Foraging and pollination activity of Xylocopa olivacea (Hymenoptera: Apidae) on Vitellaria paradoxa (Sapotaceae) flowers at Ouro-Gadji (Garoua, Cameroon)

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Abstract
To evaluate the impact of Xylocopa olivacea (Hymenoptera: Apidae) on Vitellaria paradoxa (Sapotaceae) yields, the foraging and pollination activities of this carpenter bee were studied in January 2011 and from January to February 2012 at Ouro-Gadji. Treatments included unlimited flowers access by all visitors, bagged flowers and limited visit by X. olivacea only. The seasonal rhythm of X. olivacea activity, its foraging behavior on flowers and its pollination efficiency were recorded. Results show that, carpenter bee intensively harvested nectar and pollen. The mean foraging speed was 9.84 flowers per min. The fruiting rate of unprotected flowers is significantly higher that of protected flowers. Through its pollination efficiency, X. olivacea provoked a significant increase of the fructing rate by 13.40%. Hence, conservation and installation of X. olivacea nests close to V. paradoxa populations are recommended to improve fruit and seed yields of this plant in the region.

Keywords: Xylocopa olivacea, Vitellaria paradoxa, foraging, pollination, yields

1. Introduction
In the natural environment and in agro ecosystems, flowers - feeding insects in general and Apoidea in particular have great ecological and economical importance because they have a positive influence on food production [11,14]. Effective pollination by insects can increase fruit yield and quality of seeds [5-10]. The lack of pollinating insects during flowering time can lead to kidney yields fruits and/or seeds for some crops [11,13].

Tropical trees are predominantly outcrossing and many species are self-incompatible [14, 15]. It is estimated that nearly 94% of tropical flowering plant species are animal pollinated [16]. Thus, the interactions of pollinators and tree species used by local people for seed collection are of special interest. Although crucial for the fruit set of many tropical trees, pollinators as well as pollination requirements are still unidentified for many species [17] in many regions. This is also the case for the Shea tree, Vitellaria paradoxa, which is distributed in a belt of Africa from Senegal to the Sudan/Ethiopian border [18]. The sweet fruit pulp is eaten fresh, and the kernels contain oil known as Shea butter, which is used both for cooking and as skin cream [19]. Shea fruits are also an important food resource for bats, which contribute to the dispersal of seeds [19]. Fruit production of Shea trees is known to fluctuate across years [20]. Several authors suggest that variation in pollination success plays a significant role in explaining the yearly variation of the fruit production [21-24]. Most authors recognize different species of bees as main pollinators [25, 26, 20], but according to Chevalier [25], wind may also play a role. Shea is predominantly outcrossing, but whether selfing is rare or absent remains to be tested [27]. The Shea flowers emit a strong scent of honeyand attract many visitors, especially insects and birds [22].

In Cameroon, very little information exists on the relationships between V. paradoxa and its flowering insects. Before this study, floral entomofauna of V. paradoxa have been studied in Ngoundéré [28, 29]. But it is known that floral entomofauna of a plant can vary from one region to another. This work was conducted to study the activity of X. olivacea on the flowers of V. paradoxa to assess the effectiveness of pollination on yields of this Sapotaceae in Garoua for the first time.
2. Materials and Methods

2.1 Study Site

The studies were conducted in January 2011 and from January to February in 2012 respectively at Ouro-Gadji (Latitude 9°31 48 N, Longitude 13°19 15 E and altitude 251 a.s.l.), a village located in the North West of the city of Garoua in the North Region of Cameroon. This region belongs to the Sahel-Sudanian ecologcal zone [30]. It has Sudanian climate type characterized by two annual seasons: a rainy season (April to October) and a dry season (November to March). August is the wettest month of the year [31, 30]. Annual rainfall varies from 750 to 1250 mm and the mean annual temperature is 27 °C [32, 30]. The plants chosen for observation were located on an area of 60 000 m². Vegetation was represented by the native plant species of the savannah.

2.2 Biological materials

The plant material was represented by *V. paradoxa* naturally present in the study site. The animal material was represented by *X. olivacea* and other insects naturally present in the environment.

2.3 Determination of the reproduction mode of *Vitellaria paradoxa*

On January 5 and 6, 2011, 200 inflorescences of *V. paradoxa* with flowers in bud stage were labeled among which 100 were left unattended (Figure 1) (treatment 1) and 100 were bagged using gauze bags (Figure 2) (treatment 2) to prevent visitors or external pollinating agents [33]. On January 11 and 12, 2012, the same treatments were set up, 200 inflorescences of *V. paradoxa* with flowers in bud stage were labeled among which, 100 where left unattended (treatment 3) and 100 were bagged using gauze bags to prevent visitors or external pollinating agents (treatment 4). For each year, twenty days after the wilting of the last flower, the number of formed fruits was counted in each treatment. The fruiting index (Ifr) was then calculated for each treatment using the following formula: \( I_{fr} = (F_1 / F_2) \) were \( F_1 \) is the number of formed fruits and \( F_2 \) the number of viable flowers initially set [34]. The autogamy rate (TA) was calculated using the formula: \( TA = (100 - Ifr) / Ifr \times 100 \). The autogamy rate was calculated using the formula: \( TA = (100 - TC) \times 100 \).

2.4 Study of foraging activity of *Xylocopa olivacea* on *Vitellaria paradoxa* flowers

Observations were conducted on flowers of treatments 1 and 3, from the opening of the first flower bud (8th January 2011 and 15th January 2012) to the fading of the last flower (5th February 2011, 12th February 2012) according to six daily time frames: 6-7h, 8-9h, 10-11h, 12-13h, 14-15h and 16-17h. The identity of all insects that visited *V. paradoxa* flowers was recorded at each daily time frame. All insects encountered on flowers were recorded and the cumulated results expressed in number of visits have been used to determine the relative frequency of *X. olivacea* (\( F_i \)) in the anthphophilous fauna of *V. paradoxa*.

For each year of study, \( F_i = (V_i / V) \times 100 \), where \( V_i \) is the number of visits of *X. olivacea* on flowers of free treatment and \( V \), the total number of insect visits on flowers of the same treatment [36].

During each day of investigation, before starting visit counts, the number of open flowers was counted. The same days as for the frequency of visits, the floral products (nectar and/or pollen) collected by the carpenter bee were recorded for the same date and daily time frame as that of insects’ counts. The study of this parameter indicates whether *X. olivacea* is strictly pollinivorous or nectivore or pollinivorous and nectarivorous on *V. paradoxa* flowers [37]. This can give an idea of its involvement in the pollination of this plant. The duration of the individual flower visits was recorded (using a stopwatch) according to six daily time frames: 6-7h, 8-9h, 10-11h, 12-13h, 14-15h, 16-17h [38]. The foraging speed (number of flowers visited by a carpenter bee per minute according to [39]) was calculated using the following formula [38]: \( V_d = (F_i / d_i) \times 60 \) where \( d_i \) is the time (s) given by a stopwatch and \( F_i \) is the number of flowers visited during \( d_i \). The abundance of foragers (highest number of individuals foraging simultaneously) per flower or per 1000 flowers (\( A_{1000} \)) was recorded on the same dates and time slots as the registration of the duration of visits. Abundance per flower was recorded as a result of direct counting. For determining the abundance per 1000 flowers, some foragers were counted on a known number of opened flowers and \( A_{1000} \) was calculated using the following formula: \( A_{1000} = (A_i / F_i) \times 1000 \), where \( F_i \) and \( A_i \) are respectively the number of flowers and the number of...
foragers effectively counted on these flowers at time $x$ [34]. The disruption of the activity of foragers by competitors or predators and the attractiveness exerted by other plant species on this insect was assessed by direct observations. For the second parameter, the number of times the carpenter bee went from V. paradoxa flowers to other plant species and vice versa was noted throughout the period of investigation. During each observation date, temperature and relative humidity in the station were registered after every 30 minutes using a mobile thermo-hygrometer installed in the shade [38].

2.5 Evaluation of the impact of flowering insects on Vitellaria paradoxa yields
For each year of study, it was based on the impact of flowering insects on pollination, the impact of pollination on V. paradoxa fruiting and the comparison of the fruiting rate of treatment $x$ (unprotected flowers) and treatment $y$ (bagged flowers) [33]. The fruiting rate due to the influence of foraging insects was calculated using the following formula [36]: $P_{r} = \frac{[(F_{1} - F_{x}) / F_{x}] \times 100}{},$ where $F_{x}$ and $F_{1}$ are the fruiting rate in treatment $x$ (treatment 1 or 3) and $y$ (treatment 2 or 4) respectively. The fruiting rate ($F_{x}$) of each treatment is: $F_{x} = \frac{[(F_{2} / F_{3}) \times 100]}{},$ where $F_{2}$ is the number of fruits formed and $F_{3}$ the number of flowers initially set [38].

2.6 Evaluation of the pollination efficiency of Xylocopa olivacea on Vitellaria paradoxa
To evaluate the pollination efficiency of X. olivacea, along with the development of treatments 1 and 2, 20 inflorescences were isolated (treatment 5) as those of treatment 2. Along with the development of treatments 3 and 4, 20 inflorescences were isolated (treatment 6) as those of treatment 4. Between 8 and 11 a.m. of each observation date, the gauze bag was delicately removed from each inflorescence of treatment 5 and 6, and the flowers observed for up to 15 min. Flowers visited by X. olivacea were labeled and unattended flowers were eliminated. After this manipulation, inflorescences were protected once more [38]. Twenty days after, for each study year, the contribution of X. olivacea on fruiting ($F_{x}$) was calculated using the formula: $Fr_{x} = \frac{[(Fr_{x} - Fr_{1}) / Fr_{1}] \times 100}{}.$ [37] where $Fr_{x}$ and $Fr_{1}$ are the fruiting rates in treatment $x$ (flowers protected and visited exclusively by X. olivacea) and $y$ (protected flowers).

2.7 Data analysis
Data were analyzed using descriptive statistics, Student’s $t$ - test for comparison of means of two samples, correlation coefficient ($r$) for the study of linear relationship between two variables, Chi-Square ($X^2$) for the comparison of percentages and Microsoft Excel 2010 sheet.

3. Results

3.1 Reproductive system of Vitellaria paradoxa
In 2011, the fruiting index was 0.27 and 0.10 respectively for treatment 1 and 2, while in 2012, it was 0.18 for treatment 4 and 0.08 for treatment 5. For the two cumulated years, the fruiting index was 0.22 and 0.09 respectively for treatment $x$ (unprotected flowers) and treatment $y$ (bagged flowers). Thus in 2011, the allogamy rate was 62.96% and the autogamy rate was 37.04%. In 2012, the corresponding figures were 55.55% and 44.55%. For the two cumulated years, the allogamy rate was 59.25% and the autogamy was 40.75%. It appears that V. paradoxa has a mixed mating system, autogamous-allogamous, with the predominance of allogamy over autogamy.

3.2 Activity of Xylocopa olivacea on Vitellaria paradoxa flowers
3.2.1 Frequency of the visitors of Vitellaria paradoxa
Amongst the 740 and 598 visits of 9 and 12 insects species recorded on the flowers of V. paradoxa in 2011 and 2012 respectively, X. olivacea is one of the most represented insect with 194 visits (26.29%) and 111 visits (18.56%) in 2011 and 2012 respectively. This carpenter bee species ranked second in each study year (Table 1). The difference between these two percentages is highly significant ($\chi^2 = 20.49; df = 1; P<0.001$).

<table>
<thead>
<tr>
<th>Year</th>
<th>Initial Visitors</th>
<th>Mid-Season Visitors</th>
<th>End-Season Visitors</th>
<th>Total Visitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>740</td>
<td>100</td>
<td>598</td>
<td>1338</td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

3.2.2 Floral products harvested
During each flowering period, X. olivacea harvested preferably and regularly nectar (Figure 3). The collection of pollen was less frequent (Table 2).

Table 1. Diversity of floral insects on Vitellaria paradoxa flowers in 2011 and 2012 at Ouro-Gadji, number and percentage of visits of different insects.

<table>
<thead>
<tr>
<th>Order</th>
<th>Family</th>
<th>Genus and species</th>
<th>2011</th>
<th>2012</th>
<th>Total2011/2012</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$n_{1}$</td>
<td>$p_{1} (%)$</td>
<td>$n_{2}$</td>
</tr>
<tr>
<td>Coleoptera</td>
<td>(1 sp.) (po)</td>
<td>Musca domestica (ne, po)</td>
<td>18</td>
<td>2.43</td>
<td>9</td>
</tr>
<tr>
<td>Diptera</td>
<td>Muscidae</td>
<td>Calliphora sp. (ne, po)</td>
<td>-</td>
<td>-</td>
<td>7</td>
</tr>
<tr>
<td>Hymenoptera</td>
<td>Apidae</td>
<td>Apis mellifera (ne, po)</td>
<td>203</td>
<td>27.43</td>
<td>206</td>
</tr>
<tr>
<td></td>
<td>Xylocopa olivacea (ne, po)</td>
<td>194</td>
<td>26.29</td>
<td>111</td>
<td>18.56</td>
</tr>
<tr>
<td></td>
<td>Xylocopa sp. (ne, po)</td>
<td>131</td>
<td>17.70</td>
<td>135</td>
<td>22.57</td>
</tr>
<tr>
<td>Formicidae</td>
<td>Palithotreus tarsatus (ne)</td>
<td>31</td>
<td>4.18</td>
<td>28</td>
<td>4.68</td>
</tr>
<tr>
<td>Halticidae</td>
<td>Lasiosoglossum sp. 1 (ne, po)</td>
<td>14</td>
<td>1.89</td>
<td>12</td>
<td>2.00</td>
</tr>
<tr>
<td></td>
<td>Lasiosoglossum sp. 2 (ne, po)</td>
<td>114</td>
<td>15.40</td>
<td>57</td>
<td>9.53</td>
</tr>
<tr>
<td>Sphecidae</td>
<td>Philanthus triangulum (pr)</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>0.66</td>
</tr>
<tr>
<td>Vespidae</td>
<td>Belonogaster jancze (ne)</td>
<td>27</td>
<td>3.64</td>
<td>10</td>
<td>1.67</td>
</tr>
<tr>
<td>(1 sp.) (ne)</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>0.66</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>Visitors</td>
<td>740</td>
<td>100</td>
<td>598</td>
<td>100</td>
</tr>
</tbody>
</table>

$n_{1}$: number of visits on 100 inflorescences in 16 days; $n_{2}$: number of visits on 100 inflorescences in 13 days; $p_{1}$ and $p_{2}$: percentages of visits; $p_{1} = (n_{1} / 740) \times 100$; $p_{2} = (n_{2} / 598) \times 100$; sp.: undetermined species; ne: visitor collected nectar; po: visitor collected pollen; pr: visitor hunted preys. Comparison of percentages of Xylocopa olivacea visits for two years: $\chi^2 = 20.49 (df = 1; P<0.001)$. 

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3.2.3 Relationship between visits and flowering stages

Overall, visits of X. olivacea were more numerous on treatment 1 and 3 when the number of opened flowers was highest (Figures 4A and B). A positive and highly significant correlation was found between the number of V. paradoxa opened flowers and the number of X. olivacea visits in 2011 ($r = 0.94; df = 14; p<0.05$) and in 2012 ($r = 0.93; df = 11; p<0.05$).

### Table 2: Products harvested by Xylocopa olivacea on Vitellaria paradoxa flowers in 2011 and 2012 at Ouro-Gadji.

<table>
<thead>
<tr>
<th>Years</th>
<th>Number of visits studied</th>
<th>Visits for nectar harvest</th>
<th>Visits for pollen harvest</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Number</td>
<td>%</td>
<td>Number</td>
</tr>
<tr>
<td>2011</td>
<td>194</td>
<td>157</td>
<td>80.93</td>
</tr>
<tr>
<td>2012</td>
<td>111</td>
<td>86</td>
<td>77.37</td>
</tr>
<tr>
<td>Total</td>
<td>305</td>
<td>243</td>
<td>79.67</td>
</tr>
</tbody>
</table>

3.2.4 Diurnal flower visits

Xylocopa olivacea has been active on V. paradoxa flowers throughout the day, with a peak of activity being observed between 10 and 11 a.m. in 2011 and 2012 (Figures 5A and B). The activity of X. olivacea was not significantly influenced by temperature and relative humidity. The correlation was not significant between the number of X. olivacea visits and the temperature in 2011 ($r = 0.52; df = 5; p>0.05$) and in 2012 ($r = 0.18, df = 5, p>0.05$). The correlation was not significant between the number of X. olivacea visits and relative humidity in 2011 ($r = 0.15; df = 5; p>0.05$) as well as in 2012 ($r = 0.19; df = 5; p>0.05$).
Fig 5: Daily variation of the number of Xylocopa olivacea visits on Vitellaria paradoxa flowers during 16 days in 2011 (A) and during 13 days in 2012 (B) at Ouro-Gadji, mean temperature and mean humidity of the study site.

3.2.5 Duration of a visit per flower
The mean duration of a X. olivacea visit on V. paradoxa flower varied significantly, depending on the substance taken. In 2011 the mean duration of a visit for pollen collection was 13.18 sec \((n = 50, s = 11.15, \text{maxi} = 48)\); for the collection of nectar, it was 22.87 sec \((n = 50, s = 12.53, \text{maxi} = 75)\). In 2012, the corresponding results were 16.31 sec \((n = 50, s = 13.42, \text{maxi} = 54)\) and 28.38 sec \((n = 50, s = 21.05, \text{maxi} = 82)\) for pollen and nectar harvest respectively. For the two cumulative years, the mean duration of a visit for pollen collection and that for nectar collection was 14.74 sec and 25.62 sec respectively. The difference between the duration of a visit for nectar harvest in 2011 and 2012 is significant \((t = 7.87; df = 98; p < 0.001)\), as well as the difference between durations of visit for pollen harvest in 2011 and 2012 \((t = 6.27; df = 98; p < 0.001)\). The difference between the duration of visit for pollen harvest and that for nectar harvest was highly significant in 2011 \((t = 19.94; df = 98; p < 0.001)\) as well as in 2012 \((t = 16.92, df = 98; p < 0.001)\).

3.2.6 Abundance of Xylocopa olivacea
In 2011 and 2012, the highest mean number of X. olivacea simultaneously in activity was 1 per flower \((n = 50, s = 0)\). The corresponding figures per 1000 flowers were 147.24 \((n = 50, s = 77.04, \text{maxi} = 339)\) and 97.81 \((n = 50, s = 42.31, \text{maxi} = 207)\) respectively. The difference between the mean number of foragers per 1000 flowers in 2011 and 2012 was highly significant \((t = 25.90; df = 118; p < 0.001)\). For the two cumulative years, the mean highest number of X. olivacea individuals simultaneously in activity per 1000 flowers was 122.52.

3.2.7 Foraging speed of Xylocopa olivacea on Vitellaria paradoxa flowers
Xylocopa olivacea visited between 3 and 29 flowers/min in 2011 and between 2 and 21 flowers/min in 2012. The mean foraging speed was 8.17 flowers/min \((n = 60, s = 3.54)\) in 2011 and 11.51 flowers/min \((n = 60, s = 4.11)\) in 2012. The difference between these means was highly significant \((t = -25.90; df = 118; p < 0.001)\). For the two cumulated years, the mean foraging speed was 9.84 flowers/min.

3.2.8 Influence of Wildlife
During the period of observation, flowers of many other plant species growing near V. paradoxa were visited for nectar (ne) and/or pollen (po) by X. olivacea individuals. The most representative of these plants were Mangifera indica (Anacardiaceae, ne) and Danelliola oliveri (Fabaceae, ne and po). During one foraging trip, an individual carpenter bee foraging on V. paradoxa was not observed moving to the neighbouring plant species or vice versa. Individuals of X. olivacea were disturbed in their foraging by other arthropods that were competitors for the search of pollen or nectar. These disturbances resulted in the interruption of certain X. olivacea visits. In 2011, for 194 visits of X. olivacea, 2 (1.03%) were interrupted by Lasioglossum sp.1. In 2012, for 111 visits of X. olivacea, 1 (0.90%) was interrupted by Apis mellifera. For their load of
pollen some individuals of X. olivacea who suffered such disturbances were forced to visit more flowers and/or plants during the corresponding foraging trip.

3.3 Impact of Anthophilous insects including Xylocopa olivacea in the pollination and Vitellaria paradoxa yields

During pollen and/or nectar harvest, flowers-feeding insects of V. paradoxa were in regular contact with the anthers and stigma. These arthropods therefore increased the possibilities of this Sapotaceae pollination. Table 3 presents the results on the fruiting rate in different treatments. It is clear from this table that the comparison of fruiting rates shows that the differences are highly significant between treatments 1 and 2 ($\chi^2 = 244.47; df = 1; P<0.001$) and treatments 3 and 4 ($\chi^2 = 98.77; df = 1; P<0.001$). Consequently, in 2011, the fruiting rate of unprotected flowers (treatment 1) was higher than that of protected flowers (treatment 2). In 2012, the fruiting rate of unprotected flowers (treatment 3) was higher than that of protected flowers (treatment 4). The fruiting rate due to the action of flowering insects including X. olivacea was 62.97% in 2011, 55.55% in 2012 and 59.26% for the two studied years.

Table 3: Fruiting rate according to different treatments of Vitellaria paradoxa in 2011 and 2012 at Ouro-Gadji.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Years</th>
<th>NF</th>
<th>NFF</th>
<th>FR</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (unprotected flowers)</td>
<td>2011</td>
<td>2765</td>
<td>747</td>
<td>27.01</td>
</tr>
<tr>
<td>2 (protected flowers)</td>
<td>2011</td>
<td>2458</td>
<td>246</td>
<td>10</td>
</tr>
<tr>
<td>3 (Fl.)</td>
<td>2012</td>
<td>58</td>
<td>9</td>
<td>15.51</td>
</tr>
<tr>
<td>4 (unprotected flowers)</td>
<td>2012</td>
<td>1976</td>
<td>356</td>
<td>18.01</td>
</tr>
<tr>
<td>5 (protected flowers)</td>
<td>2012</td>
<td>2386</td>
<td>191</td>
<td>8.00</td>
</tr>
<tr>
<td>6 (Fl.)</td>
<td>2012</td>
<td>46</td>
<td>6</td>
<td>13.04</td>
</tr>
</tbody>
</table>

NFS: number of flowers studied; NFF: number of fruits formed; FR: fruiting rate.
Fl.: Flowers protected and exclusively visited by Xylocopa olivacea.

3.4 Pollination efficiency of Xylocopa olivacea on Vitellaria paradoxa

From Table 3, it appears that the comparison of fruiting rates shows that the differences are significant between treatments 2 and 5 ($\chi^2 = 1.90; df = 1; P<0.001$) and treatments 4 and 6 ($\chi^2 = 1.54; df = 1; P<0.001$). Consequently, in 2011, the fruiting rate of unprotected flowers (treatment 1) was higher than that of protected flowers (treatment 2). In 2012, the fruiting rate of unprotected flowers (treatment 3) was higher than that of protected flowers (treatment 4). The fruiting rate due to the action of X. olivacea was 16.50% in 2011, 10.31% in 2012 and 13.40% for the two studied years.

4. Discussion

Xylocopa olivacea individuals were the main floral visitors of V. paradoxa after A. mellifera workers during the observation periods. This carpenter bee is known as an insect flower visitor of V. paradoxa in Ghana [40] and in the Adamawa region of Cameroon [28, 29]. Xylocopa olivacea has been shown to be the most abundant floral visitor of: Ananas comosus [41], Luffa aegyptiaca [42], Vigna unguiculata [43] and Phaseolus coccineus [44, 45]. Previous researches carried out in other parts of the country also revealed that X. olivacea ranks second among the floral insects visiting Cajanus cajan [46] and V. unguiculata [47]. This rank could be due to the relative abundance of X. olivacea in different study areas, though the abundance and diversity of floral insects to a plant varies depending on the region [48]. The significant difference between the percentages of X. olivacea visits of the two study years could be attributed to the presence of their natural nests close to the experimental site variation. The peak of X. olivacea activity on V. paradoxa flowers was located between 10.00 am to 11.00 am, which correlated with the highest availability period of nectar and pollen on this Sapotaceae. The abundance of X. olivacea individuals per 1000 flowers and the positive and highly significant correlation between the number of V. paradoxa flowers in bloom as well as the number of X. olivacea visit indicates the attractiveness of pollen and nectar with respect to this bee.

The significant difference between the duration of the pollen harvest visits and that of nectar collection visits in 2011 and 2012 could be explained by the availability and/or the accessibility of each of these floral products or the variation of diversity of flowering insects from one year to another. During each of the two flowering periods of V. paradoxa, X. olivacea intensively and regularly harvested nectar. This could be attributed to the needs of individual carpenter bees during the flowering period. The disruptions of visits by other insects reduced the duration of certain X. olivacea visits. Similar observations were made for the same carpenter bee foraging on flowers of Phaseolus coccineus [43] in Youndé and on flowers of Phaseolus vulgaris in Ngaoundéré [49]. During the collection of nectar or pollen on each flower, X. olivacea individuals regularly come into contact with the stigma and anthers. They also carried pollen with their hairs, legs, thorax, abdomen and mouth accessories from a flower of one plant to the stigma of the same flower, to the stigma of another flower of the same plant or to that of another plant; individuals of this carpenter bee can thus influence self-pollination and cross-pollination [50, 51]. Similar observations have been made for X. olivacea foraging on flowers of Phaseolus vulgaris in Western Kenya [43], on Ananas comosus flowers in Ghana [41] and on Sesbania radiata in Benin [53]. The weight of X. olivacea played a positive role in the self-pollination [42], when collecting nectar and/or pollen, X. olivacea shakes flowers; this movement could facilitate the liberation of pollen by anthers, for optimal occupation of the stigma [42]. Results of the present study confirm those of the studies carried out by [43, 44] on Phaseolus coccineus in Yaoundé and Ngaoundéré respectively, [49] on Phaseolus vulgaris in Ngaoundéré, [52] on Luffa aegyptiaca in Ghana. The present study demonstrates that during one foraging trip, an individual bee foraging on V. paradoxa scarcely visits other plant species. The higher productivity of fruits in unlimited visits when compared with bagged flowers showed that insect visits were effective in increasing cross and/or self-pollination. Higher productivity of flowers exposed to visits by X. olivacea compared with those under unlimited visits by all kinds of visitors shows that this carpenter bee is an important pollinator of V. paradoxa and thus can be targeted for the managed pollination of this plant.

The positive and significant contribution of X. olivacea to the V. paradoxa yields through its pollination efficiency is in agreement with similar findings in Yaoundé on Phaseolus coccineus [43] and in Ngaoundéré on Phaseolus vulgaris [49].

5. Conclusion

Vitellaria paradoxa is a plant species that benefit highly from pollination by insects among which, Xylocopa olivacea is the most important pollinator. This carpenter bee harvests pollen and nectar in V. paradoxa flowers. The comparison of fruits set of unprotected flowers with that of flowers visited exclusively by X. olivacea underscores the value of this pollination.
carpenter bee in increasing mature fruits rate of *V. paradoxa*. The installation of *X. olivacea* nests at the vicinity of *V. paradoxa* field is recommended for the increase of fruit yield of this plant species in the region.

6. References

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