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Full Length Research Paper

Foraging and pollination behavior of *Apis mellifera adansonii* L. (Hymenoptera, Apidae) on *Phaseolus vulgaris* (Fabaceae) flowers at Maroua (Cameroon)

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Abstract

To evaluate the impact of *Apis mellifera adansonii* on pod and seed yields of *Phaseolus vulgaris* (red and small seeds), its foraging and pollinating behavior were studied in Maroua, during the June-August 2010 and 2011 cropping seasons. Treatments included unlimited floral access by all visitors, bagged flowers to avoid all visits, and limited visits of *A. m. adansonii*. Observations were made on 108 flowers per treatment of which all flower visitors were recorded. The bee seasonal rhythm of activity, its foraging behavior on flowers, and its pollination efficiency (fruiting rate, number of seeds/pod and percentage of normal seeds) were recorded. Twenty-four insect species visit *P. vulgaris* flowers. *A. m. adansonii* was the most frequent visitor and they intensely and exclusively foraged nectar. The foraging speed was 27.98 flowers/min. The foraging activity of *A. m. adansonii* resulted in a significant increase in fruiting rate by 61.25 and 49.38%, the number of seeds/pod by 28.54 and 9.66% and the normal seeds/pod by 8.18 and 7.25%, respectively in 2010 and 2011. Hence, conservation of *A. m. adansonii* hive close to *P. vulgaris* crop fields should be recommended to improve pod and seed production in the region.

Keywords: *Apis mellifera adansonii, Phaseolus vulgaris*, Foraging, Nectar, Pollination.

INTRODUCTION

Very little information exists on the relationships between flowering insects and many plant species in Cameroon. It is well known that anthophilous insects including bees usually increase fruit and seed yields of many plant species, through pollination provision (Keller and Waller 2002, Fluri and Frick 2005, Sabbahi et al., 2005, Klein et al., 2007, Tchuenguem Fohouo et al., 2009a). In Cameroon the investigation on *Phaseolus vulgaris* are made by Kingha et al., (2012) in Ngaoundéré. *P. vulgaris* is an annual plant originated from South and Central America (Graham et al., 1997). Bean plants are bushy or upright (40 to 60 cm). Climbing stems are slightly branched; they can reach two to three meters high. The leaves are stalked, alternate and compound trifoliate, green or purple. Flowering starts 28-35 days after sowing, the flower is pink, but can vary from white to purple depending on the different varieties (Debouck 1991) and produces nectar/pollen which attract insects. The plant is autogam/allogam (Ibarra-Perez et al., 1999). Self-pollination is the rule; cross-pollination by insects is generally observed (Mackie and 1935, Barrons 1939, Wells et al., 1988, Ibarra-Perez et al., 1997, Kingha et al., 2012). In Cameroon, *P. vulgaris* is cultivated in all regions as vegetable and can be consumed raw or cooked, or transformed into flour, while the stems and leaves are used to feed livestock (Debouck 1991). Currently the production of *P. vulgaris* in Cameroon is 200,000 tons, but the projections of production is 354,000 tons by 2015 (MINADER, 2006). Therefore, it is important to investigate on the possibilities of increasing the production of this plant in Cameroon. *P. vulgaris* flowers were reported to produce fewer seeds per pod in the absence of efficient pollinators in the United States of America (Ibarra-Perez et al., 1999). Recent research conducted in Kenya (Kasina et al., 2009) in Cameroon Pando et al., 2011a and kingha et al., 2012 has revealed *A. m. mellifera* visiting *P. coccineus and P. vulgaris* flowers respectively.

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Prior to these studies, no previous research has been reported on the relationships between *P. vulgaris* and its anthophilous insects in the Far North Region of Cameroon, although, the activity and diversity of flowering insects of a plant species vary with regions (Roubik 2000). During preliminary investigations on flower-insect relationships in Maroua before 2009 (unpublished data), *A. m. adansonii* has been seen intensively visiting flowers of *P. vulgaris (small red seeds).* The main objective of this research was to gather more data on the relationships between *P. vulgaris* and flower visiting insects in Maroua, for optimal management of pollination services in Cameroun. Specific objectives were the registration of the activity of *A. m. adansonii* on *P. vulgaris* flowers, the evaluation of the impact of visiting insects on pollination, pods and seeds yields of this Fabaceae, and the estimation of pollination efficiency of *A. m. adansonii* on this plant.

MATERIALS AND METHODS

Study site, experimental plot and biological material

The studies were conducted from June-August in 2010 and 2011 respectively in the locality of Maroua (Latitude 10 ° 62 'N, Longitude 14 ° 33' E and altitude 400 m), region of the Far North. This region belongs to the ecological zone with three phytogeographical areas: Sahel-Sudanian, Sahelian and Sudanian altitude periodically flooded, with unimodal rainfall (Letouzey 1985). It has a Sahel-Sudanian climate type, characterized by two annual seasons: a long dry season (November to May) and a short rainy season (June to October); August is the wettest month of the year (Kuete et al., 1993). Annual rainfall varies from 400 to 1100 mm (Kuete et al., 1993). The annual average temperature varies between 29 and 38 ° C and a daily temperature range between 6 and 7 ° C (Kuete et al., 1993). The experimental plot is an area of 156 m^2. The animal material was represented by insects naturally present in the environment and a colony of *Apis mellifera adansonii* Latreilles (Hymenoptera: Apidae), housed in a tree located 900 m from the experimental plot. Vegetation was represented by wild species and cultivated plants. The plant material was represented by small red seeds of *P. vulgaris* provided by IRAD.

Sowing and weeding

On June 12, 2010 and June 15, 2011, the experimental plot was prepared and divided into 24 subplots, each measuring 1 × 1.5 m. Two seeds were sown in 2 lines per subplot, each of which had 5 holes per line. Holes were separated 30 cm from each other, while lines were 80 cm apart. Weeding was performed manually as necessary to maintain plots weed-free.

Determination of the reproduction system of *P. vulgaris*

July 8, 2010, 5 inflorescences de *P. vulgaris* at the bud stage were labelled on each subplot, giving a total of 216 flowers. 108 of the total flowers were allowed to be open pollinated (treatment 1) whilst the other 108 were bagged with gauze bag to prevent visitors or external pollinating agents (treatment 2). On July 16, 2011, the experiment was repeated. 20 days after shading of the last flower, the numbers of pods were assessed in each treatment. The podding index (*Pi*) was then calculated as described by Tchuenguem et al., (2001):

$Pi = F2/F1$

Where *F2* is the number of pods formed and *F1* the number of viable flowers initially set.

The allogamy rate (*Alr*) from which autogamy rate (*Atr*) was derived was expressed as the difference in podding indexes between unprotected flowers (treatment 1) and protected flowers (treatment 2) as follows (Demarly 1977):

$Alr = [(Pi1 - Pi2) / Pi1] \times 100$

Where *Pi1* and *Pi2* are respectively the podding average indexes of treatments 1 and 2.

$Atr = 100 - Alr$

Assessment of foraging activity of *A. m. adansonii* on *P. vulgaris* flowers

Observations were conducted on 108 individual opened pollinated flowers of treatment 1 each day from July 17 to 27, 2010 and from July 25, to August 5, 2011 at 1 h interval from 6.00 to 18.00 h (7 – 8 h, 9 – 10 h, 11 – 12 h, 13 – 14 h, 15 – 16 h et 17 - 18h). In a slow walk along all labelled flowers of treatment 1, the identity of all insects that visited *P. vulgaris* flowers was recorded. All insects encountered on flowers were recorded and the cumulated results expressed in number of visits to determine the relative frequency of *A. m. adansonii* in the anthophilous entomofauna of *P. vulgaris*.

In addition to the determination of the floral insect's frequency, direct observations of the foraging activity on flowers were made on insect pollinator fauna in the experimental field. The floral rewards (nectar or pollen) harvested by *A. m. adansonii* during each floral visit were registered based on its foraging behavior. Nectar foragers were expected to extend their proboscis to the base of the corolla and the stigma, while pollen gatherers were expected to scratch the anthers with their mandibles or legs (Jean-Prost 1987).

In the morning of each day, the number of opened flowers was counted. The same days as for the frequency of visits, the duration of individual flower visits was recorded (using a stopwatch) at least six times at hourly intervals between 07.00 and 18.00 h. Moreover, the number of pollinating visits which was defined as

contact between the bees and stigma upon a visit (Jacob-Remacle 1989; Freitas, 1997), the abundance of foragers defined as the highest number of individuals simultaneously foraging on a flower/or 1000 flowers (*A1000*) (Tchuenguem et al., 2004) and the foraging speed, which is the number of flowers visited by a bee per minute (Jacob-Remacle, 1989) were measured. The abundance of insects per flower was recorded following the direct counting, during the same dates and daily periods as for the registration of the duration of visits. The foraging speed (*Vb*) was calculated according to Tchuenguem et al., (2004). 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 by direct observations. The temperature and relative humidity in the station were also registered every 30 min using a mobile thermo-hygrometer during all sampling periods.

Evaluation of the effect of *A. m. adansonii* and other insects on *P. vulgaris* yields

This evaluation was based on the impact of visiting insects on pollination, the impact of pollination on fructification of *P. vulgaris*, and the comparison of yields (fruiting rate, mean number of seeds per pod and percentage of normal or well developed seeds) of treatments 1 and 2 (open and bagged pollinated flowers). The fruiting rate due to the influence of activity of insects (*Fri*) was calculated by the formula:

$Fri = \{[(Fr1 - Fr2) / Fr1] \times 100\}$

Where *Fr1* and *Fr2* are the fruiting rate in treatments 1 and 2. The fruiting rate (*Fr*) is:

$Fr = [(F2/F1) \times 100]$

Where *F2* is the number of pods formed and *F1* the number of opened flowers initially set.

At maturity, pods were harvested from each treatment and the mean number of seeds per pod and the percentage of normal seeds were then calculated for each treatment.

Assessment of the pollination efficiency of *A. m. adansonii* on *P. vulgaris*

To evaluate of the pollination efficiency of *A. m. adansonii*, 60 and 70 flowers were isolated (treatment 3) respectively in 2010 and 2011. Between 6 and 7 a.m. of each observation date, the gauze bag was delicately removed from each opened flower and this flower observed for up to 10 min. The flowers visited by *A. m. adansonii* were labeled after this manipulation. The contribution (*Frx*) of *A. m. adansonii* to fruiting was calculated by the formula:

$Frx = \{[(Fr3 - Fr2) / Fr3] \times 100\}$

Where *Fr3* and *Fr2* are the fruiting rates in treatment 3 (protected flowers visited exclusively by A. m. adansonii) and treatment 2 (protected flowers).

At maturity, pods were harvested from treatment 3 on which the number of seeds per pod were counted. The mean number of seeds per pod and the percentage of normal seeds were then calculated for each treatment.

Data analysis

Data were analyzed using descriptive statistics with Microsoft Excel 2007, 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 ($\chi 2$) for the comparison of percentages.

RESULTS

Reproduction system of *P. vulgaris*

Podding index of *P. vulgaris* was 0.50 and 0.29 respectively for treatment 1 and 2 in 2010 and 0.53 and 0.37 in 2011. Thus, in 2010 the allogamy rate was 41.83% and the autogamy rate was 58.16%; whereas in 2011, the allogamy rate was 29.31% and the autogamy rate was 70.68%. It appears that the variety of *P. vulgaris* used in our experiments (small red seeds) has a mixed reproduction regime that is autogamous-allogamous, with the predominance of autogamy over allogamy.

Activity of *A. m. adansonii* on *P. vulgaris* flowers

Frequency of floral entomofauna of *P. vulgaris*

Amongst the 348 visits of 20 insect species in 2010 and 325 visits of 20 insect species in 2011 recorded on *P. vulgaris* flowers, *A. m. adansonii* was the most frequent insect with 67 visits (19.25 %) and 55 visits (16.92 %), in 2010 and 2011, respectively (Table 1). The difference between these two percentages is not significant ($\chi 2$ = 0.61, $df = 1$, $p > 0.05$).

Floral rewards harvested

During each of the two flowering periods, *A. m. adansonii* was found to intensively and regularly collect nectar from *P. vulgaris* but no pollen collection was observed.

Relationship between visits and flowering stages

From Figure 1, a positive and significant correlation was found between the number of *P. vulgaris* opened flowers

Table 1: Diversity of floral insects on *P. vulgaris* flowers in 2010 and 2011, number and percentage of visits of different insects.

Insects			2010		2011	
Order	**Family**	**Genus, species, sub - species**	**n**	**p%**	**n**	**p%**
Hymenoptera	Apidae	*Apis mellifera adansonii* [n]	67	19.25	55	16.92
		Amegilla sp. [p]	9	2.59	0	0.00
		Thyrus sp. [p]	2	0.57	0	0.00
		Xylocopa sp. [p]	7	2.01	11	3.38
	Formicidae	*Polyrachis* sp. [n]	21	6.03	31	9.54
	Halictidae	*Lipotriches collaris* [n]	62	17.82	52	16.00
		Macronomia vulpina [n]	18	5.17	15	4.62
	Megachilidae	*Chalicodoma* sp. [n]	3	0.86	14	4.31
		Megachile sp. [n]	1	0.29	0	0.00
	Sphecidae	*Philanthus triangulum* [pr]	0	0.00	9	2.77
	Vespidae	*Synagris cornuta* [n]	5	1.44	3	0.92
Diptera	Calliphoridae	(sp. 1) [p]	9	2.59	15	4.62
		(sp. 2) [p]	11	3.16	4	1.23
Coleoptera	Scarabeidae	(sp. 1) [p]	41	11.78	37	11.38
		(sp. 2) [p]	3	0.86	0	0.00
Hemiptera	Coreidae	*Anoplocnemis curvipes* [p]	15	4.31	8	2.46
Lepidoptera	Acraeidae	*Acraea acerata* [n]	24	6.90	16	4.92
	Pieridae	*Catopsilia florella* [n]	29	8.33	25	7.69
	Pieridae	(sp. 1) [n]	0	0.00	6	1.85
Orthoptera		(1 sp.) [p]	12	3.45	7	2.15
		(2 sp.) [p]	7	2.01	2	0.62
Dictyoptera	Mantodae	(sp. 1) [pr]	0	0.00	5	1.54
Nevroptera		(sp. 1) [pr]	2	0.57	4	1.23
		(sp. 2) [pr]	0	0.00	6	1.85
Total		24 species	348	100	325	100

Comparison of percentages of *Apis mellifera adansonii* visits for two years: $\chi 2 = 0.61$ ([$df = 1$; $p > 0.5$]).
n1: number of visits on 108 flowers in 10 days.
n2: number of visits on 108 flowers in 10 days.
p1 and p2: percentages of visits.
p1 = (n1 / 348) x 100.
p2= (n2 / 325) x 100.
n: visitor collected nectar.
p: visitor collected pollen.
pr: predation.
1 sp.: undetermined species.

and the number of *A. m. adansonii* visits in 2010 ($r = 0.75$; $df = 8$; $p < 0.05$) as well as, in 2011 ($r = 0.72$; $df = 8$; $p < 0.05$).

Diurnal flower visits

A. m. adansonii foraged on *P. vulgaris* flowers throughout the day, with a peak of activity at 6 and 8 h (Figure 2). The activity of *A. m. adansonii* was influenced by climatic conditions. In 2010, the correlation between the number of *A. m. adansonii* visits on *P. vulgaris* flowers and the temperature was negative and highly significant ($r = -0.93$; $df = 11$; $p < 0.001$), but was positive and significant ($r = 0.78$; $df = 11$; $p < 0.05$) between the number of *A. m. adansonii* visits and relative humidity. In 2011, the correlation was negative and highly significant at ($r = -0.90$; $df = 11$; $p < 0.05$) between the number of *A. m. adansonii* visits on *P. vulgaris* flowers and the temperature, positive and significant ($r = 0.70$; $df = 11$;

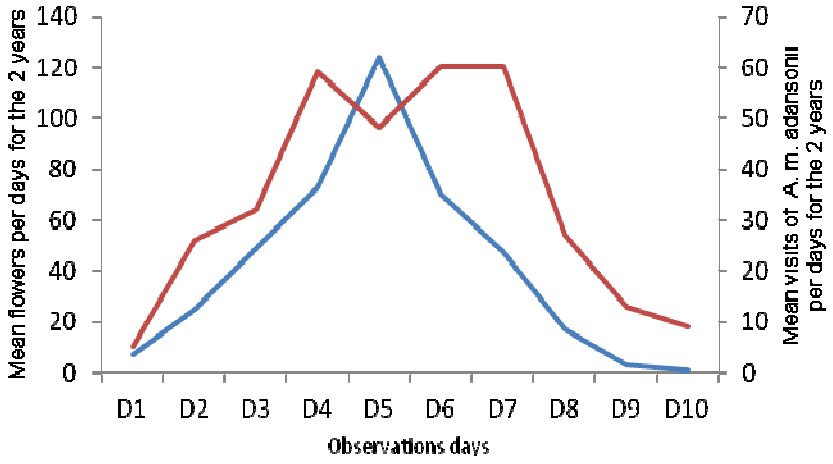

Figure 1. Variation of number of flowers and number of visits of *A. m. adansonii,* on the flowers *P. vulgaris* in 2010; 2011.

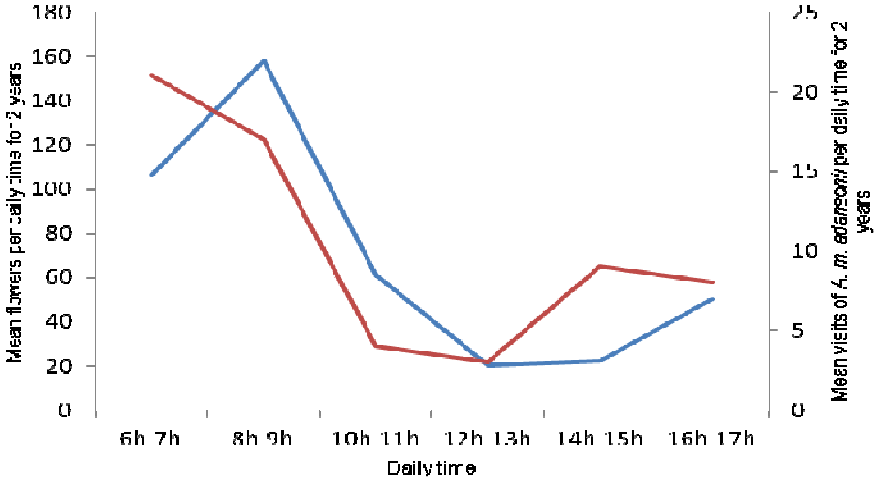

Figure 2. Variation of number of flowers and visits of *A. m. adansonii* on the flowers of *P. hirsutum* according to daily time in 2010, 2011.

$p < 0.05$) between the number of *A. m. adansonii* visits and relative humidity (Table 2).

Abundance of *A. m. adansonii*

In 2010, the highest mean number of *A. m. adansonii* simultaneously in activity was 1 per flower (n = 50; s = 0) and 194.92 per 1000 flowers (n = 46*;* s = 178.68*;* maxi = 500). In 2011, the corresponding figures were 1 (n = 50; s = 0) and 110.47 (n = 41; s = 109.51*;* maxi = 333). The difference between the mean number of foragers per 1000 flowers in 2010 and 2011 was highly significant (t = 12.36; df = 85, $p < 0.001$).

Duration of visits per flower

In 2010, the mean duration of a flower visit was 1.77 s (n = 67*;* s = 0.69; maxi = 7 s). In 2011, the corresponding data was 2.13 s (n = 55; s = 0.95; maxi = 9 s), giving a highly significant difference (t = - 13.84; df = 120, p < 0.001) between the two years. For the two cumulated years, the mean duration of a flower visit was 1.95 s.

Table 2. Daily distribution of *A. m. adansonii* on 108 *P. vulgaris* flowers over 10 days in 2010 and 2011, mean temperature and mean humidity of the study site

Year	Parameter registered	Daily period					
		6h-7h	8h-9h	10h-11h	12h-13h	14h-15h	16h-17h
2010	Number of visits	23	19	5	3	9	8
	Temperature (^{O}C)	29.12	31.95	34.5	37.54	36.14	34.52
	Hygrometry (%)	72.4	63.8	59.2	52.4	46.9	48.8
2011	Number des visits	18	14	3	2	8	7
	Temperature (^{O}C)	27.2	31.4	34.06	37.21	35.9	34.34
	Hygrometry (%)	71.8	63.8	59.79	52.9	47.2	49.11

2010: for temperature and hygrometry, each figure represents the means of 50 observations.

2011: for temperature and hygrometry, each figure represents the means of 50 observations.

Table 3. *P. vulgaris* yields under pollination treatments.

Treatment	Year	Flowers	Pods	Fruiting rate (%)	Seeds / pod		Total seeds	Normal seeds	% normal seeds
					Mean	sd			
Unlimited visits	2010	108	55	50.92	4.57	1.43	237	219	92.40
Bagged flowers	2010	108	32	29.62	3.33	1.39	99	84	84.84
Unlimited visits	2011	108	58	53.70	5.62	1.25	298	286	95.97
Bagged flowers	2011	108	41	37.96	4.86	1.05	173	154	89.01
A. m. adansonii	2010	51	39	76.47	4.66	1.24	163	158	96.93
A. m. adansonii	2011	44	33	75.00	5.38	1.12	169	162	95.85

Foraging speed of *A. m. adansonii* on *P. vulgaris* flowers

On *P. vulgaris* plants, *A. m. adansonii* visited between 2 and 51 flowers/min in 2010 and between 3 and 50 flowers/min in 2011. The mean foraging speed was 29.58 flowers/min (n = 56; s = 11.36) in 2010 and 25.76 flowers/min (n = 41; s = 10.02) in 2011. The difference between these means was significant (t = 8.68; df = 95, p < 0.001). For the two cumulated years, the mean foraging speed was 27.98 flowers / min.

Impact of anthophilous insects on pod/set formation and seed yields of *P. vulgaris*

During nectar harvest on *P. vulgaris*, some foraging insects always shake flowers and contact anthers and stigma increasing the cross and self pollination possibility of *P. vulgaris*. (Table 3),

a - When the fruiting rate was compared the differences observed were highly significant between free opened flowers (treatment 1) and bagged flowers (treatment 2), the first year ($\chi 2 = 10.18$, $df = 1$, $p < 0.001$) and the second year ($\chi 2 = 5.39$, $df = 1$, $p < 0.01$). The difference between the two years as far as treatment 1 is concerned was not significant ($\chi 2 = 0.17$; $df = 1$; $p > 0.05$). Consequently, the fruiting rate of the unprotected flowers was higher than that of protected flowers in 2010 and in 2011. The fruiting rate due to the action of flowering insects was 41.83% in 2010 and 29.31% in 2011. For all of the flowers studied, the fructification rate attributed to the influence of insects was 35.57%.

b - There was a highly significant difference between treatments 1 and 2 (t = 18.14; df = 85; p<0.001) the first year and the second year (t = 9.50; df = 97; p<0.001) as far as the mean number of seeds per pod is concerned (Table 3). For treatment 1, the difference between the two studied years was significant at (t = - 9.54; df = 111; p<0.001). Consequently, a high mean number of seeds per pod in opened flowers (treatment 1) were noticed compared to bagged flowers (treatments 2). The number of seeds per pod attributed to the activity of flowering insects was 27.13% in 2010 and 13.52% in 2011, giving an overall mean of 20.32%.

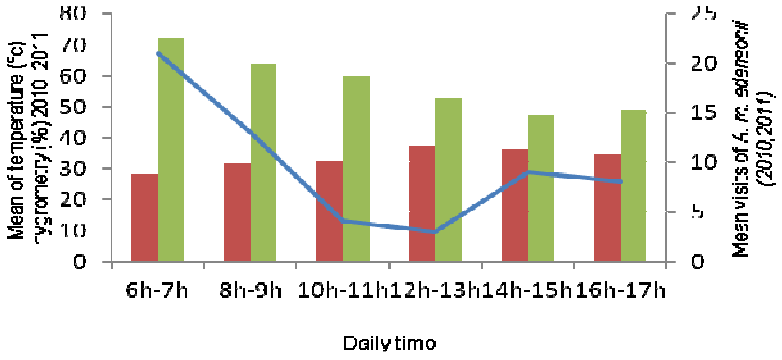

Figure 3. Mean daily of temperature and humidity and mean number of visits of *A. m. adansonii*, on the flowers of *P. vulgaris* in 2010, 2011.

c - The comparison of the percentage of normal seeds (Table 3) indicate that there were significant difference between free opened flowers (treatment 1) and bagged flowers (treatment 2) the first year ($\chi 2$= 4.50 ; df = 1; p < 0.01) and the second year ($\chi 2$= 8.61; df = 1; p<0.001). For treatment 1, the difference between the two studied years was significant ($\chi 2$= 3.18; df = 1; p < 0.01). Thus, the percentage of normal seeds in opened flowers was higher than that of protected flowers in 2010 and 2011. The percentage of the normal seeds due to the action of insects was 8.18% in 2010 and 7.27% in 2011. For all the flowers studied, the percentage of the normal seeds due to flowering insects was 7.72%.

Pollination efficiency of *A. m. adansonii* on *P. vulgaris*

During the nectar harvest from flowers, foragers were always in contact with the stigma and the anthers. The total number of visits expressed as percentage during which foragers bees came into contact with anthers and stigma was 100% during nectar harvest. Thus, this bee highly increased the pollination of *P. vulgaris* flowers.

a - The comparison of the fruiting rate (Table 3) shows that the differences observed were highly significant between treatments 2 and 3 ($\chi 2$ = 30.75; df = 1; p < 0.001) in 2010, treatments 2 and 3 ($\chi 2$ = 17.17; df = 1; p < 0.001) in 2011 and treatment 3 of the two years was not significant ($\chi 2$ = 0.03; df = 1; p > 0.05). The fruiting rate of flowers exclusively visited by *A. m. adansonii* (treatment 3) was significantly higher than that of flowers bagged during their flowering period (treatment 2) in 2010 and in 2011. The fruiting rate due to *A. m. adansonii* activity was 61.26% in 2010 and 49.38% in 2011. For all the flowers studied, the fruiting rate attributed to the influence of *A. m. adansonii* was 55.32%.

b - The comparison of the mean number of seeds per pod (Table 3) revealed that the differences observed were highly significant between treatments 2 and 3 (t = 17.97; df = 69; p < 0.001) in 2010 and treatments 2 and 3 (t = 8.81; df = 72; p < 0.001) in 2011. The difference between treatment 3 in the two studied years was significant (t = 10.90; df = 70; p < 0.001). Therefore, high mean number of seeds per pod of flowers visited exclusively by *A. m. adansonii* (treatment 3) when compared to bagged flowers (treatment 2). The percentage of the number of seeds per pod due to *A. m. adansonii* was 28.54% in 2010 and 9.66% in 2011. For all the flowers studied, the percentage of the number of seeds per pod attributed to the influence of *A. m. adansonii* was 19.10%.

c - The normal seeds expressed as percentage (Table 3) demonstrates that the differences were highly significant between bagged flowers and flowers exclusively visited by *A. m. adansonii* ($\chi 2$ = 12.76; df = 1; p < 0.001) in 2010, and in 2011 at ($\chi 2$ = 5.69; df = 1; p < 0.01), and non significant between flowers exclusively visited by *A. m. adansonii* in the two studied years ($\chi 2$ = 0.27; p > 0.05). The percentage of normal seeds of bagged flowers and those exclusively visited by *A. m. adansonii* was higher than that of protected flowers in 2010 and 2011. The percentage of the normal seeds due to *A. m. adansonii* was 8.18% in 2010 and 7.25% in 2011. For all the flowers studied, the percentage of the number of seeds per pod attributed to the influence of *A. m. adansonii* was 7.71%.

DISCUSSION

A.m. adansonii was the main floral visitor of *P. vulgaris*

during the observation period. *A. m. mellifera* in Western Kenya (Kasina et al., 2009) have been reported as the main floral visitor of this crop. *A. m. adansonii* was shown to be the most abundant floral visitors of *P. coccineus* in Yaoundé (Pando et al., 2011a) and *P. vulgaris* in Ngaoundéré (Kingha et al., 2012). The significant difference between the percentage visits of *A. m. adansonii* within studied years could be attributed to the experimental site variation.

The peak activity of *A. m. adansonii* on *P. vulgaris* flowers was located between 7.00 and 8.00 h, which correlated with the highest availability period of nectar on *P. vulgaris* flowers.

However, this decreased activity from 11.00 to 13.00 h could be related to increased temperature in the experimental field. Although, foragers preferred warm or sunny days for good floral activity (Kasper et al., 2008), the enhanced temperature positively influenced the insect activity on foraged flowers. Similarly, rainfall has been documented as an environmental factor that can disrupt the floral insect activity (McGregor, 1976).

The abundance of *A. m. adansonii* foragers on 1000 flowers and the positive and highly significant correlation between the number of *P. vulgaris* flowers as bloom, as well as, the number of *A. m. adansonii* visits indicates the attractiveness of *P. vulgaris* nectar with respect to this bee. In fact, weather during bloom was demonstrated to affect the abundance and foraging of pollinator insects (Bramel et al., 2004, Julianna and Rufus, 2010). Among the 24 insect species visiting *P. vulgaris* flowers, *A. m. adansonii* was the most abundant (18.06%), followed by *Lipotriches collaris* (16.91%).

The significant difference between the duration of visits in 2009 and 2010 could be attributed to the availability of floral products or the variation of diversity of flowering insects from one year to another. During each of the two flowering periods of *P. vulgaris*, *A. m. adansonii* intensely and regularly harvested nectar. This could be attributed to the needs of individuals during the flowering period. The disruptions of visits by other insects reduced the time frame visits of certain *A. m. adansonii*. This obliged some bees to visit more flowers for a foraging trip in order to maximize their nectar loads. Similar observations were made for *A. m. adansonii* workers foraging on flowers of *Entada africana* (Fabaceae), *P. guajava* (Myrtaceae) flowers (Tchuenguem et al., 2007), *Croton macrostachyus* (Euphorbiaceae), *Syzygium guineense var. guineense* (Myrtaceae) (Tchuenguem et al., 2008a), *Persea americana* (Lauraceae), *Vitellaria paradoxa* (Sapotaceae) (Tchuenguem et al., 2008b), *V. unguiculata* (L.) (Fabaceae) (Tchuenguem et al., 2009b), *Combretum nigricans, Erythrina sigmoidea, Lannea kerstingii, Vernonia amygdalina* (Tchuenguem et al., 2010), for *Chalicodoma cincta cinta* (Hymenoptera: Megachilidae) foraging on C. cajan (Fabaceae) flowers (Pando et al., 2011b) and *Xylocopa olivacea* workers foraging *P. vulgaris* flowers (Kingha et al., 2012).

For this research, it indicates that *A. m. adansonii* can provide benefits to pollination management of *P. vulgaris*.

During the collection of nectar on each flower, *A. m. adansonii* foragers regularly come into contact with the stigma. They were also able to carry pollen with their hairs, legs and mouth accessories from a flower of one plant to stigma of another flower of the same plant (geitonogamy), to the same flower (autogamy) or to that of another plant (xenogamy).

The significant contribution of *A. m. adansonii* in pods and seed yield of *P. vulgaris* is in agreement with similar findings in Britain (Darwin, 1858), United State of America (Ibarra-Perez et al., 1999) and in Ngaoundere (Kingha et al., 2012) which showed that *P. vulgaris* flowers produce fewer seeds per pod in the absence of efficient pollinators.

The contribution of *A. m. adansonii* to *P. vulgaris* production through its pollination efficiency was significantly higher than that of all insects on the exposed flowers. The weight of *A. m. adansonii* played a positive role during nectar collection. *A. m. adansonii* shook flowers, facilitating the liberation of pollen by anthers for the optimal occupation of the stigma (Kudom 2011). Phenomenon was also reported by Vanderborght and Rasmont (1987) for *X. bariwal*, and efficient *P. coccineus* pollinator. This Higher productivity of pods and seeds in unlimited visits when compared with bagged flowers showed that insect visits were effective in increasing cross-pollination. Our results confirmed those of Webster et al., (1982), Wells et al. (1988) and Ibarra-Perez et al. (1997) who revealed that *P. vulgaris* flowers set little pods in the absence of insect pollinators. Similar experiments in England (Free, 1966) and in Brazil (Free, 1993) have shown that pollination by insects was not always needed. Darwin (1876) showed that self-pollination of *P. vulgaris* flowers produced as many pods and seeds as exposed plants. Thus, pollination requirements may differ between plant varieties.

CONCLUSION

This study reveals that *P. vulgaris* red seed outlets is a highly nectariferous bee plant that obtained benefits from the pollination by insects among which *A. m. adansonii* is of great importance. The comparison of pods and seeds set of unprotected flowers with that of flowers visited exclusively by *A. m. adansonii* underscores the value of this bee in increasing

pods and seed yields as well as seed quality. The installation of *A. m. adansonii* hive at the proximity of *P. vulgaris* small red seed fields should be recommended for the increase of pods and seed yields of this valuable crop.

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