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Full Length Research Paper

Foraging and pollination activities of *Xylocopa olivacea* (Hymenoptera, Apidae) on *Phaseolus vulgaris* (Fabaceae) flowers at Dang (Ngaoundere-Cameroon)

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To evaluate the impact of the carpenter bee (*Xylocopa olivacea*) on pod and seed sets of *Phaseolus vulgaris* (black seed outlets), its foraging and pollinating activities were studied in Ngaoundéré, during the June-July 2009 and 2010 cropping seasons. Treatments included unlimited floral access by all visitors, bagged flowers to avoid all visits, and limited visits of *X. olivacea*. Observations were made on 120 flowers per treatment of which all flower visitors were recorded. The carpenter bee seasonal rhythm of activity, its foraging behaviour on flowers, and its pollination efficiency (fruiting rate, number of seeds/pod and percentage of normal or well developed seeds) were recorded. Twenty-four insect species visit *P. vulgaris* flowers. *X. olivacea* was the most frequent visitor and they intensely and exclusively foraged nectar. The foraging speed was 9.94 flowers/min. The foraging activity of *X. olivacea* resulted in a significant increment in fruiting rate by 48.43 and 78.18%, the number of seeds/pod by 19.38 and 18.58% and the normal seeds/pod by 15.67 and 38.25%, respectively in 2009 and 2010. Hence, conservation of *X. olivacea* nests close to *P. vulgaris* crop fields should be recommended to improve pod and seed production in the region.

Key words: *Xylocopa olivacea*, *Phaseolus vulgaris*, foraging activity, nectar, pollination, yield.

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). Up to date, no detailed work has been investigated on *Phaseolus vulgaris*.

P. vulgaris is an annual plant originated from South and Central America (Graham et al., 1997). 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 (Ibarra-Perez et al., 1999). In Cameroon, *P. vulgaris* is cultivated as vegetable and can be consumed raw or cooked; its pods are sold fresh (green beans), or transformed into flour, while the stems and leaves are used to feed livestock (Debouck, 1991). Despite the high seeds demand in the country (203053 tones/year), the quantity of *P. vulgaris* available to consumers is very low (147553 tones/years for 124746 hectares), as a result of low pod and seed yields (MINADER/DESA, 2010). Therefore, it is important to investigate on the possibilities of increasing the production of this plant in Cameroon. The plant is allogam/autogam (Ibarra-Perez et al., 1999) and its cross pollination is ensured by insects (Mackie and Smith, 1935;

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Barrons, 1939; Wells et al., 1988; Ibarra-Perez et al., 1997).

Previous researches have shown no set of seeds from undisturbed bean flowers, whereas, flowers manipulated by wing petals have a great number of seeds (Darwin, 1858). Bumblebees were indicated to be the most effective pollinator of beans when visiting blossoms to collect pollen and nectar in South Africa (Palmer, 1967). Genus *Bombus* was associated with pollination activity in common beans in North America (McGregor, 1976). *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 has revealed *Apis mellifera* to be the most abundant insect species visiting *P. vulgaris* flowers, followed by *X. calens* (currently *Xylocopa olivacea*) and *X. inconstans* (Kasina et al., 2009).

Prior to these studies, no previous research has been reported on the relationships between *P. vulgaris* and its anthophilous insects, although, the activity and diversity of flowering insects of a plant species vary with regions (Roubik, 2000).

X. olivacea is one of the common carpenter bees in Cameroon. During preliminary investigations on flower-insect relationships in Ngaoundere before 2009 (unpublished data), *X. olivacea* has been seen intensively visiting flowers of *P. vulgaris*.

The main objective of this research was to gather more data on the relationships between *P. vulgaris* and flower visiting insects for optimal management of pollination services. Specific objectives were the registration of the activity of *X. olivacea* 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 *X. olivacea* on this plant.

MATERIALS AND METHODS

Study site, experimental plot and biological material

The experiment was carried from June to July, 2009, and from June to July, 2010 at Dang (7°25.372' N, 13°32.566' E and 1092 m above sea level), Ngaoundere, Adamaoua Cameroon. This region is within the high altitude of Guinean savannah agro-ecological zone (Tchuenguem et al., 2007). The climate is characterized by a distinct rainy season (April to October) and dry season (November to March), with an annual rainfall about of 1500 mm. The mean annual temperature is 22°C, while the mean annual relative humidity is 70% (Tchuenguem et al., 2007). The experimental plot measured 437 m^2, in which *P. vulgaris of* small black seeds purchased from a local market was sown. During the study period, 31 to 51 *A. m. adansonii* Latreille (Hymenoptera: Apidae) colonies were located at 3 km in diameter around the experimental site. The vegetation was represented by crops, ornamental plants, hedge plants and native plants of savannah and gallery forests. The vegetation near the *P. vulgaris* field had various unmanaged and cultivated species including bee *X. olivacea* which nests in tree trunks and branches under natural conditions.

Sowing and weeding

On May 8, 2009 and May 5, 2010, the experimental plot was prepared and divided into 8 subplots, each measuring 8 × 4.5 m. Two seeds were sown in 6 lines per subplot, each of which had 30 holes per line. Holes were separated 25 cm from each other, while lines were 75 cm apart. Weeding was performed manually as necessary to maintain plots weed-free.

Determination of the reproduction system of *P. vulgaris*

On 28th June 2009, 30 *P. vulgaris* flowers at the bud stage were labelled on each subplot, giving a total of 240 flowers. One hundred and twenty of the total flowers were allowed to be open pollinated (treatment 1) whilst the other 120 were bagged with 1 mm square gauze bag to prevent visitors or external pollinating agents (treatment 2). On 28st June 2010, the experiment was repeated. Twelve 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 *X. olivacea* on *P. vulgaris* flowers

Observations were conducted on 120 individual opened pollinated flowers of treatment 1 each day from 29th June to 12th July, 2009 and from 29th June to 10th July, 2010 at 1 h interval from 6.00 to 17.00 h. In a slow walk along all labelled flowers of treatment 1, the identity of all insects that visited *P. vulgaris* flowers was recorded. Specimens of all insect taxa were caught with an insect net on unlabelled flowers; for each species 2 to 10 specimens were captured. These specimens were preserved in 70% ethanol (except butterflies that were preserved dry) for subsequent taxonomic identification. All insects encountered on flowers were recorded and the cumulated results expressed in number of visits to determine the relative frequency of *X. olivacea* 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 *X. olivacea* 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 sampling 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 three 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 (A_{1000}) (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 *X. olivacea* was assessed by direct observations. The temperature and relative humidity in the station were also registered every 30 min using a mobile thermo-hygrometer (techno WS-7018, Germany) during all sampling periods.

Evaluation of the effect of *X. olivacea* 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 seed 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 foraging 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 *X. olivacea* on *P. vulgaris*

To evaluate of the pollination efficiency of *X. olivacea*, 120 and 150 flowers were isolated (treatment 3) respectively in 2009 and 2010. Between 10 a.m. and 1 p.m. of each observation date and the gauze bag was delicately removed from each opened flower and this flower observed for up to 10 min. The flowers visited by *X. olivacea* were labeled after this manipulation. The contribution (*Frx*) of *X. olivacea* 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 *X. olivacea*) 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, 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) for the comparison of percentages with Microsoft Excel 2007.

RESULTS

Reproduction system of *P. vulgaris*

The podding indexes of *P. vulgaris* were 0.83, 0.27, 0.95 and 0.2, respectively for treatments 1, 2 in 2009 and 2010. The allogamy and autogamy rates in 2009 and 2010 were 67.47 and 32.53% against 78.95 and 21.05%, respectively. For the two accumulated years, the allogamy rate (*Alr*) was 73.21%, while that of autogamy (*Atr*) was 26.79%. The variety of *P. vulgaris* (small black seed) used in our experiments had a mixed reproduction regime (allogamous-autogamous), with the predominance of allogamy.

Frequency of floral entomofauna of *P. vulgaris*

Amongst the 177 visits of 15 insects species in 2009 and 157 visits of 16 insects species in 2010 recorded on *P. vulgaris* flowers, *X. olivacea* was the most frequent insect with 61 visits (34.46 %) and 36 visits (22.93 %), in 2009 and 2010, respectively (Table 1). The difference between these two percentages is significant ($\chi^2 = 5.37$, $df = 1$, $p < 0.05$).

Activity of *X. olivacea* on *P. vulgaris* flowers

Floral rewards harvested

During each of the two flowering periods, *X. olivacea* was found to intensively and regularly collect nectar from *P. vulgaris* (Figure 3) but no pollen collection was observed.

Relationship between visits and flowering stages

From Figure 2, a positive and significant correlation was found between the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits in 2009 ($r = 0.81$; $df = 10$; $p < 0.001$) as well as, in 2010 ($r = 0.15$; $df = 8$; $p < 0.05$).

Diurnal flower visits

X. olivacea foraged on *P. vulgaris* flowers throughout the day, with a peak activity between 10.00 and 13.00 h (Figure 1). The activity of *X. olivacea* was influenced by climatic conditions. In 2009, the correlation between the number of *X. olivacea* visits on *P. vulgaris* flowers and the temperature was positive and highly significant ($r =$

Table 1. Diversity of floral insects on *P. vulgaris* flowers in 2009 and 2010, number and percentage of visits of different insects.

Insects			2009		2010	
Order	**Family**	**Genus, species, sub-species**	**n_1**	**P_1 (%)**	**n_2**	**P_2 (%)**
Hymenoptera	Apidae	*Xylocopa olivacea* (nectar)	61	34.46	36	22.93
		Xylocopa sp. (nectar)	5	2.82	3	1.91
		Apis mellifera adansonii (nectar)	14	7.91	3	1.91
		Amegila sp. 1 (nectar)	2	1.13	13	8.28
		Amegila sp. 2 (nectar)	-	-	2	1.27
		Braunsapis sp. (nectar)	11	6.21	-	-
		Ceratina sp. 1 (nectar+ pollen)	-	-	24	15.29
		Ceratina sp. 2 (nectar)	-	-	11	7.01
	Halictidae	*Lasioglossum* sp. (nectar)	1	0.56	-	-
	Megachilidae	*Chalicodoma rufipes* (nectar)	28	15.82	23	14.65
		Megachile sp. 1 (nectar)	1	0.56	-	-
		Megachile sp. 2 (nectar)	-	-	1	0.64
		Megachile sp. 3 (nectar)	-	-	1	0.64
		Megachile sp. 4 (nectar)	-	-	5	3.18
		Megachile sp. 5 (nectar)	-	-	2	1.27
	Formicidae	*Camponotus flavomarginatus* (nectar)	2	1.13	-	-
		Camponotus sp. (nectar)	1	0.56	-	-
	Total Hymenoptera		126	71.19	124	78.98
Lepidoptera	Pieridae	*Eurema* sp. 1 (nectar)	1	0.56	8	5.1
		Eurema sp. 2 (nectar)	2	1.13	-	-
	Lycaenidae	(sp. 1) (nectar)	-	-	2	1.27
		(sp. 2) (nectar)	-	-	4	2.55
	Hesperiidae	*Lambrix* sp. (nectar)	2	1.13	-	-
	Total Lepidoptera		5	2.82	14	8.92
Diptera	Syrphidae	*Episyrphus* sp. (nectar)	4	2.26	-	-
Coleoptera	Meloidae	*Coryna* sp. (eat flowers)	42	23.73	19	12.1
Total			177	100	157	100

n_1: number of visits on 120 flowers in 11 days, n_2: number of visits on 120 flowers in 09 days, p_1 and p_2: percentages of visits, $p_1 = (n_1/177) \times 100$, $p_2 = (n_2/157) \times 100$. Comparison of percentages of *X. olivacea* visits for two years: $\chi^2 = 5.37$; $t = 2.32$; $p < 10^{-2}$; sp: unidentified species.

0.92; $df = 4$; $p < 0.001$), but was negative and significant at ($r = 0.85$; $df = 4$; $p < 0.05$) between the number of *X. olivacea* visits and relative humidity. In 2010, the correlation was positive and significant at ($r = 0.55$; $df = 4$; $p < 0.05$) between the number of *X. olivacea* visits on *P. vulgaris* flowers and the temperature, positive and significant at ($r = 0.36$; $df = 4$; $p < 0.05$) between the number of *X. olivacea* visits and relative humidity.

Abundance of X. olivacea

In 2009, the highest mean number of *X. olivacea* simultaneously in activity was 1 per flower (n = 394; s = 0.63) and 256 per 1000 flowers ($n = 106$; $s = 98.97$; maxi = 333). In 2010, the corresponding figures were 1 ($n = 128$; $s = 0$) and 42 ($n = 128$; $s = 15.00$; maxi = 67). The difference between the mean number of foragers per 1000 flowers in 2009 and 2010 was highly significant ($t = 21.99$; $p < 0.001$).

Duration of visits per flower

In 2009, the mean duration of a flower visit was 8.46 s ($n = 425$; $s = 8.06$; maxi = 60 s), while in 2010, the

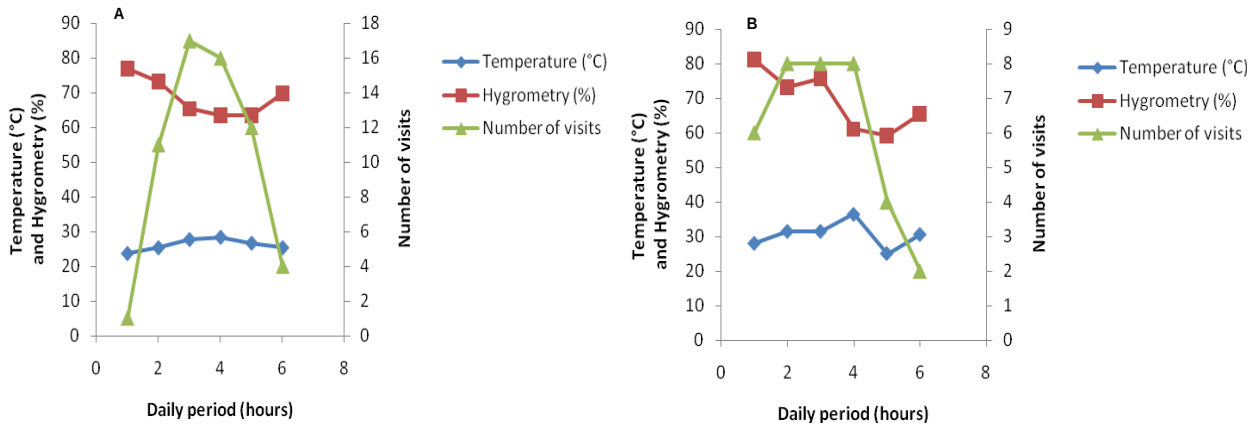

Figure 1: Daily distribution of *X. olivacea* visits on 120 and 120 *P. vulgaris* flowers over 11 days in 2009 (A) and 09 days in 2010 (B) respectively, mean temperature and mean humidity of the study site.

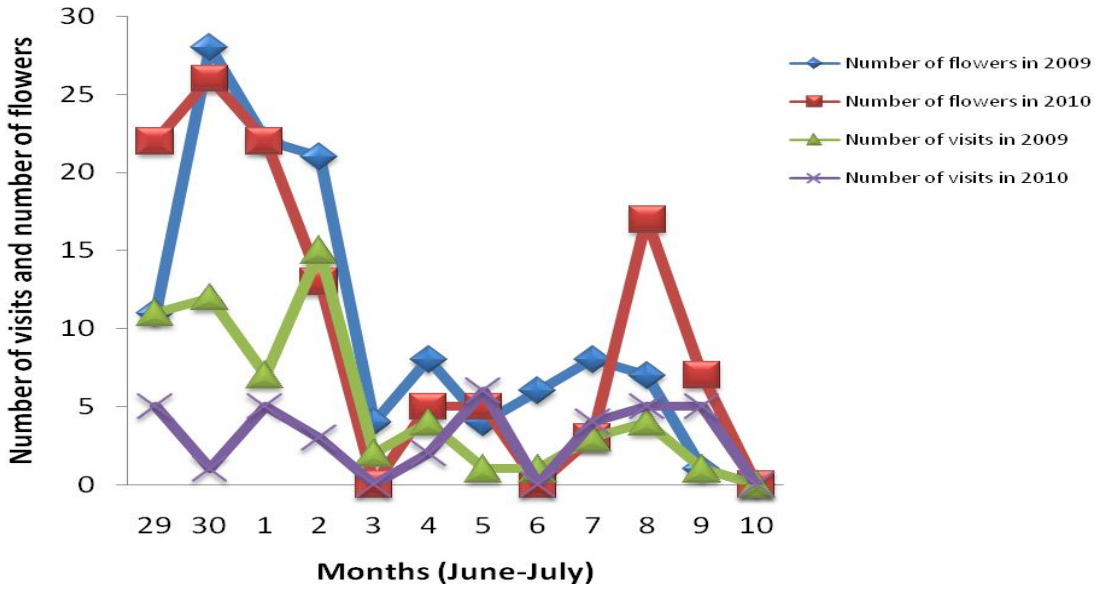

Figure 2. Seasonal distribution of the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits in 2009 and 2010.

corresponding figure was 5.12 s (n = 425; s = 2.98; maxi = 19 s), giving a highly significant difference of (t = 8.01; p < 0.001) between the two sample years. For the two cumulated years, the mean duration of a flower visit was 6.79 s.

Foraging speed of X. olivacea on *P. vulgaris* flowers

On the experimental plot, *X. olivacea* visited *P. vulgaris* corresponding figure was 5.12 s (*n* = 425*; s* = 2.98; maxi = 19 s), giving a highly significant difference of (*t* = 8.01; *p* < 0.001) between the two sample years. For the two cumulated years, the mean duration of a flower visit was 6.79 s. between 2 and 28 flowers/min in 2009 and between 4 and 20 flowers/min in 2010. The mean foraging speed was 10.45 flowers/min (*n* = 184; *s* = 12.67) in 2009 and 9.42 flowers/min (*n* = 134; *s* = 3.26) in 2010. The difference between these means was not significant (*t* = 1.06; *p* > 0.05). For the two cumulated years, the mean foraging speed was 9.94 flowers/min.

Influence of neighboring flora

During the observation period, flowers of many other plant species growing in the study area were visited by *X. olivacea* individuals, for nectar (ne) and/o pollen (po).

Figure 3. Flower of *P. vulgaris* plant showing *X. olivacea* collecting nectar on opened flower.

Among these plants were: *Tithonia diversifolia* (Asteraceae; ne and po); *Mimosa invisa* (Mimosaceae; po), *Bidens pilosa* (Asteraceae; ne and po), *Phaseolus coccineus* (Fabaceae; ne), *Cajanus cajan* (Fabaceae; ne), *Vigna unguiculata* (Fabaceae; ne and po), *Psidium guajava* (Myrtaceae; ne and po), *Senna mimosoides* (Mimosaceae; po) and *Gossypium hirsutum* (Malvaceae; ne and po). During the whole observation period individual bees foraging on *P. vulgaris* were not observed moving to a neighboring plant species and vice versa.

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

During nectar and pollen harvest on *P. vulgaris*, some foraging insects always shake flowers and contact anthers and stigma increasing the cross pollination possibility of *P. vulgaris*. When the fruiting rate was compared (Table 2), the differences observed were highly significant between free opened flowers (treatment 1) and bagged flowers (treatment 2), the first year at (χ^2 = 75.45; t = 8.69; $p < 0.001$) and the second year at (χ^2 = 138.11; t = 11.75; $p < 0.001$). The difference between the two years as far as treatment 1 is concerned was highly significant (χ^2 = 9.39; t = 3.06; $p < 0.001$). Consequently, the fruiting rate of the unprotected flowers was higher than that of protected flowers in 2009 and in 2010. The fruiting rate due to the action of flowering insects was 67.67% in 2009 and 78.95% in 2010. For all of the flowers studied, the fructification rate attributed to the influence of insects was 73.31%.

There was a highly significant difference between treatments 1 and 2 (t=3.49; p<0.001) the first year and the second year at (t=3.27; p<0.001) as far as, the mean number of seeds per pod is concerned (Table 2). For treatment 1, the difference between the two studied years were not significant at (t=0.35; p>0.05). Consequently, a high mean number of seeds per pod in opened flowers (treatment 1) were noticed compared to bagged flowers

Table 2. *P. vulgaris* mean yields under different pollination treatments.

Treatments	Years	Flowers	Pod	Fruiting rate	Seeds/pod		Total seeds	Normal seeds	% normal seeds
					mean	Sd			
Ff (unlimited visits)	2009	120	99	82.5	6.33	1.25	627	572	91.22
Pf (bagged flowers)	2009	120	32	26.67	5.16	1.76	165	129	78.18
Ff (unlimited visits)	2010	120	114	95	6.39	1.22	728	678	93.13
Pf (bagged flowers)	2010	120	24	20	5.17	1.74	124	70	56.45
Fva (*X. olivacea* flowers)	2009	29	15	51.72	6.4	1.18	96	89	92.71
Fva (*X. olivacea* flowers)	2010	144	132	91.67	6.4	1.34	851	778	91.42

Ff: free flower, Pf: protected flowers, Fva: flowers visited exclusively by *X. olivacea*.

(treatments 2). The number of seeds per pod attributed to the activity of flowering insects was 18.48% in 2009 and 19.09% in 2010, giving an overall mean of 18.79%.

The comparison of the percentage of normal seeds (Table 2) indicate that there were highly significant difference between free opened flowers (treatment 1) and bagged flowers (treatment 2) the first year (χ^2=21.86; p<0.001) and the second year (χ^2=133.02; p<0.001). For treatment 1, the difference between the two studied years was not significant (χ^2=1.71; p>0.05). Thus, the percentage of normal seeds in opened flowers was higher than that of protected flowers in 2009 and 2010. The percentage of the normal seeds due to the action of insects was 14.3% in 2009 and 39.39% in 2010. For all the flowers studied, the percentage of the normal seeds due to flowering insects was 26.85%.

Pollination efficiency of X. olivacea 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 carpenter bee highly increased the pollination of *P. vulgaris* flowers.

The comparison of the fruiting rate (Table 2) shows that the differences observed were highly significant between treatments 2 and 3 (χ^2 = 6.79; p < 0.01) in 2009, treatments 2 and 3 (χ^2 = 139.07; p < 0.001) in 2010 and treatment 3 of the two years (χ^2 = 30.16; p < 0.001). The fruiting rate of flowers exclusively visited by *X. olivacea* (treatment 3) was significantly higher than that of flowers bagged during their flowering period (treatment 2) in 2009 and in 2010. The fruiting rate due to *X. olivacea* activity was 48.43% in 2009 and 78.18% in 2010. For all the flowers studied, the fruiting rate attributed to the influence of *X. olivacea* was 63.31%.

The comparison of the mean number of seeds per pod (Table 2) revealed that the differences observed were highly significant between treatments 2 and 3 (t = 2.85; p < 0.01) in 2009 and treatments 2 and 3 at (t = 3.13; p < 0.001) in 2010. The difference between treatment 3 in the two studied years was not significant (t = 0.03; p > 0.05). Therefore, high mean number of seeds per pod of flowers visited exclusively by *X. olivacea* (treatment 3) when compared to bagged flowers (treatment 2). The percentage of the number of seeds per pod due to *X. olivacea* was 19.38% in 2009 and 18.58% in 2010. For all the flowers studied, the percentage of the number of seeds per pod attributed to the influence of *X. olivacea* was 18.98%.

The normal seeds expressed as percentage (Table 2) demonstrates that the differences were highly significant between bagged flowers and flowers exclusively visited by *X. olivacea* (χ^2 = 9.31; p < 0.001) in 2009, and in 2010 at (χ^2 = 115.96; p < 0.001), and non significant between flowers exclusively visited by *X. olivacea* in the two studied years (χ^2 = 0.19; p > 0.05). Hence, the percentage of normal seeds of bagged flowers and those exclusively visited by *X. olivacea* was higher than that of protected flowers in 2009 and 2010. The percentage of the normal seeds due to *X. olivacea* was 15.67% in 2009 and 38.25% in 2010. For all the flowers studied, the percentage of the number of seeds per pod attributed to the influence of *X. olivacea* was 26.96%.

DISCUSSION

X. olivacea was the main floral visitor of *P. vulgaris* during the observation period. Elsewhere, bumblebees in South Africa (Palmer, 1967), *A. mellifera* in Western Kenya (Kasina et al., 2009) have respectively been reported as the main floral visitor of this crop. This could be due to the absence or low abundance of this bee in those countries. *X. olivacea* was shown to be the most abundant floral visitors of *P. coccineus* in Yaoundé (Pando et al., 2011a) and *Luffa aegyptiaca* in Cape Coast site (Mensah and Kudom, 2011). The significant difference between the percentage visits of *X. olivacea* within studied years could be explained by the presence of several nests of *X. olivacea* near the experimental plot

in 2009 when compared to that of 2010. This could also be attributed to the experimental site variation.

The peak activity of *X. olivacea* on *P. vulgaris* flowers was located between 10.00 and 13.00 h, which correlated with the highest availability period of nectar on *P. vulgaris* flowers. However, this decreased activity after 16.00 to 17.00 h could be related to decreased 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 *X. olivacea* foragers on 1000 flowers and the positive and highly significant correlation between the number of *P. vulgaris* flowers at bloom, as well as, the number of *X. olivacea* 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, *X. olivacea* was the most abundant (28.7%), followed by *Coryna* sp. (17.92%), *Chalicodoma rufipes* (15.24%) and *Ceratina* sp.1 (7.65%).

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*, *X. olivacea* intensely and regularly harvested nectar. This could be attributed to the needs of individuals at flowering period. The disruptions of visits by other insects reduced the time frame visits of certain *X. olivacea*. This obliged some carpenter bees to visit more flowers for a foraging trip in order to maximize their nectar loads. Similar observations were made for *A. mellifera adansonii* workers foraging on *Entada africana* (Fabaceae) flowers, *P. guajava* (Myrtaceae) flowers (Tchuenguem et al., 2007), *Croton macrostachyus* (Euphorbiaceae) flowers, *Syzygium guineense* var. *guineense* (Myrtaceae) flowers (Tchuenguem et al., 2008a), *Persea americana* (Lauraceae) flowers, *Vitellaria paradoxa* (Sapotaceae) flowers (Tchuenguem et al., 2008b), *V. unguiculata* (L.) (Fabaceae) flowers (Tchuenguem et al., 2009b), *Combretum nigricans*, *Erythrina sigmoidea*, *Lannea kerstingii*, *Vernonia amygdalina* flowers (Tchuenguem et al., 2010) and for *Chalicodoma cincta* (Hymenoptera: Megachilidae) foraging on *C. cajan* (Fabaceae) flowers (Pando et al., 2011b).

The carpenter bee foragers had a high affinity with respect to *P. vulgaris* when compared to the neighboring plant species, indicating their faithfulness to this Fabaceae, a phenomenon known as “floral constancy” (Louveaux, 1984; Backhaus, 1993; Basualdo et al., 2000). Flower constancy is an important aspect in the management of pollination. For this research, it indicates that *X. olivacea* can provide benefits to pollination management of *P. vulgaris*.

During the collection of nectar on each flower, *X. olivacea* 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 *X. olivacea* in pods and seed yield of *P. vulgaris* is in agreement with similar findings in Britain (Darwin, 1858) and United State of America (Ibarra-Perez et al., 1999) which showed that *P. vulgaris* flowers produce fewer seeds per pod in the absence of efficient pollinators.

The contribution of *X. olivacea* to *P. vulgaris* production through its pollination efficiency was significantly higher than that of all insects on the exposed flowers. The weight of *X. olivacea* played a positive role during nectar collection. *X. olivacea* shook flowers facilitating the liberation of pollen by anthers for the optimal occupation of the stigma. Our results confirmed those of Mensah and Kudom (2011) who revealed that the development of fruits from *L. aegyptiaca* flowers that have received a single visit of *X. olivacea* produced a mean weight of 428.7 g that was 1.5 times heavier than fruits from flowers visited by *A. mellifera* (286.76 g). This phenomenon was also reported by Vanderborght and Rasmont (1987) for *X. bariwal*, an efficient *P. coccineus* pollinator.

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* black seed outlets is a highly nectariferous bee plant that obtained benefits from the pollination by insects among which *X. olivacea* is of great importance. The comparison of pods and seeds set of unprotected flowers with that of flowers visited exclusively by *X. olivacea* underscores the value of this bee in increasing pods and seed yields as well as seed quality. The installation of *X. olivacea* nests at the proximity of *P. vulgaris* small black seed fields should be recommended for the increase of pods and seed yields of this valuable crop.

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