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Foraging and pollination behavior of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Physalis micrantha* (Solanales: Solanaceae) flowers at Bambui (Nord West, Cameroon)

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Abstract
From June to July 2013 and 2014, *Physalis micrantha* flowers were observed in view to estimate the apicultural value and assess the impact of *Apis mellifera adansonii* on fruit and seed yields of this plant. Observations were made on 73 to 2212 flowers per treatment. The treatments included unlimited floral access by visitors, bagged flowers to deny all visits and, limited visits by *A. m. adansonii* only. Foraging and pollination behavior of *A. m. adansonii* were registered, the fruiting rate and the number of seeds per fruit were recorded. *A. m. adansonii* was the most frequent insects visiting flowers of *P. micrantha* in the two years. The foraging activity of *A. m. adansonii* allows the classification of this Solanaceae as a highly nectariferous and polliniferous bee plant. The pollination activity of this bee resulted in an increase in the fruiting rate by 1.68%, as well as the number of seeds per fruit by 2.09%. Conservation of *A. m. adansonii* nests close to *P. micrantha* fields could be recommended to improve fruit production, increase pollen production as a hive product and maintain bees' colonies during the raining season.

Keywords: *Physalis micrantha*, flowers, *Apis mellifera adansonii*, pollination, yields**.**

Introduction
Pollinators have been shown to be important for the production of more than 70% of 1330 species of tropical crops [1]. Honeybees are one of the most important pollinators of angiosperms because of their vegetarian diet, flower visiting habits, hairy bodies that readily pick up pollen grains and the fact that they visit many flowers of the same species during a single trip thus affecting pollination [2]. This enables the reproduction, productivity and diversification of plants [3]

Physalis micrantha (L.) of the Solanaceae family is a small herbaceous annual herb grown as weed in crop fields [4]. It is native to warm temperate and subtropical regions throughout the world [5].

It has axillary yellow flowers that are solitary and bee pollinated [6]. The fruit is a berry, which measures about 1.5 cm in diameter and is enclosed in an inflated, bladder-like calyx or husk; it is juicy, mildly astringent and sweet [7]. The unripe fruit can be cooked as a vegetable [8], while the ripe fruits are eaten as such and used as an appetizer and laxative [7, 8]. The edible fruit contains about 6% sugars, 2.7% proteins, 1.2% ash, 0.6% tannin, 0.5% pectin and is a rich source of vitamin C [9]. The extracts from the plant have shown anticancer activity [10, 11].

The demand for this fruit has increased due to its potential as antioxidant and anticancer [12 13]. *Physalis micrantha* is a plant species for which informations on insect pollination in Africa, particularly in Cameroon are still lacking. Much information exists for the West African species of Physalis as food items (leaves and fruits), medicine and sources of various secondary plant products [14]. There has been no previous research reported on the apicultural value of *P. micrantha*, as well as on the relationship between the plant and its anthophilous insects.

This study was carried out to assess the apicultural value of *P. micrantha* and the effects of foraging behavior of *A. m. adansonii* on pollination and yields of this plant species. The information gained on the interactions of *P. micrantha* flowers and *A. m. adansonii* workers could enable farmers to develop management plans that could increase the overall quality and quantity of *P. micrantha* yields and hive products.

Materials and methods

Study site, experimental plot and biological material

The experiment was carried out twice, June to July 2013 and 2014 at Bambui (3°31'35.3" N, 11°30'0.06" E and 760 m above sea level), Mezam, North West Region of Cameroon. This Region belongs to the Western Highlands agro-ecological zone [15]. The climate is tropical and characterized by two seasons: a rainy season (mid-March to mid-November) and a dry season (mid-November to mid-March); the annual rainfall varies from 2.000 to 2.800 mm; the mean annual temperature is 20°C and the mean annual relative humidity is above 85% [15]. The experimental plot was 13 m long and 10 m wide (130 m²).The biological material was represented by *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae), and others insects present in the environment. Seeds of *P. micrantha* were provided from the local seed outlets. The vegetation near *P. micrantha* field had various spontaneous and cultivated species.

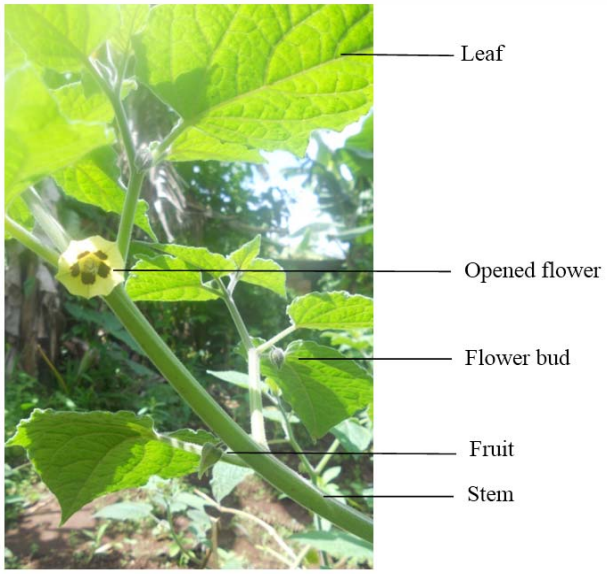

Fig 1: Part of *Physalis micrantha* plant

Sowing and weeding

The experimental plot was divided into 15 subplots (3 m long x 1 m wide each). The sowing was done the 15th April, 2013 and 18th April, 2014, on one line per subplot, the line has three holes and in each hole, two seedlings were placed. The space was 50 cm between holes. Weeding was performed manually as necessary to maintain ridge weeds-free.

Determination of the reproduction system of *Physalis micrantha*

On 09th June 2013, ten subplots carrying 30 plants with 4011 flowers at the bud stage were labeled. Five subplots carrying 15 plants with 2212 flowers were left un-attended (treatment 1) and five subplots carrying 15 plants with 1799 flowers were bagged to prevent visitors (treatment 2). On 13th June 2014, ten subplots carrying 30 plants with 4011 (3136) flowers at the bud stage were labeled. five subplots carrying15 plants with 1612 flowers were left un-attended (treatment 3) and five subplots carrying 15 plants with 1524 flowers were bagged to prevent visitors (treatment 4).

Thirty days after shedding of the last flower, the number of fruits was assessed in each treatment. The fruiting index (*Fi*) was then calculated as described by Tchuenguem *et al.* [16]:

$Fi = F2/F1$

Where *F2* is the number of fruits formed 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* (bagged flowers) as follows [17]:

$$Alr = [(FiX - FiY) / FiX] \times 100$$

Where *FiX* and *FiY* are respectively the fruiting average indexes of treatments *X* and *Y*.

$$Atr = 100 - Alr.$$

Study of the foraging activity of *Apis mellifera adansonii* on *Physalis micrantha* flowers

The frequency of *A. m. adansonii* in the flowers of *P. micrantha* was determined based on observations of flowers of treatment 1 and treatment 3 every day, during each of the following daily time frame, from 10th to 30th June 2013 and from 14th to 30th June 2014: 8 - 9 am, 10 - 11 am, 12 - 13 pm, 14 - 15 pm and 16 - 17 pm. In a slow walk along all flowers of treatment 1 and treatment 3, the identity of all insects that visited *P. micrantha* was recorded. Specimens of all insect taxa were caught with an insect net on unlabeled plant. For each species, 3 to 5 insect specimens were captured. These insects were conserved in 70% ethanol for subsequent taxonomy determination except for Lepidoptera which were conserved in wrapper following Borror and White recommendations [18]. All insects encountered on flowers were registered and the cumulated results expressed in number of visits to determine the relative frequency of *A. m. adansonii* in the anthophilous entomofauna of *P. micrantha*.

In addition to the determination of the floral insects' frequency, direct observations of the foraging activity on flowers were made on insect pollinator fauna in the experimental field. The floral products (nectar or pollen) harvested by *A. m. adansonii* during each floral visit were registered based on its foraging behavior. Nectar foragers were seen extending their proboscis to the base of the corolla while pollen gatherers scratched anthers with the mandibles or the legs.

During the same time that *A. m. adansonii* encountered on flowers were registered, the types of floral products collected by this bee were noted. In the morning of each sampling day, the number of opened flowers carried by each subplot of treatment 1 was counted.

During the same days as for the frequency of visits, the duration of the individual flower visits was recorded (using a stopwatch) during each of the following daily time frame: 9 - 10 am, 11 am - 12 pm, 13 -14 pm, 15 - 16 pm and 17 - 18 pm. Moreover, the number of pollinating visits (the bee came into contact with the stigma) and the abundance of foragers (highest number of individuals foraging simultaneously on a flower or on 1000 flowers [19]) where registered. The foraging speed was calculated according to Jacob - Remacle [20] using this formula:

$$Vb = (Fi/di) \times 60$$

Where *di* is the time (in second) given by a stopwatch and *Fi* the number of flowers visited during *di*. The disruption of the activity of foragers by competitors or predators and the attractiveness exerted by other plant species on *A. m. adansonii* was assessed. During each daily period of observations, the temperature and relative humidity of the station were registered using a mobile thermo-hygrometer, every one hour.

Evaluation of the impact of *Apis mellifera adansonii* and other insects on *Physalis micrantha* yields

For each year, this evaluation was based on the impact of insect visiting flowers on pollination, the impact of pollination on fructification of *P. micrantha*, 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). The fruiting rate due to the influence of foraging insects (Fr_i) was calculated as follows by Tchuenguem *et al.* [19]:

$$Fr_i = \{[(Fr_X - Fr_Y) / Fr_X] \times 100\}$$

Where Fr_X and Fr_Y were the fruiting rate in treatment *X* and treatment *Y*. The fruiting rate of a treatment (Fr) is:

$$F_r = [(F_2/F_1) \times 100]$$

Where F_2 is the number of fruits formed and F_1 the number of viable flowers initially set. 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 percentage of the number of seeds per fruit (*Ps*) due to the influence of foraging insects was calculated as follows by Tchuenguem *et al.* [19]:

$$Ps = \{[(s_X - s_Y) / s_X] \times 100\}$$

Where s_X and s_Y were the mean number of seeds per fruit in treatment *X* and *Y*. The percentage of normal seeds (*Pns*) due to the influence of foraging insects was calculated as follows by Tchuenguem *et al.* [19]:

$$Pns = \{[(ns_X - ns_Y) / ns_X] \times 100\}$$

Where ns_X and ns_Y were the percentage of normal seeds in treatment *X* and *Y*.

Evaluation of the apicultural value of *Physalis micrantha*

Like for other plant species [19 21, 22, 23], the apicultural value was evaluated using data on the flowering intensity of *P. micrantha* and the attractiveness of *A. m. adansonii* workers with respect to nectar and pollen.

Evaluation of the pollination efficiency of *Apis mellifera adansonii* on *Physalis micrantha*

To assess of the pollination efficiency of *A. m. adansonii*, three subplots carrying 9 plants with 87 flowers were bagged (treatment 5) in 2013 and three subplots carrying 9 plants with 82 flowers were bagged (treatment 6) in 2014.

Between 11 and 12 am of each observation date, the gauze was delicately opened from each subplot carrying new opened flowers and these flowers observed for up to 20 minutes. The flowers visited by *A. m. adansonii* were marked and the new opened flowers that were not visited were eliminated. The subplot was protected once more.

The contribution (Fr_x) of *A. m. adansonii* in the fruiting was calculated as follows by Tchuenguem *et al.* [19]:

$$Fr_x = \{[(Fr_Z - Fr_Y) / Fr_Z] \times 100\}$$

Where Fr_Z and Fr_Y were the fruiting rate in treatment *Z* (bagged flowers visited exclusively by *A. m. adansonii*) and treatment *Y* (bagged flowers). At the maturity, fruits were harvested from treatment 5 and treatment 6 and the number of seeds per fruit counted. The mean number of seeds per fruit and the percentage of normal seeds were then calculated for each treatment.

The percentage of the number of seeds per fruit (*Psa*) due to the influence of *A. m. adansonii* was calculated as follows by Tchuenguem *et al.* [19]:

$$Psa = \{[(s_Z - s_Y) / s_Z] \times 100\}$$

Where s_Z and s_Y were the mean number of seeds per fruit in treatment *Z* and *Y*. The percentage of normal seeds (*Pnsa*) due to the influence of *A. m. adansonii* was calculated as follows by Tchuenguem *et al.* [19]:

$$Pnsa = \{[(ns_Z - ns_Y) / ns_Z] \times 100\}$$

Where ns_Z and ns_Y were the percentages of normal seeds in treatment Z and Y.

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 the association between two variables, chi-square (χ^2) test for the comparison of two percentages using SPSS statistical software (version 19.0; SPSS, Inc., Chicago, Illinois, USA) and Microsoft Excel 2010.

Results

Reproduction system of *Physalis micrantha*

The fruiting index of *P. micrantha* was 0.60, 0.57, 0.71 and 0.66, respectively for treatments 1, 2, 3 and 4. Thus, in 2013 allogamy rate was 5.68% and autogamy rate was 94.32%. In 2014, the corresponding figures were 7.59% and 92.41%. For the two years combined, allogamy rate was 6.64% and autogamy rate was 93.37%. It appears that *P. micrantha* used in our experiments has a mixed reproduction system with the predominance of autogamy over allogamy.

Frequency of *Apis mellifera adansonii* in the floral entomofauna of *Physalis micrantha*

Among the 1105 and 1014 visits of 12 and 13 insect species counted on *P. micrantha* flower in 2013 and 2014, respectively, *A. m. adansonii* was the most represented insect with 681 visits (61.63%) and 420 visits (41.42%), in 2013 and 2014, respectively (Table 1). The difference between these two percentages is highly significant ($\chi^2 = 165.38$ [$df = 1$, $p < 0.001$]).

Table 1: Diversity of flowering insect species on *Physalis micrantha* in 2013 and 2014, number and percentage of visits of different insects

Order	Family	Insects	2013		2014	
		Genus, species, Sub-species	n_1	p_1 (%)	n_2	p_2 (%)
Diptera	Drosophilidae	*Drosophila* sp.*	36	3.26	41	4.04
	Muscidae	*Musca domestica**	66	5.97	75	7.40
	Syrphidae	*Paragus borbonicus**	13	1.18	28	2.76
Hymenoptera	Apidae	*Amegilla* sp. **	88	7.96	78	7.69

		Apis mellifera adansonii **	681	61.63	420	41.42
		Braunsapis sp. **	17	1.54	21	2.07
		Ceratina sp. **	12	1.09	14	1.38
		*Dactylurina staudingeri***	18	1.63	33	3.25
		*Lasioglossum atricum***	4	0.36	9	0.89
		*Melipoluna erythra***	13	1.18	23	2.27
	Formicidae	*Camponotus flavomarginatus**	146	13.21	252	24.85
	Megachilidae	*Megachile* sp. **			2	0.20
Lepidoptera	Acraeidae	*Acraea acerata**	11	1.00	18	1.78
Total			1105	100.00	1014	100.00

n_1: number of visits on 2212 flowers in 15days; n_2: number of visits on 1612.flowers in 15 days; P_1 and p_2: percentages of visits; $p_1 = (n_1 / 1105) \times 100$; $p_2 = (n_2 / 1014) \times 100$;

* Visitor collected nectar; ** Visitor collected nectar and pollen.

Comparison of percentages of *A. m. adansonii* visits for the two years: $\chi^2 = 165.38$ ([$df = 1$; $P < 0.001$])

Activity of *Apis mellifera adansonii* on *Physalis micrantha* flowers

Floral products harvested

During each of the two flowering periods, *A. m. adansonii* foragers were found to collect nectar and pollen on *P. micrantha* flowers (figure 2).

Fig 2: Apis mellifera *adansonii* collecting nectar in a flower of *Physalis micrantha*

Rhythm of visits according to the flowering stages

Visits were most numerous when the number of open flowers was highest (Figure 3). Furthermore, a positive and significant correlation was found between the number of *P. micrantha* opened flowers and the number of *A. m. adansonii* visits in 2013 ($r = 0.63$ [$df = 12$; $p < 0.05$]) as well as in 2014 ($r = 0.82$ [$df = 13$; $p < 0.05$]).

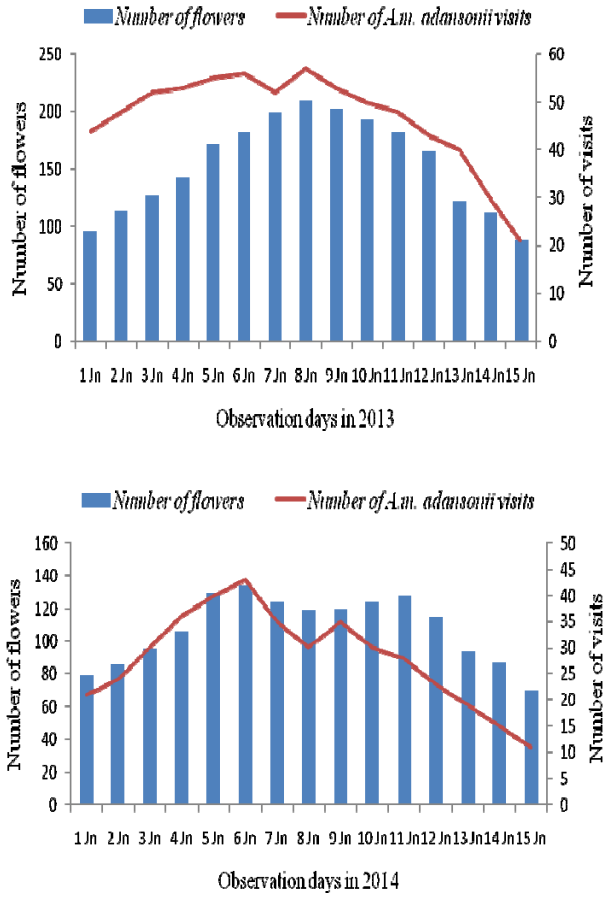

Fig 3: Variations of the number of *Physalis micrantha* opened flowers and the number *Apis mellifera adansonii* visits in function of days of observation in 2013 and in 2014. Jn : june.

Daily rhythm of visits

Apis mellifera adansonii foraged on *P. micrantha* flowers throughout the blooming period, with a peak of activity situated between 11 and 12 am (table 2). Climatic conditions have influenced the activity of *A. m. adansonii*. The correlation was: positive and significant in 2013 ($r_{2013} = 0.52$ [$df = 82$; $p < 0.05$]), between the number of *A. m. adansonii* visits on *P. micrantha* flowers and the temperature; positive and not significant in 2014 ($r_{2014} = 0.12$ [$df = 88$; $p > 0.05$]) between the number of *A. m. adansonii* visits on *P. micrantha* flowers and the temperature. It was: negative and significant ($r_{2013} = -0.51$ [$df = 82$; $p < 0.05$] between the number of visits and relative humidity in 2013; negative and not significant ($r_{2014} = -0.29$ [$df = 88$; $p > 0.05$]) between the number of visits and relative humidity in 2014.

Table 2: Daily distribution of *Apis mellifera adansonii* visits on 2212 and 1612 flowers over 15 days in 2013 and 2014 respectively, mean temperature and mean humidity of the study site

Year	Parameters	Daily period (hours)					
		7–8	9–10	11-12	13–14	15–16	17-18
2013	Number of visits	0	100	265	215	101	0
	Temperature (°C)	24.44	26.47	29.21	30.56	29.41	25.95
	Hygrometry (%)	57	53.64	45	41.14	45.07	56.07
2014	Number of visits	0	99	188	94	39	0
	Temperature (°C)	23.53	25.24	27.22	30.04	28.41	26.34
	Hygrometry (%)	54.79	57.14	49.07	44.86	50.36	53.57

Abundance of *Apis mellifera adansonii*

In 2013, the highest mean number of *A. m. adansonii* simultaneously in activity was one per flower (n = 48; s = 0) and 83 per 1000 flowers (n = 55; s = 42; maxi= 209). In 2014, the corresponding figures were one per flower (n = 70; s = 0) and 73 per 1000 flowers (n= 58; s = 40; maxi = 167). The difference between the mean number of foragers per 1000 flowers in 2013 and 2014 was highly significant (t = 6.70 [df = 111, $p < 0.001$]).

Duration of visits per flower

In 2013 and 2014, the mean duration of *A. m. adansonii* visit was 34.57 sec (n = 166; s = 26.31; *maxi* = 186.78 sec) and 33.52 sec (n = 183; s = 19.08; *maxi* = 94.21 sec) respectively. The difference between these two means was highly significant (t = 3.99 [df = 347; $P < 0.001$]). For the two cumulated years, the mean duration of a flower visit was 34.02 sec (n = 349, s = 22.78).

Apicultural value of *Physalis micrantha*

During the two flowering periods of *P. micrantha*, a well elaborated activity of *A. m. adansonii* workers was registered on flowers. In particular, there were good daily and seasonal frequency of visits, high density of workers per plant, good nectar harvest, good pollen collection and fidelity of the workers to flowers. Furthermore, each *P. micrantha* plant can produce 80 to more than 250 flowers. These data point out the good attractiveness of *P. micrantha* nectar and pollen to *A. m. adansonii*. They allow *P. micrantha* to be classified as a highly nectariferous and polliniferous bee plant.

Impact of insect activity on pollination and pollination efficiency of *Apis mellifera adansonii* on yields of *Physalis micrantha*

During nectar and pollen harvest from *P. micrantha*, foraging insects always shook flowers and are regularly made contact with the anthers and stigma, increasing the possibility of *P. micrantha* pollination. The comparison of the fruiting rate (Table 3) revealed that the differences observed were significant between treatment 1 and treatment 2 (χ^2 = 4.62 [df = 1; $p < 0.05$]) and highly significant between treatment 3 and treatment 4 (χ^2 = 7.11 [df = 1; $p < 0.01$]). In all the visited flowers, *A. m. adansonii* made contact with the anthers and stigma and carried pollen. With this pollen, the bee flew frequently from flower to flower of the same species. The comparison of the fruiting rate (Table 3) revealed that the differences observed were highly significant between treatment 2 and treatment 5 (χ^2 = 5.42 [df = 1; $P < 0.01$]) and not significant between treatment 4 and treatment 6 (χ^2 = 0.66 [df = 1; $P > 0.05$]).

Table 3: Fruiting rate, mean number of seeds per pod and percentage of normal seeds according to the treatments of Physalis micrantha

Year	Treatments	Nfs	Nff	Fr	Nspf		Nsf	Nns	Pns
					m	sd			
2013	1 (Fup)	2212	1320	59.91	365	132	18272	18060	98.84
	2 (Fpp)	1799	1013	56.51	352	111	17596	17344	98.57
	5 (Fvx)	87	60	68.97	367	90	14696	14404	98.01
2014	3 (Fup)	1612	1122	70.89	369	74	18432	18144	98.44
	4 (Fpp)	1524	1000	65.51	335	84	16752	16308	97.35
	6 (Fvx)	82	57	71.46	370	89	14788	14452	97.73

Fup: flowers from unprotected plants; Fpp: flowers from protected plants; Fvx: flowers visited exclusively by *A. m. adansonii*; Nfs: number of flowers studied; Nff: number of fruits formed; Fr: fructification rate; Nspf: number of seeds per fruit; *m*: mean; sd: standard deviation; Nsf: number of seeds formed; Nns: number of normal seeds; Pns: percentage of normal seeds.

From Table 3, we documented the following:

(1) The Fruiting rate or fruit formation was higher in flowers left unprotected for unlimited visits (where high diversity of insects was observed) than in the bagged flowers. The percentage of fruiting rate attributed to insect activity was 05.03%.

(2) The Fruiting rate was higher in *A. m. adansonii* visited flowers than in flowers left unprotected for unlimited visits. This suggests a high pollination deficit in the crop, indicating the need for *A. m. adansonii* management to increase fruiting. The percentage of fruiting rate due to *A. m. adansonii* activity was 2.66%.

(3) The mean number of seeds per fruit was higher in flowers left unprotected for unlimited visits than in the bagged flowers. The comparison of the mean numbers of seeds per pod revealed that the differences observed were highly significant between treatment 1 and treatment 2 (t = 2.74 [df = 98; $P < 0.001$]) and treatment 3 and treatment 4 (t = 10.53 [df = 98; P< 0.001]). The percentage of the number of seeds per pod due to insect activity was 6.41%.

(4) The number of seeds per fruit was also higher in *A. m. adansonii* visited flowers than in the bagged flowers, demonstrating that although *P. micrantha* has a high autogamous tendency, allogamy would increase yields significantly. The comparison of the mean numbers of seeds per pod revealed that the differences observed were highly significant between: treatment 2 and treatment 5 (t = -3.32 [df = 88; $P < 0.001$]); treatment 4 and treatment 6

(t = -8.83 [df = 88; P < 0.001]). The percentage of the number of seeds per pod attributable to *A. m. adansonii* activity was 3.03%.

(5) Normal seed yield in flowers left unprotected for unlimited visits was higher than that in the bagged flowers. The comparison of the percentages of normal seeds revealed that the differences observed were highly significant between: treatment 1 and treatment 2 (χ^2 = 5.19 [df = 1; p < 0.01]); treatment 3 and treatment 4 (χ^2 = 50.99 [df = 1; p < 0.001]). The percentage of normal seeds attributed to the influence of insects was 0.69%.

(6) Normal seed yield in *A. m. adansonii* visited flowers was lower than that in flowers left unprotected for unlimited visits. This reveals a low pollination in the crop. The comparison of the percentages of normal seeds revealed that the differences observed were highly significant between treatment 2 and treatment 5 (χ^2 = 14.88 [df = 1; P < 0.001]) and significant between treatment 4 and treatment 6 (χ^2= 4.66 [df = 1; P < 0.05]). The percentage of normal seeds attributed to *A. m. adansonii* activity was 0.32%.

Discussion

A mixed reproduction regime with the predominance of autogamy over allogamy could be explained by the structure of the flower [24]. The flowers are self-compatible and usually self-pollinated [25, 26]. *P. micrantha* is a self-compatible plant, but may nevertheless benefit from pollinator visitation, as has been demonstrated for other self-compatible crops [27, 28]

A. m. adansonii was the main floral visitor of *P. micrantha* during the observation periods. In cape gooseberry (*Physalis peruviana*) fields, the presence of potential pollinators such as *Bombus* spp. *Xylocopa* spp. and *A. mellifera* has been reported [29]. Bumblebees are described as the main pollinator of *Physalis* species [30] but Connolly and Anderson [31] also observed *Lassioglosum* spp. visiting the flowers in Connecticut. This could be due to the fact that the abundance and diversity of insects floral of a plant vary depending on the regions [1].

The significant difference between the percentages of *A. m. adansonii* visits for the two studied years could be attributed to the variation of the abiotic factor (Temperature and relative humidity) as reported by Julianna & Rufus [32] on Highbush blueberry (*Vaccinium corymbosum*) in America.

The peak in *A. m. adansonii* activity on *P. micrantha* in the morning is correlated with the availability of nectar and/or pollen in *P. micrantha* flowers; similarly, this is the period during which the stigma of *P. micrantha* flowers has optimal receptivity for pollen or the weather conditions. In fact, Bramel *et al*. [33] and Julianna & Rufus [32] reported that the weather during bloom affects abundance and foraging of insect pollinators. The high abundance of *A. m. adansonii* on 1000 flowers and the positive and significant correlation between the number of *P. micrantha* flowers bloom and number of *A. m. adansonii* visits underscore the attractiveness of *P. micrantha* floral products to this bee.

As a highly nectariferous and polliniferous apicultural plant, *P. micrantha* could be cultivated and protected to strengthen *A. m. adansonii* colonies.

The significant difference observed between the duration of visits in 2013 and 2014 could be explained by visits interruptions by other insects' visit. Interruption takes place when there is a heavy rain, collisions between visitors, visitor capture attempts by a predator or approach the flower already occupied by a first visitor.

The present study shows that during one foraging trip, an individual bee foraging on a given plant species scarcely visited another plant species. This result indicates that *A. m. adansonii* shows flower constancy [34] for the flowers of *P. micrantha* studied. Flower constancy is an important aspect in management of pollination and this shows *A. m. adansonii* can provide the advantages of pollination management for *P. micrantha*. Investment in *A. m. adansonii* management may provide high returns to investment on this crop. During the collection of nectar and pollen on each flower, *A. m. adansonii* foragers regularly come into contact with the stigma. They could enhance auto-pollination, which has been demonstrated in the past [35, 36]. *A. m. adansonii* would provide allogamous pollination through carrying of pollen with their furs, legs and mouth accessories, which is consequently deposited on another flower belonging to different plant of the same species [37].

The positive and significant contribution of *A. m. adansonii* in the fruit and seeds yields of *P. micrantha* is justified by the action of this bee on pollination. The yield (fruits, seeds, percentage of normal seeds in fruits) recorded in all the treatment can be attributed to the predominance of autogamy of this specie and the important role of the pollinating insects. The flowers that were exposed to pollinators provided more fruits and more seeds than protected plants, in agreement to previous results reported on other solanaceous crop species in Mexico [38] and in Western Kenya [39]. The high fruiting rate observed in 2014 compared to 2013 could be explained by the high number of visitation of the main pollinators. The significant contribution of *A. m. adansonii* and other insects in the fruit and seeds yields of *P. micrantha* is similar to the findings in New Zealand [36] and Ghana [40] which showed that solanaceous crops produce less seeds per pod in the absence of efficient pollinators. Similar experiments on crop species realized in Brazil [41] have shown that pollination by insects was not always needed. Thus, pollination requirements may differ between plant varieties and /or region.

Conclusion

In Bambui, Cameroon, *P. micrantha* is a highly nectariferous and polliniferous bee plant that benefits from pollination by insects, among which *A. m. adansonii* is the most important. The comparison of fruits and seeds set of unprotected flower with that of flower visited exclusively by *A. m. adansonii* underscores the value of this bee in increasing fruit and seed yields as well as seed quality. The investment in management of *A. m. adansonii* in terms of nest provision at the proximity of *P. micrantha* field is worthy while for growers.

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