

## Flower visitors and impact of bee pollination on the fruit set of cashew (*Anacardium occidentale* L.) in the north-eastern of Côte d'Ivoire

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### Abstract

Cashew is one of major crops of which depend several farmers in Côte d'Ivoire. Despite, the economic and social importance of this crop, there is little information on cashew pollination biology in this country. This study was conducted in the Kapkin area (north-east of Côte d'Ivoire) where three cashew orchards was investigated. The objectives were (i) to determine cashew flowers visitors; (ii) to evaluate the activity period of mainly flowers visitors during the daily and their relative visitation rates; (iii) to assess the effect of pollination on cashew fruit set through three treatments (Control, spontaneous natural self-pollination and natural cross-pollination). Results revealed that percentage of pollinating visits to cashew flowers by bees was 99.3 %, a higher rate than other insect groups. The most abundant species were *Apis mellifera* (66.49 %), *Braunsapis* sp.2 (11.40 %) and *Pachynomia atrinervis* (8.56 %). Most of bees foraged with a high visit rate in the late morning and early afternoon, coinciding with the period of greatest availability of floral rewards. Large bees visited more flowers per time unit ( $8.8 \pm 0.8$  flowers/min) than medium bees ( $3.7 \pm 0.3$  flowers/min) and small bees ( $3.5 \pm 0.2$  flowers/min). *Apis mellifera* are efficient pollinators of cashew orchard. On average control treatment (55.76 %) and natural cross pollination (50.10 %) produced more fruit set than spontaneous natural self-pollination (4.78 %). Thus, cashew orchards requires cross-pollination for maximum yields.

**Keywords:** Pollination, bees, cashew, fruit set, Côte d'Ivoire

### Introduction

Among the cultivated plants, cashew nut is one of the most traded nuts in the world and it is an important source of income to small holders in the tropics of America, Asia, and Africa, where climatic conditions are favorable for its economic cultivation <sup>[1]</sup>.

Cashew tree is an evergreen perennial that is hardy and fast growing, with a symmetrical, umbrella shaped canopy. Although the tree resembles a large bush, it is a true evergreen tree and often attains heights of over 10 m. Roots grow vertically to a considerable depth and to a radius twice the canopy spread <sup>[2]</sup>. Concerning reproductive structures of cashew, the tree is andromonoecious, bearing male and hermaphrodite flowers on the same panicle. Male flowers possess one large protruding stamen and five to nine small inserted ones. Hermaphrodite flowers are similar to male flowers except that they also possess a functional pistil, consisting of a stigma, style and single ovule ovary. The stigma is usually held higher than the anther in hermaphrodite flowers <sup>[3]</sup>. The style extends above the anthers to the same height as the long anther of the male flowers. The flowers open almost any time of the day, but the peak period of opening is 9:00-11:00 hrs. About 70 % of the perfect flowers fail to set fruit, resulting in only one or two mature nuts per inflorescence. Flowering to nut maturity takes about 55 to 70 days. The flowers produces a low amount of nectar, which is attractive to bees, flies, wasps, ants and others insects <sup>[4]</sup>.

In West Africa and particularly in Côte d'Ivoire, pollination is vital ecosystem service because the economy relies on agriculture. Long-established in northern Côte d'Ivoire to combat the advance of desert, cashew became the most important cash crop in 20 regions out of 31 existing and

source of monetary income for more than 5,000,000 people, including 500,000 smallholders <sup>[5, 6]</sup>. Actually, cashew has become a second most export crop after cocoa due to its important weight in the national economy (valued at more than 700 million USD) <sup>[7]</sup>. Also, the Côte d'Ivoire has become the first worldwide producer and exporter of raw cashew nuts with 25% of the global production and 50% of the world's supply <sup>[8, 9]</sup>.

Despite, the economic and social importance of Cashew in Côte d'Ivoire, there is little information on cashew pollination biology in this country <sup>[10, 11, 12]</sup>. Yet, to understand plant reproduction and floral evolution in generalist plant species, a thorough understanding of each pollinator taxon's effectiveness, visitation rate, and variation in visitation rates over time is essential. Differences in visit duration among pollinators have been implicated in influencing pollinator effectiveness, with visit duration being positively related to both pollinator efficiency and effectiveness <sup>[13, 14]</sup>. Night flying insects and wind pollination does not seem to be important as attempts to trap wind borne pollen have been unsuccessful played no role in cashew pollination <sup>[15]</sup>. Wunnachit *et al.* <sup>[16]</sup> have shown that cashew is highly outcrossing and relies on biotic pollinators to achieve adequate pollination. Also, according to Heard *et al.* <sup>[15]</sup>; Freitas and Paxton <sup>[17]</sup>; Bhattacharya <sup>[18]</sup>, bees have been implicated as the major cashew pollinators'.

In this study we investigated some aspects of cashew pollination biology within three different cashew orchards in the North East of Côte d'Ivoire. Our study has three aims: (1) to determine cashew flowers visitors; (2) to evaluate the activity period of mainly flowers visitors during the daily and their relative visitation rates; (3) to assess the effect of pollination on cashew fruit set through three treatments

(Control, spontaneous natural self-pollination and natural cross-pollination).

We expected to provide information that will support cashew producers in successfully managing pollinating bees to improve yield. Moreover, the generation of empirical data on the effectiveness of native bees as pollinators may contribute to an improvement of on farming friendly practices within cashew orchards and their surroundings that will conserve natural populations of wild pollinators.

## Materials and methods

### Study area

This study was conducted in the Kapkin area (N 08°39'16.7"; W 003°47'04.6") in the north-east of Côte d'Ivoire, from 26 December 2018 to 10 February 2019 during flowering period.

The mean annual precipitation recorded until the 1960s in this area was 1150 mm <sup>[19]</sup> while the mean annual temperature was 27°C. Rainfall occurs during one rainy season, from March to October while the dry season is observed from November to February. The rainiest month is September and the warmest month is January. The mean annual relative air humidity is 60% <sup>[20]</sup> and can reach 90% during the rainy season. This area is an area of transitional habitats ranging from forests to savannas which include all types of savanna, forests, and riparian grasslands. The main crops are the cassava fields, yam, but the main cash crop is the cashew

We investigated three cashew orchards: orchard 1 (N 08°39'09.3"; W 003°46'44.1"), orchard 2 (N 08°36'42.8"; W 003°46'37.9") and orchard 3 (N 08°39'06.9"; W 003°47'28.8").

The three orchards were well maintained but without the use of pesticides. Orchard 1 was located 200 m from an apiary.

### Sampling method

In each orchard, three plots of 50 m x 25 m were set up. A cashew tree was selected and marked every 25 m of the experimental device, i.e. 6 trees per plot.

### 1. Inventory of bees species visiting cashew inflorescences

Entomological net method was used to sample bee species visiting cashew inflorescences. The observer walked along the perimeter of the plot and stopped every 25 m at each marked tree to capture the bees on the inflorescences using entomological net. For each sampling day in a plot, captures were made at the following times: 8:00; 10:00; 12:00; 14:00 and 16:00 hrs. Each marked tree was observed for 5 minutes, giving a total of 30 minutes of sampling per plot. During this observation period, bees that were caught above the inflorescences formed a sample. Samples were stored in vials containing 70 % alcohol.

### 2. Foraging efficiency

At each sampling hour, after the insect collect, a second tour was conducted to observe and record the number of flowers visited, the time spent on each flower by the main pollinators. During the observations, bees' species was categorized into three groups according to their size (small, medium, large).

Individuals in each group was then closely monitored continuously for up to one minute, or 60 seconds while they were actively foraging at flowers. After each minute of

observation, each observed bee was captured and put in a vial containing 70 % alcohol to be identified. For each observation sequence, total time spent on flowers (TF) and total observation time (TT) was noted. The total number of flowers visited over the entire observation period (NF) was also recorded for each sequence. The average number of flowers visited per time unit (NF/TT) and the average time spent in each visited flower or handling time (TF/NF) <sup>[21]</sup> was recorded.

### 3. Influence of temperature and humidity on the daily activity of the most abundant bee species

The climatic parameters measured during the study were temperature and humidity. On each sampling day, data were collected from a climate station in each orchard. The values were recorded at different sampling times (8:00; 10:00; 12:00; 14:00 and 16:00 hrs).

A correlation was established between these daily climate readings and the daily activity of bee species, using PAST software version 3.09.

### 4. Impact of pollination by insects on fruit set

Pollination experiments were conducted using the method of Dafni <sup>[22]</sup>. Nine inflorescences at bud stage were selected from each tree in the experimental set-up according to their accessibility and they were labelled. Three treatments were then applied to these inflorescences, i.e. three inflorescences per treatment on the same tree:

#### Treatment 1

**Control:** the three inflorescences chosen as controls on each tree were not manipulated in any way (Figure 1A).

#### Treatment 2

**Spontaneous natural self-pollination:** the three inflorescences per tree were isolated in nylon tulle to exclude any insect visits (Figure 1B).

#### Treatment 3

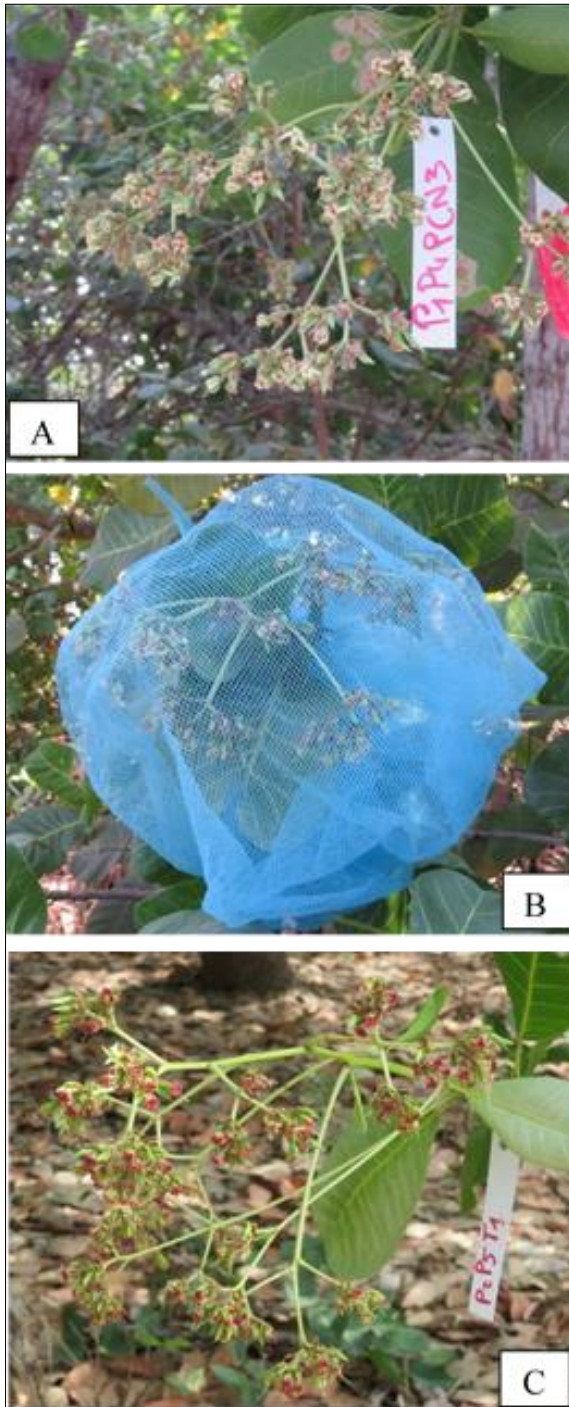
**Natural cross-pollination:** each day after their selection, the three inflorescences per tree were observed in order to remove all the stamens, leaving only the stigmas (Figure 1C).

After selection of inflorescences, to monitor fruit set, they were observed every fortnight (15 days) during the study period. During the observations, male flowers, hermaphrodite flowers, aborted fruits and intact fruits were counted. After counting, aborted fruits were removed from the inflorescences and intact fruits were marked so that the number of new fruits and aborted fruits could be determined at the next observation.

The aborted fruit rate and fruit set rate were calculated using these formula:

$$\text{Fruit set rate} = \frac{\text{total number of fruits}}{\text{number of hermaphrodite flowers}} \times 100$$

$$\text{Aborted fruit rate} = \frac{\text{number of aborted fruits}}{\text{total number of fruits}} \times 100$$



**Fig 1:** Pollination treatments on cashew inflorescences

**Statistical analysis**

The sampling efficiency was determined using the program EstimateS 8.0.0. Diversity of bees’ assemblages and its evenness are measured by Simpson’s index. The Bray-Curtis index was calculated for the measurement of the β-diversity on one hand and the determination of the similarity of species composition between cashew orchards on the other hand. Comparison of the relatives’ abundances of bees’ species within orchards and comparison between the different pollination tests was done with the non-parametric multivariate analysis of variance using Kruskal-Wallis test. The choice of this test was due to the non-normal distribution of data and the heterogeneity of variances. These indexes was run on PALEontological STatistics (PAST) version 3.09 at a significance level of 0.05.

**Results**

**Number and nature of floral visits by insect group**

The flowers attract different visitors belonging to Hymenoptera, Lepidoptera, Diptera, Hemiptera and Coleoptera. The insects that visited the cashew flower were predominantly bees, they are the highest number of visits (n=1175). During this period other insects also pay their visits, but less frequently, not regularly and often without touching the stigma. They collect nectar only and thereby do not participate in pollen transfer. Ant were recorded to reside in the flowers. Ant, Hemiptera and Coleoptera stayed on the vegetative parts or move slowly towards flower base throughout the day, without touching stigmas. Diptera and Lepidoptera were seen bending sideways for nectar collection without touching stigmas.

In the present study Ant, Wasp, Butterfly, Coleoptera and Hemiptera were rare visiting cashew flowers with respectively 8.63 %, 8.57%, 6.10 %, 0.68 %, 0.21 % while bees represented over 60 % of floral visitors (Table 1).

The percentage of pollinating visits to cashew flowers by bees was 99.3 %, relatively higher than that of other insect groups (Table 1). Groups such as wasps and flies recorded pollinating visits of 2 % and 4.8 % respectively. On the other hand, no pollinating visits were observed in the other four groups (butterfly, ant, Coleoptera and Hemiptera).

These results suggest that bees are the most regular visitors and probably the most effective pollinators of cashew flowers.

**Table1:** Number and nature of floral visits by insect group. *O:* orchard, *be:* Bee, *W:* Wasp, *F:* Fly, *Bu:* Butterfly, *C:* Coleoptera, *H:* Hemiptera, *A:* Ant

	Taxonomic group							Total
	Be	W	F	Bu	C	H	A	
O1	434	76	88	34	5	3	48	688
O2	355	43	82	37	1	0	52	570
O3	386	44	96	45	7	1	64	643
Total number of visits	1175	163	266	116	13	4	164	1901
Percentage of number visits	61.81	8.57	13.99	6.10	0.68	0.21	8.63	
Number of flowers visited	5824	540	352	114	0	4	0	
Number of pollinating visits	5785	11	17	0	0	0	0	
Percentage of pollinating visits (%)	99.3	2	4.8	0	0	0	0	
Resource collected (N, Nectar; P, Pollen)	N, P	N	N	N	-	-	-	

**Overall taxonomic structure of the observed bee species**

During this study, 2043 individuals belonging to 3 families (Apidae, Halictidae and Megachilidae), 12 genera and 20 species were collected. Apidae was the most abundant family (89.99 %; n= 3678), followed by the Halictidae (9.98 %; n= 408) and Megachilidae (0.02 %, n=1 individuals).

The most abundant species were respectively *Apis mellifera* (66.47 %), *Braunsapis* sp.2 (11.40 %) and *Pachynomia atrinervis* (8.56 %). Cashew orchard 1 had the highest number of individuals (n= 802), following by orchard 2 (n= 648) and orchard 3 (n= 593) (Table 2).

**Table 2:** Relative abundance of bees' species in three cashew orchards

Genus	Bee species	orchard1	orchard2	orchard3	Total	Relative abundance (%)
<i>Apis</i>	<i>Apis mellifera</i>	527	436	395	1358	66.47
<i>Meliponula</i>	<i>Meliponula ferruginea</i>	3	10	1	14	0.68
	<i>Meliponula bocandei</i>	8	16	0	24	1.17
	<i>Meliponula togoensis</i>	1	11	0	12	0.59
<i>Hypotrigona</i>	<i>Hypotrigona gribodoi</i>	0	1	16	17	0.83
	<i>Hypotrigona</i> sp.	3	9	45	57	2.79
<i>Ceratina</i>	<i>Ceratina</i> sp.	3	0	0	3	0.15
<i>Xylocopa</i>	<i>Xylocopa olivacea</i>	10	14	11	35	1.71
	<i>Xylocopa albiceps</i>	0	3	5	8	0.39
<i>Braunsapis</i>	<i>Braunsapis</i> sp. 1	28	31	17	76	3.72
	<i>Braunsapis</i> sp. 2	150	42	41	233	11.40
<i>Pachynomia</i>	<i>Pachynomia atrinervis</i>	65	68	42	175	8.56
	<i>Pachynomia flavicarpa</i>	1	3	14	18	0.88
<i>Stictonomia</i>	<i>Stictonomia schubotzi</i>	0	1	2	3	0.15
<i>Lasioglossum</i>	<i>Lasioglossum</i> sp. 1	0	1	0	1	0.05
	<i>Lasioglossum</i> sp. 2	0	1	3	4	0.20
	<i>Lasioglossum</i> sp. 3	0	1	1	2	0.10
<i>Pseudapis</i>	<i>Pseudapis interstinervis</i>	1	0	0	1	0.05
<i>Megachile</i>	<i>Megachile</i> sp.	1	0	0	1	0.05
	Total	802	648	593	2043	100

**Bee species diversity and composition**

The values of the sampling coverage showed that at least 70 % of the expected species were sampled in each habitat (mean = 87.1 %). The highest sampling coverage was obtained in the orchard 3 (96.7 %), followed respectively by orchard 1 (86.3 %) and orchard 2 (78.3 %) (Table 3). Orchard 2 had the highest number of species (16), followed by the orchard 1 (14 species) and the orchard 3 (Table 3). In

the orchard 1, four (4) species occurred exclusively, one (1) was observed exclusively in the orchard 2 and no single species was observed in orchard 3 (Table 3). There was no significant difference in the bee species richness between orchards ( $\chi^2=0.52$ ;  $df=2$ ;  $p>0.05$ ). The highest values of Simpson and Evenness indexes were found for the orchard 3 (respectively 0.54 and 0.51), followed by the orchard 2 (0.53 and 0.47) and the orchard 1 (0.52 and 0.42) (Table 3).

**Table 3:** Metrics of bee diversity in the different habitats

Orchard	Total species richness	Sampled coverage	Simpson's index	Evenness's Index	Unique species per habitat
1	14	86.3	0.52	0.42	4
2	16	78.3	0.53	0.47	1
3	13	96.7	0.54	0.51	0

In this study, when fixing the threshold of dissimilarity to 60 %, the results reveal that the percentage of dissimilarity were respectively 15 % between orchard 2 and orchard 3; 18 % between orchard 1 and orchard 2; 23 % between orchard

1 and orchard 3. The percentage of similarity was then high between orchard 2 and orchard 3, based on the Bray-Curtis index (Table 4).

**Table 4:** Dissimilarity assessment of bees' assemblages between the visited habitats

	Orchard 1	Orchard 2	Orchard 3
orchard 1	0		
orchard 2	0.18	0	
orchard 3	0.27	0.15	0

**Foraging efficiency**

The most abundant bee species were categorised into three groups: small, medium and large. The number of flowers visited differed significantly between bee groups ( $\chi^2=29.07$ ;  $df=2$ ;  $p<0.05$ ). This number was significantly higher between small bees and large bees

( $p<0.05$ ) and between medium bees and large bees ( $p<0.05$ ). However, there was no significant difference between small bees and medium bees ( $p>0.05$ ). Large bees visited more flowers per time unit ( $8.8\pm 0.8$  flowers/min) than medium bees ( $3.7\pm 0.3$  flowers/min) and small bees ( $3.5\pm 0.2$  flowers/min). There was significant difference among the

three major groups of pollinators in time spent in each visited flower ( $\chi^2=191.2$ ;  $df=2$ ;  $p<0.05$ ). On average, small bees spent more time in each visited flower than the two other groups (medium bees and large bees). No significant difference was observed time spent in each visited flower between large bees and medium bees, but high significant

difference was recorded between small bees and large bees ( $p<0.05$ ), and between medium bees and large bees ( $p<0.05$ ). Moreover, medium bees had more flight time (27.9 s), following by large bees (27 s) and small bees (17.8 s) (Table 5).

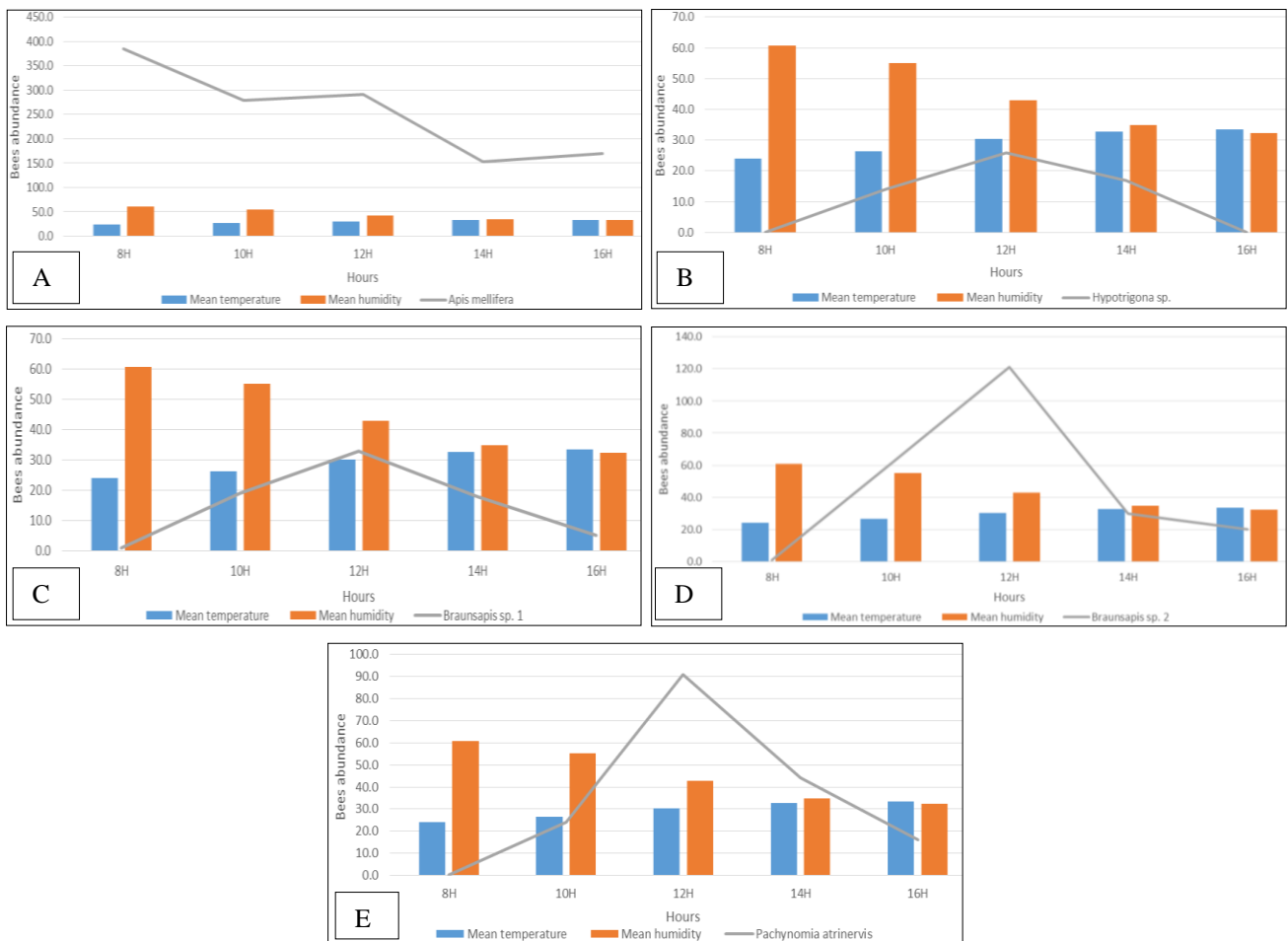
**Table 5:** Average number of flowers visited, flower visitation rate (NF/TT), average time spent in flower or handling time (TF), total observation time (TT) and flight time (TT- TF)/NF. "Handling time" is the average time spent in each visited flower; "Flight time" is the average time spent in flight between consecutive flower visits

Size of pollinators	Total number of flowers visited	Average number of flowers visited	Visitation rate (flowers/min) x100	Handling time (s)	total observation time (min)	Flight time (s)
Large	265	8.8±0.8	29.4	3±0.5	30	27
Medium	118	3.7±0.3	12.3	2.1±0.1	30	27.9
Small	104	3.5±0.2	11.6	12.2±0.6	30	17.8

**Effect of the influence of some abiotic factors on the daily activity of the most abundant species**

For *Apis mellifera*, the number of bee’s individuals decreased from 8:00 to 10:00 hrs, increased gradually until it reaches a peak at 12:00 hrs. Then the number of foragers dropped after midday (from 12:00 to 16:00 hrs). From 16:00 hrs, there is a slight increase in the number of individuals of this species (Figure 2A). The peak visiting time for *Hypotrigena* sp., *Braunsapis* sp. 1, *Braunsapis* sp. 2 and *Pachynomia atrinervis* was at 12:00 (Figure 2B; Figure 2C; Figure 2D, Figure 2E). There was a slightly significant negative correlation between the number of *A. mellifera*

individuals visiting flowers and temperature ( $R^2=0.834$ ,  $p=0.03$ ), and significant positive correlation with relative humidity ( $R^2=0.829$ ,  $p=0.03$ ). For the other species, positive correlation (no significant) was found between the number of individuals visiting flowers and temperature (*Hypotrigena* sp.:  $R^2=0.041$ ,  $p=0.74$ ; *Braunsapis* sp.1:  $R^2=0.052$ ,  $p=0.7$ ; *Braunsapis* sp.2:  $R^2=0.017$ ,  $p=0.83$ ; *Pachynomia atrinervis*:  $R^2=0.159$ ,  $p=0.51$ ), but negative correlation (no significant) was found with relative humidity (*Hypotrigena* sp.:  $R^2=0.028$ ,  $p=0.7$ ; *Braunsapis* sp.1:  $R^2=0.036$ ,  $p=0.7$ ; *Braunsapis* sp.2:  $R^2=0.009$ ,  $p=0.87$ ; *Pachynomia atrinervis*:  $R^2=0.129$ ,  $p=0.55$ ).



**Fig 2:** Daily activity patterns of: (A) *Apis mellifera*; (B) *Hypotrigena* sp.; (C) *Braunsapis* sp. 1; (D) *Braunsapis* sp. 2 and (E) *Pachynomia atrinervis*, in the cashew orchards

### Impact of bee pollination on cashew fruit set

The three pollination treatments tested in this experiment set fruits, and there were high significant differences ( $\chi^2 = 13.35$ ,  $df = 2$ ,  $p=0.001$ ) among them (Table 6). On average control (55.76 %) and natural cross pollination (50.10 %) produced more fruit set than spontaneous natural self-pollination (4.78 %), natural cross pollination does not result in more fruit compared to the control treatment (Table 6). There were high significant differences in the average of fruit set between control and spontaneous natural self-pollination ( $p=0.005$ ), between control and natural cross pollination ( $p=0.04$ ) and between spontaneous natural self-pollination and natural cross pollination ( $p=0.005$ ). On

average, fruits originating from the natural cross pollination (68.63 %) showed the lower percentage of aborted fruits than spontaneous natural self-pollination (71.89 %) and control treatment (73.56 %) (Table 6). There were high significant differences in the percentage of aborted fruits among the three treatments ( $\chi^2 = 14.92$ ,  $df = 2$ ,  $p<0.05$ ). High significant differences in the percentage of aborted fruits were also found between control and spontaneous natural self-pollination ( $p=0.002$ ) and between spontaneous natural self-pollination and natural cross pollination ( $p=0.002$ ). But no significant difference was observed between control and natural cross pollination ( $p=0.07$ ).

**Table 6:** Effect of three treatments (control, spontaneous natural self-pollination and natural cross pollination) on fruit set of cashew. Values (mean $\pm$ S.E.) followed by different letters in the same row are significantly different based on Kruskal-Wallis test at  $p < 0.05$

Reproduction parameters	Treatments		
	Control	Spontaneous natural self-pollination	Natural cross pollination
Males flowers	2888.3 $\pm$ 426.1	3004 $\pm$ 135.3	2660.3 $\pm$ 302.6
Hermaphrodites flowers	427.3 $\pm$ 66.1	320 $\pm$ 11.3	329.7 $\pm$ 36.8
Fruit set	238.3 $\pm$ 41.9 <sup>a</sup>	15.3 $\pm$ 1.8 <sup>b</sup>	168 $\pm$ 20.8 <sup>c</sup>
Fruit set rate (%)	55.76	4.78	50.10
Aborted fruit	175.3 $\pm$ 37.2 <sup>a</sup>	11 $\pm$ 2 <sup>b</sup>	115.3 $\pm$ 19.1 <sup>a</sup>
Aborted fruit rate (%)	73.56	71.89	68.63

### Discussion

#### Number and nature of floral visits by insect group

Cashew flowers offer pollen and nectar as forage to the visitors, but the quantities secreted is relatively small and sufficient only for metabolically undemanding pollinator<sup>[23]</sup>. In spite of the meagre floral reward of cashew, different kinds of insects, belonging to Hymenoptera, Lepidoptera, Diptera and Coleoptera were seen visiting the cashew flowers. In this study, bees were found to visit predominantly flowers and to brush against the stigmas, so they clearly transfer pollen. On the other hand, the other insects' groups visit less frequently, not regularly and very often without touching the stigma. They collect nectar only and therefore do not participate in pollen transfer.

The percentage of pollinating visits to the cashew flowers by bees is 99.3 %, which is a relatively higher rate than other groups of insects. This result is consistent with that of Freitas *et al.*<sup>[24]</sup> in Northeast Brazil, which showed that bees were the most frequent visitors (94 %) of cashew orchards and were the main pollinators of this crop.

#### Overall taxonomic structure of the observed bee species

In our study, 2043 individuals belonging to 3 families (Apidae, Halictidae and Megachilidae), 12 genera and 20 species were identified. On the other hand, a similar study carried out in the same region by Soro<sup>[10]</sup>, collected 12 species of bees divided into 2 families (Apidae and Halictidae). As for Freitas *et al.*<sup>[24]</sup> in Northeast Brazil and Bhattacharya<sup>[18]</sup> in India, they recorded respectively 14 and 5 species of bees in cashew orchards.

The highest number of Apidae individuals found in our study can be due to the fact that bee species of this family form colonies with hundreds of individuals and exhibit a wide range of food sources<sup>[25]</sup>. Apidae are very polytrophic and Halictidae have a fairly wide choice for plants. On the other hand, Megachilidae are limited in their choice by the accessibility of the stamens to the movements of their ventral brush. Halictidae and Megachilidae include only solitary species, although some of them have some degree

of socialization. But Apidae family includes both solitary, social and very social species<sup>[26]</sup>. This social character of the Apidae would explain their abundance in a given environment.

Our results showed that *Apis mellifera* had the highest number of individuals. This result is consistent with that of Freitas *et al.*<sup>[24]</sup> who demonstrated that *A. mellifera* represents 53 % of visitors, in an orchard of cashew nut in northeastern Brazil.

The high number of individuals of *A. mellifera* observed in Orchard 1 compared to the other two orchards is probably due to its proximity to an apiary distant to 200 m.

Although *A. mellifera* have been reported to forage up to 10 km from their nests, most foraging apparently takes place within a radius of 5 km from the colony<sup>[27]</sup>.

Low values of evenness index in our study reveal that individuals are unequally distributed among species and also suggest the dominance of one species (*A. mellifera*) in the three orchards.

#### Foraging efficiency

Our findings showed that large bees visited more flowers per time unit than medium bees and small bees. However, small bees spent more time in each visited flower than the two other groups (medium bees and large bees). This result is in consistent with other studies, in which the pollinator taxa that were more effective with respect to pollen deposition<sup>[28]</sup> or seed yield<sup>[29]</sup> spent less time foraging per flower. Several components of effectiveness were correlated with foraging time per flower.

This study has supported the previous investigations which were shown variation between interspecific pollinators in foraging rates<sup>[21]</sup>. Studies of Sahli and Conner<sup>[30]</sup> indicated that pollinator effectiveness and efficiency were functions of both behavior and morphology. While studying the abundance and flower visitation rate of the pollinators of *Lavandula latifolia* (Labiatae), Herrera<sup>[21]</sup> was explained that the differences in flower visitation rate was by differences in flower handling time (HT) and HT decreased

with increasing proboscis length. He attributed the interspecific variation in flower handling time should be mainly related to differential efficiency in nectar extraction or efficiency at flower manipulation.

If body mass has some direct influence on the nectar extraction process (e.g., via power output of tongue muscles and lapping rate), then the relationship existing between body mass and proboscis length<sup>[31]</sup> could help to explain the exponential relationship between handling time and proboscis length. Results reported by Harder<sup>[32]</sup> for bumble bees support this hypothesis. This author found that morphologically dissimilar bees drank nectar at different rates because glossa length affected lapping rate and volume ingested per lap, and body mass affected lapping rate. Results from this study also showed that differences in pollinator effectiveness can partially be explained by size, with larger pollinators effecting greater seed set. Kandori<sup>[33]</sup> found the same relationship in *Geranium*. Although body size can predict a pollinator's effectiveness at setting seeds, it is not predictive of a pollinator's ability to remove pollen.

### **Influence of temperature and humidity on the daily activity of the most abundant bee species**

According to Bhattacharya<sup>[18]</sup>, nectar volume and sugar concentration are most abundant in cashew flowers between 11 am and 3 pm. Nectars volumes dropped substantially by late afternoon, presumably as a result of evaporation and/or harvesting by insects. Active regulation of nectar sugar content and maintenance of constant nectar volume by the flowers was not observed. A steady occurrence of nectar volume and concentration between 11 am and 3 pm may increase the chance of multiple visits to a panicle by bees, leading to pollen removal from anthers and subsequent deposition on stigmas. Nectar volume and sugar concentration may be important in relation to the variation in visiting abundance of insects, which varies from tree to tree in the orchards. In our study, bees and other insects forage over short time spans with more visits in late morning to afternoon, which might be due to the higher nectar volume and sugar concentration at this time. Insects' visitors may concentrate their visits during a period of high availability of floral rewards<sup>[34]</sup>. The results of this study show that *A. mellifera* is the only species whose activity is negatively influenced by an increase in temperature and positively by a decrease in hygrometry during the day. On the other hand, the foraging activity of most of the wild bees collected was positively influenced by temperature and negatively by hygrometry. This result is in line with that of Eardley *et al.*<sup>[35]</sup>, who state that the majority of wild bees are thermophilic insects. Furthermore, according to Joshi and Joshi<sup>[36]</sup>, *A. mellifera* workers start foraging at 6 h 17 min, but this time can vary greatly depending on the region. According to Herrera<sup>[37]</sup>, body mass is a determining factor in thermoregulation in insects. The largest insects, i.e. those with the lowest surface-to-volume ratio, are the most susceptible to rapid heating. Large pollinating insects such as honeybees are thought to be less active during the hottest hours to avoid an uncontrolled rise in their body temperature, while insects with a higher surface-to-volume ratio (some butterfly species) are less sensitive to extreme temperatures. *Apis mellifera* visited the flowers throughout the day, including when they were most receptive to pollination and were probably the most efficient pollinators.

### **Impact of bee pollination on cashew fruit set**

According to Holanda-Neto *et al.*<sup>[38]</sup>, cashew has a selective mechanism of abortion, whereby fruits resulting from self-fertilization are 75% shed by the tree between days 9 and 15, in contrast with 51% of fruits shed after a cross fertilization. The presence of bees in cashew is therefore necessary to increase the fruiting rate. From the bagging experiment it is clear that bees are the effective pollinating agents of cashew, this finding being in accordance with Freitas and Paxton<sup>[39]</sup>, who reported the comparative value of introduced and native bees in cashew pollination in NE Brazil. After feeding, most of the bees move to a nearby cashew tree, an ideal behavior for effective cross-pollination. The open pollinated flowers set more fruits than the flowers restricted to visitors. The absence of cross pollen may reduce fruit production, as the controlled self-pollinated flowers set less fruits. Holanda-Neto *et al.*<sup>[38]</sup> suggested that low fruit set in cashew is due to self incompatibility.

A delay in anther dehiscence of hermaphrodite cashew flowers may diminish the chances of self-pollination, although the great number of male flowers per tree may increase the level of geitonogamy<sup>[40]</sup>. According to Freitas and Paxton<sup>[39]</sup>, *Centris tarsata* (Apidae) and *Apis mellifera* had statistically similar efficiencies at setting seed in cashew orchards in Brazil. But pollination by bees other than *Apis* is not negligible. Complimentary pollination between honeybees and wild pollinators enhancing crop yield has been reported recently<sup>[41]</sup> and this may also be the case for cashew.

### **Conclusion**

This study revealed that the percentage of pollinating visits to cashew flowers by bees was 99.3%, a higher rate than for other insect groups. 2043 bee individuals belonging to 3 families (Apidae, Halictidae and Megachilidae), 12 genera and 20 species were collected. Apidae was the most abundant family. The most abundant species were *Apis mellifera*, *Braunsapis* sp.2 and *Pachynomia atrinervis*. Most of the bees foraged with a high visit rate in the late morning and early afternoon, coinciding with the period of greatest availability of floral rewards. *Apis mellifera* are efficient pollinators of cashew orchard, a crop that requires cross-pollination for maximum yields. Also, pollination by bees improves fruit set of cashew trees.

It would therefore be beneficial to encourage bee's species into orchards. This includes preserving natural populations of bees in natural vegetation surrounding orchards and introducing hives into orchards to improve the availability of bees. The combination of crop cultivations and beekeeping could provide an opportunity for Côte d'Ivoire to develop its agriculture and could contribute to improved yields and the diversification of farmers' incomes.

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