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Foraging and Pollination Behaviour of *Xylocopa Olivacea* Fabricius 1787 (Hymenoptera: Apidae) on *Phaseolus Vulgaris* L. (Fabaceae) Flowers at Yabassi (Douala, Cameroon)

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Abstract

To evaluate impact of carpenter bee, *Xylocopa olivacea*, on pod and seed set of *Phaseolus vulgaris,* its foraging and pollinating activities were studied in Yabassi, for two rainy seasons (May - July 2021 and May - July 2022). Observations were made on 60 inflorescences per treatment. The treatments included unlimited floral access by all visitors, bagged flowers to deny all visits, and limited visits by *X. olivacea* only. In addition, all flower visitors were recorded. The carpenter bee's seasonal rhythm of activity, its foraging behavior on flowers, its pollination efficiency, the fructification rate and the number of seeds per pod were recorded. Individuals from 11 species of insects were recorded visiting flowers of *P. vulgaris* in the 2 years. *Xylocopa olivacea* was the most frequent (58.71%), followed by *Apis mellifera* (15.78%) and *Lipotriches collaris* (10.02%). *Xylocopa olivacea* mainly foraged for nectar resources. The mean foraging speed was 7.62 flowers/min. Flowers visited by *X. olivacea* had higher fruiting rate compared with others, while those bagged had the lowest rate. In addition, seed formation was higher in *X. olivacea* visited flowers compared with all others. The results show that this crop experiences pollination deficit even under normal circumstances, considering that flowers visited by *X. olivacea* had higher yields compared with those under unlimited access by all visitors. The fruiting rate, the number of seeds/pod and the percentage of normal seeds of unprotected flowers were significantly higher than those of protected flowers from insects. *X. olivacea* foraging resulted in a significant boost of the fruiting rate by 29.54%, as well as the number of seeds/pod by 25.36% and the percentage of normal seeds by 15.12% in 2021 and 13.56% in 2022. Conservation of *X. olivacea* nests close to *P. vulgaris* fields could be recommended to improve pod and seed production.

Keywords: *Phaseolus Vulgaris*, Pollination, *Xylocoa Olivacea*, Yield

Introduction

Very little information exists on the relationships between flowering insects and many plant species in Cameroon. Vegetable and fruit crops depend upon insect pollination for yield and fruit quality. It is known that generally anthophilous insects and bees usually increase the fruit and seed yields of many plant species, through pollination provision [1, 2, 3, 4, 5, 6]. Phaseolus vulgaris is an annual plant originated from South and Central America [7]. 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 seeding; the flower is pink, can vary from white to purple depending on the different varieties [8]. And produces nectar/pollen which attract insects. Bean plant is autogam/allogam [9]. Self-pollination is the rule; cross-pollination by insects is generally observed [10, 11, 9]. 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 [12]. Currently the production of P. vulgaris in Cameroon is 200,000 tons, but the projections of production is 354,000 tons by 2015 [13]. So, 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 [9]. Recent research conducted in Kenya [14] in Cameroon [12, 15], has revealed *A. m. mellifera* visiting *P. vulgaris* flowers. There has been no previous research reported on the relationship between *P. vulgaris* and its anthophilous insects, although the activity and diversity of flowering insects of a plant species vary with regions [16].

This study was carried out to measure the effects of foraging behavior of *X. olivacea* on yields of *P. vulgaris*. *X. olivacea* is one of the common carpenter bees in Cameroon. During preliminary investigations on flower–insect relationships in Yabassi before 2020 (unpubl. data), *X. olivacea* have been seen intensively visiting flowers of *P. vulgaris* (small red seeds). This bee can be managed for pollination [17]. The main objective of this research was to gather more data on the relationships between *P. vulgaris* and flower visiting insects in Yabassi, for optimal management of pollination services in Cameroun. 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 out twice, from May to July 2021 and April to June 2022 at Yabassi (4°44.27’1 N, 9°57’53 ′E, 18.1 m above sea level), in Douala, litoral Cameroon. This region belongs to the forest agro - ecological zone. The climate is of the equatorial type, characterized by two seasons: a rainy season (March to November) and a dry season (December to February). The annual rainfall is 4000 mm. The average annual temperature vary between 22°C and 32°C, while the mean annual relative humidity is 75%. The experimental plot was 24 on 8 m where seeds of *P. vulgaris* purchased from the local seed outlets were planted. The bee *X. olivacea* digs its nest in the trunks of trees under natural conditions.

Sowing and Weeding

On the 9 May 2021 and 12 May 2022 the experimental plot was divided into twenty-four subplots (1 x 1.5 m each). The sowing was done on tree lines per subplot, each line with five holes and in each hole, three seeds were placed. The space was 30 cm between holes and 50 cm between lines. Weeding was performed manually as necessary to maintain weed-free plots.

Determination of the Reproduction System of *P. Vulgaris*

On 5 June 2021, 24 inflorescences of *P. vulgaris* at the bud stage were labeled, among which 12 inflorescences (218 flowers) were left unattended and 12 inflorescences (212 flowers) bagged to prevent visitors. On 10 June 2022, 24 inflorescences of *P. vulgaris* with flowers at the bud stage were labeled, among which 12 inflorescences (221 flowers) were permitted unlimited visits and 12 inflorescences (234 flowers) bagged. Ten days after shedding of the last flower of labeled inflorescences, the number of pods was assessed in each treatment. The podding index was then calculated as described by [18]:

$$Pi = F2/F1$$

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 [19]:

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

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 208 individual opened pollinated flowers of treatment 1 each day from July 17 to 27, 2021 and from July 25, to August 5, 2022 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 labeled inflorescences of treatment 1 and treatment 3, the identity of all insects that visited *P. vulgaris* was recorded. For 6 - 10 min observations per inflorescences, before moving to a different treatment. Specimens of all insect taxa were caught with an insect net on unlabelled inflorescences; for each species of insect, 3 – 5 specimens were captured. These specimens were conserved in 70% ethanol for subsequent taxonomy determination. All insects encountered on flowers were registered 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 floral insect 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 *X. olivacea* during each floral visit were registered based on its foraging behavior. Nectar foragers were seen extending their proboscises to the base of the corolla while pollen gatherers scratched anthers with the mandibles or the legs. During the same time that *X. olivacea* encounters on flowers were registered, we noted the type of floral products collected by this bee. This parameter was measured to determine if *X. olivacea* is strictly a pollenivore, nectarivore or pollenivore and netarivore. This could give an idea of its implication as a cross-pollinator of *P. vulgaris*. In the morning of each sampling day, the number of opened flowers carried by each labeled inflorescence was counted.

During the same days as for the frequency of visits, the duration of the individual flower visits was recorded (using a stopwatch) at least three times: 8.00 - 9.00 hours, 10.00 - 11.00 hours, 12.00 - 13.00 hours and 14.00 - 15.00 hours.

Moreover, the number of pollinating visits (the bee coming into contact with the stigma), the abundance of foragers (highest number of individuals foraging simultaneously on a flower or on 1000 flowers: [20].

$$\mathrm{Alr} = [(\mathrm{PiX} - \mathrm{PiY})\ \mathrm{PiX}] \times 100 \quad (2)$$

Where PiX and PiY are respectively the podding average indexes of lot X and lot Y.

$$Atr = 100 - Alr \quad (3)$$

and the foraging speed, according to [21], is the number of flowers visited by a bee per min. According to [20], the foraging speed could be calculated by this formula:

$$Vb = (Fi\ di) \times 60 \qquad (4)$$

Where di is the time (s) given by a stopwatch and Fi is 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 *X. olivacea* was assessed.

The frequency of *X. olivacea* in the flowers of *P. vulgaris* was determined based on observations on flowers of treatment 1 and treatment 3, every day, from 17 June to 3 July 2021 and from 5 to 27 May 2022, at 7.00 - 8.00 hours, 9.00 - 10.00 hours, 11.00 - 12.00 hours, 13.00 - 14.00 hours and 15.00 - 16.00 hours. Flowers typically were completely opened at 7.00 and closed before 16.00 h.

Estimaton of the Frequency of *X. Olivacea* on the Flowers of *P. Vulgars*

During each daily period of observations, the temperature and relative humidity at the station was registered using a mobile thermo-hygrometer every 30 min.

Evaluation of the Effect of *X. Olivacea* and Other Insects on *P. Vulgaris* Yields

This evaluation was based on the impact of insects visiting flowers 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 seeds) of treatment X (unprotected inflorescences) and treatment Y (protected inflorescences). The fruiting rate due to the influence of foraging insects (Fri) was calculated by the formula:

$$Fri = \{[(FrX - FrY)\ FrX] \times 100\} \qquad (5)$$

Where FrX and FrY were the fruiting rate in treatment X and treatment Y. The fruiting rate of a treatment (Fr) is:

$$Fr = [(F2\ F1) \times 100] \qquad (6)$$

Where F2 is the number of pods formed and F1 the number of viable flowers initially set. At maturity, pods were harvested from each lot and the number of seeds per pod counted. The mean number of seeds per pod and the percentage of normal seeds (well-developed seeds) were then calculated for each lot. The impact of flowering insects on seed yields was evaluated using the same method as mentioned above for fruiting rate [20].

Assessment of the Pollination Efficiency of *X. Olivacea* on *P. Vulgaris*

To assess of the pollination efficiency of *X. olivacea,* 8 inflorescences were isolated (treatment 5) in 2021 and 6 inflorescences were isolated (treatment 6) in 2022. Between 9.00 hours and 13.00 hours of each observation date, the gauze bag was delicately removed from each inflorescence carrying new opened flowers and this inflorescence observed for up to 20 min. The flowers visited by *X. olivacea* were marked and the new opened flowers that were not visited were elimi- nated. The inflorescence was protected once more.

The contribution (Frx) of *X. olivacea* in the fruiting was calculated by the formula:

$$Frx = \{[(Fr3 - Fr2) / Fr3] \times 100\} \qquad (7)$$

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 the two samples, correlation coefficient (r) for the study of the association between two variables, chi-square ($X2$) for the comparison of two percentages using SPSS statistical software and Microsoft Excel.

Results

Reproduction System of Runner Bean

The podding index of *P. vulgaris* was 0.85, 0.53, 0.88 and 0.68, respectively for treatment 1, treatment 2, treatment 3 and treatment 4. Thus, in 2021 allogamy rate was 22.64% and autogamy rate was 22.27%. It appears that the variety of *P. vulgaris* used in our experiments had a mixed reproduction regime with the predominance of autogamy over allogamy.

Frequency of Floral Entomofauna of *P. Vulgaris*

Among the 1049 and 947 visits of 11 and 10 insect species recorded on *P. vulgaris* flower in 2021 and 2022, respectively, *X. olivacea* was the most represented insect with 818 visits (59.38%) and 984 visits (58.71%), in 2021 and 2022, respectively (Table 1). The difference between these two percentages is not significant ($X2 = 0.36$ [df = 1; $P > 0.05$)]) because of the constancy of carpenter bees on the *P. vulgaris* flowers during the two years.

In 2021, the highest mean number of *X. olivacea* simultaneous in activity was two per flower ($n = 70$; $s = 0$) and 230.56 per 1000 flowers ($n = 72$; $s = 3.71$; maxi = 251.14). In 2022, the corresponding numbers were also two ($n = 70$; $s = 0$) and 221.56 ($n = 80$; $s = 4.83$; maxi = 295.9).

The difference between the mean number of foragers per 1000 flowers in 2021 and 2022 is not significant ($t = 0.83$ [df = 150; $P = 0.47$]).

Table 1: Diversity of flowering insects on *Phaseolus vulgaris* in 2021 and 2022, number and percentage of visits of different insects

Insects			2021		2022		Total	
Order	**Family**	**Species**	n_1	P_1 (%)	n_2	P_2 (%)	n_t	P_t (%)
Hymenoptera	Apidae	*Apis mellifera*	143	13,63	172	18,16	**315**	**15,78**
		Xylocopa olivacea	623	59,38	549	57,97	**1172**	**58,71**
		Lipotriches collaris	103	9,81	96	10,13	**199**	**9,96**
		Chalicodoma rufipes	32	3,05	23	2,42	**55**	**2,75**
		Macronomia vulpina	45	4,28	56	5,91	**101**	**5,06**
	Vespidae	*Synagris cornuta*	6	0,57	2	0,21	**8**	**0,40**
	Formicidae	*Polyrachis* sp. N	43	4,09	17	1,79	**60**	**3,01**
Diptera	Muscidae	*Musca domestica*	32	3,05	9	0,95	**41**	**2,05**
Coleoptera		*Coryna* sp.	8	0,76	1	0,10	**9**	**0,45**
Lepidoptera	Acraeidae	*Acrea acerata*	5	0,47	4	0,42	**9**	**0,45**
	Pieridae	*Catopsilia flerella*	9	0,85	18	1,90	**27**	**1,35**
Total			**1049**	100	**947**	100	**1996**	**100**

n_1: number of visits on 865 flowers in 15 days; n_2: number of visits on 769 flowers in 13 days; n_t: number of visits on 1634 flowers in 20 days; p_1, p_2 and pt: percentages of visits; $p_1 = (n_1 / 1049) * 100$; $p_2 = (n_2 / 947) * 100$; $pt = (n_t / 1996) * 100$; sp.: Undetermined species.

(A) (B)

Fig 1: Insects harvesting products on *P. vulgaris* flowers: *X. olivacea; Apis mellifera*

Activity of *X. Olivacea* on *P. Vulgaris* Flowers

Floral Products Harvested

From our field observations, *X. olivacea* were found to collect nectar and pollen on *P. vulgaris* flowers. Nectar collection was intensive and regular (more than 90% of visits each year), whereas pollen collection was very low (Table 2). Other individuals collect, during the same floral visit, both nectar and pollen.

Table 2: Products harvested by *X. olvacea* on flowers of *P. vulgaris* in 2021 and 2022

Year	Nomber of visits studied	Visits for nectar harvest		Visits for pollen harvest		Visits for nectar and pollen harvest	
		Number	**%**	**Number**	**%**	**Number**	**%**
2021	623	513	82.18	74	11.87	36	5.7
2022	549	451	82.14	69	12.56	29	5.2

Rhythm of Visits According to the Flowering Stages

Visits were most numerous when the number of open flowers was highest (Fig. 2). Furthermore, a positive and Visits were most numerous when the number of openpositive and significant correlation was found between the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits in 2021 (r = 0.87 df = 11; $P < 0.001$) as well as in 2022 (r = 0.91; df = 13; $P < 0.001$).

Daily Rhythm of Visits

Xylocopa olivacea foraged on *P. vulgaris* flowers throughout the blooming period, with a peak of activity between 9 and 10 am daily (Table 3). Climatic conditions influenced the activity of *X. olivacea*. In 2021, the correlation was negative and significant (r = -0.91 [df = 3; $P < 0.05$]) between the number of *X. olivacea* visits on *P. vulgaris* flowers and the temperature, while it was positive and significant (r = 0.91 [df = 3; $P < 0.05$]) between the number of visits and relative humidity.

Impact of Insect Activity on Pollination and Pollination Efficiency of *X. Olivacea* on Yield of *P. Vulgaris*

During nectar and/or pollen harvest on *P. vulgaris,* foraging insects always shook flowers and regularly contacted anthers and stigma, increasing cross-pollination possibility of *P. vulgaris*. The comparison of the fruiting rate (Table 4) shows the differences observed are highly significant between treatments 1 and 2 (*X2* = 64.18 [df = 1; $P < 0.001$]) and treatments 3 and 4 (X^2= 31.99 [df = 1; $P < 0.001$]). The difference between treatments 1 and 3 was not significant (X^2= 1.21 [df = 1; $P > 0.05$]).

On all visited flowers, *X. olivacea* contacted anthers and carried pollen. With this pollen, the carpenter bee flew frequently from flower to flowers of the same species. *Xylocopa olivacea* came into contact with visited flowers during 100% of visits. Thus, this bee highly increased the pollination possibilities of *P. vulgaris* flowers. The comparison of the fruiting rate (Table 3) showed that the differences observed were highly significant between treatments 2 and 5 (X^2 = 9.87 [df = 1; $P < 0.001$]) and treatments 4 and 6 (X^2= 12.15 [df = 1; $P < 0.001$]). The difference between treatments 5 and 6 was not significant (X^2= 0.41 [df = 1; $P > 0.05$]).

In Table 4, we documented:

- High fruiting rate or pod formation during unlimited visits (where high diversity of insects were observed) compared with bagged flowers; the percentage of the fruiting rate attributed to the insects was 26.31%;
- Highest fruiting on *X. olivacea* visited flowers than even the unlimited visited flowers. This suggests high pollination deficit in the crop, indicating need for *X. olivacea* management to increase fruiting. The percentage of the fruiting rate due to *X. olivacea* activity was 18.75%;
- High mean number of seeds per pod in unlimited visits compared with bagged flowers. The comparison of the mean number of seeds per pod has shown that the difference observed was highly significant between treatments 1 and 2 (t = 17 [df = 1913; P < 0.001]), treatments 3 and 4 (t = 13; [df = 2742; P < 0.001]) and treatments 1 and 3 (t = 0.77; [df = 2815; P > 0.05]). The percentage of the number seeds per pod due to the action of insects was 29.54%;
- The number of seeds per pod also highest in *X. olivacea* and lowest in bagged, showing that although *P. vulgaris* has high autogamy.

Seeds per pod also highest in *X. olivacea* and lowest in bagged, showing that although *P. vulgaris* has high autogamous tendency, allogamy would increase yields significantly higher. The comparison of the mean number of seeds per pod has shown that the differences observed were highly significant between treatments 2 and 5 (t = 7.83 [df = 114; P < 0.001]) and treatments 4 and 6 (t = 4.69 [df = 107; P < 0.001]). The percentage of the number of seeds per pod attributable to the influence of *X. olivacea* was 25.36%;

Higher normal seed yield for unlimited visits treatment compared with bagged flowers. The comparison of the percentage of normal seeds showed that the observed differences were highly significant between treatments 1 and 2 (X^2= 248.90 [df = 1; P < 0.001]) and treatments 3 and 4 (X2= 160.5 [df = 1; P < 0.001]). The percentage of normal seeds attributed to influence of insects was 15.12%;

Highest normal seeds yield in *X. olivacea* visited flowers than even the unlimited visited flowers. This may show high pollination deficit on the crop, indicating need for *X. olivacea* management to increase developed seeds. The comparison of the percentages of normal seeds has shown that the differences were highly significant between treatments 2 and 5 (X^2 = 56.30 [df = 1; P < 0.001]) and treatments 4 and 6 (X^2= 33.29 [df = 1; P < 0.001]). The percentage of the normal seed yields attributed to the influence of *X. olivacea* was 13.56%.

In short, the influence of *X. olivacea* on pod and seed yields was positive and significant. A positive and highly significant correlation was found between the number of pods and the number of *X. olivacea* visits on *P. vulgaris* inflorescences, in 2021 (r = 0.64 [df = 94; P < 0.001]) as well as in 2022 (r = 0.72 [df = 74; P < 0.001]).

Duration of Visits Per Flower

In 2021 and 2022, the mean duration of *X. olivacea* visits was 8.11 sec (n = 60; s = 3.22; max = 15 sec) and 6.79 sec (n = 70; s = 1.12; max = 13) for nectar harvests respectively. The difference between the duration of the visit to harvest nectar in 2021 and 2022 was not significant (t = 2.71 [df = 128; P = 0.007]). For pollen, the corresponding numbers were 6.12 sec (n = 60; s = 2.44; max = 19 sec) and 2.77 sec (n = 70; s = 1.27; max = 7 sec) in 2021 and 2022, respectively. The difference between duration of visit for pollen in 2021 and 2022 was significant (t = 5.71 [df = 162; P < 0.001]). The mean duration of *X. olivacea* visits per *P. vulgaris* flower varied significantly according to the type of food harvested (t_{2021} = -6.03 [df = 118, P < 0.001]; t_{2022} = -19.76, [df = 138, P < 0.001]).

Foraging Speed of *X. Olivacea* on *P. Vulgaris* Flowers

On the experimental plot of *P. vulgaris, X. olivacea* visited between three and 25 flowers/min in 2021 and between four and 21 flowers/min in 2022. The mean foraging speed was 10.65 flowers/min (n = 60; s = 2.2) in 2021 and 11.57 flowers/ min (n = 70; s = 2.78) in 2022, which is not significantly different (t = 0.62 [df = 128; P = 0.71]).

Influence of Neighboring Flora

The vegetation near the *P. vulgaris* field had various unmanaged and cultivated species. During the observation period, flowers of many other plant species growing near *P. vulgaris* were visited by *X. olivacea,* Flowers were visited mainly for nectar (n) and/or pollen (p). *Ipomoea involucrata* (Convovulaceae, n) and *Psidium guajava* (Myrtaceae; p). During one foraging bout, some individual bees foraging on *P. vulgaris* were observed moving to the neighboring plant and vice versa.

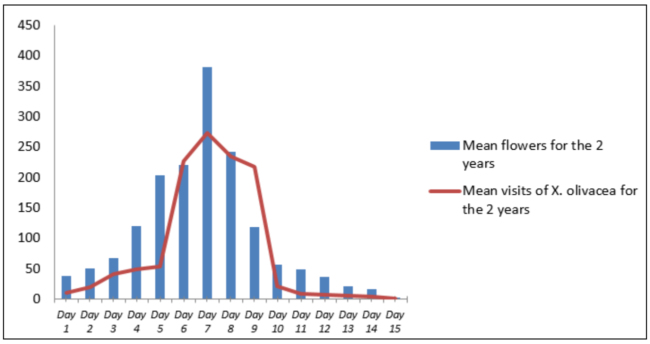

Fig 2: Seasonal distribution of the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits in 2021 and 2022

Table 3: *Phaseolus vulgaris* yields under pollination treatments

Treatment	Year	Flowers	Pods	Fruiting rate	Mean	Sd	Total seeds	Normal seeds	% normal seeds
Unlimited visits	2021	60	51	85	7.21	1.12	1126	1029	89.87
Bagged flowers	2021	60	32	53.33	5.65	1.34	789	546	69.77
Unlimited visits	2021	60	53	88.33	6.73	1.3	1691	1511	90.30
Bagged flowers	2022	60	41	58.33	5.34	1.17	1053	819	77.82
X. olivacea flwers	2021	56	46	82.14	6.21	0.91	1096	914	96.55
X. olivacea lowers	2022	49	38	77.55	6.58	1.02	875	716	95.36

Sd, standard deviation

Discussion

Xylocopa olivacea was the main floral visitor of *P. vulgaris* during the observation periods. This bee was shown to be the most abundant floral visitors of *P. vulgaris* in Ngaoundéré [12]. In Yaoundé *Xylocopa calens* was the main floral visitor of *P. coccineus* during the observation periods [22] and *Luffa aegyptiaca* in Cape Coast site [23]. However, in other parts of the world such as Great Britain [24], Colombia [25] and Poland [26], other bees *Bombus terrestris, Xylocopa barrival* and *Apis mellifera,* respectively, have been reported as the main floral visitors of this crop. This could be due to absence of this bee in those countries or its lower abundance. The none significant difference between the percentages of *X. olivacea* visits for the 2 years of study could be explained by fidelity and constancy of this insect on *P. vulgaris* flowers. The activity peak 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 or the period of highest availability of the nectar and/or pollen on flowers, reported by [26]. This period is correlated to this is likewise the period in which the stigma of *P. vulgaris* has optimal receptivity to pollen [27]. Although, foragers preferred warm or sunny days for good floral activity [28].

The high abundance of *X. olivacea on P. vulgaris* flowers underscores the attractiveness of *P. vulgaris* floral rewards to this bee. Of 11 species of insects visiting the flowers of *P. vulgaris*; *X. olivacea* is the most abundant species (58.71%), followed by *Apis mellifera* (15.78%) and *Lipotriches collaris* (10.02%). The attractiveness of *P. vulgaris* nectar could be partially explained by its reported high production and total sugar concentration in which most of the plant species fall [29]. According to [25] and [26], nectar produced by *P. coccineus* (sugar concentration: 35–45%), attracts various insects in natural conditions. The significant difference observed between the duration of pollen harvest visits and that of nectar collection visits could be explained by the accessibility of each of these floral products. Pollen is produced by the anthers, which are situated on the top of the stamen and are thus easily accessible to *X. olivacea,* whereas nectar is between the base of the style and stamens and is thus less accessible [30]. The weight of *X. olivacea* played a positive role: when collecting nectar and/or pollen, *X. olivacea* shakes flowers. This movement could facilitate the liberation of pollen by anthers, for the optimal occupation of the stigma. This phenomenon was also reported by [25] for *X. bariwal.* The fact that an individual bee exploiting the *P. vulgaris* plot was not observed visiting another plant species indicates that *X. olivacea* shows constancy for the flowers of this plant species. Flower constancy is an important aspect in management of pollination and this shows *X. olivacea* can provide the advantages of pollination management for *P. vulgaris.* Investment in *X. olivacea* management may provide high returns on this crop. During the collection of nectar and pollen on each flower, *X. olivacea* regularly comes into contact with the stigma. It could enhance auto-pollination, which has been demonstrated in the past [31, 32, 33, 27, 24]. *Xylocopa olivacea* would provide allogamous pollination through carrying of pollen within their silks, legs, mouth accessories and thorax, which is consequently deposited on another flower belonging to a different plant of same species. This has also been observed by other studies [27, 24, 26]. The positive and significant contribution of *X. olivacea* in the pod and seed yields of *P. vulgaris* is similar to findings in Great Britain [24] and USA [35] which showed that *P. vulgaris* flowers produce fewer seeds per pod in the absence of efficient pollinators. Similar experiments in England [36] and in Brazil [32] have shown that pollination by insects was not always needed. [31]. 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. Higher productivity of flowers exposed to visits by *X. olivacea* may be compared with those flowers under unlimited visits by all kinds of visitors, and this shows that this bee is a main pollinator of *P. vulgaris* and thus can be targeted for managed pollination of this crop. Where comparisons were possible, there was not significant difference in the percentage of flowers setting pods, either between unlimited visits, between flowers visited exclusively by *X. olivacea* or between years. Higher productivity of unlimited visits compared with bagged flowers explains that insects' visits were effective in increasing cross-pollination. Our results confirm those of [32, 36, 34] that *P. coccineus* flowers set few pods in the absence of insect pollinators (Table 4). [27, 34] showed that self-pollination of *P. coccineus* flowers produced fewer set pods than cross-pollination. But in Yaounde [22] experiments hawe shown that, self-pollination of *P. coccineus* flower produced more set pods or/and seeds than cross- pollination. This result suggests that pollination requirements may differ between varieties. Similar experiments by [37] in Russia also showed that pollination by insects was not always need.

The comparison of pod and seed setting of unprotected inflorescences with that of inflorescences visited exclusively by *X. olivacea* underscores the value of this bee in increasing pod and seed setting, as well as seed quality. This study thus shows investment in management of *X. olivacea* in terms of nest provision at the proximity of *P. vulgaris* fields is worthwhile for growers.

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 *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 red seed fields should be recommended for the increase of pods and seed yields of this valuable crop.

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