



Impact of a single flower visit of *Xylocopa olivacea* (Hymenoptera: Apidae) on *Phaseolus vulgaris* Bigarre variety (Fabaceae) pod and seed production at Dang (Ngaoundéré, Cameroon)

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Abstract

To evaluate the impact of a single flower visit of *Xylocopa olivacea* on the production of *Phaseolus vulgaris* Bigarre variety, its foraging and pollinating activities were studied at Dang in June 2018 and 2019. The experiments were carried out on 540 flowers labeled at bud stage and divided in four treatments: two differentiated according to the presence or absence of flowers protection regarding insect visits; the third protected and uncovered when flowers were opened, to allow *X. olivacea* visits and the fourth with the flowers protected, uncovered when they were opened, then rebagged without any visit. Results indicate that among 11 insect species recorded on flowers, *X. olivacea* ranked second and harvested nectar. Throughout the pollination efficiency of a single flower visit, *X. olivacea* provoked a significant increase of the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed by 39.48 %, 18.19 %, 49.62 % and 31.53 % respectively. The conservation and installation of *X. olivacea* nests close to *P. vulgaris* fields is recommended to improve its pod production and seed quality.

Keywords: dang, *phaseolus vulgaris*, production, *xylocopa olivacea*.

1. Introduction

The common bean, *Phaseolus vulgaris* is an annual plant native to South and Central America ^[1, 2]. It is the world's most important food legume for direct human consumption ^[3]. In terms of safe and healthy food supply, beans are a significant source of carbohydrates, protein, fibre, minerals, vitamins and unsaturated fatty acids, such as linoleic and oleic acids ^[4]. Furthermore, consumption of beans protects against oxidative stress, cardiovascular diseases, diabetes and metabolic syndromes ^[5]. *Phaseolus vulgaris* crop maintains also soil fertility by fixing atmospheric nitrogen and thus keeping diversity and stability of agricultural systems ^[6]. Despite these attributes, its yield is very low (870 Kg / ha) in Cameroon while the seed demand is increasing over the years in this country ^[7, 8]. Therefore, it is important to investigate on the possibilities of increasing the production of common bean in Cameroon. To expect substantial yields, farmers should consider all factors that can improve the production of this crop. Among these factors is pollinating insects. Indeed, more than 70 % of the world's crop species depend on anthophilous pollination for their survival or evolution ^[9, 10, 11, 12]. Xylocopes are the best pollinators of legumes because they better trigger the flower pollination mechanism than other bees ^[13, 14]. Moreover, several studies have shown that *X. olivacea* increases pod and seed production of *P. vulgaris* ^[15, 16, 17, 18]. Up to date, no previous study has been reported on the relationships between *P. vulgaris* var. Bigarre and *X. olivacea*. Besides, the activity and diversity of flowering insects of a plant vary with place and period ^[19]. The main objective of this study was to contribute to the understanding of the relationships between *P. vulgaris* var. Bigarre and *X. olivacea* for their optimal

management. It had four specific objectives : determine the place of *X. olivacea* in *P. vulgaris* floral entomofauna ; study of the activity of this carpenter bee on common bean flowers ; assess the impact of flowering insects including *X. olivacea* on pod and seed production of this Fabaceae ; evaluate the pollination efficiency of this Apidae on *P. vulgaris*.

2. Material and methods

2.1 Material

2.1.1 Study site

The experiment was carried out in June 2018 and 2019 at Dang, in the experimental fields of the Unit for Apply Apidology (latitude 07°25.38'N, longitude 13°32.37'E and altitude 1092 m above sea level) of the Faculty of Science, University of Ngaoundéré, Adamawa region in Cameroon. This region belongs to the high altitude Guinean savannah agro-ecological zone ^[20]. The climate is characterized by a rainy season (April to October) and a dry season (November to March), with an annual rainfall of about 1500 mm ^[20]. The mean temperature is 22 °C, while the mean relative humidity is 70 % ^[21]. The vegetation is represented by crops, ornamental, hedge and native plants of savannah and gallery forests.

2.1.2 Biological materials

The plant material was *P. vulgaris* Bigarre variety seeds (Fig 1) bought at the local market of Dang. The animal material was mainly represented by insects naturally present in the environment of the study site. The number of *X. olivacea* nests located close to the experimental field was 8 in 2018 and 12 in 2019.

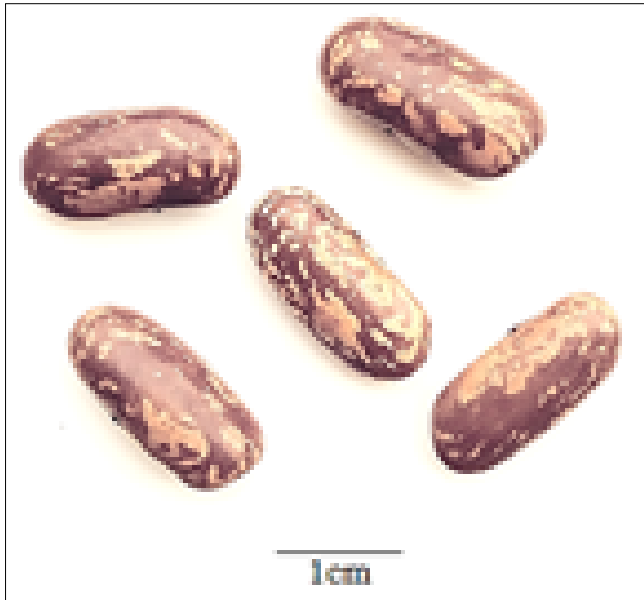


Fig 1: Seeds of *Phaseolus vulgaris* variety Bigarre bought at local market of Dang in 2018.

2.2 Methods

2.2.1 Sowing and weeding

From April 28th to May 10th 2018 and from April 30th to May 12th 2019, the experimental plot was delimited, ploughed and divided into eight subplots, each measuring 8*4.5 m². On May 13th 2018 and May 19th 2019, sowing was done on six lines per subplot, each of which had 32 holes per line. Three seeds were sown per hole. Holes were separated 25 cm from each other, while lines were 75 cm apart [15]. From germination (May 19th 2018 and May 25th 2019) to the blooming (June 13th 2018 and June 20th 2019), the field was regularly weeded with hoe and was performed manually as necessary to keep plots weed-free until the maturation of pods. A week after germination, the plants were thinned and only two were left per hole.

2.2.2 Determination of the reproduction mode of *Phaseolus vulgaris*

On June 13th 2018, 240 flowers at bud stage were labeled and divided in two treatments: 120 unprotected flowers (treatment 1) and 120 bagged flowers using gauze bags net to avoid all visits (treatment 2) [22]. Similarly, on June 21th 2019, 240 flowers at the budding stage were labeled of which 120 were left unprotected (treatment 5), while 120 were bagged (treatment 6). For each cropping year, a week after shedding of the last labeled flower, the number of pods was assessed in each treatment. The podding index (P_i) was then calculated as described by [22]: $P_i = F_b / F_a$, where F_a is the number of viable flowers initially set and F_b the number of formed pods. The allogamy rate (Alr) from which derives the autogamy rate (Atr) was expressed as the difference in podding indexes between treatment X (unprotected flowers) and treatment Y (bagged flowers) [23]: $Atr = \{[(P_{iX} - P_{iY}) / P_{iX}] * 100\}$, where P_{iX} and P_{iY} are the podding indexes in treatments X and Y respectively; $Alr = 100 - Atr$.

2.2.3 Determination of the place of *Xylocopa olivacea* on *Phaseolus vulgaris* entomofauna

Observations were conducted on flowers of treatments 1 and 5, every day, from 14th to 19th 2018 and from 22th to 29th June 2019. During each observation day, before starting

visit counts, the number of open flowers in each treatment was counted. Data were taken according to six daily time frames: 6 - 7 am, 8 - 9 am, 10 - 11 am, 12 - 13 pm, 14 - 15 pm and 16 - 17 pm. In a slow walk along all labeled flowers of treatments 1 and 5, the identity of insects that visited *P. vulgaris* flowers was recorded [22]. All insects encountered on flowers were registered [24] and the cumulated results expressed as the number of visits to determine the relative frequency of each insect species in anthophilous entomofauna of *P. vulgaris* [25]. Data obtained were used to determine the frequency of visits (F_i) of each insect species on *P. vulgaris* flowers. For each study period, $F_i = [(V_i / V_t) * 100]$, with V_i the number of visits of insect i on treatment with unprotected flowers and V_t the total number of insect visits of all recorded insect species on these flowers [22]. Specimens (3 to 5) for all insect taxa, excluding *Apis mellifera* were caught using insect net on unlabeled flowers and conserved in 70 % ethanol, excluding butterflies that were preserved dry [26] for subsequent taxonomic identification.

2.2.4 Study of the foraging activity of *Xylocopa olivacea* on *Phaseolus vulgaris* flowers

2.2.4.1 Floral product harvested

The floral products (nectar or pollen) harvested by *X. olivacea* during each floral visit were recorded based on its foraging behavior. Nectar foragers were expected to extend their proboscis in the corolla, while pollen gatherers were supposed to scratch anthers using mandibles and legs [27]. During the same time that *X. olivacea* visits on flowers were registered, the type of floral product collected by this carpenter bee was noted [24].

2.2.4.2 Duration of visits and foraging speed

During the same days as for the frequency of visits, the duration of individual flower visits was recorded (using stopwatch) according to six daily time frames: 7 - 8 am, 9 - 10 am, 11 - 12 am, 13 - 14 pm, 15 - 16 pm and 17 - 18 pm. Moreover, the number of visits during which the bee came into contact with the stigma [28] was registered. Regarding the foraging speed (F_s) which is the number of flowers visited by an individual bee per minute [28], data were registered during the same dates and according to same time frames and daily period as for duration of visits. The stopwatch, previously set to zero was switched on as soon as an individual landed on a flower and the number of visited flowers was concomitantly counted. The stopwatch was stopped as soon as the visitor was lost to sight or when it left *P. vulgaris* flower for another plant species. The foraging speed (F_s) was calculated using the following formula: $F_s = (N_f / d_v) * 60$, where d_v is the time (sec) given by a stopwatch and N_f the number of flowers visited during d_v . During the observation, when a forager returns to previously visited flower, counting is performed as two different flowers [24].

2.2.4.3 Abundances per flower and per 1000 flowers

The abundances of foragers (highest numbers of individuals foraging simultaneously) per flower and per 1000 flowers (A_{1000}) were recorded on the same dates and daily time frames as for the registration of duration of visits. Abundance per flower was recorded as a result of direct counting. For determining the abundance per 1000 flowers, foragers were counted on a known number of opened

flowers and A_{1000} was calculated using the following formula: $A_{1000} = [(Ax / Fx) * 1000]$ (6), where Fx and Ax are respectively the number of flowers and the number of foragers effectively counted on these flowers at time x [29].

2.2.5 Foraging ecology

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 [24]. For the second parameter, the number of times that the carpenter bee left *P. vulgaris* flowers to other plant species and vice versa was noted through the investigation period [24]. During each daily period of investigation, ambient temperature and relative humidity in the station were registered every 30 minutes using a mobile thermo-hygrometer (Technoline WS9119) [24] installed in the shade.

2.2.6 Evaluation of the impact of the flowering insects including *Xylocopa olivacea* on *Phaseolus vulgaris* yields

Parallel to the constitution of treatments 1, 2, 5 and 6, 600 flowers at bud stage were protected in 2018 and 2019 to form two treatments:

- treatments 3 in 2018 and 7 in 2019: 200 flowers protected using gauze bag nets to prevent insect visits and destined to receive one visit of *X. olivacea*. As soon as the flowers were opened, each flower of treatments 3 and 7 were inspected. Hence, gauze bag was delicately removed and this flower was observed for up to 10 minutes; the flowers visited by *X. olivacea* were marked and then reprotected. Unvisited flowers by this carpenter bee were included in treatment 4 and 8.

- treatments 4 in 2018 and 8 in 2019: 100 flowers protected using gauze bag nets and destined to be uncovered then rebagged without the visit of insects or any other organism. As soon as each flower of treatments 4 and 8 was opened, the gauze bag was removed and the flower was observed for up to 10 minutes while avoiding the visit by *X. olivacea* or any other organism. At maturity, pods were harvested and counted from each treatment. The mean number of seeds per pod, the percentage of normal (well developed) seeds [30] and the mean weight of a seed were then evaluated.

The estimation of the effect of insects including *X. olivacea* on *P. vulgaris* production was based on the impact of flowering insects on pollination, the impact of pollination on *P. vulgaris* podding and the comparison of yields (podding rate, number of seeds per pod, percentage of normal seeds and the mean weight of a seed) of treatments 1, 2, 4, 5, 6 and 8. For each observations year, the podding rate due to the flowering insects including *X. olivacea* (Pri) was calculated using the following formula:

$Pri = \{[(PX - PZ) / (PX + PY - PZ)] * 100\}$ [31], where PX , PY and PZ are the podding rates in treatment X (flowers left in free pollination), treatment Y (flowers protected from all insect visits) and treatment Z (flowers bagged then uncovered and rebagged without insect or any other organism visit). The podding rate of a treatment (Pr) is giving by the following formula: $Pr = [(b / a) * 100]$, where a is the number of viable flowers initially set and b the number of formed pods [22]. The impact of flower visiting insects including *X. olivacea* on the number of seeds per pod, the percentage of normal seeds and the mean weight of a seed were evaluated using the same method as mentioned above for the podding rate.

2.2.7 Assessment of the pollination efficiency of *Xylocopa olivacea* on *Phaseolus vulgaris*

The contribution of *X. olivacea* on the podding rate, the number of seeds per pod, the percentage of normal seeds and the mean weight of a seed was calculated using the data of treatments 3 and 4 for 2018 and those of treatments 7 and 8 for 2019. For each observation year, the contribution of *X. olivacea* on the podding rate (PrX) was calculated using the following formula: $PrX = \{[(PC - PZ) / PC] * 100\}$, where PC is the podding rate in treatment C (flowers visited exclusively by the carpenter bee, *X. olivacea*) [32]. The impact of *X. olivacea* on the number of seeds per pod, the percentage of normal seeds and the mean weight of a seed were evaluated using the same method as mentioned above for the podding rate.

2.2.8 Data analysis

Data were analyzed using descriptive statistics (means, standard deviation and percentages), ANOVA (F) for the general comparison of means of more than two samples, student's t -test for the comparison of means of two samples, Pearson correlation coefficient (r) for the study of the association between two variables and chi-square (χ^2) for the comparison of percentages, using Microsoft Excel 2016 software and R commander version i386 3.2.0.

3. Results

3.1 Reproduction mode of *Phaseolus vulgaris*

The podding indexes of *P. vulgaris* were 0.83, 0.56, 0.9 and 0.57 for treatments 1, 2, 5 and 6 respectively. Thus in 2018, the allogamy rate was 34.94 % whereas the autogamy rate was 65.06 %. In 2019, the corresponding figures were 36.67 % and 63.33 %. For the two cumulated years, the allogamy rate was 35.80 % and the autogamy rate was 64.20 %. It appears that the variety of *P. vulgaris* studied has a mixed reproduction mode, allogamous and autogamous, with the predominance of autogamy over allogamy. Our result is not on line with those obtained by Kingha *et al.* [15] at Dang (Ngaoundéré) on *P. vulgaris* Black Seed variety. According to these authors, allogamy predominates over autogamy. It could be explained by the difference between the diversity of anthophilous insects, which is one of the factors that can influence the reproduction mode of a plant [33].

3.2 Place of *Xylocopa olivacea* in *Phaseolus vulgaris* floral entomofauna

Among 241 and 197 visits of nine and ten insect species recorded on *P. vulgaris* flowers in 2018 and 2019 respectively, *X. olivacea* ranked second with 47 visits (17.01 %) after *Chalicodoma rufipes* in 2018 and first with 60 visits (30.46 %) in 2019 (Table 1). The difference between the percentages of *X. olivacea* visit for the two years is highly significant ($\chi^2 = 7.05$; $df = 1$; $P < 0.001$). This difference could be the consequence of climatic factors and seasonal variations in flower resources availability. It can also be attributed to the variation of the number of *X. olivacea* nests in the study site from one year to another (8 nests in 2018 and 12 in 2019). Other observations have revealed that *X. olivacea* is one of the most frequent insect visitors on flowers of *Luffa aegyptiaca* [34], *P. coccineus* [35], *P. vulgaris* Black Seed variety [15], *Vigna unguiculata* [36], *Vitellaria paradoxa* [37], *P. vulgaris* Large White Seeds variety [18] and *Cajanus cajan* [38].

Table 1: Diversity of flowering insects on *Phaseolus vulgaris* in 2018 and 2019 at Dang, number and percentage of visits of different insects.

Insects			2018		2019		Total _{2018/2019}	
Order	Family	Genus et species	<i>n</i> ₁	<i>P</i> ₁ (%)	<i>n</i> ₂	<i>P</i> ₂ (%)	<i>n</i> _T	<i>P</i> _T (%)
Hymenoptera	Apidae	<i>Apis mellifera</i> (ne, po)	10	4.15	1	0.51	11	2.51
		<i>Amegilla acraensis</i> (ne)	-	-	10	5.08	10	2.28
		<i>Amegilla</i> sp. (ne)	-	-	1	0.51	1	0.22
		<i>Ceratina</i> sp. (ne)	30	12.45	17	8.63	47	10.73
		<i>Tyreus</i> sp. (ne)	22	9.13	-	-	22	5.02
		<i>Xylocopa inconstans</i> (ne)	29	12.03	35	17.77	64	14.61
		<i>Xylocopa olivacea</i> (ne)	41	17.01	60	30.46	101	23.05
	Halictidae	<i>Lasioglossum</i> sp. (po)	22	9.13	14	7.11	36	8.21
	Megachilidae	<i>Chalicodoma rufipes</i> (ne)	49	20.33	53	26.90	102	23.28
<i>Megachile torrida</i> (ne)		17	7.05	-	-	17	3.88	
Lepidoptera	Pieridae	<i>Eurema</i> sp. (ne)	21	8.71	6	3.05	27	6.16
Total			241	100	197	100	438	100
			9 species		10 species		11 species	

*n*₁ and *n*₂: number of visits on 120 flowers in 2018 and 2019; *P*₁ and *P*₂: percentages of visits in 2018 and 2019; sp: undetermined species; ne: collection of nectar; po: collection of pollen; $P_1 = (n_1 / 241) * 100$; $P_2 = (n_2 / 197) * 100$.

3. 3 Activity of *Xylocopa olivacea* on *Phaseolus vulgaris* flowers

During each flowering period, individuals of *X. olivacea* were found (Fig 2) to harvest intensively and exclusively nectar on *P. vulgaris* flowers.

3.3.1 Floral product harvested



Fig 2: *Xylocopa olivacea* collecting nectar in a *Phaseolus vulgaris* var. Bigarre flower at Dang in 2018.

3. 3. 2 Rhythm of visits according to the flowering stages
Xylocopa olivacea visits were more numerous on treatments

1 and 5 when their number of opened flowers was highest (Fig 3).

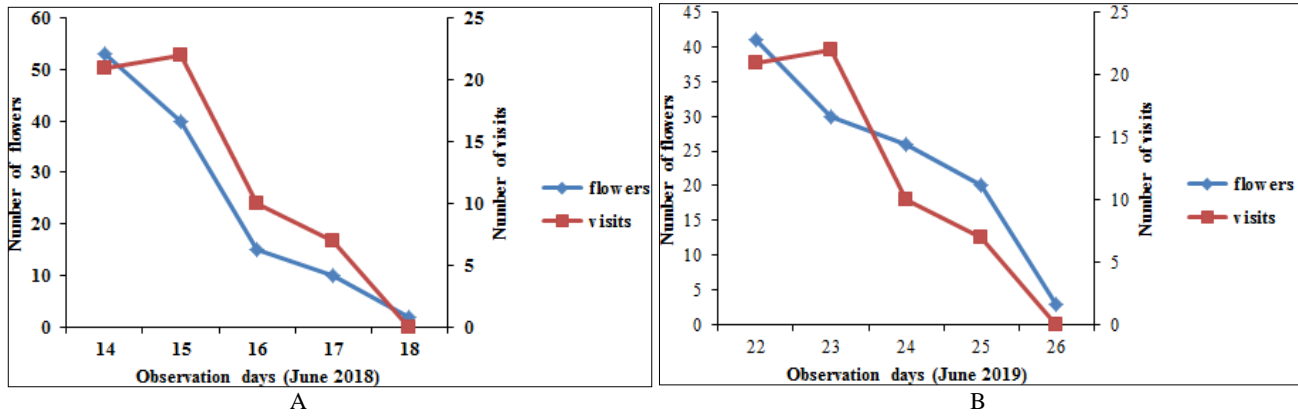


Fig 3: Seasonal variations of the number of *Phaseolus vulgaris* opened flowers and the number of *Xylocopa olivacea* visits on these organs in 2018 (A) and 2019 (B) at Dang.

Moreover, we found a positive and highly significant correlation between the number of *X. olivacea* visits and the number of *P. vulgaris* opened flowers in 2018 ($r = 0.95$; $df = 4$; $P < 0.01$) (Fig 3 A) as well as in 2019 ($r = 0.91$; $df = 4$; $P < 0.01$) (Fig 3 B). This result highlights the good attractiveness of the nectar of *P. vulgaris* towards *X. olivacea*. In Chad, Mainkete *et al.* [18] have also found a positive and highly significant correlation between the

number of *X. olivacea* visits and the number of *P. vulgaris* opened flowers.

3. 3. 3 Daily rythm of visits

The carpenter bee was active on *P. vulgaris* flowers from 8 am to 5 pm in 2018 and from 8 am to 3 pm in 2019. The peak of activity was situated between 10 and 11 am in 2018 as well as in 2019 (Fig 4).

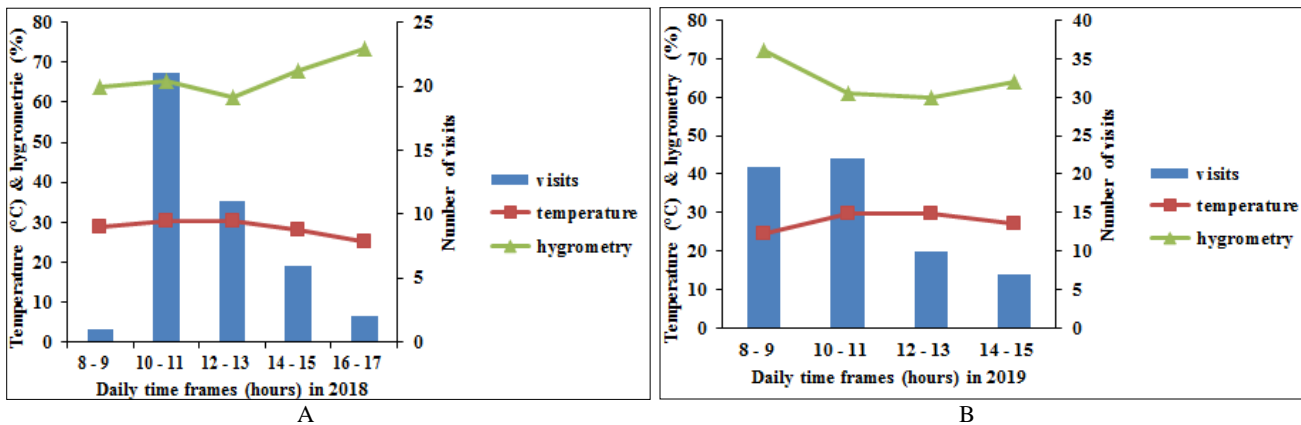


Fig 4: Variation of the temperature, the humidity and the number of *Xylocopa olivacea* visits on *Phaseolus vulgaris* flowers according to the daily frames time in 2018 (A) and 2019 (B) at Dang.

Ambiant temperature and relative humidity did not influenced the activities of *X. olivacea* on *P. vulgaris* (Fig 4). In 2018, the correlation was not significant between the number of *X. olivacea* visits and the temperature ($r = 0.68$; $df = 3$; $P > 0.05$), and between the same number of visits and the relative humidity ($r = - 0.37$; $df = 3$; $P > 0.05$). Equally, in 2019, the correlation was not significant between the number of *X. olivacea* visits and the temperature ($r = - 0.18$; $df = 2$; $P > 0.05$), and between the same number of visits and the relative humidity ($r = 0.37$; $df = 2$; $P > 0.05$). The peak of activity could be linked to the period of highest availability of nectar on the *P. vulgaris* flowers. The same result have been obtained at Doyaba (Chad) by Mainkete *et al.* [18] on the same plant species indicating that the peak of activity of *X. olivacea* was situated between 10 and 11 am. According to Pando *et al.* [35], the peak of activity of this carpenter bee on *P. coccineus* flowers was situated between 9 am and 10 am in Yaoundé (Cameroon).

3. 3.4 Abundance of Xylocopa olivacea

In 2018, the highest mean number of *X. olivacea* individuals simultaneously in activity was 1 per flower ($n = 76$; $s = 0$) and 208.61 per 1000 flowers ($n = 46$; $s = 125.67$; $maxi = 500$). In 2019, the corresponding figures were 1 per flower ($n = 73$; $s = 0$) and 220 per 1000 flowers ($n = 33$; $s = 117.04$; $maxi = 500$). There is no difference between these two means ($t = 0.43$; $df = 77$; $P > 0.05$). For the two cumulated years, the highest mean number of *X. olivacea* individuals simultaneously in activity per 1000 flowers was 214.55. This last result is higher than that pointed out at Dang by Kingha *et al.* [15] who observed that the abundance of this carpenter bee was 149 per 1000 flowers on *P. vulgaris* Black Seed variety. The difference between these two means is highly significant ($t = 4.60$; $df = 311$; $P < 0.001$). This difference could be explained by the variation of the number of *X. olivacea* nests over the years. Indeed, during the two years of observation, we registered 20 nests compared to 3 noted by these authors.

3. 3. 5 Duration of visits per flower

In 2018 and 2019 the mean duration of *X. olivacea* visit per flower was 6.80 sec ($n = 66$; $s = 3.62$; $maxi = 16$) and 4.08 sec ($n = 60$; $s = 1.66$; $maxi = 10$) respectively. The difference between these two means is highly significant ($t = 5.46$; $df = 124$; $P < 0.001$). This difference could be explained by the availability of nectar in the visited flowers or the variation of diversity of flowering insects from one year to another. For the two cumulated years the mean duration per flower was 5.51 sec. In Chad, according to Mainkete *et al.* [18], the mean duration of *X. olivacea* visit per flower was 7.06 sec on *P. vulgaris* var. Large White Seeds. The difference between these two means is highly significant ($t = 3.34$; $df = 879$; $P < 0.001$). This difference could be explained by the availability of nectar on flowers of each variety of *P. vulgaris* studied.

3. 3. 6 Foraging speed

In *P. vulgaris* field, the mean foraging speed of *X. olivacea* was 8.90 flowers per minute ($n = 69$; $s = 5.45$; $maxi = 30$) in 2018 and 7.07 flowers per minute ($n = 49$; $s = 2.85$; $maxi = 13$) in 2019. The difference between these two means is significant ($t = 2.35$; $df = 116$; $P < 0.05$). For the two cumulated years, the mean foraging speed was 8.14 flowers per minute. The later difference could be explained by the accessibility and availability of nectar or the distance separating the flowers visited during the various foraging trips. This foraging speed is smaller than that recorded by Basga *et al.* [37] on *Vitellaria paradoxa* in Garoua (Cameroon). These authors noted that the mean foraging speed of *X. olivacea* was 9.84 flowers/min. The difference between these two means is highly significant ($t = 4.44$; $df = 236$; $P < 0.001$). This difference could be explained by the availability and accessibility of nectar on each plant species.

3. 3. 7 Influence of the fauna

Individuals of *X. olivacea* were disturbed in their foraging

activity by other individuals of the same species or those from other species, which were competitors for *P. vulgaris* nectar.

In 2018, for 66 visits, two (1.32 %) were interrupted by *X. olivacea* and four (2.64 %) by *C. rufipes*. In 2019, for 60 visits, three (1.8 %) were interrupted by *X. olivacea*, five (3 %) by *C. rufipes* and three (1.8 %) by *X. inconstans*. In order to obtain their optimal nectar load, individuals of *X. olivacea* who suffered from such disturbances were forced to visit more flowers during the corresponding foraging trip. The perturbation of individuals of *X. olivacea* in their foraging activity by other insect species have been observed by Basga *et al.* [37] on *Vitellaria paradoxa* flowers in Garoua (Cameroon) and Mainkete *et al.* [18] on flowers of *P. vulgaris* Large White Seeds variety in Doyaba (Chad).

3. 3. 8 Influence of neighboring flora

During the flowering period of *P. vulgaris*, flowers of other plant species surrounding *P. vulgaris* field were visited by *X. olivacea* for either nectar (ne) or pollen (po).

Among these plants were: *Tithonia diversifolia* (Asteraceae: ne and po) and *Crotalaria retusa* (Fabaceae: ne). During the two years of study, we observed no passage of *X. olivacea* from *P. vulgaris* flowers to flowers of another plant species and vice versa.

Hence during foraging trips on *P. vulgaris*, individuals of *X. olivacea* were faithful to this Fabaceae. The faithfulness of individuals of *X. olivacea* to *P. vulgaris* was also reported at Dang (Ngaounéré, Cameroon) by Kingha *et al.* [15] and at Doyaba (Sarh, Chad) by Mainkete *et al.* [18].

3.4 Impact of anthophilous insects including *Xylocopa olivacea* on *Phaseolus vulgaris* production

The podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed in the different treatments of *P. vulgaris* are shown in table 5. This table shows that:

Table 5: Podding rate, mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed according to the different treatments of *Phaseolus vulgaris* in 2018 and 2019 at Dang.

Years	Treatments	NF	NP	PrR (%)	Number of seeds/pod		TNS	NS	% NS	WS (g)
					<i>m</i>	<i>df</i>				
2018	T1 (Uf)	120	100	83.33	2.56	0.82	218	161	73.85	0.41
	T2 (Pf)	120	65	54.17	1.88	1.78	47	18	38.30	0.24
	T3 (Fpvx)	150	140	93.33	2.7	0.98	351	254	72.36	0.37
	T4 (Fpww)	100	56	56	2.15	0.95	58	19	32.76	0.26
2019	T5 (Uf)	120	108	90	2.96	1.05	308	222	72.08	0.28
	T6 (Pf)	120	68	56.67	2.36	0.87	85	39	45.88	0.20
	T7 (Fpvx)	146	122	83.56	2.64	0.77	293	206	70.31	0.30
	T8 (Fpww)	100	51	51	2.22	0.89	82	32	39.02	0.20

NF: number of flowers; NP: number of pods; PrR: podding rate; TNS: total number of seeds; NS: number of normal seeds; %NS: percentage of normal seeds; WS: mean weight of a seed; g: gramme; *m*: mean; *df*: standard deviation; Uf: unprotected flowers; Pf: protected flowers; Fpvx: flowers visited exclusively by the carpenter bee, *X. olivacea*; Fpww: flowers bagged then uncovered and rebagged without visit by insect or any other organism.

a) The podding rates were 83.33 %, 54.17 %, 93.33 %, 53 %, 90 %, 56.67 %, 83.56 % and 51 % in treatments 1 to 8 respectively. The differences between these eight percentages are globally highly significant ($\chi^2 = 140.02$; $df = 7$; $P < 0.001$). The two - by - two comparisons showed that the difference observed is highly significant between treatments 1 and 2 ($\chi^2 = 23.78$; $df = 1$; $P < 0.001$) and between treatments 5 and 6 ($\chi^2 = 34.09$; $df = 1$; $P < 0.001$). Consequently in 2018 and 2019, the podding rate of

unprotected flowers (treatments 1 and 5) was higher than that of protected flowers (treatments 2 and 6).

b) The mean numbers of seeds per pod were 2.56, 1.88, 2.7, 2.15, 2.96, 2.36, 2.64 and 2.22 in treatments 1 to 8 respectively. The differences between these eight means are globally highly significant ($F = 7.11$; $df_1 = 7$; $df_2 = 547$; $P < 0.001$). Two - to - two comparisons showed that the difference observed is significant between treatments 1 and 2 ($t = 3.31$; $df = 108$; $P < 0.05$) as well as between

treatments 5 and 6 ($t = 3.42$; $df = 138$; $P < 0.05$). Consequently in 2018 as well as in 2019, the mean number of seeds per pod of unprotected flowers was higher than that of protected flowers.

c) The percentages of normal seeds were 73.85 %, 38.30 %, 72.36 %, 32.76 %, 72.08 %, 45.88 %, 70.31 % and 39.02 % in treatments 1 to 8 respectively. The differences between these eight percentages are globally highly significant ($\chi^2 = 106.30$; $df = 7$; $P < 0.001$). Pairwise comparisons showed that the difference observed is highly significant between treatments 1 and 2 ($\chi^2 = 22.30$; $df = 1$; $P < 0.001$) as well as between treatments 5 and 6 ($\chi^2 = 20.49$; $df = 1$; $P < 0.001$). Hence in 2018 as well as in 2019, the percentage of normal seeds of unprotected flowers was higher than that of protected flowers.

d) The mean weights of a seed were 0.41 g, 0.24 g, 0.37 g, 0.26 g, 0.28 g, 0.20 g, 0.30 g and 0.20 g in treatments 1 to 8 respectively. The differences between these eight means are globally highly significant $F = 7.11$; ($df_1 = 7$, $df_2 = 1347$; $P < 0.001$). Pairwise comparisons showed that the difference observed is highly significant between treatments 1 and 2 ($t = 9.95$; $df = 262$; $P < 0.001$) as well as between treatments 5 and 6 ($t = 1.56$; $df = 273$; $P < 0.01$). Thus in 2018 as well as in 2019, the mean weight of a seeds of unprotected flowers was higher than that of protected flowers.

In 2018, the contribution of anthophilous insects in the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed were 33.53 %, 21.13 %, 51.76 % and 38.46 % respectively. In 2019, the corresponding figures were 40.77 %, 23.87 %, 41.90 % and 28.57%. For the two cumulated years, the numeric contribution of anthophilous insects were 37.15 %, 22.50 %, 46.83 % and 33.52 % for the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed respectively.

3.5 Pollination efficiency of *Xylocopa olivacea* on *Phaseolus vulgaris*

During the nectar harvest, individuals of *X. olivacea* always came into contact with anthers and stigma. Thus they increased self-pollination or cross-pollination possibilities of visited flowers.

The podding rates due to *X. olivacea* were 40 % in 2018, 38.96 % in 2019 and 39.48 % for the two cumulated years. The difference was highly significant between treatments 3 and 4 ($\chi^2 = 49.38$; $df = 1$; $P < 0.001$) as well as between treatments 7 and 8 ($\chi^2 = 30.15$; $df = 1$; $P < 0.001$). Therefore, in 2018 and 2019, the podding rate of flowers visited by *X. olivacea* was higher than that of flowers protected, uncovered and rebagged without the visit of insect or any other organism.

The comparison of the mean number of seeds per pod (Table 5) shows that the difference was not significant between treatments 3 and 4 ($t = 2.03$; $df = 59$; $P > 0.05$) as well as between treatments 7 and 8 ($t = 2.45$; $df = 146$; $P > 0.05$).

The comparison of the percentage of normal seeds (Table 5) shows that the difference was highly significant between treatments 3 and 4 ($\chi^2 = 35.18$; $df = 1$; $P < 0.001$) as well as between treatments 7 and 8 ($\chi^2 = 27.04$; $df = 1$; $P < 0.001$). Hence, in 2018 and 2019, the percentage of normal seeds of flowers visited by *X. olivacea* was higher than that of flowers protected, uncovered and rebagged without visit of insect or any other organism.

The comparison of the mean weight of a seed (Table 5) shows that the difference was highly significant between treatments 3 and 4 ($t = 7.47$; $df = 407$; $P < 0.001$) while the difference is not significant between treatments 7 and 8 ($t = 1.58$; $df = 273$; $P > 0.05$). Thus, in 2018, the mean weight of a seed from flowers visited by *X. olivacea* was higher than that of flowers protected, uncovered and rebagged without visit of insect or any other organism.

In 2018, the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed due to *X. olivacea* were 40 %, 20.37 %, 54.73 % and 29.73 % respectively. In 2019, the corresponding figures were 38.96 %, 16 %, 44.50 % and 33.33 %.

For the two cumulated years, the numeric contribution of *X. olivacea* via a single flower visit on the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed were 39.48 %, 18.19 %, 49.62 % and 31.53 % respectively.

During the nectar harvest on *P. vulgaris* flowers, *X. olivacea* individuals always shake flowers and come into contact with anthers and stigma. Similar observation was reported by Kingha *et al.* [15] on *P. vulgaris* Black Seed variety at Dang (Cameroon) and by Masiga *et al.* [13] on *P. vulgaris* Julia variety in Kenya. *Xylocopa olivacea* individuals could enhance self-pollination by applying pollen of a flower on its own stigma or on the stigma of another flower of the same plant (geitonogamy) [22]. This carpenter bee could provide allogamous pollination through carrying a pollen on their hairs, legs and mouth accessories from a flower of one plant, which is consequently deposited on another flower belonging to a different plant of the same species (xenogamy) [22, 39]. 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. Kingha *et al.* [15] have also found that, throughout its foraging and pollination activities, this carpenter bee increased significantly the podding rate, the number of seeds per pod and the percentage of normal seeds of *P. vulgaris* Black Seed variety by 63.31 %, 18.98 % and 26.96 % respectively. In fact, by laying on flowers, the individuals of *X. olivacea* could facilitate the release of pollen for the optimal occupation of the stigma. According to McGregor [33], the fruiting is mainly depend on pollination intensity. Moreover, studies made by Masiga [16], Ndayikeza *et al.* [17] and Mainkete *et al.* [18] in Kenya, Burundi and Chad (Doyaba) respectively revealed that *P. vulgaris* pod and seed yields were low in the absence of pollination by this carpenter bee. These studies show that *X. olivacea* is an efficient pollinator of *P. vulgaris*.

4. Conclusion

The results obtained from this study reveal that *P. vulgaris* Bigarre variety is a plant that benefits from the pollination by insects, among which *Xylocopa olivacea* is one of the most important and harvest exclusively nectar. The comparison of pod and seed sets of flowers visited once exclusively by *X. olivacea* with those of flowers bagged then uncovered and reprotected without the visit of this carpenter bee or any other organism underscores the value of this carpenter bee in increasing the podding rate, the mean number of seeds per pod, the percentage of normal seeds and the mean weight of a seed of *P. vulgaris*. Thus conservation and installation of *X. olivacea* nests close to *P. vulgaris* Bigarre variety is recommended to improve its pod

production as well as its seed quality and to favor the population of this carpenter bee in the Adamawa region.

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