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Research Article

Impact of a single flower visit of *Xylocopa olivacea* (Hymenoptera, Apidae) on pod and seed yields of *Phaseolus vulgaris* (Fabaceae)

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Abstract

At the MINADER Plant Multiplication Farm in Ngaoundere (Cameroon), to evaluate the impact of a single visit of *Xylocopa olivacea* Fabricius 1841 (Hymenoptera: Apidae) on pod and seed yields of *Phaseolus vulgaris* L. (Fabaceae) variety Porrillo 693, its foraging and pollinating activities were studied, during 2018 and 2019 rainy seasons. Treatments included unlimited flowers access by all flowering insects, bagged flowers, flowers exclusively visited by *X. olivacea* and bagged flowers, opened and closed without any insect or other organism visits. The foraging behavior of *X. olivacea* on flowers, its pollination efficiency, the fruiting rate, the number of seeds per pod and the percentage of normal seeds were evaluated. *Xylocopa olivacea* was the most frequent visitor and had intensely and exclusively collected nectar.There was a significant increase of fruiting rate (24.64%), the number of seeds per pod (6.45%) and the percentage of normal seeds (28.33%) due to flowering insects including *X. olivacea*. However, through its pollination efficiency, *X. olivacea* alone provoked a significant increase of the fruiting rate (22.52%), the number of seeds per pod (13.85%) and the percentage of normal seeds (33.59%). Therefore, the conservation of *X. olivacea* nest close to *P. vulgaris* (var. Porrillo 693) fields is recommended to improve pod and seed production of this Fabaceae in the Region.

Key words: *Phaseolus vulgaris*, *Xylocopa olivacea*, flowers, yield, pollination

1. Introduction

Phaseolus vulgaris is native to Central and South America (Graham *et al.*, 1997). In Cameroon, it is the second most widely consumed seed legume after peanuts (MINADER, 2012). Its mean annual production is estimated at 327526 tonnes of seeds per year over 285858 hectares (MINADER, 2015). The plant is grown for its immature pods, seeds and leaves that serve as food (Graham *et al.*, 1997). The Adamaoua Region produced 8234 tonnes for a cultivated area of 7392 hectares (MINADER, 2020). However, national, sub-regional and international demand for common beans continues to grow over the years (Djeugap *et al.*, 2014).

The relationships between *P. vulgaris* and flowering insects have been weakly studied. According to Palmer (1967), in South Africa, bumblebees are the main pollinators of this plant. In North America, McGregor (1976) reports the genus *Bombus* as pollinators of common beans. In the United States of America, Ibarra-Perez *et al.* (1999) showed that flowers of *P. vulgaris* produce pods with a low number of seeds in the absence of efficient pollinating insects. Studies in Kenya have shown that *Apis mellifera* is the most abundant bee species on the flowers of *P. vulgaris*, followed by *X. olivavea* and *X. inconstans* (Kasina *et al*., 2009). Douka and Tchuenguem (2013) indicated that the honey bee *Apis mellifera adansonii* was the main pollinating insect of *P. vulgaris* variety Small Red Seed in Maroua, Cameroon. The work of Kingha *et al*. (2012) at Dang-Cameroon and Longin *et al.* (2014) in Burundi showed that *X. olivacea* is the main pollinating insect of *P. vulgaris* variety Small Black Seed. In Doyaba (Sarh, Chad), Mainkété *et al.* (2019) reported that on the flowers of *P. vulgaris* var. Large White Seed, *X. olivacea* ranked first with 22% of 1268 visits from 16 insect species recorded on its flowers.

To our knowledge, there are no published scientific data on the relationships between *P. vulgaris* var. Porrillo 693 and its flowering insects in Cameroon. It therefore useful to carry out investigations on this variety of beans in the Adamaoua Region, to enrich the database of the relationships between plant-flowering insect species in Cameroon and Africa.

The present work is a contribution to the mastery of the relationships between *P. vulgaris* var. Porrillo 693 and its flowering insects, for their optimal management in Cameroon.

Specific objectives were to:

- determine the place of *X. olivacea* among the flowering fauna of *P. vulgaris*;
- study the foraging activity of this bee on the Fabaceae flowers;
- Assess the impact of flowering insects, including *X. olivacea* on pollination, pod and seed yields of this plant;
- determine the pollination efficiency of a single flower visit of *X. olivacea* on this plant species.

2. Material and Methods

2.1. Study site and biological material

The study was conducted from June to September 2018 and from May to July 2019, at the MINADER Plant Multiplication Farm (latitude of 7°19'34,68756 N, a longitude of 13°35'45,8574 E, a altitude of 1112 m.a.s.l.), Ngaoundere, Adamaoua Cameroon. This Region belongs to the high-altitude Guinean savannah agro-ecological zone. The climate is characterized by a rainy (April to October) and a dry season (November to March), with an annual rainfall of about 1500 mm. The mean annual temperature is 22°C, while the mean annual relative humidity is 70% (Amougou *et al*., 2015).

The animal material was mainly represented by insects naturally present in the environment. The plant material was made of *P. vulgaris* var. Porrillo 693 whose seeds were bought at the local market in Ngaoundere town.

2.2. Experimental design

The experimental plot was an area of 437 m^2 (Figure 1) in which *P. vulgaris* seeds purchased was sown.

2.3. Sowing and weeding

On June 23th, 2018 and Avril 28th, 2019, the experimental plot was cleaned and divided into eight subplots, each measuring 8*4.5 m^2. Each subplot was made of six lines, each line having 16 holes, and two seeds were sown per hole. Spacing between two successive holes was 50 cm, and 75 cm between two successive lines (Mainketé *et al*., 2019). Weeding was performed manually to maintain plots weedfree.

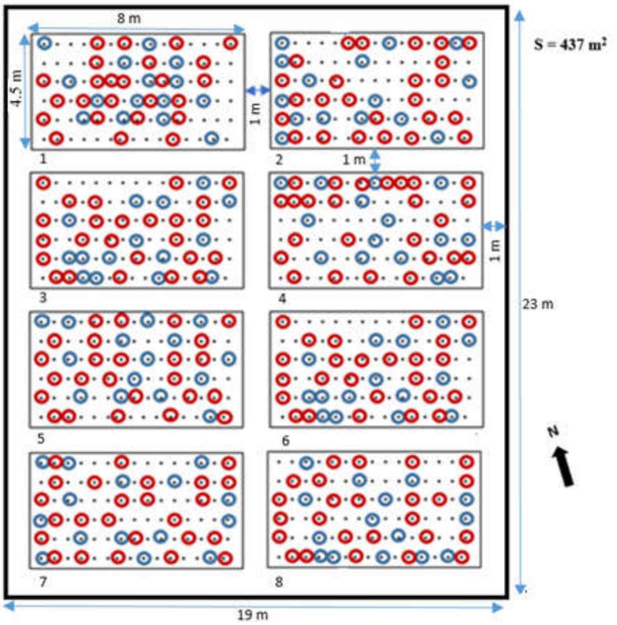

Figure 1 : Experimental design of *Phaseolus vulgaris* at the MINADER Plant Multiplication Farm in Ngaoundere in 2018 and 2019.

1 to 8 : Subplots numbers

- : *Phaseolus vulgaris* plant

: Plant on which treatments 1, 2, 5 and 6 have been applied

: Plant on which treatments 3, 4, 7 and 8 have been applied

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

Observations were done on flowers of treatments 1 and 5, from the opening of the first flower to the fading of the last flower. These observations were done according to six daily time frames: 6-7h, 8-9h, 10-11h, 12-13h, 14-15h and 16-17h. The identity of insects that visited *P. vulgaris* flowers was recorded at each daily time frame. All insects encountered on flowers were recorded and the cumulated results expressed as number of visits have been used to determine the relative frequency of *X. olivacea* (*Fx*) among the flowering fauna of *P. vulgaris*.

For each year, $Fx = [(Vx / Vi) * 100]$, where *Vx* is the number of visits of *X. olivacea* on flowers of free treatment and *Vi*, the total number of insect visits on flowers of the same treatment (Tchuenguem *et al*., 2001).

During each investigation's day, before starting with the recording of the insect visits, the number of open flowers was counted in treatments 1 and 5. On the same days as for the record of frequency of visits, the floral products (nectar and/or pollen) collected by the carpenter bee were recorded the same date at daily time frame. The study of this parameter indicates whether *X. olivacea* is strictly polliniferous and/or nectariferous on *P. vulgaris* flowers (Tchuenguem and Dounia, 2014). With the aid of a stopwatch, the duration of the individual flower visits was recorded at six daily time frames: 7-8h, 9-10h, 11-12h, 13-14h, 15-16h and 17-18h (Tchuenguem, 2005). The foraging speed (number of flowers visited by a carpenter bee per minute) according to Jacob-Remacle (1989) was calculated using the following formula : $Vb = (Fi/di) * 60$ where *di* is the time given by a stopwatch and *Fi* is the number of flowers visited during *di* (Tchuenguem, 2005). The abundance of foragers (highest number of individuals foraging simultaneously) per flower and per 1000 flowers (*A1000*) was recorded the same dates and time slots as for the registration of the duration of visits (Tchuenguem *et al*., 2001). Abundance per flower was recorded as a result of direct counting. To determine the abundance per 1000 flowers, some foragers were counted on a known number of opened flowers and *A1000* was calculated using the following formula: $A1000 = [(Ax / Fx) * 1000]$, where *Fx* and *Ax* are respectively the number of flowers and the number of foragers effectively counted on these flowers at time *x* (Tchuenguem, 2005). The disruption of the activity of foragers by competitors or predators and the attractiveness of other plant species on this insect were assessed through direct observations. For the second parameter, the number of times the carpenter bee went from *P. vulgaris* flowers to other plant species and vice versa was noted throughout the periods of investigation. During each observation date, temperature and relative humidity of the experimental site were registered every 30 minutes using a mobile thermo-hygrometer installed in the shade (Tchuenguem, 2005).

2.5. Evaluation of the effect of *Xylocopa olivacea* and other insects on *Phaseolus vulgaris* yields

The evaluation was based on the impact of visiting insects on pollination, the impact of pollination on fruiting, and the comparison of yields (podding rate, mean number of seed per pod and percentage of normal or well developed seeds) of treatments 1 or 5 (unprotected flowers) and 2 or 6 (bagged flowers). The podding rate due to the influence of foraging insects (*Fri*) was calculated using the formula: $Fri = \{[(FrX - FrY) / FrX] * 100\}$ where *FrX* and *FrY* are the podding rate in treatments *X* and *Y*. The podding rate (*Fr*) is: $Fr = [(Fb/Fa) * 100]$ where *Fb* is the number of formed pods and *Fa* the number of opened flowers initially set (Tchuenguem, 2005).

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

2.6. Evaluation of the pollination efficiency of *Xylocopa olivacea* on *Phaseolus vulgaris*

Parallel to treatments 1, 2, 5 and 6, 600 flowers were protected in 2018 and 2019, and two treatments were formed:

1) treatments 3 in 2018 or 7 in 2019 made of 200 flowers protected using gauze bags to prevent insect visitors and destined exclusively to be visited by *X. olivacea*. As soon as the flowers were opened, each flower of treatments 3 and 7 was inspected. The gauze bag was gently removed thereafter and the flower was observed for up to 10 minutes; the flowers visited by *X. olivacea* was marked and protected there after (Mainketé *et al.*, 2019) ;

2) treatments 4 in 2018 or 8 in 2019 made of 100 flowers destined to be open and close without a visit of insects or any other organisms. As soon as the flowers were opened, each flower of treatments 4 and 8 was observed. Hence, the gauze bag was carefully removed and was therefore observed for up to 10 minutes while avoiding the visit of an insect or any other organism.

For each observation period, the contribution of *X. olivacea* in the podding rate, the number of seeds per pod and the percentage of normal seeds were calculated for each treatment.

For each observation year, the contribution of *X. olivacea* in the podding rate (*FrX*) was calculated using the formula: $FrX = \{[(Fra - Frb)/Fra]*100\}$, where *Fra* and *Frb* are podding rate in treatment *a* (flowers visited exclusively by *X. olivacea*) and treatment *b* (bagged flowers then opened and closed without any insect or other organism visits).

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

2.7. Statistical analysis

Data were subjected to descriptive statistics, student's *t*-test for the comparison of means of the two samples, Pearson correlation coefficient (*r*) for the study of the association between two variables, and chi-square ($\chi 2$) for the comparison of percentages. We also used Microsoft Excel 2016 software and R 2.13.0.

3. Results

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

3.1.1. Frequency of visits

Amongst the 51 and 105 visits of 3 and 6 insects species recorded on *P. vulgaris* flowers in 2018 and 2019 repectively, *X. olivacea* was the most abundant insect with 45 visits (88.23%) in 2018 and 51 visits (48.57%) in 2019 (Table 1). The difference between these two percentages is very highly significant ($\chi 2 = 36.39$; $df = 1$; $P < 0.001$)

Table 1. Diversity of flowering insects on *Phaseolus vulgaris* flowers in 2018 and 2019 at the MINADER Plant Multiplication Farm in Ngaoundere, number and percentage of visits of different insects.

Insects				2018		2019		2018/2019	
Order	Family	Genus and species		n_1	p_1 (%)	n_2	p_2 (%)	n_T	p_T (%)
Hymenoptera	Apidae	*Amegilla* sp. 1 (ne)		4	7.84	21	20	25	16.03
		Amegilla sp. 2 (ne)		2	3.92	17	16.19	19	12.18
		***Xylocopa olivacea* (ne)**		**45**	**88.23**	**51**	**48.57**	**96**	**61.54**
	Megachilidae	*Megachile* sp. (ne)		-	-	11	10.48	11	7.05
Lepidoptera	Pieridae	*Eurema* sp. (ne)		-	-	3	2.86	3	1.92
		Catopsilia florella (ne)		-	-	2	1.90	2	1.28
		Total	**Visits**	**51**	**100**	**105**	**100**	**156**	**100**
			Species	**3**		**6**		**9**	

n_1 and n_2: number of visits on 120 flowers in 04 days, p_1 and p_2: percentages of visits, $p_1 = (n_1/51) * 100$; $p_2 = (n_2/105) * 100$. Comparison of percentages of *Xylocopa olivacea* visits (2018/2019): $\chi 2 = 0.00$; $df = 1$; $P < 0.001$; ne: collection of nectar

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3.1.2. Floral products harvested

During each flowering period, *X. olivacea* was seen collecting intensively and regularly nectar from *P. vulgaris* flowers (Figure 2).

Figure 2. Flower of *Phaseolus vulgaris* variety Porrillo 693 showing *Xylocopa olivacea* collecting nectar on opened flower.

3.1.3 Relationship between visits and flowering stages

Overall, visits of *X. olivacea* were more numerous when the number of opened flowers was higher (Figure 3). The correlation was highly significant between the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits in 2018 ($r = 0.99$; $df = 2$; $p < 0.01$) as well as in 2019 ($r = 0.99$; $df = 2$; $p < 0.01$).

3.1.4. Daily rhythm of visits

The activity of *X. olivacea* on *P. vulgaris* flowers begins in the morning around 7 a.m. and decreases around 5 p.m. It appears from figure 4 that, the carpenter bee was active on flowers throughout the blooming period, with a peak of activity observed between 12 a.m. and 1 p.m. in 2018 and 10 and 11 a.m. in 2019. There is no correlation between the number of *X. olivacea* visits and the temperature in 2018 ($r = 0.96$; $df = 4$; $P > 0.05$) as well as in 2019 ($r = 0.29$; $df = 4$; $P > 0.05$). Similarly, the number of visits and relative humidity is not correlated in 2018 ($r = -0.94$; $df = 4$; $P > 0.05$) as well as in 2019 ($r = 0.015$; $df = 4$; $P > 0.05$).

3.1.5. Duration of a single foraging visit per flower

In 2018, the mean duration of a flower visit was 3.15 sec ($n = 195$; $s = 1.23$; $maxi = 7$), while in 2019, the corresponding figure was 8.74 sec ($n = 117$; $s = 1.89$; $maxi = 13$), giving a very highly significant difference ($t = 28.50$; $P < 0.001$) between the two sampling years.

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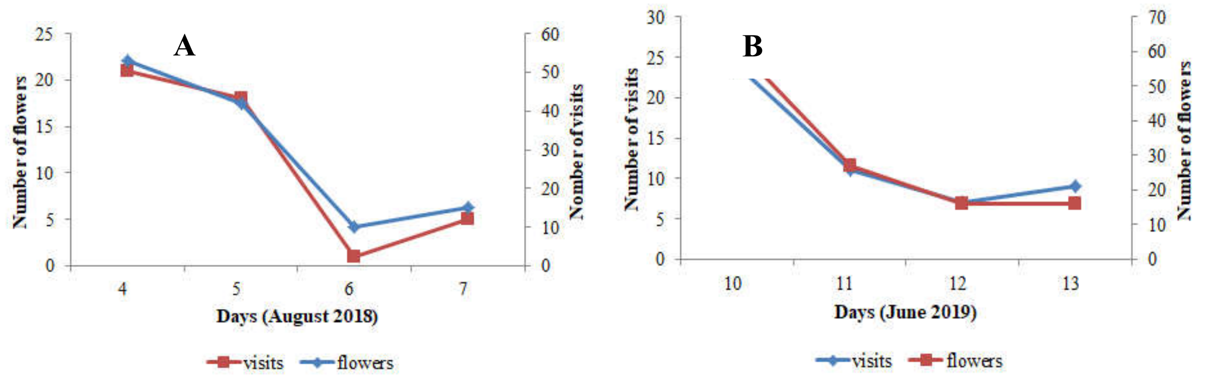

Figure 3: Seasonal variation of the number of *Phaseolus vulgaris* opened flowers and the number of *Xylocopa olivacea* visits in 2018 (A) and 2019 (B) at the MINADER Plant Multiplication Farm in Ngaoundere.

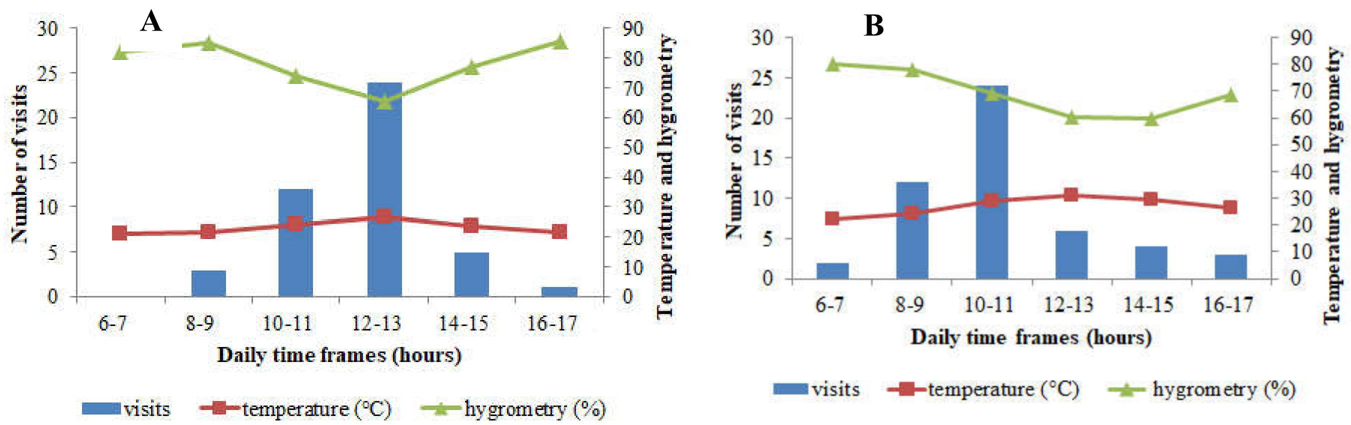

Figure 4: Daily distribution of *Xylocopa olivacea* visits on *Phaseolus vulgaris* flowers in 2018 (A) and 2019 (B) as influenced by temperature and humidity at the MINADER Plant Multiplication Farm in Ngaoundere.

3.1.6. Abundance of *Xylocopa olivacea*

In 2018, the highest mean number of *X. olivacea* simultaneously active was one per flower (n = 69, s = 0) and 22 per 1000 flowers (n = 82, s = 16.75, *maxi* = 100). In 2019, the corresponding figures were 1 per flower (n = 93, s = 0) and 64 per 1000 flowers (n = 102, s = 33.38, *maxi*= 243). The difference between the mean number of *X. olivacea* per 1000 flowers in 2018 and in 2019 is very highly significant (t = 11.15; P < 0.001).

3.1.7. Foraging speed of *Xylocopa olivacea* on *Phaseolus vulgaris* flowers

Xylocopa olivacea visited between 1 and 18 flowers/min in 2018 and between 1 and 17 flowers/min in 2019. The mean foraging speed was 8 flowers/min (n = 59, s = 3.21) in 2018 and 7 flowers/min (n = 110, s = 2.29) in 2019. The difference between these means is significant (t = 3.24; P < 0.05).

3.1.8. Influence of neighboring flora

During each observation periods, flowers of four other plant species growing in the experimental area were visited by *X. olivacea* individuals, for nectar (ne) and/or pollen (po). These plants included: *Bidens pilosa* (ne and po), *Phaseolus vulgaris* var. Large White Seed (ne), *Tithonia diversifolia* (ne and po) and *Zea mays* (po). However, on a foraging trip, *X. olivacea* individuals were faithful to *P. vulgaris* flowers. No passage of insects from the flowers of this fabaceae to the flowers of neighboring plants has been observed and vice versa.

3.1.9. Influence of wildlife

Individuals of *X. olivacea* were disturbed in their foraging activity by other arthropods that were competitors for pollen or nectar. These disturbances resulted in the interruption of some *X. olivacea* visits. In 2018, from 193 visits of *X. olivacea*, 2 (1.04%) were interrupted by *Amegilla* sp. 1 and 3 (1.55%) by *Delta* sp. In 2019, from 117 visits of *X. olivacea*, 05 (4.27%) were interrupted by *Amegilla* sp. 1, 03 (2.56%) by *Megachile* sp., 02 (1.70%) by *Amegilla* sp. 2 and 01 (0.85%) by *X. olivacea*. These interruptions occurred during the approach of a flower already occupied by a first visitor. For their load of nectar, some individuals of *X. olivacea* who suffered such disturbances were forced to visit more flowers and/or plants during the corresponding foraging trip.

3.2. Impact of anthophilous insects including *Xylocopa olivacea* on the pollination, pod and seed yields of *Phaseolus vulgaris*

The podding rate was significant different between treatments 1 and 2 ($\chi^2 = 32.09$; $df = 1$; $P < 0.001$; table 2) and treatments 5 and 6 ($\chi^2 = 14.52$; $df = 1$; $P < 0.001$; table 2). Consequently, in 2018 and 2019, the podding rate of unprotected flowers (treatments 1 and 5 respectively) was higher than that of flowers protected during their flowering period (treatments 2 and 6 respectively).

The mean number of seeds per pod was significant different between treatments 1 and 2 ($t = 5.12$; $df = 170$; $P < 0.001$; table 2) and treatments 5 and 6 ($t = 3.98$; $df = 156$; $P < 0.001$; table 2). As a matter of fact, in 2018 and 2019, the mean number of seeds per pod in opened flowers was higher than that of flowers bagged during their flowering period.

The percentage of normal seeds showed significant difference between treatments 1 and 2 ($\chi^2 = 133.28$; $df = 1$; $P < 0.001$; table 2) and treatments 5 and 6 ($\chi^2 = 3.91$; $df = 1$; $P < 0,05$; table 2). Hence, in 2018 and 2019, the percentage of normal seeds of exposed flowers was higher than that of flowers bagged during their flowering period.

In 2018, the numeric contributions of anthophilous insects on the podding rate, the mean number of seeds per pod and the percentage of normal seeds were 21.75%, 12.26% and 34.50% respectively. In 2019, the corresponding figures were 28.70%, -0.46% and 18.62% respectively. For the two cumulative years, the numeric contributions of flowering insects were 24.64%, 6.45% and 28.33% on the podding rate, the number of seeds per pod and the normal seeds, respectively.

3.3. Pollination efficiency of *Xylocopa olivacea* on *Phaseolus vulgaris*

The podding rate (Table 2) was significantly different between treatments 3 and 4 ($\chi^2 = 8.74$; $df = 1$; $P < 0.01$) and treatments 7 and 8 ($\chi^2 = 23.12$; $df = 1$; $P < 0.001$). Thus, in 2018 and 2019, the podding rate of flowers exclusively visited by *X. olivacea* (treatments 3 and 7 respectively) was significantly higher than that of flowers bagged, opened and closed without insect or any other organism visit during their flowering period (treatments 4 and 8) respectively.

The mean number of seeds per pod (Table 2) was different between treatments 3 and 4 ($t = 11.30$; $ddl = 237$; $P < 0,001$), while no significant difference was noted between treatments 7 and 8 ($t = 1.66$; $df = 205$; $P > 0,05$). In 2018, the difference was significant between the mean number of seeds per pod of bagged flowers and visited exclusively by *X. olivacea* (treatment 3) and those of bagged flowers, then opened and closed without an insect or any other organism visit (treatment 4).

The percentage of normal seeds was significant different between treatments 3 and 4 ($\chi^2 = 243.95$; $df = 1$; $P < 0.001$; table 2) and treatments 7 and 8 ($\chi^2 = 62.75$; $df = 1$; $P < 0.001$; table 2). In 2018 as well as in 2019, the percentage of normal seeds of flowers exclusively visited by *X. olivacea* (treatments 3 and 7 respectively) was higher than that of bagged flowers, opened and closed without insect or any other organism visit during their opening period (treatments 4 and 8respectively).

In 2018, the numeric contributions of *X. olivacea* on the podding rate, the number of seeds per pod and the normal seeds via a single flower visit were 16.01%, 25.99% and 36.38% respectively. In 2019, the corresponding figures were 31.62% and 27.88% respectively for the podding rate and the normal seeds. For the two cumulative years, the corresponding figures were 22.52%, 25.99% and 33.59% respectively.

Table 2: Podding rate, number of seeds per pod and percentage of normal seeds according to different treatments of *Phaseolus vulgaris* in 2018 and 2019 at the MINADER Plant Multiplication Farm in Ngaoundere

Years	Treatments	NF	NFP	PrR (%)	Seeds/pod		TNS	NS	% NS
					m	*sd*			
2018	1 (unprotected flowers)	120	107	89.16	5.51	1.15	574	530	92.33
	2 (bagged flowers)	120	68	56.66	4.58	0.90	312	189	60.57
	3 (flowers visited exclusively by *X. olivacea*)	127	111	87.40	6.58	1.01	737	700	94.97
	4 (bagged flowers, opened and closed without visit)	173	127	73.41	4.87	1.14	619	374	60.42
2019	5 (unprotected flowers)	120	93	77.50	3.63	1.35	338	274	81.07
	6(bagged flowers)	120	65	54.17	4.41	1.09	282	210	74.47
	7(flowers visited exclusively by *X. olivacea*)	151	123	81.46	3.31	1.23	410	364	88.78
	8 (bagged flowers, opened and closed without visit)	149	83	55.70	3.65	1.29	303	194	64.03

NF: Number of flowers; NFP: Number of formed pod; PrR: Podding rate; TNS: Total number of seeds; NS: Normal seeds; % NS: Percentage of normal seeds; *m*: mean; *sd*: standard deviation.

4. Discussion

During our observations, a whole guild of insects visited the flowers of *P. vulgaris*. Of these insects, *X. olivacea* was the most abundant. This carpenter bee is the most abundant floral visitor of *P. vulgaris* Black Seed Outlets variety (Kingha *et al*., 2012) and *P. vulgaris* Large White Seed variety (Mainkété *et al*., 2019). However, bumblebees in South Africa (Palmer, 1967) and *Apis mellifera* in Western Kenya (Kasina *et al*., 2009) have respectively been reported as the main floral visitor of this crop. These observations confirm that the flowering entomofauna of a plant species may vary with regions (Tchuenguem, 2005).

During each flowering period, *X. olivacea* was seen collecting intensively and regularly nectar from *P. vulgaris* flowers. This could be attributed to the needs for individuals carpenter bees during the flowering period. Similar observations were done by Kingha *et al*. (2012) at Dang (Cameroon) and Mainkete *et al*. (2019) at Dobaya (Chad) on *P. vulgaris* with the same bee species. Pollen from this plant would not be easily accessible for *X. olivacea*. In fact, the pollen collection by this insect is passive. Because of its large size, it facilitates the opening of the anthers and the pollen is released. Similar observations were done by Heslop-Harrison and Heslop-Harrison (1983) who underscored the difficulty of insects in accessing the pollen of *P. coccineus*.

The positive and highly significant correlation between the number of *P. vulgaris* opened flowers and the number of *X. olivacea* visits and the high abundance of *X. olivacea* per 1000 flowers, indicates the high attractiveness of nectar with respect to this carpenter bee. This could be due to the smells released by all these flowers. Among floral traits, olfactory signals play an essential role since they allow detection and provide information on the host plant from at long distance (Raguso, 2008). They can sometimes act in synergy with visual signals like the shape and color of the flower (Schiesti, 2015).

The intense activity of this bee during sunny periods could be correlated with the period of highest production and availability of nectar on this Fabaceae. As reported by Kasper *et al.* (2008), foragers preferred warm or sunny days for good floral activity. The leaflets of all legumes are arranged vertically in full sun; therefore the flowers are better exposed to insects, so they can receive a greater number of visits (Pham-Delégue *et al*., 1987).

The difference between the duration of visits per flowers could be related to the availability of nectar in the visited flowers. According to Pappers *et al*. (1999), foragers take a longer time to obtain their maximum load of nectar on flowers where this resource is easily accessible and available in large quantities.

The variations observed in foraging speeds are due to the accessibility of the nectar, the availability of this products, the distances between the flowers exploited during different foraging trips and the frequency of interruptions of *X. olivacea* visits as reported by Kingha (2014) in Dang.

Individuals of *X. olivacea* were faithful to the flowers of *P. vulgaris* during the foraging trips. In fact, flowering insects are generally capable of memorizing and recognizing the shape, the color and the smell of flowers visited during previous foraging trips. This phenomenon, well known to *Apis mellifera* bee is called «floral constancy» (Basualdo *et al*., 2000). For *X. olivacea*, similars results were obtained by Pauly *et al*. (2009) on *Cassia occidentalis* in Benin and by Kudom and Kwapong (2010) on *Ananas comosus* in Ghana.

During nectar harvest on *P. vulgaris*, some foraging insects always shake flowers and therefore, contact anthers and stigma, increasing the cross pollination possibilities of this Fabaceae.The higher productivity of pods and seeds in unlimited visits when compared with bagged flowers showed that insect visits were effective in increasing cross and/or self-pollination. Our results confirmed those of Kingha *et al*. (2012) and Mainkete *et al*. (2019); who found that *P. vulgaris* flowers set less pods and seeds in the absence of insect pollinators in Ngaoundéré and Chad respectively.

During the nectar harvest from flowers, individuals of *X. olivacea* were always in contact with the stigma and the anthers. Thus, this carpenter bee highly increased the pollination of *P.vulgaris* flowers.The weight of *X. olivacea* played a positive role in self-pollination.When collecting nectar, *X.olivacea* shakes flowers; this movement could facilitate the release of pollen by anthers, for the optimal occupation of the stigma (Mensah and Kudom, 2011). *Xylocopa olivacea* individuals carried pollen with their hairs, legs, thorax, abdomen and mouth parts from one flower to another on the same plant or ther plants. Individuals of this carpenter bee thus influence selfpollination and cross-pollination (Rao, 1996). Similar observations were done with the same bee on the same plant flowers in Chad (Mainkete *et al*., 2019).

5. Conclusion

At the MINADER Plant Multiplication Farm in Ngaoundere, *P. vulgaris* var. Porrillo 693 used in this experiment is a highly nectariferous bee plant that benefits from the pollination by insects among which *X. olivacea* is the most important.The comparison of pod and seed sets of unprotected flowers with those exclusively visited by *X. olivacea* underscores the value of this carpenter bee in increasing podding rate, the number of seeds/pod and percentage of normal seeds of *P. vulgaris*.The nesting of *X. olivacea* at the vicinity of *P. vulgaris* var. Porrillo 693 is recommended to improve the pod and seed yields of this valuable crop.

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Authors Contributions

Kingha TBM contributed to bibliographic research, helped to identify insects and wrote the manuscript. Adamou M. contributed to the data analysis and helped to identify insects. Nebissi R. and Aboubakar I. collected the data. Faïbawa E. contributed to the data analysis.

Declaration of interests

The authors declare that they have no conflicting interests.

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