* [18].

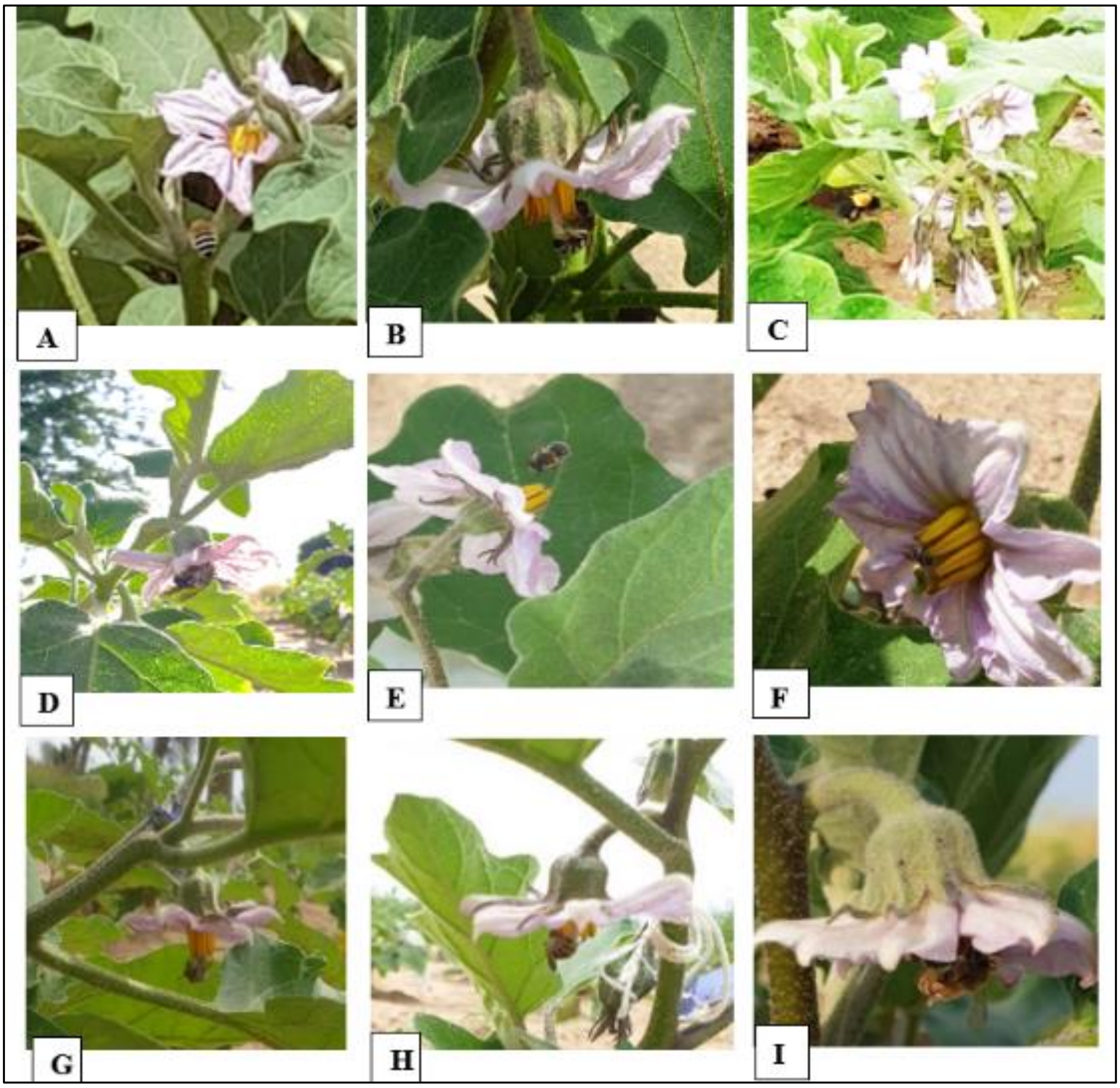

Figure 8 Some pollinating insects collecting and carrying pollen from *Solanum melongena* flowers into the nest or hive (A : *Amegilla calens, B : Seladonia sp. C : Xylocopa olivacea, D : Xylocopa sp., E : Nomiapis bispinosa, F : Lasioglossum costulatum, G : Lipotriches sp., H : Megachille sp., I : Apis mellifera*)

Overall, during the 19 days of observation, insects were encountered daily on *S. melongena* flowers, as shown in Table 2. From this table, we can see that *S. melongena* has more or less frequent visitors. Thus, there are: (a) very frequent visitors with a frequency of visits exceeding 50% of the total number of observation days [8]: *Sphaerophoria scripta*, *Apis mellifera*, *Amegilla calens*, *Lasioglossum costulatum*, *Lipotriches* sp., *Nomiapis bispinosa* and *Seladonia* sp.; (b) frequent visitors with a visit frequency between 25% and 50% of the total number of observation days [8]: *Musca domestica*, *Chrysomya* sp., *Xylocopa* sp., *Xylocopa olivacea* and *Megachille* sp.; (c) rare visitors with a visit frequency of less than 25% of the total number of observation days [8]. These results suggest that the flowers of *S. melongena* produce large quantities of pollen that attract insects that remain constant to it during its flowering period. [16] found in Sri Lanka that *Amegilla comberi*, *Amegilla* sp., *Gnathonomia nasicana*, *Leuconomia* sp., and *Hoplonomia westwoodi* are constant to the flowers of this same Solanaceae. Table 2 also shows that the frequency of *Seladonia* sp. and *Lasioglossum costulatum* in 19 days of observation is 100%. This would be proof of the good attachment and a good quality of these bees to *S. melongena* pollen. In contrast, work by Barbara & Ochieng [17] in Kenya showed that *Xylocopa caffra* and *Macronomia rufipes* were the most frequent bees on the flowers (100% of the total number of observation days) of this same plant species. This could be due to the absence or low presence of *Seladonia* sp. and *Lasioglossum costulatum* during this study period in Kenya.

Table 2 Number and percentage of days of visits by different floricultural insects to *Solanum melongena* at Dourga in 2022 and 2023

Insects	**Dourga 2022**		**Dourga 2023**		**Dourga accumulates**		**Harvested product**
	n_1	f_1	n_2	f_2	n_t	f_t	
Musca domestica	-	-	5	50	5	26.32	P in situ
Chrysomya sp.	4	44.44	5	50	9	47.37	P in situ
Apis mellifera	6	66.67	8	80	14	73.68	P harvest-take away
Xylocopa olivacea	7	77.78	-	-	7	36.84	P harvest-take away
Xylocopa sp.	8	88.89	-	-	8	42.11	P harvest-take away
Amegilla calens	8	88.89	8	80	16	84.21	P harvest-take away
Formicidae (gn. sp.)	4	44.44	-	-	4	21.05	P in situ
Seladonia sp.	9	100	10	100	19	100	P harvest-take away
Lasioglossum costulatum	9	100	10	100	19	100	P harvest-take away
Nomiapis bispinosa	7	77.78	6	60	13	68.42	P harvest-take away
Lipotriches sp.	6	66.67	6	60	12	63.16	P harvest-take away
Megachile sp.	-	-	6	60	6	31.58	P harvest-take away

n_1 : number of days of insect presence during 9 days of observations in 2022 ; n_2 : number of days of insect presence during 10 days of observations in 2023 ; nt : number of days of insect presence during 19 observations days in 2022 and 2023 ; f_1 : relative frequency of insect visits $(n_1/9)*100$; f_2 : relative frequency of insect visits $(n_2 / 10)*100$; ft : relative frequency total of insect visits $(nt/19)*100$.

3.4. Rhythm of insect visits

3.4.1. Rhythm of insect visits depending of the rate at which Solanum melongena flowers bloom

The number of insect visits to *S. melongena* flowers varied according to the number of flowers in bloom (Figure 9). There was a significant and positive correlation between these two parameters ($r_{2022} = 0.93$; [$df = 7$; $p < 0.05$] ; $r_{2023} = 0.70$; [$df = 8$; $p < 0.05$]).

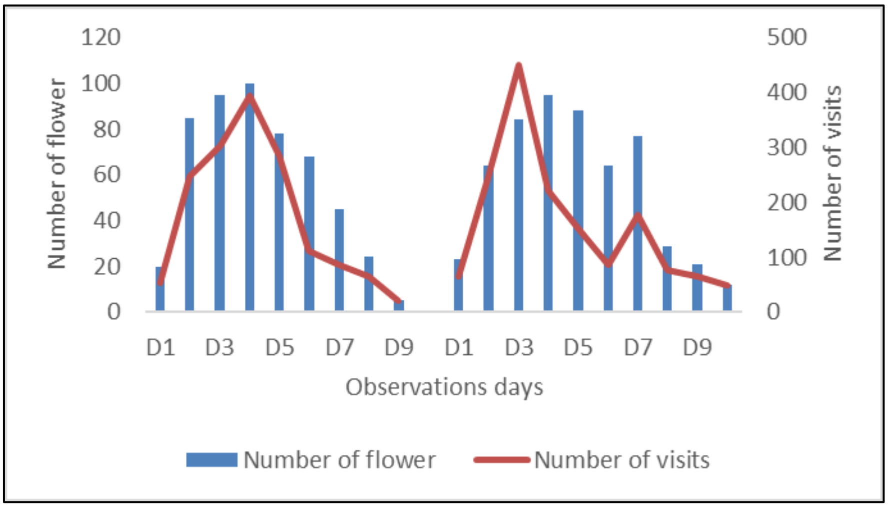

Figure 9 Seasonal variations in the number of open *Solanum melongena* flowers and the number of insect visits in 2022 and 2023 at Dourga

The positive and significant correlations highlight the good attractiveness of the pollen of *S. melongena* flowers to these flowering insects. They illustrate the principle of optimal foraging that characterizes certain bees according to Roubik *et al.* [36]. These results are in line with those of Faegri & Pijl [37], who indicate that the number of flowers in bloom is an essential factor that plays an important role in the orientation of insects towards flowers.

3.4.2. Rhythm of insect visits according to daily observation time slots

During the observation period, insects were active on eggplant flowers between 6-3 pm, and the daily foraging period varied from insect to insect (Table 3). [17] in Kenya found that insects were active on flowers of the same plant from 7-3 pm. The peak of activity for all insects was in the morning between 8-9 am, with 50.36% of visits. This could be explained by the fact that this is the time of day when pollen from flowers in full bloom is available and easily accessible to the insects, or when the optimal foraging strategy is adopted by them. In general, the massive presence of pollinating insects on flowers at a given time slot most often coincides with the period when pollen from the host plant is most available. [15], had already mentioned that increased pollen exploitation in the morning is characteristic of its availability and accessibility. However, the drop in flower activity observed after 2-3 pm time slot (3.01% of visits) could be linked either to the reduction in pollen quantity on the one hand and/or the gradual closure of flowers on the other, linked to temperature and humidity which, according to Ahmed & Aslam [38], would have an influence.

Table 3 Variation in the number of insect visits to *Solanum melongena* flowers by time slot over 19 days of observation in 2022 and 2023 at Dourga

Insects	**Frequency of insects visites by time slots**										
	6-7 am		**8-9 am**		**10-11 am**		**12-1 pm**		**2-3 pm**		**A**
	V_1	P_1	V_2	P_2	V_3	P_3	V_4	P_4	V_5	P_5	
Musca domestica	7	50	2	14.29	2	14.29	3	21.43	-	-	14
Sphaerophora scripta	10	22.22	24	53.33	9	20	2	4.44	-	-	45
Chrysomya sp.	6	7.40	21	25.93	27	33.33	26	32.10	1	1.23	81
Apis mellifera	55	14.10	193	49.49	87	22.31	42	10.77	13	3.33	390
Xylocopa olivacera	8	5.76	70	50.36	38	27.34	17	12.23	6	4.31	139
Xylocopa sp.	16	8.93	98	54.75	45	25.14	15	8.38	5	2.79	179
Amegilla calens	-	-	211	47.63	154	34.76	66	14.90	12	2.71	443
Formicidae (gn. sp.)	6	25	12	50	2	8.33	2	8.33	2	8.33	24
Seladonia sp.	50	3.76	711	47.55	303	34.47	133	10.91	32	3.29	1229

Lasioglossum costulatum	11	4.38	92	36.65	110	43.82	31	12.35	7	2.78	251
Nomiapis bispinosa	23	11.62	104	52.52	42	21.21	23	11.62	6	3.03	198
Lipotriches sp.	10	11.76	35	41.18	25	29.41	10	11.76	5	5.88	85
Megachile sp.	17	22.67	15	20	25	33.33	12	16.00	6	8.00	75
Total	**219**	**6.94**	**1588**	**50.36$^{\Omega}$**	**869**	**27.56**	**382**	**12.12**	**95**	**3.01**	**3153**

V_1 : number of visits between 6-7 am ; V_2 : number of visits between 8-9 am ; V_3 : number of visits between 10-11 am ; V_4 : number of visits between 12-1 pm ; V_5 : number of visits between 2-3 pm ; P_1 : percentage of visits between 6-7 am ; P_2 : percentage of visits between 8-9 am ; P_3 : percentage of visits between 10-11 am ; P_4 : percentage of visits between 12-1 pm ; P_5 : percentage of visits between 2-3 pm ; ***Pi*** **:** percentage of insect visits i = (n / A) × 100 ; (Ω) : peak of insect set visitation activity ; A : Total.

3.5. Impact of insects on *Solanum melongena* pollination

Table 4 shows the number and percentage of visits by some pollinating insects in regular contact with the anthers and stigma of open-pollinated flowers of *S. melongena*. The table shows that all the insects recorded had contact with anthers and/or stigmas : (a) ten (10) flowering insects species had 100% contact with anthers and three (03) flowering insect species had a frequency of contact with anthers between 50% ≤ f < 100% ; (b) nine (09) flowering insect species had a frequency of contact with stigmas greater than 50% and four (04) floricultural insects had a percentage of contact with stigmas less than 50%. During the course of their activities, these pollinating insects moved from flower to flower and were in regular contact with the anthers and/or pistil. According to Delaplane *et al.* [30], this passage from flower to flower can lead to self-pollination, with pollen grains falling onto the stigma of the same flower. In the same vein, [39] report that the mouthparts and fur, by carrying pollen grains to the stigma of another flower, participate in cross-pollination. By comparing the regularity index, relative frequency and specific behavior of each insect on the *S. melongena* flower, we were able to group these insects into three pollinators categories. Thus, according to Tchuenguem [8], major pollinators are characterized by a high regularity index (R > 0.05) coupled with good pollen harvesting : *A. mellifera*, *A. calens*, *Seladonia* sp., and *L. costulatum* ; minor pollinators are characterized by a low regularity index (0.001 ≤ R ≤ 0.05) coupled with good pollen harvesting : *X. olivacea*, *Xylocopa* sp., *N. bispinosa*, *Lipotriches* sp. and *Megachile* sp. and occasional pollinators characterized by a very low regularity index (R < 0.001) coupled with an absence of pollen-seeking behavior and/or their ability to destroy flower organs. In Kenya, [17] and in Sri Lanka, [16] found that *X. caffra*, *M. rufipes*, *A. calens*, *X. flavorufa*, *Pseudapis* sp., *X. albiceps*, *Hoplonomia westwoodi* and *Pachynomia* sp. are the most apt and efficient pollinators to participate in the pollination of this Solanaceae.

Table 4 Index of regularity, number and percentage of insect visits with contact to anthers and stigmas of *Solanum melongena* at Dourga in 2022 and 2023

Insects					***NVCP***			
	Index of regularity			n_t	**Anthers**		**Stigmas**	
	R_{2022}	R_{2023}	R_{Total}		n_a	P_a (%)	n_s	P_s (%)
Musca domestica	-	0.0044	0.0012	14	14	100	05	35.71
Sphaerophora scripta	0.0144	0.0207	0.0176	45	42	93.33	17	37.78
Chrysomya sp.	0.0080	0.0054	0.0068	81	81	100	33	40.74
Apis mellifera	0.0678	0.1163	0.0911	390	390	100	380	97.43
Xylocopa olivacea	0.0790	-	0.0162	139	139	100	135	97.12
Xylocopa sp.	0.0891	-	0.0239	179	179	100	171	95.53
Amegilla calens	0.1057	0.1294	0.1183	443	443	100	403	90.97
Formicidae (gn. sp.)	0.0068	-	0.0016	24	21	87.50	06	25.00
Seladonia sp.	0.3395	0.4393	0.3898	1229	1229	100	1200	97.64
Lasioglossum costulatum	0.0789	0.0806	0.0796	251	251	100	136	54.18
Nomiapis bispinosa	0.0378	0.0461	0.0430	198	195	98.48	142	72.82
Lipotriches sp.	0.0302	-	0.0170	85	85	100	55	64.70

Megachile sp.	-	0.0283	0.0075	75	75	100	63	84.00

R = (P/100) * (*f*/100) ; *P* : percentage of insect visits (tableau 1) ; *f* : relative frequency of insect visits (n_t / 19) * 100 ; *nt* : number of visits studied ; *NVCP* : number of visits with contact to the anther and/or pistil, n_a : number of visits with contact to the anthers ; n_s : number of visits with stigmatic contact ; P_a : percentage of visits with contact to the anthers ; P_s : percentage of visits with stigmatic contact.

3.6. Impact of insects on *Solanum melongena* seed yields

Table 5 shows the fruiting rate, number of seeds per fruit and percentage of normal seeds obtained in the different treatments.

- flowers left to open pollination produced more fruit than isolated flowers. Fruiting rates were 95.83%, 61.67%, 87.50% and 52.50% in treatments A, B, A' and B' respectively. Two-by-two comparisons of percentages show highly significant differences in both 2022 (χ^2_{2022} = 41.85; [*df* = 1; *p* < 0.001]) and 2023 (χ^2_{2023} = 51.74; [*df* = 1; *p* < 0.001]). This shows that, despite the predominance of autogamy, insects play a significant role in fruit production. The fruiting rate due to the influence of floricultural insects was 35.65 %. This contribution is higher than that obtained by [31] in Brazil, which was 29.50 %, and lower than that of Shanika *et al.,* [16] in Sri Lanka, which was 62.50%. These differences can be explained by the fact that the major pollinators of *S. melongena* are not the same in these different countries. Indeed, the potential effective pollinator of *S. melongena* found in Dourga is *Seladonia* sp. In contrast, these authors found that *Hoplonomia westwoodi* and *Melipona fasciculata* in Sri Lanka and Brazil respectively are the major pollinators of this Solanaceae.

Table 5 Fruit and seed yields in different *Solanum melongena* treatments

Parameters	Treatments (A, A')	Treatments (B, B')	Comparisons (A et B ; A' et B')
Rf_{2022}	95.83%	61.67%	χ^2_{2022} = 41.85; [*ddl* = 1; *P* < 0.001]*
Ns/f_{2022}	1164 (*n* = 30, *s* = 682.85)	983 (*n* = 30, *s* = 517.81)	Z_{2022} = 1.14; [*ddl* = 58; *P* > 0.05]
Ns_{2022}	93.31%	80,43%	χ^2_{2022} = 2411.62; [*ddl* = 1; *P* < 0.001]*
Rf_{2023}	87.50%	52.50%	χ^2_{2023} = 51.74; [*ddl* = 1; *P* < 0.001]*
Ns/f_{2023}	1177 (*n* = 30, *s* = 254.62)	993 (*n* = 30, *s* = 195.32)	Z_{2023} = 3.09; [*ddl* = 58; *P* < 0.01]*
Ns_{2023}	81.43%	77.97%	χ^2_{2023} = 120.32; [*ddl* = 1; *P* < 0.001]*

Rf : fructing rate, ***Ns/f*** : number of seeds per fruit, ***Ns*** : percentage of normals seeds, * : meaning ful to *P* < 0.05.

- the average number of seeds per fruit was 1164 (*n* = 30, *s* = 682.85), 983 (*n* = 30, *s* = 517.81), 1177 (*n* = 30, *s* = 254.62) and 993 (*n* = 30, *s* = 195.32) in treatments A, B, A' and B' respectively. The number of seeds from flowers visited by insects was higher than the number protected from them. [40, 41] in the USA and Argentina respectively also reported that flowers left to insect activity produced more seeds than those protected. A comparison of the average number of seeds per fruit between treatments A and B was found to be non-significant (Z_{2022} = 1.14; [*df* = 58; *P* > 0.05] on the one hand, and significant between treatments A' and B' (Z_{2023} = 3.09; [*df* = 58; *P* < 0.01]) on the other. As for 2023, this result is similar to those found by [16] in Sri Lanka. The numerical contribution of insect activity on the number of seeds per fruit is 12.65%. This result is higher than that obtained on *Capsicum annuum* in West Cameroon by Pando *et al.* [42], which was 5.30%. This could be explained by the presence of pests such as *Podogriscina decolorata*, *Epilachna borealis*, *Zonocerus variegatus*, *Acrida ungarica* and *Neoconocephalus robustus*, which are major destroyers of *C. annuum* flower petals in this region.

- the percentages of normal seeds were 93.3%, 80.43%, 81.43% and 77.97% in treatments A, B, A' and B' respectively. It appears that the percentage of normal seeds from open-pollinated flowers (treatments A or A') was higher than that from protected flowers (treatments B or B'). Comparison between the two treatments reveals a highly significant difference in both years, 2022 (χ^2_{2022} = 2411.62; [*df*=1; *P* < 0.001]) and 2023 (χ^2_{2023} = 120.32; [*df* = 1; *P* < 0.001]). The percentage of normal seeds due to insects was 11.72%.

4. Conclusion

At Dourga, 13 species of exclusive pollen-harvesting insects were inventoried on the flower of *S. melongena*, belonging to two orders and divided into seven families. These insects belong mainly to the order Hymenoptera, with *Seladonia* sp. being the most frequent, accounting for 38.98% of visits. These insects forage from 6-3 pm, with a peak in total visits between 8-9 am (50.36% of visits). Given the absence of nectar production by the flower of this plant, two categories of foragers were identified, those consuming pollen "in situ" (Diptera) and those collecting and carrying pollen back to the nest or colony (Hymenoptera). Flowers left to pollinate freely produced more fruit and higher-quality seeds. The numerical contributions of these insects were 35.65%, 12.65% and 11.72% for fruiting rate, number of seeds per fruit and percentage of normal seeds respectively. In order to benefit from the ecosystem service of insect pollinators, it is recommended that treatments of eggplant plants with chemical pesticides be avoided during the plant's flowering period.

Compliance with ethical standards

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Disclosure of conflict of interest

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

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