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Original Article

Importance of flies for *Mangifera indica* cv. Kent (Anacardiaceae) pollination and fruit set in the Sudano-Sahelian area of Cameroon

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Abstract

Field experiments were conducted to find out the floral activity of insects on *Mangifera indica* cv. Kent (Anacardiaceae) for assessing the impact on pollination and fruit set in 2018/2019 and 2019/2020 seasons. Two treatments were made with open-pollinated flowers (treatment A) and secondly bagged panicles (treatment B). The diversity of the entomofauna and certain foraging parameters were recorded in treatment A and a comparison of fruit set was made for both treatments. Twenty-six insect species were recorded overall. Bees were sporadic with a relative abundance of only < 9%. The order Diptera with a relative abundance of 89.35% was the most species-rich. *Chrysomya putoria* (Calliphoridae) and an undetermined species belonging to the genus *Sarcophaga* (Sarcophagidae) were constant species. These flies were active daily during study with a peak of activity at the 7:00-10:00 a.m. recorded time interval. Flower visits by flies were noted as 89% for nectar harvesting and 11% for pollen collection. During their foraging activity, flies induced the pollination of hermaphroditic flowers which resulting in an improvement in mango fruit yields. The rate of mature fruit per panicle was 0% in treatment B during both years, with 1.07% in 2018/2019 and 1.85% in 2019/2020 in treatment A. Flies are here identified as essential flower-visiting insects and pollinators of *M. indica* which guaranteed fruiting of this crop in Maroua (Cameroon).

Keywords: Mango tree, Diptera, Yield, Self-incompatibility, Cross pollination

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Introduction

Pollination services are known to provide substantial benefits to human populations and agriculture in particular (Breeze et al., 2011). Honey bees (*Apis mellifera*) are often assumed to provide the majority of pollination services to agriculture (Klein et al., 2007), but recent studies cast doubt on this long held-belief (Breeze et al., 2011). It has been demonstrated that other insect groups constitute important pollinators

(Larson et al., 2001). Wild pollinators are very diverse and exhibit various traits (Fontaine et al., 2006). Flies are known to be the prominent flower visitors and pollinators of several crops (Rader et al., 2009). For instance, in the UK, two hoverfly species *Eupeodes latifasciatus* and *Episyrphus balteatus* (Diptera: Syrphidae) increased strawberry yields by over 70% and doubled the proportion of marketable fruit (Hodgkiss et al., 2018).

Despite the growing appreciation of flies as pollinators, there is a lack of community-wide studies of flower visitation and hence, their contribution in pollinating services in an agronomic context remains largely unexplored (Larson et al., 2001). In sub-Saharan Africa, the relative contribution of flies in the study of plant-pollinator networks, in particular, remains in its infancy and the lack of studies impedes their management in an agro-ecological context.

The mango tree *Mangifera indica* L. is a cultivated plant species native to South Asia, particularly in India and Burma (Singh et al., 2005). It was introduced to Africa in the 16th century by Arabs and is widely cultivated nowadays in tropical countries for its juicy fruit. The cultivar Kent with green-red epicarp originates from Peru and is currently widespread in the world. Along with Palmer, it constitutes the most widely cultivated introduced cultivars in the Far North region of Cameroon (Bidima, 2016).

Among tropical fruits, the mango is one of those with the greatest economic potential (Calatrava et al., 2013). The increased demand for this fruit in world markets has led to an increase in production in African countries that were not originally mango producers (Ngamo et al., 2010). India ranks as the highest mango-producing country in the world with 13,649,400 tonnes followed by China (3,976,716) and Indonesia (2,013,123) (Galan, 2004). Mexico is the largest producer in America (1,855,359) and Nigeria with 734,000 tonnes is the leading African mango producer (Galan, 2004). Commercially, the mango is ranked second in the international tropical fruit trade, both in quantity and value (Calatrava et al., 2013). In Cameroon, mango is a seasonal fruit (Bidima, 2016) which constitutes an important source of financial income that improves the living conditions of producers (Eyebe et al., 2014).

Mangifera indica has an andromonoecious floral system (Singh, 1960). The flowers of this plant species are grouped in panicles which bear both perfect, or hermaphroditic, flowers having both pistil and staminate structures and purely male, or staminate, flowers (Singh, 1960). Crop productivity is dependent on both natural and artificial factors (Deuri et al., 2018). Pollination is a vital factor for fruit production in *M. indica*, as it is in so many other fruit crops that rely upon pollination for quantitative and qualitative fruit production (Klein et al., 2007). Yet, very little is known about pollinators and their effects on the yield of *M. indica* in Africa and particularly in Cameroon.

This research work aims to highlight the importance of insect floral visits in the production of mango fruit, given its importance to the Far North region of Cameroon, in economic terms. It also seeks to highlight the importance and reliance of insect pollinators in general in the Far North region in particular. The specific objectives were to 1) compile an inventory of the floral entomofauna associated with the mango tree; 2) study the parameters of the main flower-visiting species we listed; 3) estimate the impact of abundant insect species in fruit production of the mango tree.

Material and Methods

Study site

Field experiments took place in Makabaye, a neighbourhood in Maroua, Far North region of Cameroon (10°34.560'N; 14°17.426'E; 444 m a.s.l.). Figure 1 shows the location of the field site. Experiments were conducted during the blooming period of *M. indica*, for two consecutive seasons from October 2018 to February 2019 and from October 2019 until January 2020 respectively. These experiments were carried out inside private mango farms, each of about 2500 m^2.

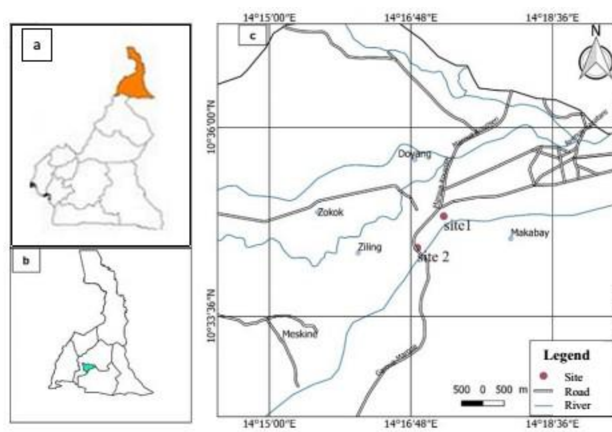

Figure-1. Location of the study site experimental design and data collection protocol

Three bagged and un-bagged panicles per plant were randomly set up on ten mango trees and split into two treatments for analysis: treatment A with flowers exposed for pollination as normal and treatment B with bagged panicles excluding flower activity of pollinators using 50 x 30 cm. gauze bags.

Observations of insects visiting mango flowers were made on the male and hermaphroditic flowers from treatment A twice a week between 06:00 a.m. and 06:00 p.m. (local time). The number of insect morphospecies visiting these flowers were registered each observation day at three specific time periods: 7:00 – 10:00 a.m., 11:00 a.m. – 2:00 p.m., and 3:00-6:00 p.m. A transect walk at each selected mango tree was carried out during each time interval, with three observation passes carried out of each flagged panicle within treatment A. During these passes, the numbers of visiting insects were counted, with panicles observed for 6 minutes each time interval. Since some insect visits could have been observed more than once across different panicles, counts were expressed as the number of visits. At least two voucher specimens per anthophilous morphospecies according to their relative abundance were collected using an entomological hand net. Collected specimens were preserved in 90% ethanol. Subsequently, the insects were sorted into a family, pinned, dried, and kept in entomological boxes which were sent for taxonomic identification.

Insect identification

Voucher specimens of hoverflies were deposited at the Department of Invertebrates of the Royal Museum for Central Africa (Tervuren, Belgium) for identification. This was done by KJ while blowflies, snout flies, and flesh flies were identified at the Department of Environmental Sciences and Natural Resources, University of Alicante (Spain) by ATC using morphology and various Neotropical identification keys (Rognes and Paterson, 2005; Lutz et al., 2018). All the identified specimens were sent back to us after identification and are now stored at the Laboratory of Entomology (Department of Biological Sciences, Faculty of Science, University of Maroua, Cameroon) where an insect collection is being curated. Other insect species were compared with the reference collection available in the laboratory of entomology of the Institute of Agricultural Research for the Development (IRAD) of Yaoundé in Cameroon.

Foraging parameters of flower-visiting insects

Several activity parameters of flower-visiting insect species were studied, including; species richness or the number of insect species recorded foraging on the flowers, compositional diversity (using the relative or centesimal abundance of different taxa associated with mango tree flowers), the daily rhythm of activity according to the observation time intervals, frequency of occurrence or frequency of appearance of each insect visitor, duration of individual visits on male and hermaphroditic flowers (using a stopwatch) and foraging speed or number of flowers visited per minute for the most abundant species. Moreover, the visit preference of more abundant insect species was recorded by specifying the floral product harvested (i.e., nectar or pollen) by the insect on the flower visited. Nectar harvesting was coded Ne and Po was used for pollen collection. Nectar harvesters were observed at the bottom of both type of flowers orienting their mouthparts to the level of the nectary while pollen collectors directly scratched the anthers with their mouthparts. The foraging behaviour of main foragers was also highlighted.

Statistical analysis

Data analysis were subjected to descriptive statistics using SPSS 20.0 software. The Student's *t-test* was used for the comparison of means between two values and the X^2 test was applied for the comparison between two proportions.

The relative abundance (F) was calculated using the following formula: F (%) = [(ni/N) x 100] where F (%) represents the relative abundance of flower visits of species i; ni the number of visits by individuals of the species and N the total number of visits by individuals of all species combined.

The frequency of occurrence (C) is the ratio between the number of surveys containing the species considered (Pi) and the total number of surveys (P): C (%) = [(Pi/P) x 100]. The C-values obtained enabled to categorize of flower-visiting insects of *M. indica* according to Bigot and Bodot (1973): very accidental species or sporadic species ($C < 10$ %), accidental species ($10\ \% \leq C \leq 24$ %); accessory species ($25\ \% \leq C \leq 49$ %), and constant species ($C \geq 50$ %).

For evaluating the influence of flower-visiting insect activity on the fruit set rate of *M. indica*, comparisons were made between tagged clusters from each treatment based on the estimates of the fruit set rate or the ratio actual fruit formed/number of bisexual flowers and the mean rate of mature fruits or the mean of ratio number of mature fruits/number of bisexual flowers per panicle.

Results

Compositional diversity of the mango tree entomofauna

Table 1 shows the different taxa of the floral entomofauna associated with *M. indica* as well as their relative abundance. The arrangement of these taxa made it possible to assess the rank each of them occupies at different levels.

The insect species identified on the flowers of *M. indica* are grouped into 4 orders: Diptera (true flies) (5 families and 12 species), Hymenoptera (bees, wasps, ants) (4 families and 11 species), Coleoptera (beetles) (2 families and 2 species), and Lepidoptera (butterflies and moths) represented by a monospecific family.

Table-1. Species richness and relative abundance of the flower-visiting entomofauna associated with *Mangifera indica* in Makabaye in 2018/2019 and 2019/2020

Different taxa			2018/2019		2019/2020		Total	
Orders	**Families**	**Species,**	**n_1**	***F* (%)**	**n_2**	***F* (%)**	**n_1+n_2**	**%**
Diptera	Calliphoridae	*Chrysomya putoria*	1327	49.75	1477	58.91	2804	54.19
		Chrysomya albiceps	103	3.86	83	3.31	186	3.59
		Chrysomya chloropyga	64	2.40	57	2.14	121	2.34
		Chrysomya marginalis	24	0.90	-	-	24	0.46
	Total Calliphoridae		1518	56.91	1617	64.50	3135	60.59
	Sarcophagidae	*Sarcophaga* sp. 1	556	20.84	454	18.11	1010	19.52
		Sarcophaga sp. 2	122	4.57	36	1.43	158	3.05
	Total Sarcophagidae		678	25.42	490	19.54	1168	22.57
	Rhiniidae	*Rhyncomya pruinosa*	74	2.77	82	3.27	156	3.01
		Rhyncomya soyauxi-forcipata	13	0.48	6	0.24	19	0.36
	Total Rhiniidae		87	3.26	88	3.51	175	3.38
	Syrphidae	*Toxomerus floralis*	26	0.97	31	1.23	57	1.10
		Mesembrius caffer	12	0.45	7	0.30	19	0.36
		Paragus borbonicus	8	0.30	-	-	8	0.15
	Total Syrphidae		46	1.72	38	1.51	84	1.62
	Muscidae	*Musca domestica*	38	1.42	23	0.91	61	1.18
Total Diptera			**2367**	**88.75**	**2256**	**89.98**	**4623**	**89.35**
Hymenoptera	Apidae	*Apis mellifera*	57	2.14	13	0.52	70	1.35
		Xylocopa olivacea	31	1.16	27	1.07	58	1.12
		Xylocopa inconstans	23	0.86	34	1.35	57	1.10
		Xylocopa torrida	11	0.41	3	0.12	14	0.27
		Dactylurina staudingeri	7	0.26	-	-	7	0.13
	Total Apidae		129	4.84	77	3.07	206	3.98
	Formicidae	*Camponotus brutus*	33	1.23	61	2.43	94	1.82
		Pheidole megacephala	17	0.64	21	0.84	38	0.73
		Myrmicaria sp.	6	0.22	-	-	6	0.12
	Total Formicidae		56	2.10	82	3.27	138	2.66
	Vespidae	*Belonogaster juncea*	28	1.05	11	0.44	39	0.75
		Polistes canadensis	21	0.79	33	1.31	54	1.04
	Total Vespidae		49	1.83	44	1.75	93	1.80
	Megachilidae	*Anthidium* sp.	3	0.11	-	-	3	0.06
Total Hymenoptera			**237**	**8.88**	**203**	**8.09**	**440**	**8.50**
Coleoptera	Coccinellidae	*Coccinella septempunctata*	34	1.27	19	0.76	53	1.02
	Scarabaeidae	*Pelidnoda* sp.	17	0.64	23	0.91	40	0.77
Total Coleoptera			**51**	**1.91**	**42**	**1.67**	**93**	**1.79**
Lepidoptera	Acraeidae	*Acraea acerata*	12	0.45	6	0.24	18	0.35
4 Orders	**12 Families**	**26 Species**	**2667**	**100**	**2507**	**100**	**5174**	**100**

n_1 = visits by individuals in 2018/2019; n_2 = visits by individuals in 2019/2020; *F* (%) = Relative abundance.

Among these orders, Diptera was predominant with a relative abundance of 88.75% in 2018/2019 and 89.98% in 2019/2020. The other three orders accounted for 11.25% and are thus classified: Hymenoptera (8.88% in 2018/2019 and 8.09% in 2019/2020), Coleoptera (1.91% in 2018/2019 and 1.67% in 2019/2020), and Lepidoptera (0.45% in 2018/2019 and 0.24% in 2019/2020). In both seasons, the differences are not significant between the relative abundance values within the same order ($p > 0.05$); this is an illustration of the stability of the floral entomofauna associated with *M. indica* at the order level from year to year.

The different species of insects listed on the flowers of the mango tree are grouped into 12 families. In decreasing order of their relative abundance are Calliphoridae (49.75% in 2018/2019 and 58.91% in 2019/2020), Sarcophagidae (25.42% in 2018/2019 and 19.54% in 2019/2020), Apidae (4.84% in 2018/2019 and 3.07% in 2019/2020), Rhiniidae (2.77% in 2018/2019 and 3.27 in 2019/2020), Formicidae (2.10% in 2018/2019 and 3.27% in 2019/2020), Vespidae (1.83% in 2018/2019 and 1.75% in 2019/2020), Syrphidae (1.72% in 2018/2019 and 1.51% in 2019/2020), Muscidae (1.42% in 2018/2019 and 0.91% in 2019/2020), Coccinellidae (1.27% in 2018/2019 and 0.76% in 2019/2020), Scarabeidae (0.64% in 2018/2019 and 0.91% in 2019/2020), Acraeidae (0.45% in 2018/2019 and 0.24% in 2019/2020), and Megachilidae (0.11% in 2018/2019 and 0% in 2019/2020).

The flower visiting entomofauna of *M. indica* was diverse with 26 species observed during the two cumulative experimental seasons with in particular 2667 visits of 26 species in 2018/2019 and 2507 visits of 21 species in 2019/2020. According to their increasing relative abundance, the various listed insect species are classified as follows: *Anthidium* sp. (0.11% in 2018/2019 and 0% in 2019/2020), *Myrmicaria* sp. (0.22% in 2018/2019, 0% in 2019/2020), *Dactylurina staudingeri* (0.26% in 2018/2019, 0% in 2019/2020), *Paragus borbonicus* (0.30% in 2018/2019, 0% in 2019/2020), *Xylocopa torrida* (0.41% in 2018/2019, 0.12% in 2019/2020), *Acraea acerata* (0.45% in 2018/2019, 0.24% in 2019/2020), *Rhyncomya soyauxi-forcipata* (0.48% in 2018/2019, 0.24% in 2019/2020), *Mesembrius caffer* (0.45% in 2018/2019, 0.30% in 2019/2020), *Chrysomya marginalis* (0.90% in 2018/2019, 0% in 2019/2020), *Pheidole megacephala* (0.64% in 2018/2019, 0.84% in 2019/2020), *Belonogaster juncea* (1.05% in 2018/2019, 0.44% in 2019/2020), *Pelidnota* sp. (0.64% in 2018/2019, 0.91% in 2019/2020), *Coccinella septempunctata* (1.27% in 2018/2019, 0.76% in 2019/2020), *Polistes canadensis* (0.79% in 2018/2019, 1.31% in 2019/2020), *Xylocopa inconstans* (0.86% in 2018/2019, 1.35% in 2019/2020), *Toxomerus floralis* (0.97% in 2018/2019, 1.23% in 2019/2020), *Xylocopa olivacea* (1.16% in 2018/2019, 1.07% in 2019/2020), *Musca domestica* (1.42% in 2018/2019, 0.91% in 2019/2020), *Apis mellifera* (2.14% in 2018/2019, 0.52% in 2019/2020), *Camponotus brutus* (1.23% in 2018/2019, 2.43% in 2019/2020), *Chrysomya chloropyga* (2.40% in 2018/2019, 2.14% in 2019/2020), *Rhyncomya pruinosa* (2.77% in 2018/2019, 3.27% in 2019/2020), *Sarcophaga* sp. 2 (4.57% in 2018/2019, 1.43% in 2019/2020), *Chrysomya albiceps* (3.86% in 2018/2019, 3.31% in 2019/2020), *Sarcophaga* sp. 1 (20.84% in 2018/2019, 18.11% in 2019/2020), and *Chrysomya putoria* (49.75% in 2018/2019, 58.91% in 2019/2020). Overall, *M. indica* is an essentially attractive plant species to flies which, due to their relative abundance, are thought to play a major role in the pollination of mango flowers.

Frequency of occurrence

Table 2 gives the frequency of occurrence *C* of the flower-visiting insect species recorded foraging on *M. indica* flowers.

Following Bigot and Bodot (1973) insect species were classified into four groups: 1) constant species: *C. putoria* and *Sarcophaga* sp. 1; 2) accessory species: *C. albiceps*, *C. chloropyga*, *C. brutus*, *R. pruinosa*, *M. domestica*, *X. olivacea*, *T. floralis*, *M. caffer*, *C. septempunctata*, and *Sarcophaga* sp. 2; 3) accidental species: *A. mellifera*, *Pelidnota* sp., *C. marginalis*, *A. acerata*, *R. soyauxi-forcipata*, *P. megacephala*, *P. borbonicus*, and *X. torrida*; 4) sporadic species: *Myrmicaria* sp., *B. juncea*, *X. inconstans*, *P. canadensis*, *Anthidium* sp. In all, the category of a given insect species did not change over the two years of study.

Daily rhythm of insect activity

Figure 2 shows the distribution of insect visits on the flowers of *M. indica* according to the observation time frames. In both years, flower-visiting insects of *M. indica* were observed throughout the day. Foraging activity was high in the morning (7:00-10:00 a.m.), decreased at midday (11:00 a.m.- 2:00 p.m.) and increased again in the evening (3:00-6:00 p.m.). The daily rhythm of insect activity was highly correlated with the group of constant species, namely *C. putoria* (Calliphoridae) and *Sarcophaga* sp. (Sarcophagidae) in 2018/2019 ($r = 0.99$; $df = 2$; $p < 0.05$) and in 2019/2020 ($r = 0.99$; $df = 2$; $p < 0.05$).

Table-2. Frequency of occurrence C_1 and C_2 for each of the flower visiting insect of *Mangifera indica* and the different categories according to Bigot and Bodot (1973).

	2018/2019		2019/2020		
Species	P_1	C_1 (%)	P_2	C_2 (%)	**Insect categories**
Chrysomya putoria	28	87.50	20	100.00	Constant species ($C \geq 50\%$)
Sarcophaga sp. 1	21	65.63	18	90.00	
Chrysomya albiceps	15	46.88	9	45.00	Accessory species ($25\% \leq C \leq 49$)
Sarcophaga sp. 2	15	46.88	9	45.00	
Chrysomya chloropyga	13	40.63	9	45.00	
Camponotus brutus	11	34.37	9	45.00	
Musca domestica	11	34.37	9	45.00	
Xylocopa olivacea	9	28.13	8	40.00	
Toxomerus floralis	9	28.13	7	35.00	
Rhyncomya pruinosa	9	28.13	8	40.00	
Mesembrius caffer	9	28.13	7	35.00	
Coccinella septempunctata	9	28.13	6	30.00	
Apis mellifera	3	18.75	2	10.00	Accidental species ($10\% \leq C \leq 24\%$)
Pelidnota sp.	3	18.75	4	20.00	
Chrysomya marginalis	3	18.75	-	-	
Acraea acerata	3	15.63	2	10.00	
Rhyncomya soyauxi-forcipata	5	15.63	3	15.00	
Pheidole megacephala	5	15.63	2	10.00	
Paragus borbonicus	5	15.63	-	-	
Xylocopa torrida	3	12.50	3	15.00	
Dactylurina staudingeri	4	12.50	-	-	
Myrmicaria sp.	3	9.38	-	-	Sporadic species ($C < 10$ %)
Belenogaster juncea	2	6.25	1	5.00	
Xylocopa inconstans	2	6.25	1	5.00	
Polistes canadensis	2	6.25	1	.00	
Anthidium sp.	2	6.25	-	-	

Legend: $C = [(P_i/P) \times 100]$ = Frequency of occurrence P_i = Number of samples containing a given insect species; P = 30 in 2018/2019 and 20 in 2019/2020 = Total number of samples

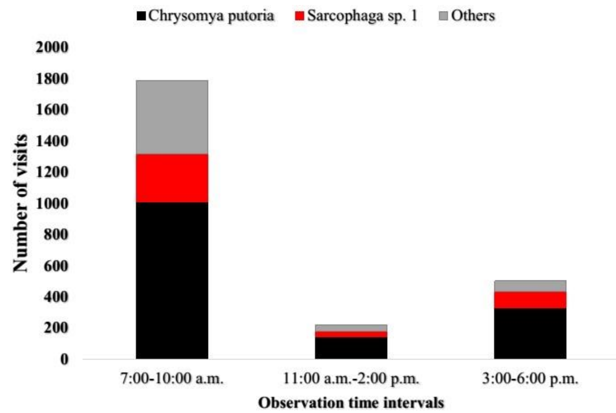

Figure-2. Cumulative values of the variation of insect visits as a function of daily time intervals

Floral products harvested

Figure 3 is an illustration of the repartition of floral products (nectar and pollen) harvested by constant species. Of over 200 observations of *C. putoria* visits, 88% (in 2018/2019) and 92% (in 2019/2020) were for nectar harvesting and only 12% and 8% for pollen collection during both years respectively. The difference between these proportions was significant in 2018/2019 ($X^2 = 186.04$; $df = 1$; $p < 0.05$) and in 2019/2020 ($X^2 = 190.04$; $df = 1$; $p < 0.05$). Of over 200 observations of *Sarcophaga* sp. 1 visits, 92% (in 20182019) and 97% (in 2019/2020) were found to be nectar foraging visits, while only 8% and 3% were for pollen harvesting. The difference between both proportions was significant in 2018/2019 ($X^2 = 190.13$; $df = 1$; $p < 0.05$) and in 2019/2020 ($X^2 = 200.05$; $df = 1$; $p < 0.05$). Based upon our evidence *C. putoria* and *Sarcophaga* sp. 1 can be said to be highly nectarophagous on the flowers of mango trees in Maroua.

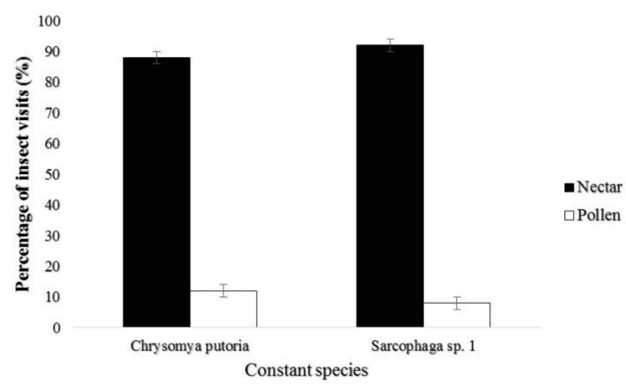

Figure-3. Cumulative value on the variation in floral products harvested

Duration of visit

As direct pollen collection was scarce, the duration of visits was measured only for nectar harvesting (table 3).

Table-3. **Mean duration of an insect visit as a function of floral sex and years**

	Mean duration of the visit (sec)			
Insect species	***n***	**Floral sex**	**2018/2019**	**2019/2020**
Chrysomya putoria	30	Male	7.38 ± 2.03a	6.79 ± 1.73a
	30	Bisexual	11.97 ± 4.17b	13.01± 3.58b
Sarcophaga sp. 1	30	Male	5.67 ± 3.22a	5.81 ± 2.42a
	30	Bisexual	7.89 ± 3.21b	8.21± 2.92b

Mean values in the same column (mean duration of a given insect species as a function of the floral sex) with different letters vary significantly ($P < 0.05$)

For *C. putoria*, the average duration of nectar collection on a male flower was 7.38 ± 2.03 sec in 2018/2019 and 6.79 ± 1.73 sec in 2019/2020; the difference between these two means was not significant ($t = 1.28$; $df = 58$; $p > 0.05$). On hermaphrodite flowers, the corresponding values were: 11.97 ± 4.17 sec and 13.01 ± 3.58 sec; the difference between these values was also not significant ($t = 1.79$; $df = 58$; $p > 0.05$). The difference between the average duration of visits was however significant between male flowers and hermaphrodite flowers in 2018 ($t = 8.57$; $df = 58$; $p < 0.05$) and in 2019 ($t = 11.08$; $df = 58$; $p < 0.05$).

For *Sarcophaga* sp. 1, the average duration of a nectar collection visit on a male flower was 5.67 ± 3.22 sec in 2018/2019 and 5.81 ± 2.42 sec in 2019/2020; the difference between these two means was not significant ($t = 0.71$; $df = 58$; $p > 0.05$). On a hermaphrodite flower, the corresponding values were: 7.89 ± 3.21 sec and 8.21 ± 2.92 sec; the difference between these values was also not significant ($t = 1.67$; $df = 58$; $p > 0.05$). The difference between the average visits and the average duration of visits on a male flower and a hermaphrodite flower was significant in 2018 ($t = 5.13$; $df = 58$; $p < 0.05$) and in 2019 ($t = 7.28$; $df = 58$; $p < 0.05$).

Overall, the mean duration of a floral visit varied from year to year, and for the same year from insect to insect, depending on whether the type of flower visited was male or hermaphrodite.

Foraging speed

The values of the mean foraging speed, as well as the mean duration of a visit, were exclusively recorded for *C. putoria* and *Sarcophaga* sp. 1 given their high relative abundance compared to the other insects listed. Table 4 shows the average values of foraging speed in 2018/2019 as well as in 2019/2020. This was 4.18 ± 1.27 flowers/minute (n = 30) in *C. putoria* and 2.63 ± 1.07 flowers/minute (n = 20) in Sarcophaga sp. 1 in 2018/2019. The difference between these two means was significant ($t = 4.67$; $df = 49$; $p < 0.05$). The corresponding values in 2019/2020 were respectively 4.31 ± 1.43 flowers/minute (n = 30) and 2.57 ± 1.38 flowers/minute (n = 20) for $t = 5.14$; $df = 49$; $p < 0.05$. The significant differences obtained here assume that *C. putoria* visited more flowers per unit time than *Sarcophaga* sp. 1. Furthermore, the difference in the average value of the foraging speed for each insect species was not significant over the two years of the experiment.

Table-4. **Mean values of the foraging speed as a function of years and constant insect species**

	Mean foraging speed (flower/min)		
Insects	***n***	**2018/2019**	**2019/2020**
Chrysomya putoria	30	4.18 ± 1.27a	4.31 ± 1.43a
Sarcophaga sp. 1	20	2.63 ± 1.07b	2.57 ± 1.38b

Mean values in the same column with different letters vary significantly ($P < 0.05$)

Foraging behavior of anthophilous insects of *Mangifera indica*

During their foraging activity on the flowers of *M. indica*, *C. putoria* and *Sarcophaga* sp. 1 showed almost similar foraging behavior. Indeed, taking into account the small size of the flowers of the host plant, these flies were permanently in contact with the reproductive organs of the male and hermaphrodite flowers. Although more attached to collecting nectar than pollen, in either case, contact with the anthers on both types of flowers and the stigma on the hermaphroditic flowers was found to be constant. During their floral activity, individuals visited the flowers of one panicle one after the other. In addition, insect transitions were also noted from the flower of a given panicle to a neighboring one. It is therefore very likely that these insects, during their nectar foraging trips, promoted pollination of mango flowers by transferring pollen grains on the stigma as they moved from panicle to panicle.

Impact of insect activities on fruit production of the mango tree

The results reported in table 5 below indicate the influence of insect flower visits on the evolution of fruit yields of *M. indica* in Makabaye. From this table, the following main results emerge: all hermaphrodite flowers did not form fruit reaching maturity; the average fruiting rate varied from 37.53% in treatment B to 53.24% in treatment A in 2018/2019 and from 39.10% to 67.25% in 2019/2020. The difference in these values is significant between the two treatments in 2018/2019 (X^2 = 7.54; *df* = 1; $p < 0.05$) and in 2019/2020 (X^2 = 16.83; *df* = 1; $p < 0.05$); no fruit from hermaphrodite flowers within treatment B reached physiological maturity in either 2018/2019 and 2019/2020; only open pollination (treatment A) allowed the production of edible fruits, indicating the important role played by *C. putoria* and *Sarcophaga* sp. 1 the most abundant and frequent species in the pollination and production of the mango tree in Maroua. Several young mangoes that formed within treatment B were dropped one month after the fruit started to set but 3 to 9 fruits reached physiological maturity per panicle in treatment A yearly, i.e. an average rate of mature fruits of 1.07% in 2018/2019 and 1.85 % in 2019/2020. Overall, the mango tree depends for its fruit production on floral visits from anthophilous insects, among which the Diptera play a major role.

Table-5. **Fruit set on *Mangifera indica* cv. Kent from treatments A and B**

Seasons	Treatments	n	⚥	F	F1 (%)	Fm	M (%)
2018/2019	A	30	432 ± 107	230 ± 11	53.24	4.63 ± 1.96	1.07 ± 0.53
	B	30	397 ± 94	149 ± 75	37.53	0.00	0.00
2019/2020	A	30	406 ± 89	273 ± 89	67.25	7.51 ± 1.67	1.85 ± 0.89
	B	30	289 ± 78	113 ± 74	39.10	0.00	0.00

Legend: n = Number of panicles; ⚥ = hermaphrodite flowers; F = Number of young fruits formed; F1 = fruiting rate; Fm = mean number of mature fruits/panicle; M (%) = mean ratio of mature fruit per panicle.

Discussion

A large number of insect species belonging to the orders Diptera, Hymenoptera, Coleoptera and Lepidoptera have already been reported on mango tree flowers in India (Spencer and Kennard, 1955), Australia (Anderson et al., 1982), Costa Rica (Free and Williams, 1976), Florida (Free and Williams, 1976), Jamaica (Galan et al., 1997), and the Canary Islands (Jiron and Hedström, 1985). The above-mentioned insect orders are the same as we had listed active on *M. indica* flowers in Maroua.

The results also reveal the upsurge of flies as the main flower-visiting insects of the mango tree in our experimental site. Among these flies, the main active species belong to the families Calliphoridae (*Chrysomya putoria*) and Sarcophagidae (*Sarcophaga* sp. 1) although we recorded 26 insect species visiting *M. indica* flowers. Our results are in agreement with those of several other authors who indicated flies as the main pollinators of mango trees throughout the world. In Israel, Dag and Gazit (2000) revealed two Calliphoridae (*Chrysomya albiceps* and *Lucilia sericata*) and the house fly *Musca domestica* as the main pollinating insects of *M. indica*; in Isräel, Costa Rica, India, the Philippines, Brazil, Colombia, several species of Blowflies have been noted as major visitors in the mango tree flower entomofauna (Corredor and García, 2011; Kumar et al., 2012).

Another important aspect that emerges from this study is the virtual absence of the honey bee in the floral entomofauna of *M. indica* despite the presence in the experimental site of a colony of this species. This work is therefore a perfect illustration that *A. mellifera* can discriminate certain plant species in their direct environment. This would be linked to the notion of preference that characterizes this bee species. Indeed, it is known in the literature that *M. indica* produces pollen and nectar in very small quantities (Singh, 1960). The honey bee, being a thrifty species, would prefer to forage on other plant species so that the work-energy associated with movement is not greater than that devoted to foraging (Ségeren et al., 1996). Nevertheless, some other work has shown that social bees are the main pollinators of the mango tree. This is particularly the case with *Apis mellifera* in South Africa (Carvalheiro et al., 2010) and in Japan (Sasaki et al., 1998), *Apis dorsata*, *A. florea*, and *A. cerena* in India (Siqueira et al., 2008) and in Taiwan (Sung et al., 2006). From the above, the floral entomofauna can vary from one plant species to another and for the same plant species, from one agro-ecological region to another (Klein et al., 2007). Moreover, a particular pollinating insect may be predominant on a particular plant in a given agro-ecological zone; while in another agro-ecological zone, this same insect may be absent or play a less important role in the pollination of the same plant species (Mesler et al., 1980).

Regarding fruit yield of *M. indica*, our results revealed the low involvement of self-pollination in mango production. Indeed, the hermaphrodite flowers are self-pollinated but the incompatibility of some pollen and stigmas cause failure in mango fruit set (Huda et al., 2015). This is why in caged treatments, almost all of the fruit aborts and drops, and even though these fruits are formed, none of them reach maturity (Singh et al., 2005). In some Indian mango tree cultivars such as Dashehari, Langra, Chausa and Bombay Green, fruit set after self-pollination gives negligible results in the range of 0.0-1.68% (Sharma and Singh, 1970). The rates of formation of mature fruits from self-pollination have already been obtained for cultivars 'Amrapali' (0.37%) and ika Mallika (0%) (Dutta et al., 2013). According to the observations of Gehrke-Vélez et al. (2012), self-pollination in the mango tree is at the origin of the morphological deterioration of the fruits and therefore of the substantial reduction in production. This is because self-pollinated stigmas result in the formation of embryos, but self-incompatibility follows in the early stages of embryonic development. This has resulted in abortion of immature fruits and, in advanced cases, abnormal development of fruits called "nubbins" (Gehrke-Vélez et al., 2012). Young fruit drop of the self-pollinated variety 'Amrapali' has been reported to be significant during the first 18 days of development, and about 99% of self-pollinated hermaphrodite flowers drop during this period (Dutta et al., 2013).

On the other hand, treatment A in which the flowers were exposed to the pollination activity of the associated floral entomofauna mainly flies formed fruits which result in physiological and therefore physical maturity. The important role of insect pollinators in mango production has been recognized in many mango-producing countries in the world (Huda et al., 2015). Usman et al. (2001) found that cross pollination had contributed largely to the increase of mango fruit set, hence external agents are necessary to transfer the pollen of mango flowers and assume fruit set and maturity. In the case of this study, two true fly species namely *C. putoria* and *Sarcophaga* sp. 1 were more abundant and active on the flowers of the host plant *M. indica*. However, it is also to be noted a large percentage of fall of young fruits during the setting in treatment A. This drop of young fruits is a specific characteristic of reproduction and development in fruit plants which imposes abscission on a large number of fruits (Mc Collum et al., 1987). According to Brown and Mc Neil (2006), the development of the last fruits formed on a tree is limited, not only by the lack of resources, but also by evolutionary genetic strategies; including a selective abortion strategy at the expense of higher fruits.

Conclusion

This work deals with the importance of flies on pollination and fruit set in *M. indica* plantation in Maroua, Cameroon. The lack of insect pollinators is detrimental to fruit set in the variety Kent studied. Indeed, the fertilization resulting from self-pollination induced the drop of the young fruits because of self-incompatibility. However, the effective fruit production of *M. indica* depends on the combination action of flower-visiting insects, *C. putoria* and *Sarcophaga* sp. 1 being the main pollen vectors.

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Azo'o Ela M: Conceived the idea, reviewed literature and edited manuscript
Bouba AB: Collected and analyzed data and wrote the first draft of the manuscript
Djenatou P: Substantially contributed to field works and data collection & analysis
Fohouo FNT: Reviewed and edited the manuscript and gave final approval