



Dynamics And Impact Of Flowering Insects On *Sesamum indicum* L. (Pedaliaceae) Production In Maroua (Far-North, Cameroon)

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Abstract

The study of the variability of the flower visiting entomofauna between Palar and Djarengol-Kodek (Maroua, Cameroon) and the influence of the pollination type were carried out in 2020 for assessing their impact on sesame production. Three treatments of 50 plants each were used according to whether the flowers were open-pollinated (TA) or protected using mosquito net cages (TB) and plastic cages (TC) for analysis. The diversity and composition of the entomofauna were compared between localities from TA as well as the

resulting pod and seed yields of the crop. 21 and 12 insect species were found foraging on sesame flowers in Palar and Djarengol-Kodek respectively. Hymenoptera had a high relative abundance > 92% at both sites and played a key role in pollinating the flowers of the host plant species. The diversity index was higher in Palar ($H' = 3.10$) than in Djarengol-Kodek ($H' = 2.64$). The Jaccard similarity index between both sites was $J = 0.43$. During their floral activity, these bees promoted autogamy, geitonogamy and xenogamy on *S. indicum* flowers. The impact of the floral activity of bees on sesame pod and seed yields was in the range of 17.92% - 29.27% and 12.97% - 18.39% in Djarengol-Kodek and Palar respectively with a significant difference between these values ($X^2 = 156.20$; $df = 1$; $P < 0.001$ and $X^2 = 69.74$; $df = 1$; $P < 0.001$). These differences showed the important role of the variability of the composition and the relative abundance of pollinators on sesame production between sites. Moreover, bee pollination (TA) highly increased anemophily (TB) and cleistogamy (TC) in sesame. Encourage producers to adopt more environmental friendly management methods to help preserve the habitat of sesame pollinator species for better productivity is an important practice.

Keywords: Apidae, Diversity, Flowering Insect, Pollination, Sesame, Yield

Introduction

Insects forage nectar from flowers for their energy needs and collect pollen which supplies them and their offspring with protein, lipids, and nutrients (Baum *et al.*, 2011). During their floral activity, they ensure the intra and interflowered transfer of pollen grains from the producing anthers to the receptive stigmas which precedes fertilization (Guerriat, 1996). Pollinating insects include certain species of beetles, butterflies, true flies, and above all, bees that maintain a deep network with flowers (Canto-Aguilar and Parra-Tabla, 2000). As a bee goes from flower to flower, pollen grains get caught in the branched hairs, which facilitates their collection and transfer (Vaissière, 2002). Moreover, their flower constancy during a foraging trip restricts the venture to feed on other flower types and make them efficient and precise pollen vectors for a given plant species in bloom (Hill *et al.*, 1997; Chittka *et al.*, 1999; Raine *et al.*, 2006).

More than 200,000 species of bees worldwide contribute to the survival and evolution of more than 80% of plant species (Michener, 2007). These Hymenoptera, both native and social, play an essential role in global food production (Klein *et al.*, 2007). Bees commonly carry tens of thousands of pollen grains on their fur and deposit large quantities on the stigmas of plants (Allen-Wardell *et al.*, 1998). The immediate consequence of this activity is the efficient gametic selection of pollen tubes which leads to a quantitative increase in fruit and seed yields (Vaissière, 2002). Also,

qualitatively, by going from flower to flower, bees transport pollen from genetically different individuals and the deposition of allo-pollen allows cross-fertilization and reproduction of all plant species, even self-incompatible ones (Vaissière, 2002).

Despite the essential involvement of bees in plant breeding, crop pollination is commonly cited as an example of an endangered ecosystem service (Kevan and Phillips, 2001). All over the world, populations of domestic and wild bees are declining (Forister *et al.*, 2019). The destruction of nesting sites linked to the fragmentation of biotopes, extensive urbanization, atmospheric pollution (van Langevelde *et al.*, 2018), spreading of phytosanitary products, diseases, and the scarcity of a range of suitable plants, contributes to dangerously reduce the pollinating entomofauna of plant species (Haubruge *et al.*, 2006; Sánchez-Bayo and Wyckhuys, 2019).

Sesame (*Sesamum indicum* L.) is a major oilseed crop in many tropical and subtropical regions around the world (Kamel *et al.*, 2013). This culture is popular through its vegetable oil which ranks sixth in the world, making Burma, India, China, Ethiopia, Sudan, Uganda, Nigeria, Bangladesh, Egypt and Pakistan the main producers (FAOSTAT, 2012). In Cameroon more particularly, the Far North region is suitable for the cultivation of sesame, the seeds of which are commonly eaten dried or in caramelized form. Information on insect pollination are lacking at the level of sesame growers in the Sudano-Sahelian region of Cameroon. Though pesticides are used to limit the harmful action of insect pests incriminated in the decline in sesame production, these pesticides are indiscriminate and reduce also the number and diversity of useful insects such as pollinators. This can cause the expected pod or seed yields to drop considerably (Southwick and Southwick, 1992).

The present study has as main objective the search for entomological knowledges that could facilitate the increase and sustainable production of *S. indicum* in parallel trials in Maroua. This work aims in particular to: 1) evaluate the diversity of flowering insects associated with sesame production; 2) estimate the impact of the pollinating activity of these insects on the pod and seed yields of the crop; and 3) identify some local causes of the decline of pollinators in the study localities.

Materials and methods

Study sites

The present study was carried out in Maroua, capital of the Far North region of Cameroon, more precisely in two neighborhoods namely Palar (10.616360 N; 14.290423 E) in Maroua I commune and Djarengol-Kodek (10.616825 N; 14.348442 E) in Maroua III commune (Figure 1). Maroua is located in the Sudano-Sahelian agroecological zone of Cameroon. The climate of this region has two seasons; the dry and rainy seasons. The former runs

from November to May followed by the latter that runs from June to October. The mean rainfall recorded yearly stood at about 1000 mm, temperatures ranged from 27 to 43°C, the mean value of the relative humidity is about 40% yearly (Morin, 2000). Maroua actual solar potential increased to 3490.86 hours or 1933.07 kW.h.m² per year (Fotsing *et al.*, 2018). The vegetation is dominated by plant species such as Neem *Azadirachta indica* (Meliaceae), Cailcedrats *Kaya senegalensis* (Meliaceae) and *Cassia (Senna) siamea* (Caesalpinaceae) which occupy large areas in urban agglomerations and reforestation areas (Raunet, 2003). The soils of the Far North region are of six types, namely poorly evolved soils, vertisols, hydromorphic soils, tropical ferruginous soils, crude mineral soils and halomorphic planosols (Muller and Gavaud, 1979).

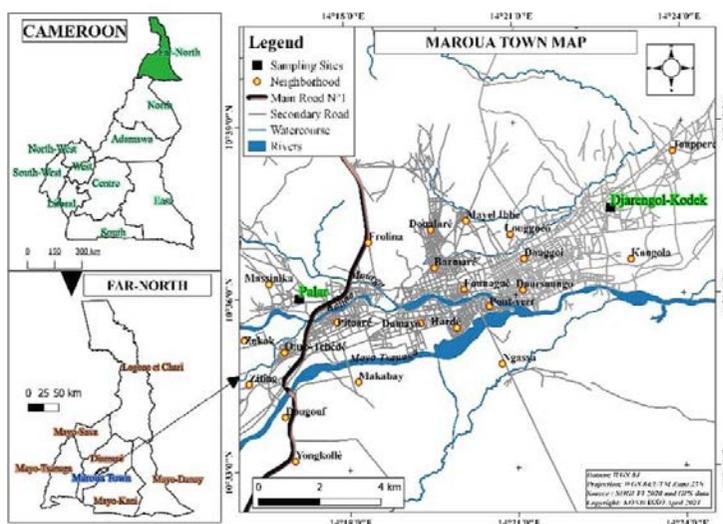


Figure 1. Location of study sites (By Ndouwe, 2020)

Materials

Plant material consisted of *S. indicum* of the white and smooth seeds variety provided by the Institute of Agricultural Research for Development (IRAD) of Maroua. The animal material consisted of insects naturally present in the immediate environment of both experimental sites. Some small agricultural equipment (machetes, hoes, graduated string, rake) was necessary for the establishment of the cultivation plots, and some technical equipment was used for setting up treatments (planks, rolls of mosquito net, rolls of plastic tulle, nails) and collecting flower visiting insects (70% ethanol, hand net, pins and entomological boxes).

Methods

From the 19th to 20th July 2020, an experimental plot of 500 m² of square shape was cleared and ploughed with animal traction. The sowing was done along the plough lines at the rate of 10 to 15 seeds per pocket in the two sites on July 29, 2020. The distance between the lines was 80 cm and 35 cm on the lines. Two weeks after germination, plantlets were maintained to two per hole; only the most vigorous were preserved. From germination to the appearance of the first flowers, weeding was done with a hoe every two weeks. Likewise, from flowering to maturity of the pods, weeding was done by hand. Before flower buds anthesis, the experimental field was delimited in three distinct treatments (figure 2), a T_A treatment in which the flowers of 50 plants labeled at random were kept open-pollinated; a T_B treatment in which 50 plants were kept in mosquito net cages to exclude insect floral activity; and a T_C treatment in which 50 plants were kept in plastic tulle cages topped with wire mesh to exclude insect activity and minimize the effect of the wind on the flowers.



Figure 2. Experimental devices showing the different treatments (Ndouwe, 2020)

Observations on the flowers of the T_A treatments were made alternately in both sites from September 3 to October 17, 2020, between 6:00 a.m. and 5:00 p.m. following these time intervals: 6:00-7:00 a.m., 8:00-9:00 a.m., 10:00-11:00 a.m., 12:00-1:00 p.m., 2:00-3:00 p.m. and 4:00-5:00 p.m. An observer walked along each flagged plant within the treatment T_A at each site and recorded insect activity on blooming flowers. Overall, one to ten insect specimens, depending on their relative abundance, were captured and retained for identification. The direct count of insect flower visits to sesame was made and the result expressed as the number of visits. This operation enabled to determine the compositional diversity of the entomofauna associated with sesame flowers. In addition, foraging parameters such as the daily rhythm of insect flower visits according to the observation time intervals, the frequency of the floral products collected, the average duration of the floral visit recorded

(using a stopwatch), and the foraging speed or average number of flowers visited per a minute were taken into account only in the Palar site (Jacob-Remacle, 1989; Tchuenguem *et al.*, 2002).

The relative abundance made it possible to determine the place occupied by each insect species in the floral entomofauna of sesame. Also called centesimal frequency, relative abundance f (%) is the ratio of the number of visits of a given insect species (nv)/total number of visits of all species combined (N) (Sabir *et al.*, 2011).

The Shannon Diversity Index was calculated by the following formula:

$$H' = -\sum [(ni/N) \times \log_2 (ni/N)]$$

Where H' is the specific diversity (in bits);

Σ is the sum of the results obtained for each of the insect species;

n_i is the sample of the species i ;

N is the total number of visits of insect species recorded;

\log_2 is the base 2 logarithm.

The Jaccard similarity index J was used to determine the degree of similarity of the sesame flower entomofauna between both study sites. The following formula was used:

$$J = [(a/a + b + c)]$$

Where a = number of common species between both sites;

b = number of unique insect species for Palar site 1 (total number of insect species recorded in this site - number of common species a);

c = number of unique insect species for Djarengol-Kodek site 2 (total number of insect species recorded in this site - number of common species a).

The estimates of yields in each treatment was based on calculating the mean number of pods per plant and the mean number of seeds per pod. The added value in pods due to the floral activity of insects was deduced by the following formula (Tchuenguem *et al.*, 2001):

$$P_i = \{[(F_a - F_b)/F_a] \times 100\}$$

F_a = mean number of pods per plant in the T_A treatment;

F_b = mean number of pods per plant in the T_B treatment;

P_i = Percentage of pods due to flower-visiting insects.

The formula used to infer the contribution of the floral activity of insects on the seed yield according to Tchuenguem *et al.* (2001) was:

$$P_g = \{[(G_a - G_b)/G_a] \times 100\}$$

G_a = Average number of seeds per pod in the T_A treatment;

G_b = Average number of seeds per pod in the T_B treatment;

P_g = Percentage of seeds due to the floral activity of insects.

Data analysis was done using descriptive statistics. Analysis of Variance (ANOVA) was used to compare the means between the three treatments T_A, T_B and T_C using SPSS statistical software (version 19.0; SPSS, Inc., Chicago, Illinois, USA). In each case, the means are followed by the standard deviation and the differences are significant at $P < 0.05$. The X^2 test was used for comparing two proportions and the t -test of Student for the comparison between two means.

Results

Diversity of flower visiting insects on *Sesamum indicum*

During observations in the Maroua region in 2020, 1,836 visits by 21 insect species belonging to 9 families and 3 orders were counted on the flowers of *S. indicum* in Palar. In Djarengol-Kodek during the same period, 499 visits of 12 species belonging to 5 families and 2 orders were counted. Table 1 shows the compositional diversity of the flower visiting insects listed on sesame as well as their relative abundance.

Table 1. Insects recorded on the flowers of *Sesamum indicum*, number of visits and relative abundance (Palar and Djarengol-Kodek in 2020)

Ordre	Famille	Genre et Espèce	Palar		Djarengol-Kodek		
			n_1	f_1 (%)	n_2	f_2 (%)	
Hymenoptera	Apidae	<i>Apis mellifera</i>	677	36.87	186	37.27	
		<i>Xylocopa inconstans</i>	135	7.35	97	19.44	
		<i>Xylocopa pubescens</i>	168	9.15	75	15.03	
		<i>Xylocopa olivacea</i>	77	4.19	24	4.81	
		<i>Xylocopa ustulata</i>	71	3.86	-	-	
		<i>Amegilla</i> sp. 1	69	3.75	-	-	
		<i>Amegilla</i> sp. 2	48	2.61	-	-	
		<i>Thyreus</i> sp.	-	-	17	3.40	
		Total Apidae		1231	67.04	399	79.95
		Megachilidae	<i>Megachile aurifera</i>	222	12.09	24	4.81
			<i>Chalicodoma</i> sp.	48	2.61	-	-
			<i>Chalicodoma torrida</i>	204	11.11	8	1.61
<i>Chalicodoma rufipes</i>	18		0.98	-	-		
<i>Chalicodoma cincta</i>	12		0.66	-	-		
Total Megachilidae		504	27.45	32	6.42		
Halictidae	<i>Lipotriches collaris</i>	40	2.18	24	4.81		
	<i>Lipotriches notabilis</i>	26	1.41	-	-		
	<i>Trinchostoma sjostedti</i>	-	-	6	1.20		
Total Halictidae		66	3.59	30	6.01		
Total Hymenoptera		1801	98.09		92.38		
Diptera	Bombyliidae	(1 sp.)	14	0.76	-	-	

	Syrphidae	<i>Phytomia</i> sp.	4	0.22	-	-
Total Diptera			18	0.98	-	-
Lepidoptera	Nymphalidea	<i>Hypolimnas misippus</i>	2	0.11	-	-
	Papilionidea	<i>Papilio demodecus</i>	2	0.11	-	-
	Pieridae	<i>Eurema exima</i>	6	0.33	12	2.41
		<i>Catopsilia florella</i>	5	0.27	9	1.80
	Acraeidae	<i>Acraea acerata</i>	2	0.11	17	3.41
Total Lepidoptera			17	0.93	38	7.62
Total			1836	100.00	499	100.00
			21 species		12 species	

Legend: n_1 & n_2 = number of insect species visits; f_1 & f_2 = relative abundance of insect species

The table illustrates that the Hymenoptera were the most frequently encountered order with a relative abundance of 98.09% in Palar and 92.38% in Djarengol-Kodek. They are represented by the Apidae (67.04% in Palar and 79.95% in Djarengol-Kodek), the Megachilidae (27.45% and 6.42%) and the Halictidae (3.59% and 6.01%). Among bee species, *Apis mellifera* had the highest relative abundance with 36.87% in Palar and 37.27% in Djarengol-Kodek; followed by *Megachile aurifera* (12.09%), *Chalicodoma torrida* (11.11%), *Xylocopa pubescens* (9.15%) and *X. inconstans* (7.35%) in Palar; *X. inconstans* (19.44%) and of *X. pubescens* (15.03%) in Djarengol-Kodek. Other bee species had a relative abundance of less than 5%; *X. olivacea* (4.19%), *X. ustulata* (3.86%), *Amegilla* sp. 1 (3.75%), *Amegilla* sp. 2 (2.61%), *Lipotriches collaris* (2.18%), *A. torrida* (1.85%), *L. notabilis* (1.41%), *C. rufipes* (0.98%) and *C. cincta* (0.66%) in Palar and *X. olivacea* (4.81%), *Chalicodoma* sp. (4.81%), *L. collaris* (4.81%), *Thyreus* sp. (3.40%) and *C. torrida* (1.61%) in Djarengol-Kodek. The other orders of insects, namely Lepidoptera and Diptera, were in the minority with a relative abundance of 1.91% in Palar; whilst the order Lepidoptera had a relative abundance of 7.62% in Djarengol-Kodek. It is clear that *S. indicum* at the study sites was an important plant for aculeate bee species given the high relative abundance of these in the floral entomofauna of the crop.

Diversity index of the entomofauna in both sites

The Shannon diversity index calculated at the two sites was respectively $H' = 3.10$ bits in Palar and $H' = 2.64$ bits in Djarengol-Kodek. The specific diversity is low at Djarengol-Kodek ($H' < 3$ bits) compared to Palar where it is said to be average ($3 < H' < 4$). The Palar site is therefore richer in sesame anthophilous insect species than that of Djarengol-Kodek.

Similarity of the entomofauna between sites

From the results reported in table 1, it appears that the number of common insect species between Palar and Djarengol-Kodek is $a = 10$; the number of insect species found only in Palar is $b = 11$; the number of insect species found only in Djarengol-Kodek is $c = 2$. These different values result in the Jaccard similarity index $J = 0.43$. From the above, it appears that the similarity between Palar and Djarengol-Kodek is 43 %, noting a difference of around 57 % of species between the two sites, with the Palar site being richer in species.

Insect activity on *Sesamum indicum* flowers

Variation of insect flower visits according to time intervals

Figure 3 specifies the variation in floral visits of insects in general according to the daily observation time slots. The visits of insects on the flowers of *S. indicum* began in the morning at dawn (6 a.m.), peaked between 10-11 a.m. and ended around 5 p.m. when the flowers were closed.

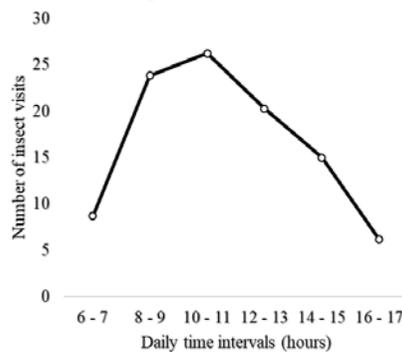


Figure 3. Insect floral visits based on the daily observation intervals (Palar, 2020)

Floral products collected

Table 2 shows the results on the proportion of the different floral products harvested by the most abundant and constant visitors of *S. indicum* flowers. From this table, it emerges that among 50 floral visits by *A. mellifera*, 76% were devoted to collecting nectar and 24% for pollen; out of 50 flower visits studied in *M. aurifera* 84% were for nectar harvesting and 16% to pollen collection; in *C. torrida*, 90% of the visits studied were devoted to nectar and 10% to pollen. Finally, Xylocopes were exclusively attached to the nectar of *S. indicum* which they forage in the extrafloral position, given their enormous size.

Table 2. Proportions of floral products levied on sesame flowers (Palar, 2020)

Insect species	<i>n</i>	Nectar	<i>p</i> (%)	Pollen	<i>p</i> (%)
<i>Apis mellifera</i>	50	38	76	12	24
<i>Megachile aurifera</i>	50	42	84	8	16

<i>Chalicodoma torrida</i>	50	45	90	5	10
<i>Xylocopa pubescens</i>	50	50	100	0	0
<i>Xylocopa inconstans</i>	50	50	100	0	0

n = number of visits; *p* = percentage of visits

Average duration of a floral visit

Table 3 illustrates the mean duration of one visit per flower by certain bee species. Only floral visits to collect nectar were recorded, as pollen collection visits were scarcer. Overall, the average duration of a floral visit for nectar collection varies from 3.03 ± 1.70 sec. in *X. inconstans* to 3.18 ± 2.50 sec. in *X. pubescens*, 6.38 ± 4.11 sec. in *C. torrida*, 7.73 ± 4.75 sec. in *A. mellifera* and 7.89 ± 4.40 sec in *M. aurifera*. The difference between these means was significant ($F = 17.21$; $df = 4, 245$; $P < 0.001$).

Table 3. Mean duration of a bee visit on *Sesamum indicum* flowers (Palar, 2020)

		<i>n</i>	Duration of a bee visit (sec)		
			<i>m</i> ± <i>sd</i>	<i>mini</i>	<i>maxi</i>
<i>Apis mellifera</i>	Ne	50	$7.73 \pm 4.75a$	1	30
<i>Megachile aurifera</i>	Ne	50	$7.89 \pm 4.40a$	1	20
<i>Chalicodoma torrida</i>	Ne	50	$6.38 \pm 4.11b$	1	22
<i>Xylocopa pubescens</i>	Ne	50	$3.18 \pm 2.50c$	1	21
<i>Xylocopa inconstans</i>	Ne	50	$3.03 \pm 1.70c$	1	11

The mean values followed by different letters are significant; *m* = mean; *sd* = standard deviation *n* = sample; *mini* = minimum; *maxi* = maximum

Average foraging speed

The mean foraging speed on *S. indicum* flowers was recorded on the same bees as for the duration of the visit. Table 4 shows that the mean foraging speed values varied from 7.88 ± 6.74 flowers/min in *A. mellifera* to 8.67 ± 6.06 flowers/min in *M. aurifera*, 10.28 ± 8.33 flowers/min in *C. torrida*, 10.57 ± 7.45 flowers/min in *X. inconstans* and 10.66 ± 9.68 flowers/min in *X. pubescens*. The difference between these means is significant ($F = 5.47$; $df = 4, 245$; $P < 0.001$). The high average values of the different foraging speeds of the insects studied is an index of their well-development of interfloral activity in favor of cross-pollination.

Table 4. Mean foraging speed of bees on *Sesamum indicum* flowers (Palar, 2020)

	<i>n</i>	Foraging speed (flower/min)		
		<i>m</i> ± <i>sd</i>	<i>mini</i>	<i>maxi</i>
<i>Apis mellifera</i>	50	$7.88 \pm 6.74a$	2	14
<i>Megachile aurifera</i>	50	$8.67 \pm 6.06a$	4	16
<i>Chalicodoma torrida</i>	50	$10.28 \pm 8.33b$	3	17
<i>Xylocopa inconstans</i>	50	$10.57 \pm 7.45b$	4	27
<i>Xylocopa pubescens</i>	50	$10.66 \pm 9.68b$	7	25

The mean values followed by different letters are significant; *m* = mean; *sd* = standard deviation *n* = sample; *mini* = minimum; *maxi* = maximum

Estimates of pod and seed yields

Table 5 summarizes the yield data in the different treatments of *S. indicum* in Palar and Djarengol-Kodek. Overall, the mean number of pods per plant and the mean number of seeds per pod were significantly higher in the open-pollinated treatment T_A compared with the protected treatments (T_B and T_C) in both sites.

Table 5. Yields in the different treatments of sesame in Palar and Djarengol-Kodek

T	n ₁	Mean number of pods/plant	n ₂	Mean number of seeds/pods
T _A	50	64.80 ± 34.91a	100	69.81 ± 8.88a
T _B	50	45.56 ± 25.22b	100	56.97 ± 9.73b
T _C	50	39.56 ± 18.44b	100	53.49 ± 11.93b
Palar		<i>F</i> = 21.18; <i>df</i> = 2, 147		<i>F</i> = 8.31 ; <i>df</i> = 2, 297
T _A	50	43.52 ± 21.42a	100	53.28 ± 10.37a
T _B	50	35.72 ± 17.04b	100	46.37 ± 6.94b
T _C	50	33.44 ± 11.49b	100	43.96 ± 8.45b
Djarengol-Kodek		<i>F</i> = 10.74; <i>df</i> = 2, 147		<i>F</i> = 6.07 ; <i>df</i> = 2, 297

The mean values followed by different letters are significant; *n* = sample; T = treatment

In Palar, the average number of pods per plant was 64.80 ± 34.91 in T_A, 45.56 ± 25.22 in T_B and 39.56 ± 18.44 in T_C. The difference between these means was found to be significant (*F* = 21.18; *df* = 2, 147; *P* < 0.001). The pairwise comparison of the different treatments shows that the difference was significant between T_A and T_B (*P* < 0.001), T_A and T_C (*P* < 0.001); however, this difference was not significant between both T_B and T_C (*P* = 0.613). The contribution of bees to improving the number of pods per plant was estimated at about 29.70 %. Likewise, the average number of seeds per pod was 69.81 ± 8.88 in T_A, 56.97 ± 9.73 in T_B and 53.49 ± 11.93 in T_C. The overall difference between these mean values was significant (*F* = 8.31; *df* = 2, 297; *P* < 0.001). The two-by-two comparison between these values showed that the difference was not significant between T_B and T_C (*P* = 0.827) and significant between T_A and T_B (*P* < 0.001,) and between T_A and T_C (*P* < 0.001). The contribution of bees to improving the number of seeds per pod was estimated at 18.39 %.

In Djarengol-Kodek, the average number of pods per plant varied from 43.52 ± 21.42 in T_A to 33.72 ± 17.04 in T_B and 31.44 ± 11.49 in T_C with a significant difference between these values (*F* = 10.74; *df* = 2, 147; *P* < 0.001). The pairwise comparison between the treatments showed a significant difference between T_A and T_B (*P* < 0.001), T_A and T_C (*P* < 0.001) and a non-significant difference between T_B and T_C (*P* = 0.517). The contribution of bees to improving the number of pods per plant is estimated at 17.92 %. The mean number of seeds per plant varied from 53.28 ± 10.37 in T_A to 46.37 ± 6.94 in T_B and 43.96 ± 8.45 in T_C with a significant difference between these values (*F* = 6.07; *df* = 2, 297; *P* < 0.001). The pairwise comparison between the

treatments showed a significant difference between T_A and T_B ($P < 0.001$), T_A and T_C ($P < 0.001$) and a non-significant difference between T_B and T_C ($P = 0.249$). The contribution of bees to improving the number of seeds per pod is estimated at 12.97 %.

The average number of pods per plant in T_A was 64.80 ± 34.91 in Palar and 43.52 ± 21.42 in Djarengol-Kodek; the difference between these means was significant ($t = 17.86$; $df = 98$; $P < 0.001$). Likewise, the average number of seeds per pod obtained from studied plants in T_A was 69.81 ± 8.88 in Palar and 53.28 ± 10.37 in Djarengol-Kodek with a significant difference between both values ($t = 13.44$; $df = 198$; $P < 0.001$).

The comparison of the contribution of bees to the increase in pod yields between Palar (29.70 %) and Djarengol-Kodek (17.92 %) was significant ($X^2 = 156.20$; $df = 1$; $P < 0.001$); similarly, the difference in the contribution of bees to the increase in grain yields between Palar (18.39 %) and Djarengol-Kodek (12.97 %) was also significant ($X^2 = 69.74$; $df = 1$; $P < 0.05$). As a result, pod and seed yields were higher at the Palar site compared with Djarengol-Kodek. This difference would probably be related to the diversity and relative abundance of pollinating insects at the Palar site compared with those at Djarengol-Kodek.

Discussion

This study on the insect pollination of sesame showed that out of 21 insect species recorded at the Palar study site and 12 insect species listed in Djarengol-Kodek on sesame flowers, the order Hymenoptera was the most representative in terms of relative abundance and species richness. Despite the preponderance of the honey bee *A. mellifera* at both study sites, native bees such as Carpenter bees, Leafcutter bees, and Halictids showed an equally large collective relative abundance. These results are consistent with those previously obtained in Cameroon, more from Bambui in the area of the western highlands (Atibita *et al.*, 2016), in Maroua in the Sudano-Sahelian zone (Pando *et al.*, 2018), in Ngaoundéré in the Sudano-Guinean zone (Tchuenguem and Népidé, 2018) and in Obala in the tropical rainforest zone (Pharaon *et al.*, 2018). Moreover, similar results are consistent with results from other countries around the world; including India (Kumar and Lenin, 2000), Egypt (Mahfouz *et al.*, 2012; Kamel *et al.*, 2013) and Tanzania (Ngongolo *et al.*, 2015). The above studies also identified Hymenoptera as the most numerous anthophilous insects on sesame flowers. The bees, which are the main foragers of sesame flowers, are also to some extent its main pollinators. It therefore follows that sesame is a mellitophilous plant species as already found above by other previous studies.

The results also indicated a different diversity index between study sites with a low index at Djarengol-Kodek and an average index at Palar. Moreover,

the Jaccard similarity index of around 0.43 supports the relative difference in sesame floral entomofauna between both experimental sites. The Djarengol-Kodek site is located in an area which is subject to strong anthropogenic pressure; this is justified by advanced urbanization marked in particular by the proximity to the new Maroua-Bogo road and the construction of many houses contributing to the extension of this neighborhood of Maroua. These investment activities are responsible for the fragmentation of the habitat of sesame pollinators in the site, which negatively impacts the survival of pollinators such as bees. It is known in the literature that bees nest in tree hollows, dead wood, caves and galleries dug in the ground (Michener, 2007), the surrounding flower beds and farms being their sources of food. The intensification of civil engineering works in a locality contributes to the loss of native bee fauna particularly in abundance and in diversity (Forister *et al.*, 2019). Observed declines in pollinator populations due to human pressures is of critical concern because pollination is an essential regulating ecosystem service (Bartholomé and Lavorel, 2019). Humans are altering the composition of biological communities through a variety of activities that increase rates of species invasions and species extinctions, at all scales, from local to global (Hooper *et al.*, 2005).

Unlike Djarengol-Kodek, the Palar experimental site does not yet have a propensity for urbanization. The major activities carried out there have an agricultural inclination. The trees planted there from the operation “Green Sahel” to fight against desertification are in good condition for tree nesting bee species. Thus, the relative stability of this site is an important factor in safeguarding the pollinating fauna in terms of the number of species and the relative abundance of these.

The numerical and compositional diversity of the floral entomofauna of *S. indicum* varies from one biome or biogeographic region to another, for a given biome, from one agroecological zone to another, within of the same agroecological zone from one site to another and within the same site from one year to another (Klein *et al.*, 2007). In this last aspect, the results of Pando *et al.* (2018) indicate *Megachile (Chalicodoma) aurifera* as the main insect pollinator of sesame in Palar in 2015, unlike the present study which indicates that predominantly the honey bee was the main pollinator here at the same site five years later. Overall, the dynamics of sesame flower visiting entomofauna are effective both spatially and temporally.

During their floral activity, the recorded bee species collected much more nectar than pollen. *S. indicum* appears to be a highly nectariferous plant species, the visiting bees being mainly nectarophagous. Thus, the foraging activity of bees on *S. indicum* indicates that this plant species has a strong beekeeping potential then, can be used to sustain the nutritional needs of bees in terms of pollen and carbohydrates. The peak of insect activity in the flowers

of *S. indicum* was found to be during the morning. This certainly corresponded with the period of optimal availability of nectar at the flower level. Indeed, there is a strong correlation between the abundance of foragers and the availability of food resources, bees being thrifty insects (Kasper *et al.*, 2008).

The floral structure of *S. indicum* is of the hermaphrodite or bisexual type, which predisposes sesame to self-pollination (Ashri, 2007). During their floral activity, visiting bees maximize self-pollination of *S. indicum*; in fact, when searching for nectar, certain bee species such as *A. mellifera* burrow into the flower to collect the nectar at the bottom and promote contact between androecium and gynoecium maximizing self-pollination. In addition, the visiting bees were able to promote geitonogamy which is marked by interfloral pollination on the same plant and xenogamy or cross pollination; the latter form of pollination is all the more likely as allogamy exists in *S. indicum* (Andrade *et al.*, 2014). Other bee species such as *Xylocopes* or Carpenter bees, due to their large size, collected sesame nectar in an extrafloral position; they promote, by their vibrations, the fall of pollens on the stigma through sonication or "buzz pollination" which characterizes them (Corbet and Huang, 2014).

The high yields obtained in T_A compared with those obtained in T_B and T_C, both in Palar and Djarengol-Kodek, were attributed to the pollinating action of bees on the flowers of *S. indicum* in the former treatment. According to Jean-Prost (1987), the more pollen grains a flower receives, the more potential it has to transform into fruit containing many seeds. Higher yields of sesame pods and seeds are thus dependent on bee pollination. Other studies have noted increased pod and seed yields of sesame due to the floral activity of pollinating insects. Tchuenguem and Népidé (2018) showed that in Ngaoundéré, *A. mellifera* increased the fruiting rate and the percentage of normal seeds of sesame by 28.13% and 6.24 % respectively. According to Pharaon *et al.* (2018), the fruiting rate attributed to the floral activity of *A. mellifera* on *S. indicum* caused a significant increase in the number of seeds per pod of 17.54 % in 2016 and 8.77 % in 2017. In Egypt, Mahfouz *et al.* (2012) found that insects increased sesame seed yields by about 35.55 % in 2010 and 33.39% in 2011. Overall, improving pod and seed yields of sesame manifests as the economic value of ecological services provided by the bee species recorded.

The fact that there is no significant difference on the average number of pods and seeds between T_B and T_C is related to the fact that in sesame, the flowers are able to self-pollinate without necessarily depending on external agents (Andrade *et al.*, 2014). Indeed, it is well known in the literature that sesame is cleistogamous (Bedigian, 2010). Thus, pollen vectors such as wind and insects can only bring an additional amount of pollen to the amount received by each flower after cleistogamy.

Bees are an important factor in the production of sesame. However, the variability of the bee fauna influences the quantitative yields of this crop; this justifies the significant differences obtained in terms of the mean number of pods per plant and the mean number of seed sets per pod between both locations. The greater the number and relative abundance of pollinating bee species, the greater the production; and vice versa. In all, long-term global trends in sesame yield and production reveal increasing pollinator dependency (Aizen *et al.*, 2008).

Conclusion

This study in Maroua showed that 21 insect species were recorded at the Palar study site and 12 insect species were listed on sesame flowers in Djarengol-Kodek. The order Hymenoptera was the best represented with a relative abundance of over 92 %. Within this order, the Apidae family was in the majority with *A. mellifera* and several wild bee species such as *X. inconstans*, *X. pubescens*, *C. torrida*, and *C. rufipes* as the main pollinating insects of sesame in the two study sites. The plurality and preeminence of bee species in the flower visiting entomofauna of sesame makes it an essentially mellitophilous plant species, that is to say, which is more attractive to bees. These bees were fond of nectar on the flowers of the host plant studied. During their foraging activity, they favored the pollination of sesame flowers leading to a substantial increase in pod and seed yields. The comparison of the species diversity between the two sites showed that Palar is richer than Djarengol-Kodek given the relative stability of the first site compared to the second which is highly anthropized. This fact also has an impact on the yield of pods and seeds in treatments maintained in open pollination between the two localities with a higher production rate in Palar than in Djarengol-Kodek. The protection of the nesting sites of bees considered as the main pollinators of sesame in Maroua is essential not only for their own survival but also to avoid pollination shortages for the increased production of this crop.

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