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Pollination efficiency of *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae) on *Croton macrostachyus* (Euphorbiaceae) flowers at Dang, Ngaoundéré, Cameroon

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Abstract

To evaluate the impact of *Apis mellifera adansonii* on fruit and seed yields of *Croton macrostachyus*, the foraging and pollinating activities of worker bees were studied in Ngaoundéré. From May to June in 2013 and 2014, the experiments were carried out on 375 inflorescences divided in three treatments: two treatments differentiated according to the presence or absence of protection regarding honeybee and other insects visits; the third protected and uncovered when flowers were open, to allow honeybee visits. Worker's seasonal rhythm of activity, their foraging behavior on flowers, their pollination efficiency, the fruiting rate and percentage of normal seeds were evaluated. Results show that, honeybee foraged on *C. macrostachyus* flowers throughout its whole blooming period. This bee intensely harvested nectar and pollen. The mean number of individuals foraging simultaneously on 1000 flowers was 21.25 in 2013 and 56.14 in 2014. The mean duration of a visit per flower was 6.07 sec in 2013 and 5.69 sec in 2014. The mean foraging speed was 10.61 flowers/min in 2013 and 12.28 flowers/min in 2014. The fruiting rate and the percentage of normal seeds of unprotected inflorescences were significantly higher than those protected from insects. Through its pollination efficiency, this bee provoked a significant increase of fruiting rate by 44.82% (2013) and 61.85% (2014) as well as the percentage of normal seeds by 78.60% (2013) and 76.69% (2014). The installation of honeybee colonies close to *C. macrostachyus* populations could be recommended to increase fruit and seed yields and to increase honey production in the region.

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Introduction

The basic food of each honey bee colony are nectar and pollen (Crane, 1999; Weidenmüller and Tautz, 2002). Nectar is transformed into honey and pollen and honey are stored in the hive for future use (Tchuenguem *et al*., 2008a). These substances have been exploited by human for million of years (Crane, 1999). Honey and pollen production depends mainly on the abundance of some plant species and their attractiveness to honey bees (Williams and Carreck, 1994; Segeren *et al*., 1996). Thus the sustainable beekeeping in a given region needs a detailed knowledge of bee plants which grow in the environment of the hives (Segeren *et al*., 1996; Riedacker, 1996; Bakenga *et al*., 2000; Leven *et al*., 2005; Paterson, 2006).

Croton macrostachyus is a spontaneous plant species with mean height reaching 25 m; its leaves are simple, alterns, turning to orange before falling; the inflorescence is a thin terminal bunch reaching 35 cm of length (Arbonnier, 2002). Dominant colour of opened flower is whitish (Tchuenguem *et al*., 2008a) and each flower produces nectar and pollen which attract *Apis mellifera adansonii* (Fichtl and Adi, 1994; Tchuenguem *et al*., 2008a). The fruit is an almost globular capsule with 8-12 mm of diameter (Arbonnier, 2002). In West Africa, different parts of the plant are taken as decoction to treat constipation, stomachache and women barrenness; they are also used to treat pains and wounds due to Guinea worm (Burkill, 1994). In Cameroon, owing to increasing demand for hive products such as honey and pollen, beekeeping needs to be developed (Tchuenguem *et al*., 2008a). Highest quantities of honey consumed or marketed in this country come from the Adamawa region which has a climate particularly favorable to the proliferation of bees (Inades, 2000a). Despite the country's potentiality in producing honey, this activity faced a domestic offer less to nationwide demand (FAO, 2000; Tsafack *et al*., 2011). Before this research, no previous work has been reported on the pollination efficiency of *A. m. adansonii* on *C. macrostachyus* flowers. Preliminary studies by Tchuenguem *et al*. (2008a) reported that at Ngaoundéré, *A. m. adansonii* visits *C. macrostachyus* flowers to harvest nectar and pollen.

The main objective of this work carried out in Ngaoundéré was to contribute to the understanding of the relationships between *C. macrostachyus* and its flower visiting insects, for their optimal management. Specific objectives were: (a) the registration of the activity of *A. m. adansonii* on *C. macrostachyus* flowers; (b) the evaluation of the apicultural value of this plant; (c) the evaluation of the impact of flowering insects on pollination, on fruit and seed yields of this Euphorbiaceae, and (d) the estimation of the pollination efficiency of *A. m. adansonii* on *C. macrostachyus*.

Materials and methods

Study site

Experiments were carried out from May to June 2013 and from May to June 2014 at Dang (Latitude 7°25.365 N, Longitude 13°32.572 E and Altitude 1083 a.s.l.), a village located in the North of the city of Ngaoundéré, in the Adamawa Region of Cameroon. This Region belongs to the high-altitude Guinean-savanna agro-ecological zone. The climate is characterized by two seasons: a rainy season (April to October) and a dry season (November to March). The annual rainfall is about 1500 mm. The mean annual temperature is 22°C while the mean annual relative humidity is 70%. The vegetation is represented by crops, ornamental plants, hedge plants and native plants of savanna and gallery forests.

Biological materials

The plant material was represented by *C. macrostachyus* naturally presents in the study site. The biological material was represented by individuals of *A. m. adansonii* Latreille (Hymenoptera: Apidae) and other insects naturally present in the environment.

Determination of the mating system of Croton macrostachyus

In May 13th, 2013, 240 inflorescences of *C. macrostachyus* with flowers in bud stage were labelled among which 120 were left unprotected (treatment 1) and 120 were bagged using gauze bags (treatment 2) to prevent insect visits (Roubik, 1995).

In May 13th, 2014, the same treatments were set up, 240 inflorescences of *C. macrostachyus* with flowers in bud stage were labelled among which 120 were left unprotected (treatment 4) and 120 were bagged using gauze bags to prevent insect visits (treatment 5).

For each studied years, 10 days after the shading of the last labelled inflorescence, the number of formed fruits was assessed in each treatment.

The fruiting index was then calculated as described by Tchuenguem *et al.* (2001): $Pi = F2 / F1$, where $F2$ is the number of formed fruits and $F1$ the number of viable flowers initially set.

The allogamy rate (*Alr*) from which derives the autogamy rate (*Atr*) was expressed as the difference in fruiting indexes between treatment X (unprotected flowers) and treatment Y (protected flowers) (Demarly, 1977).

$Alr = [(PiX - PiY) / PiX] \times 100$, where PiX and PiY are respectively the mean fruiting indexes in treatment X and treatment Y.

$Atr = 100 - Alr$

Estimation of the frequency of Apis mellifera adansonii *visit on* Croton macrostachyus *flowers*

The frequency of *A. m. adansonii* on *C. macrostachyus* flowers was determined based on observations on flowers of treatments 1 and 4, every day, from May 15th to June 18th, 2013 and 2014. Data were taken according to six daily time frames: 6-7h, 8-9h, 10-11h, 12-13h, 14-15h and 16-17h. By observing labelled flowers of treatments 1 and 4, all visits of insects on *C. macrostachyus* flowers were recorded. Specimens of all insect taxa (3 to 5 per species) were caught with an insect net on unlabeled flowers and conserved in 70% ethanol for later identification. All insects encountered on flowers were registered and the cumulated results expressed as the number of visits to determine the relative frequency of *A. m. adansonii* in the entomofauna of *C. macrostachyus* (Tchuenguem, 2005).

Data obtained were used to determine the frequency of visits (*Fi*) of each insect species on *C. macrostachyus* flowers. For each studied period, $Fi = \{[(Vi) / VI] \times 100\}$ with *Vi* the number of visits of insect *i* on flowers of treatment with unprotected flowers, and *VI* the total number of visits of all recorded insect species on these flowers.

Study of Apis mellifera adansonii *activity on* Croton macrostachyus *flowers*

In addition to the determination of the pollinator abundance, direct observations of the foraging activity on flowers were made on *A. m. adansonii*. The floral product harvested (nectar or pollen) by worker bees during a floral visit were registered based on the foraging behavior of each forager. Nectar foragers were seen extending their proboscis to the base of the corolla and the stigma, while pollen gatherers directly scratched the anthers with their mandibles or legs (Jean-Prost, 1987). In the morning of each sampling date, the number of opened flowers was counted, while the duration of the individual flower visits was recorded (using stopwatch) according to six time frames: 7-8h, 9-10h, 11-12h, 13-14h, 15-16h and 17-18h.

Moreover, the number of pollinating visits (bee comes into contact with the stigma) (Oertel, 1961), the abundance of foragers (highest number of individuals foraging simultaneously on a flower or on 1000 flowers) and the foraging speed (number of flowers visited by a bee species per minute) (Jacob-Remacle, 1989) were measured on the same dates and time frames as the registration of the duration of visits. The foraging speed (*Vb*) was calculated using the following formula: $Vb = (Fi / di) \times 60$, were *di* was the time given by a stopwatch, and *Fi*, the number of flowers visited during *di*. The interruptions of the activity of foragers by competitors or predators and the attractiveness exerted by other plant species flowers on *A. m. adansonii* were assessed.

During each observation date, temperature and relative humidity were registered after every 30 minutes using a mobile thermo-hygrometer.

Evaluation of the impact of flowering insects on Croton macrostachyus *yields*

This evaluation was based on the impact of flowering insect on pollination, the impact of pollination on *C. macrostachyus* fruiting, and the comparison of yields (fruiting rate, mean number of seed per fruit and percentage of normal seeds) of treatment X (unprotected flowers) and treatment Y (bagged flowers) (Roubik, 1995).

The fruiting rate due to the influence of foraging insects (*Fri*) was calculated using the formula: Fr_i = {[(*Fr*X - *Fr*Y) / *Fr*X] x 100} were *Fr*X and *Fr*Y are the fruiting rate in treatment X and treatment Y respectively. The fruiting rate of treatment (*Fr*) is *Fr* = [(*F2* / *F1*) x 100], where *F2* is the number of fruits formed and *F1* the number of viable flowers initially set (Tchuenguem *et al.*, 2001). At maturity, fruits were harvested from each treatment and the number of seeds per fruit counted. The mean number of seeds per fruit and the percentage of normal (well developed) seeds were then calculated for each treatment. The impact of flower visiting insects on seed yields was evaluated using the same method as mentioned above for fruiting rate.

Assessment of the pollination efficiency of Apis mellifera adansonii on Croton macrostachyus

Parallel to the constitution of treatments 1 and 2, treatment 3 was set up with 135 bagged inflorescences as those of treatment 2. Parallel to the constitution of treatments 4 and 5, treatment 6 was set up with 135 bagged inflorescences as those of treatment 5. Between 11h and 12h, then 15h and 16h (2013); and between 11h and 12h, then 13h and 14h (2014), the gauze bag was delicately removed from each inflorescence of treatments 3 and 6 carrying out new opened flowers and observed up to 20 minutes. Visited flowers by *A. m. adansonii* were marked and the inflorescence was rebagged thereafter.

The contribution of *A. m. adansonii* in the fruiting (*Frx*) was calculated using the following formula: *Frx* = {[(*Fr*Z - *Fr*Y) / *Fr*Z] x 100} (Tchuenguem, 2005), where *Fr*Z and *Fr*Y are the fruiting rate in treatment Z (flowers visited exclusively by *A. m. adansonii*) and treatment Y (bagged flowers).

At maturity, fruits were harvested from each of the treatments 2, 3, 5 and 6. The number of seeds per fruit was counted.

The mean number of seeds per fruit and the percentage of normal seeds were then calculated for each treatment. The impact of *A. m. adansonii* on seed yields was evaluated using the same method as mentioned above for fruiting rate.

Data analysis

Data were analyzed using descriptive statistics, student's *t*-test for the comparison of means of two samples, correlation coefficient (*r*) for the study of linear relationship between two variables, chi-square (χ^2) for the comparison of two percentages, ANOVA for the comparison of means of more than two samples and Microsoft Excel 2010 sheet.

Results

Mating system of Croton macrostachyus

In each of treatments 1 and 2 (2013) and 4 and 5 (2014), 120 inflorescences were investigated. In 2013, the fruiting index was 0.34 and 0.25 respectively for treatments 1 and 2, while in 2014 it was 0.24 for treatment 4 and 0.17 for treatment 5. Hence, *TC* and *TA* were respectively 26.47% and 73.53% in 2013 against 29.17% and 70.83% in 2014. For the two cumulated years; *TC* = 27.82% and *TA* = 72.18%.

Thus *C. macrostachyus* has a mixed mating system, allogamous and autogamous, with the predominance of autogamy over allogamy.

Frequency of Apis mellifera adansonii *visit on* Croton macrostachyus *flowers*

Among the 6502 and 6921 visits of 15 and 16 insect species recorded on *C. macrostachyus* flowers in 2013 and 2014 respectively, *A. m. adansonii* was the most represented insect with 2268 visits (34.88%) and 2524 visits (36.47%), in 2013 and 2014 respectively. The difference between these two percentages is not significant ($\chi^2 = 3.68$; $df = 1$; $P > 0.05$) (Table 1).

Table 1. Diversity of floral insects on *Croton macrostachyus* in 2013 and 2014, number and percentage of visits of different insects at Dang.

Insects			2013		2014		$Total_{2013/2014}$	
Order	Family	Genus, Species, Sub – species	n_1	P_1 (%)	n_2	P_2 (%)	n_T	P_T (%)
Coleoptera	Chrysomelidae	(1 sp.) (ne)	19	0,29	-	-	19	0,14
	Lycidae	*Lycus latissimus* (ne)	310	4,77	309	4,46	619	4,61
	Scarabeidae	(1 sp.) (ne)	2	0,03	5	0,07	7	0,05
	Total Coleoptera		331	5,09	314	4,53	645	4,80
Diptera	Calliphoridae	*Calliphora* sp. 1 (ne)	2494	38,36	2503	36,16	4997	37,24
		Calliphora sp. 2 (ne)	43	0,66	50	0,72	93	0,69
	Syrphidae	(1 sp.) (ne)	12	0,18	35	0,51	47	0,35
		(1 sp.) (ne)	-	-	28	0,40	28	0,21
	Total Diptera		2549	39,20	2616	37,79	5165	38,49
Hemiptera	Pyrrhocoridae	*Dysdercus voelkeri* (ne)	30	0,46	30	0,43	60	0,45
Hymenoptera	Apidae	*Apis mellifera adansonii* (ne, po)	2268	34,88	2524	36,47	4792	35,71
		Meliponula furruginea (ne, po)	-	-	12	0,17	12	0,09
		Xylocopa olivacea (ne, po)	3	0,05	7	0,10	10	0,08
		Total Apidae	2271	34,93	2543	36,74	4814	35,88
	Formicidae	*Camponotus brutus* (ne)	227	3,49	234	3,38	461	3,44
		Polyrachis sp. (ne)	613	9,43	685	9,90	1298	9,67
		(1 sp.) (ne)	382	5,88	391	5,65	773	5,76
		Total Formicidae	1222	18,80	1310	18,93	2532	18,87
	Sphecidae	*Philanthus triangulum* (ne)	55	0,85	55	0,79	105	0,78
	Vespidae	*Belonogaster juncea* (ne)	43	0,66	43	0,62	86	0,64
	Total Hymenoptera		3586	55,16	3951	57,08	7537	56,17
Lepidoptera	Zygenidae	(1 sp.) (ne)	1	0,02	10	0,14	11	0,08
Total			6502	100	6921	100	13418	100
			15 species		16 species		17 species	

Comparison of percentages of *Apis mellifera adansonii* visits for the two years: ($\chi^2 = 3.68$; $df = 1$; $P > 0.05$).

n_1: number of visits on 120 inflorescences in 30 days, n_2: number of visits on 120 inflorescences in 30 days, p_1 and p_2: percentages of visits, sp.: undetermined species, ne: visitor collected nectar, po: visitor collected pollen. $p_1 = (n_1 / 6502) \times 100$, $p_2 = (n_2 / 6921) \times 100$.

Activity of Apis mellifera adansonii *on* Croton macrostachyus *flowers*

Floral products harvested

During each flowering season, *A. m. adansonii* foragers were found to intensively and regularly collecting nectar and pollen on *C. macrostachyus* flowers. On Fig. 1. *A. m. adansonii* is shown collecting nectar on *C. macrostachyus* flowers.

Rhythm of visits according to the flowering stages

Visits were numerous when the number of opened flowers was highest on *C. macrostachyus* (Fig. 2.).

Furthermore, we found a positive and significant correlation between the number of opened flowers and the number of visits in 2013 ($r = 0.42$; $df = 28$; $P < 0.05$) but not significant in 2014 ($r = 0.08$; $df = 28$; $P > 0.05$).

Daily rhythm of visits

A. m. adansonii starts its foraging activity on *C. macrostachyus* flowers around 9 am and foraged throughout its blooming period, with two peaks situated between 11h and 12h then between 15h and 16h in 2013, and between 11h and 12h then between 13h and 14h in 2014 (Fig. 3.).

Weather conditions influenced the activity of *A. m. adansonii*. In 2013, the correlation was not significant between the number of *A. m. adansonii* visits and the temperature ($r = 0.54$; $df = 4$; $P > 0.05$); while it was significant between the number of visits and relative humidity ($r = 0.85$; $df = 4$; $P < 0.05$).

Table 2. Fruiting rate, mean number of seeds per fruit and normal seed percentage according to different treatments of *Croton macrostachyus* in 2013 and 2014 at Dang.

Treatments	Studied years	Number of flowers shower	Number of fruits formal	Fruiting rate (%)	Seeds/fruit		Total seeds	Number of normal seeds	% normal seeds
					Mean	Sd			
1 (unprotected flowers)	2013	10313	3510	34.03	1.63	0.82	195	130	66.67
2 (bagged flowers)		10142	2564	25.28	1.18	0.48	141	52	36.88
3 (flowers exclusively visited by *Apis mellifera adansonii*)		5245	2351	44.82	2.11	1.16	285	224	78.60
4 (unprotected flowers)	2014	10236	2406	23.50	1.04	0.87	125	77	61.6
5 (bagged flowers)		9987	1690	16.92	1.01	0.97	121	43	35.54
6 (flowers exclusively visited by *Apis mellifera adansonii*)		4123	2550	61.85	2.19	1.13	296	227	76.69

In 2014, the correlation was significant between the number of *A. m. adansonii* visits and the temperature (r = 0.86; df = 4; P < 0.05); while it was not significant between the number of visits and relative humidity (r = - 0.78; df = 4; P > 0.05).

Abundance of Apis mellifera adansonii *foragers*

In 2013, the highest mean number of *A. m. adansonii* simultaneously in activity was 1 per flower (n = 676; s = 0) and 21.25 per 1000 flowers (n = 272; s = 13.50; *maxi* = 83). In 2014, the corresponding values were 1 per flower (n = 2365; s = 0) and 56.14 per 1000 flowers (n = 636; s = 48.42; *maxi* = 278).

The difference between these two means was highly significant (t = 161.19; df = 906; P < 0.001).

Duration of visits per flower

In 2013, the mean duration of a visit of *A. m. adansonii* per flower was 6.07 seconds (n = 1213; s = 4.21; *maxi* = 59). In 2014, the corresponding value was 5.69 seconds (n = 2203; s = 3.75; *maxi* = 59).

The difference between these two means is highly significant (t = 75.82; df = 3414; P < 0.001).

During each flowering season, *A. m. adansonii* harvest passively pollen (without scratching the anthers) and actively nectar (proboscis was extended to the base of the corolla) (Fig. 1.).

Foraging speed of Apis mellifera adansonii on Croton macrostachyus flowers

A. m. adansonii visited between 3 and 60 flowers per minute in 2013 as well as in 2014. The mean foraging speed was 10.61 flowers per minute (n = 265; s = 5.68) in 2013 and 12.28 flowers per minute (n = 836; s = 6.42) in 2014.

The difference between these two means is highly significant (t = 53.72; df = 1099; P < 0.001).

Fig. 1. *Apis mellifera adansonii* collecting nectar on *Croton macrostachyus* flowers at Dang in 2014.

Influence of fauna

Individuals of *A. m. adansonii* were interrupted in their foraging activity by other individuals of the same or different species. They were either predators or competitors for nectar or pollen. In 2013, for 1213 visits of *A. m. adansonii*, 8 (0.66%) were interrupted whereas in 2014 for 2203 visits, 44 (2%) were interrupted. This action forces the interrupted bee to visit a greater number of flowers during its foraging trips, to get its nectar or pollen loads (Klein *et al.*, 2007).

Influence of neighboring flora

During the observation on *C. macrostachyus*, flowers of many other plant species surrounding the study area were visited by *A. m. adansonii* workers, for nectar (ne) or pollen (po). Among those plants were *Tithonia diversifolia* (Asteraceae; ne and po); *Mimosa invisa* (Mimosaceae; po); *Lantana camara* (Verbenaceae; ne); *Bixa orenalla* (Bixaceae; ne and po); *Cosmos sulphureus* (Asteraceae; ne and po) and *Sida rhombifolia* (Malvaceae; ne and po). During one foraging trip on *C. macrostachyus* flowers, *A. m. adansonii* foragers scarcely visited another plant species.

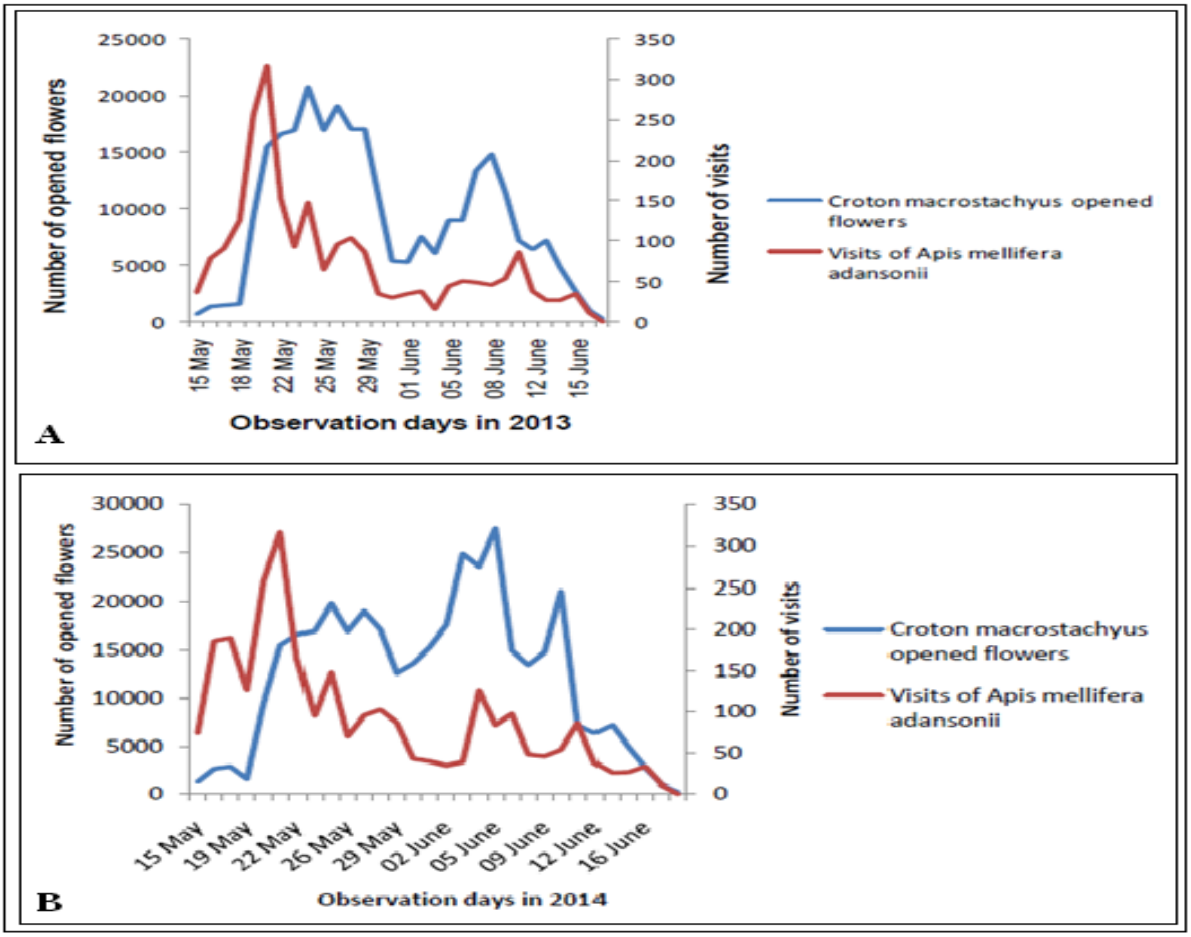

Fig. 2. Seasonal variation of the number of *Croton macrostachyus* opened flowers and the number of *Apis mellifera adansonii* visits in 2013 (A) and 2014 (B).

Apicultural value of Croton macrostachyus

During the flowering periods of *C. macrostachyus*, a well elaborated activity of *A. m. adansonii* workers was register on its flowers. In particular, there was high density of workers, a very good harvest of nectar and pollen, and a fidelity of workers on flowers. Moreover, each *C. macrostachyus* plant can produce more than 20000 flowers. These data pointed out the very good attractiveness of *C. macrostachyus* nectar and pollen to *A. m. adansonii*. They allow *C. macrostachyus* to be classified in the category of very highly nectariferous and highly polliniferous bee plants.

Impact of flowering insects on Croton macrostachyus *yields*

During nectar harvest on flowers, foragers regularly contacted anthers and pollen adhered all over its body increasing (by this action) cross pollination possibility of *C. macrostachyus*. Table 2 presents the results on fruiting rate, number of seeds per fruit and percentage of normal seeds in different treatments.

a)- The fruiting rate due to flowering insects was 34.03% in treatment 1 (unprotected flowers) and 25.28% in treatment 2 (bagged flowers) (2013);

it was 23.50% in treatment 4 and 16.92% in treatment 5 (2014). The comparison of these percentages shows that the difference are very highly significant between treatments 1 and 2 (χ^2 = 187.68; *df* = 1; *P* < 0.001) as well as between treatments 4 and 5 (χ^2 = 135.64; *df* = 1; *P* < 0.001).

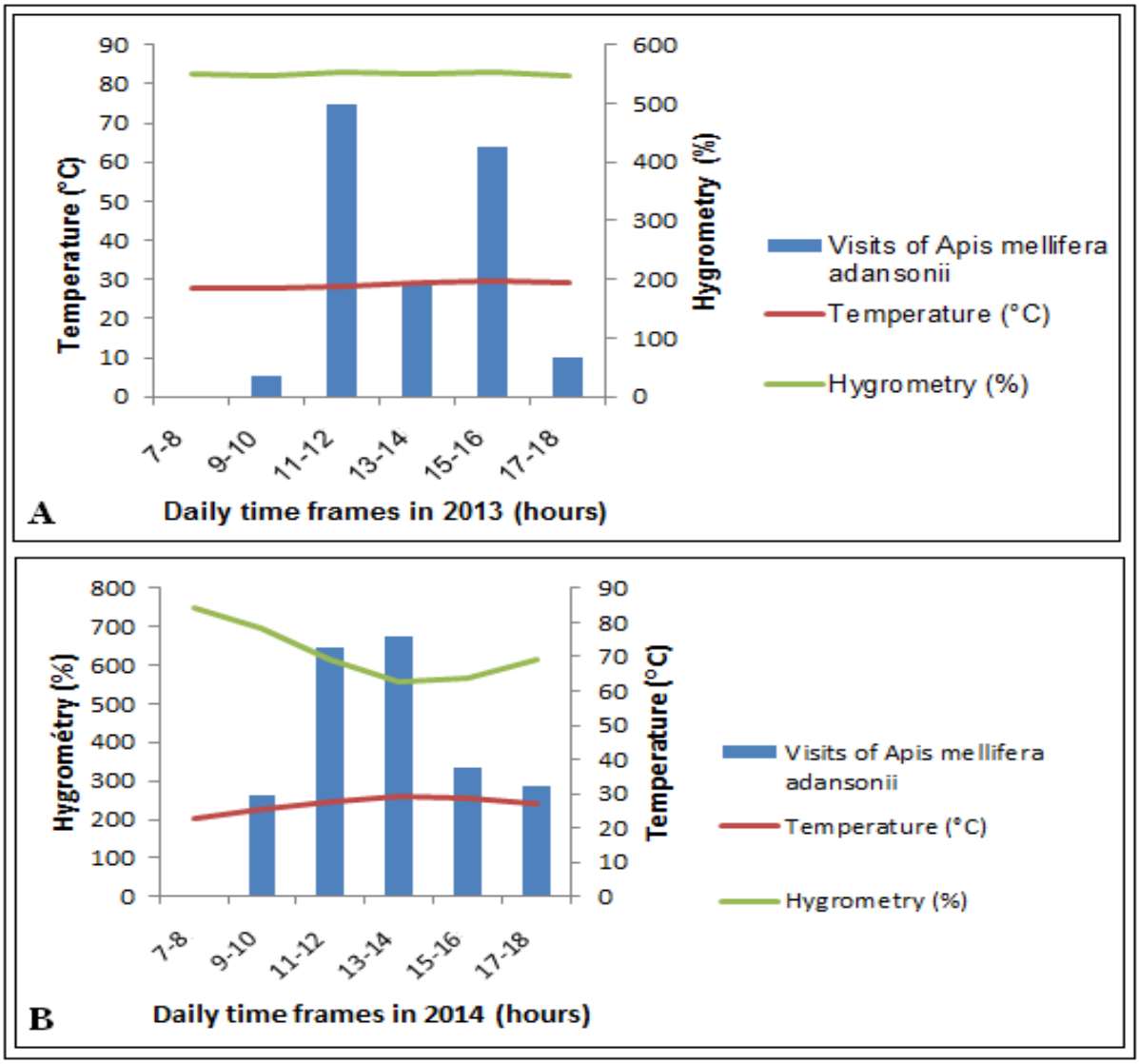

Fig. 3. Daily variation of *Apis mellifera adansonii* visits on *Croton macrostachyus* flowers in 30 days in 2013 (A) and 2014 (B), mean temperature and mean humidity of study site.

b)- The mean number of seeds per fruit due to insects was 1.63 in treatment 1 and 1.18 in treatment 2; the corresponding figures were 1.04 treatment 4 and 1.01 in treatment 5. The comparison of these means shows that the difference is very highly significant between treatments 1 and 2 (*t* = 956.43; *df* = 6072; *P* < 0.001) as well as in treatments 4 and 5 (*t* = 32.63; *df* = 4094; *P* < 0.001).

c)- The percentage of normal seeds due to the action of insects including *A. m. adansonii* in 2013 was 66.67% in treatment 1 and 36.88% in treatment 2. The corresponding figures were 61.6% and 35.54% in treatments 4 and 5. The comparison of these figures shows that the difference is very highly significant between treatments 1 and 2 (χ^2 = 29.25; *df* = 1; *P* < 0.001) as well as in treatments 4 and 5 (χ^2 = 16.72; *df* = 1; *P* < 0.001). For the cropping years, the difference between the percentage of normal seeds from treatments 1 and 4 and normal seeds from treatments 2 and 5 was very highly significant (χ^2 = 23.32; *df* = 1; *P* < 0.0001).

Pollination efficiency of Apis mellifera adansonii on Croton macrostachyus

During nectar and pollen harvest on flowers, foragers regularly contacted anthers and carried pollen. The percentage of the number of visits during which *A. m. adansonii* came into contact with the anthers of the visited flowers was 100% in 2013 as well as in 2014. Consequently this bee increased possibilities of the pollination of *C. macrostachyus* flowers.

The global comparison of different means (Table 2) shows that the difference is very highly significant in 2013 (F = 35.97; df = 374; P < 0.0001) and 2014 (F = 58.49; df = 374; P < 0.0001).

a)- The fruiting rate due to *A. m. adansonii* was 44.82% in 2013 and 61.85% in 2014. The difference between these two percentages is highly significant (χ^2 = 268.20; df = 1; P < 0.001). The difference between treatments 2 (bagged flowers) and 3 (flowers exclusively visited by *A. m. adansonii*) was highly significant (χ^2 = 607.35; df = 1; P < 0.001), as well as between treatments 5 (bagged flowers) and 6 (flowers exclusively visited by *A. m. adansonii*) (χ^2 = 2802.15; df = 1; P < 0.001).

For the two studied periods, the fruiting rate of flowers exclusively visited by *A. m. adansonii* was higher than those of bagged flowers.

b)- The mean number of seeds per fruit due to *A. m. adansonii* was 2.11 in 2013 and 2.19 in 2014. The comparison of these means shows that the difference is very highly significant between treatments 2 and 3 (t = - 1304.79; df = 4913; P < 0.001) in 2013 as well as in 2014 (t = - 1121.56; df = 4238; P < 0.001).
During the observations periods, the mean number of seeds per fruit in treatment exclusively visited by *A. m. adansonii* was higher than those of bagged flowers.

c)- The percentage of normal seeds due to *A. m. adansonii* was 78.60% in 2013 and 76.69% in 2014. The comparison of percentages between treatments 2 and 3 shows that the difference is very highly significant (χ^2 = 71.96; df = 1; P < 0.001), as well as between treatments 5 and 6 (χ^2 = 63.73; df = 1; P < 0.001).

For the both studied periods, the difference between the percentage of normal seeds from flowers isolated and visited exclusively by *A. m. adansonii* (treatments 3 and 6) and protected flowers (treatments 2 and 5) was very highly significant (χ^2 = 67.70; df = 1; P < 0.001).

Discussion

Activity of Apis mellifera adansonii *on* Croton macrostachyus *flowers*

Results indicate that *A. m. adansonii* collects nectar and pollen on *C. macrostachyus* flowers. The same results were obtained by Tchuenguem *et al.* (2008a) at Ngaoundéré on the same plant species. But in West Cameroon, Dongock *et al.* (2004) reported the collection of nectar only in flowers of this Euphorbiaceae. The harvest of nectar and pollen of *C. macrostachyus* by *A. m. adansonii* has also been reported in Ethiopia (Fichtl and Adi, 1994). Thus, the type of floral products harvested by *A. m. adansonii* on a given plant species can vary with the regions. In addition, in previous studies, Nebojs˘a *et al.* (2013) also observed the collection of nectar and pollen on *Brassica napus* flowers by this honeybee in Serbia. The observed variations could mainly be explained by the availability of pollen or nectar on flowers and by the needs of honeybee colonies.

It is known that the foraging activity of honeybees begins early in the morning and ends in the evening (Abou-Shaara, 2014). The peaks of activity of *A. m. adansonii* observed on *C. macrostachyus* flowers could be linked to the period of highest availability of nectar and pollen. The interruptions of visits reduced the duration of certain *A. m. adansonii* visits. This obliged some workers to visit more flowers during a foraging trip, in order to obtain their maximal pollen and nectar loads. Similar findings were made for *A. m. adansonii* workers foraging on flowers of *C. macrostachyus* (Euphorbiaceae), *Syzygium guineense* var. *guineense* (Myrtaceae) (Tchuenguem *et al.*, 2008a); *Persea americana* (Lauraceae), *Vitellaria paradoxa* (Sapotaceae) (Tchuenguem *et al.*, 2008b);

Vigna unguiculata (Fabaceae) (Tchuenguem *et al*., 2009b); *Combretum nigricans*, *Erythrina sigmoidea*, *Lannea kerstingii*, *Vernonia amygdalina* (Tchuenguem *et al*., 2010); *Physalis micrantha* (Solanaceae) (Esther *et al*., 2015).

The observed high abundance of workers was due to the ability of honeybees to recruit a great number of foragers for the exploitation of good food sources (Frisch, 1969; Louveaux, 1984; Schneider and Hall, 1997). The positive correlation between the number of *C. macrostachyus* flowers and the number of honeybee visits underscores the high attractiveness of *C. macrostachyus* nectar and pollen for *A. m. adansonii*. The positive correlation between this bee and blooming progression was obtained by Annelise *et al*. (2011) in Southern Brazil.

Present study shows that during one foraging trip, an individual bee foraging on *C. macrostachyus* scarcely visited another plant species. This result indicated that *A. m. adansonii* shows flower constancy (Louveaux, 1984; Basualdo *et al*., 2000; Montgomery, 2009) on *C. macrostachyus* flowers. This floral constancy is due to the fact that, individual forager of honeybees is generally capable to memorize and recognize the shape, colour and odour of the flowers visited during previous foraging trips (Hill *et al*., 1997; Wright *et al*., 2002).

Impact of Apis mellifera adansonii activity on the pollination and yields of Croton macrostachyus

During the collection of nectar and pollen on each *C. macrostachyus* flower, *A. m. adansonii* workers regularly come into contact with stigma and anthers. The same results were found in Ngaoundéré on *Anona senegalensis*, *C. macrostachyus*, *Psorospermum febrifugum* and *Syzygium guineense* var. *guineense* flowers (Tchuenguem *et al*., 2008a); on *Persea americana*, *Vitellaria paradoxa* flowers (Tchuenguem *et al*., 2008b); on *Callistemon rigidus* flowers (Fameni *et al*., 2012); on *Glycine max* flowers (Stephanie *et al*., 2015); in Maroua on *Glycine max* flowers (Tchuenguem and Dounia, 2014); on *Phaseolus vulgaris* var. small red seeds flowers (Douka and Tchuenguem, 2013); in Bambui on *Physalis micrantha* flowers (Esther *et al*., 2015). The same results were also found in northeastern Brazil by Neves and Viana (2011) on the monoecious plants *Jatropha mollissima* (Pohl) Baill. and *Jatropha mutabilis* (Pohl) Baill. (Euphorbiaceae), in Brazil by Rômulo *et al*. (2012) on castor bean (*Ricinus communis*).

They could thus enhance self-pollination by applying pollen of one flower onto its own stigma.

A. m. adansonii could provide allogamous pollination through carrying pollen with their hair, silk, legs, mouthparts, thorax and abdomen, which is subsequently touching stigma of other flowers belonging to a different plant of the same species (geitogamy).

The intervention of *A. m. adansonii* in the pollination of this plant species is seemingly more real since its density per 1000 flowers and its foraging speed are high. The peaks of *A. m. adansonii* on *C. macrostachyus* flowers can be explained by the optimal receptivity period of the stigma of this Euphorbiaceae.

The positive and significant contribution of *A. m. adansonii* in fruit and seed yields of *C. macrostachyus* can be justified by the action of this honey bee on pollination.

The numeric contribution of *A. m. adansonii* to *C. macrostachyus* yields through its pollination efficiency was significantly higher than that of all insects on the exposed flowers. This shows that *A. m. adansonii* is one of the major insect pollinators of *C. macrostachyus*. The numeric contribution of *A. m. adansonii* was reported by Tchuenguem *et al*. (2009a, 2009b); Azo'o *et al*. (2010); Ximena *et al*. (2010); Djonwangwé *et al*. (2011a, 2011b); Fameni *et al*.(2012); Mazi *et al*. (2013); Adamou and Tchuenguem (2014); Emerson *et al*. (2014); (Esther *et al*., 2015).

Conclusion

At Dang, *C. macrostachyus* is a plant species that obtained benefits from the pollination by insects among which *A. m. adansonii* is the most frequent pollinator which harvested nectar and pollen. The comparison of fruit and seed yields of bagged flowers, to those visited exclusively by *A. m. adansonii*, underscores the value of this bee in increasing fruit and seed yields as well as seeds quality. As a highly nectariferous and polliniferous bee plant, *C. macrostachyus* should be planted and protected to increase honey production and to strengthen *A. m. adansonii* colonies.

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