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Influence of *Xylocopa* sp. (Hymenoptera: Apidae) on *Solanum aethiopicum* L., 1763 production in Far-North, Cameroon

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ABSTRACT

A study on the mutualism between *Solanum aethiopicum* and an undescribed bee species belonging to the genus *Xylocopa* was carried out in Meskine (Soudano-Sahelian agroecological zone, Cameroon) during the dry season. Throughout two consecutive years (2019 and 2020), experiments were conducted on 540 tagged flowers that were categorized into four different treatments each year: 120 flowers unprotected, 120 flowers protected from insects using gauze bags, 200 flowers bagged to prevent visits from insects and later opened to single visits of *Xylocopa* sp. and 100 flowers bagged to prevent any insect visits, then opened and re-bagged to avoid further visits on the flowers. The results revealed that among 19 anthophilous insect species, *Xylocopa* sp. was the most frequent. These bees exclusively and intensively collected the pollen from eggplant flowers during the day. The mean duration of *Xylocopa* sp. visit per flower was 32.32 seconds and the mean foraging speed was 4.69 flowers per minute. The mean number of this bee on *S. aethiopicum* was 362.04 per 1000 flowers. *Xylocopa* sp. significantly increase fruiting rate by 82.99% and the percentage of normal seeds by 7.40%. To ensure the eggplant field's long-term viability in Maroua, conservation and installation of *Xylocopa* sp. is recommended.

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KEYWORDS: *Xylocopa* sp., *Solanum aethiopicum*, pollination, production.

INTRODUCTION

Originating from Africa, *Solanum aethiopicum* or bitter eggplant is a dicotyledonous vegetable of the family Solanaceae [1]. *Solanum aethiopicum* is one of the three species of eggplants cultivated with *S. melongena* and *S. macrocarpum* [2]. The stem of Solanaceae is erect, bushy, and 50 cm to 2 m in height depending on the climate [3]. The flowers, white or purple, solitary, are carried in the axils of the leaves [3]. The fruits are berries of a wide variety of shapes (ovoid, pear-shaped, spherical, cylindrical, and very elongated) and of different colors (from ivory white, yellow, green, and more generally purple, purplish to almost black) [3]. *Solanum aethiopicum* is a very important vegetable for both rural and urban communities in African countries [4]. This plant is highly cultivated by traditional farmers and plays an important role in the subsistence and economy of poor farmers and consumers throughout the developing world [4]. The leaves and fruit are used for cooking stews and soups. Solanaceae is predominantly cultivated for its fruit vegetable which provides food security for human beings with a mean fruit consumption value of 3.7 kg/inhabitant/year [5]. The world production tonnage of *S. aethiopicum* was estimated to be 46 million in 2014 with India and China as the main producers [6]. Cameroon was ranked 65th in

2014 with 1912 tonnes [6]. The fruit is rich in phenolic compounds and antioxidant alkaloids with favorable effects on metabolic syndrome [7]. It has pharmacological properties such as anti-inflammatory, antimicrobial, antiasthmatic, antihypertensive, antitumoral, hypotensive, diuretic, hypoglycemic and antinociceptive [8]. The plant is also used in treating diarrhea, hypertension, syphilis, gonorrhoea, asthma, and constipation [9].

About 10000 wild bee species represent the global apidofauna in the world [10]. These insects are prominent in sunny biotopes where they play an important role related to the pollination of wild and cultivated plant species [11, 12]. Long ago, the importance of wild bees in pollinating plants was neglected [13]. However, several studies have reported on the implication of native bees or wild pollinators on the improvement of crop yields through their pollination activity [14-31]. Among the wild pollinator species, the genus *Xylocopa*, due to their size and weight, are the best pollinators of legume flowers [32]. Carpenter bees are among bee species that vibrate flowers for pollen collection through sonication [33]. Since these strong rapid vibrations made a buzzing sound and enable pollen harvesting, it is intentionally used by these bees [33]. Overall, the family Solanaceae is among plant families which are pollinated by buzzing bees [34]. Despite their importance as a pollinating agent of Solanaceae, peasants are not aware of their implication in improving fruit and seed yields of crops in the field. Yet, bee pollination remains an important production factor in agronomy.

This research aims to determine the interactions between insect pollinators and *S. aethiopicum* in the Sudano-Sahelian agroecosystem of Cameroon. More specifically, this work aims at 1) determining the diversity of entomophilous insects associated with *S. aethiopicum*; 2) studying the dynamism of a single flower visit of *Xylocopa* sp. on the production of eggplant, and 3) assessing temporal changes of flowering insects community and identifying external factors affecting the biomass of pollinating insects associated with eggplant.

MATERIALS AND METHODS

Study site

Experiments were carried out in a plantation within the Institute of Agricultural Research for Development in Meskine, Maroua neighbourhood, Diamaré Division, Far-North Region of Cameroon from November to April in 2019 and 2020. Maroua is of the Sudano-Sahelian agroecological zone with two unequal seasons, the long dry season (November-May) and the short rainy season (June-October). The choice of the site was motivated by the intense practice of smallholder agricultural activities by farmers of the locality. The geographical coordinates corresponding to 10 32', 26" N; 014 14', 53" E; 424 m above sea level was taken by the Brand Garmin GPS II +.

Materials

The plant material consisted of *S. aethiopicum* seeds purchased from the local market at Meskine. The animal material was represented by insects spontaneously present in the environment including *Xylocopa* sp. and which visited the flowers of *S. aethiopicum*. Some agricultural (hoes, cutlass, motor pump, sewage), technical (decameter, rope, GPS II +, hygrothermometer, chronometer), and entomological (70% ethanol, bottles of 600 mL, butterfly vials, gauze bags, hand net, and boxes) materials were used.

Methods

Setting up the nursery and the experimental device

On November 10th, 2019, and November 15th, 2020 a nursery of 2 m² surface and 10 cm height was delimited, cleared, and plowed, and then the seeds of *S. aethiopicum* were dropped on the ground and then covered with a thin layer of soil for protection against mice. After 3 to 7 days depending on the viability of the seeds, young seedlings emerged. The nursery was watered daily in the evening for the first two weeks. After the expansion of the cotyledons, the nursery was watered beforehand according to the degree of soil moisture until the transplanting in the field after 4 to 6 weeks of sowing when they have 5 to 6 leaves and are 12 to 15 cm high. From 15th to 22nd December 2019 and from 5th to 10th January 2020, in parallel to the establishment of the nursery, an experimental plot with an area of 437 m^2 was set up.

Transplanting and maintenance of plants

On 24th December 2019 and 12th January 2020 in the morning, the experimental plot of *S. aethiopicum* was watered as well as the nursery. At sunset, the vigorous plants from the nursery were selected, pulled, and then transplanted, at a rate of six lines per sub-plot and two plants per pocket spaced 50 cm on the lines and between lines. After transplanting, the plants were immediately watered. Every two days, during the first two weeks, and every four days thereafter, the experimental plot was watered by drainage. From transplanting to the appearance of the first flower bud, weeding was performed using a hoe each week. From flowering to fruit maturity, weeding was done by hand.

Description of the different treatments

At bud stage, 540 flowers were tagged and four treatments implemented over both years:

- Treatment 1 (2019) or 5 (2020): 120 flower buds left to open-pollination on which no insects were captured [35];
- Treatment 2 (2019) or 6 (2020): 120 flower buds protected from insects with gauze bags of 1 mm^2 mesh [35];
- Treatment 3 (2019) or 7 (2020): 200 flower buds protected from insects, intended for studying pollination efficiency by *Xylocopa* sp. [36];
- Treatment 4 (2019) or 8 (2020): 100 flower buds protected from insects then destined for opening and closing without insect visits [36].

Determination the diversity of flowering insects of *Solanum aethiopicum*

From February 12th to March 15th, 2019, and March 2rd to April 12th, 2020, observations were made daily on the flowers of treatments 1 and 5, according to six one-hour intervals of daily time: 6-7 a.m., 8-9 a.m., 10-11 a.m., 12-1 p.m., 2-3 p.m. and 4-5 p.m. [35]. Each forager found on the open flowers was counted and marked during each time interval to determine the diversity of flower-visiting insects associated with *S. aethiopicum* for each study season. The centesimal frequency (F_i) which is the ratio of the number of visits of insect *i* to the total number of visits of all insects was assessed according to the following formula $F_i = [(V_i) / V_t) * 100]$, where: V_i = the number of visits of insect *i* on marked and unmarked flowers; V_t = the number of visits of all insects on the same flowers [35]. On the open and unmarked flowers, the different insects were captured and then kept for future identification.

Behavior of *Xylocopa* sp. on *Solanum aethiopicum* flowers

The activities of the carpenter bee on the flowers of *S. aethiopicum* were evaluated during the following time slots: 7-8 a.m., 9-10 a.m., 11-12 a.m., 1-2 p.m., 3-4 p.m. and 5-6 p.m. [37]. By counting and direct observation, some parameters such as the abundance of foragers per flower and the type of floral product collected were noted. According to [38] the ethology of foraging of an insect is a function of the type of floral product collected. Thus, if the insect pushes its mouthparts or its head into the bottom of the corolla of a flower, it is a nectar seeker; if with its mandibles and legs, it scratches the anthers, it is a pollen harvester [38].

The abundance per 1000 flowers (A_{1000}) was determined by the method described in [37] using the following formula: $A_{1000} = [(A_x / F_x) * 1000]$ where: F_x = number of opened flowers; A_x = number of individuals of *Xylocopa* sp. counted on these flowers at a given time *x*.

The duration of the visit was evaluated using a stopwatch set to zero and started as soon as a forager landed on a flower and stopped as soon as it left it [39]. Moreover, the foraging speed (Fs) was estimated using the following formula:

$Fs = [(N_f / d_x) * 60]$ where: d_x = time given by the stopwatch (in seconds); N_f = number of flowers corresponding to d_x [35].

During these observations, when a forager returns to a previously visited flower, the count was considered as a new visit [39]. The interruption of forager's visit was recorded by direct observations and the flower visitors were captured for identification. The ambient temperature and hygrometry of the site were recorded every 30 minutes [35].

Evaluation of the contribution of flower-visiting insects including *Xylocopa* sp. on *Solanum aethiopicum* production

Based on the impact of flower-visiting insects on pollination, the impact of pollination on fruiting, and the comparison of the percentage of normal seeds were determined for each treatments. The fruiting rate due to the foraging of flowering insects including *Xylocopa* sp. was determined using the following formula: (*Fri*). $Fri = \{[(F_X - F_Z) / (F_X + F_Y - F_Z)] * 100\}$ where: F_X = the fruiting rate in treatments 1 or 5; F_Y = the fruiting rate in treatments 2 or 6; F_Z = the fruiting rate in treatments 4 or 8 [29].

The fruiting rate of a treatment *(Fr)* was determined by the formula $Fr = [(N_f / N_{fv}) * 100]$ where N_f = the number of fruits formed; N_{fv} = the number of flowers initially borne [35].

The average number of seeds per fruit and the percentage of normal seeds were evaluated in the same way as the fruiting rate.

Determination of the repercussion of *Xylocopa* sp. on *Solanum aethiopicum* production

This parameter was highlighted based on treatments 3 and 4 in 2019 and then 7 and 8 in 2020. The fruiting rate attributable to *Xylocopa* sp. (F_X) was estimated using the formula mentioned in [35]: $F_X = \{[(F_3 - F_4) / F_3)] * 100\}$, where: F_3 = fruiting rate in treatment 3 or 7; F_4 = flowers protected and then uncovered and protected again without visits of insects or other organisms 4 or 8. The number of seeds per fruit and the percentage of normal seeds attributed to *Xylocopa* sp. were evaluated in the same manner as the fruiting rate.

Data processing

The collected data were keyed in Excel 2016 sheet for analysis. The following statistical tests were used:

- Student *t*-test for the comparison of two means from two samples
- Chi-square test ($\chi 2$) for the comparison of percentages
- Pearson's correlation coefficient (*r*) for the study of the linearity between two parameters
- Analysis of Variances (ANOVA) for the comparison of means from several treatments.

Overall, the analysis was performed using Rcmder software version Ri 386.3.3.3.

RESULTS

Position of *Xylocopa* sp. in the entomofauna of *Solanum aethiopicum*

During observations in the Maroua region, 374 and 573 visits of 10 and 14 insect species were recorded on unprotected flowers of *S. aethiopicum* (treatments 1 and 5), in February 2019 and March 2020, respectively (Table 1).

Xylocopa sp. was the most frequent flower visitor in the two years studied, with 33.95% of visits in 2019 and 31.41% in 2020. There is no difference between the percentages of visits for the two years of observations concerning the carpenter bee (χ^2 = 0.67; *ddl* = 1; $P > 0.05$).

Requirement and frequency of visits

The purpose of *Xylocopa* sp. was to specifically search for pollen on the flowers of the Solanaceae during the two years of study. This pollen search starts from 6 a.m. and intensifies exponentially between 8-9 a.m. followed by a strong gradual regression at 12-1 p.m. and a slight increment in the evening around 5 p.m. (2019). Fig. 1 illustrates the variation in the rate of visits of *Xylocopa* sp. according to the time of observation during both years.

For 94 visits recorded for the pollen collection in both years' study, 32.98% was designated for 2019 and 67.02% for 2020. The difference between these two percentages of pollen harvesting visits during two years is highly significant (χ^2 = 21.78; *ddl* = 1; $P < 0.001$).

Rate of visits of *Xylocopa* sp. according to the number of flowers opened by *Solanum aethiopicum*

During the observations, the number of flowers opened on *S. aethiopicum* did not influence the number of visits by *Xylocopa* sp. Statistical analysis showed a positive but non-significant correlation between the number of opened flowers and the number of visits by *Xylocopa* sp. in 2019 ($r = 0.33$; *ddl* = 5; $P > 0.05$) and 2020 ($r = 0.43$; *ddl* = 5; $P > 0.05$) (Fig. 2).

Regarding forager abundance, the highest number of *Xylocopa* sp. individuals jointly active on a flower was 1 in both years. The average abundance per 1000 flowers (A_{1000}) was 411.17 ± 29.62 ($n = 66$; $s = 240.67$) in 2019 and 312.91 ± 15.54 ($n = 51$; $s = 110.98$) in 2020. The difference between these two means is highly significant (t = 2.91; *ddl* = 115; $P < 0.001$). For both years, A_{1000} = 362.04 ± 16.26 ($n = 117$; $s = 175.83$).

Duration of visits

In 2019 and 2020, the mean duration of a visit by *Xylocopa* sp. per *S. aethiopicum* flower for pollen collection was 34.87 ± 3.26 sec ($n = 31$; s =18.17;

Table 1. Insects recorded on *Solanum aethiopicum* flowers in 2019 and 2020 in Meskine, number and percentage of visits of different insects.

Insects			2019		2020		Total	
Order	**Family**	**Genus and species**	n_1	P_1(%)	n_2	P_2 (%)	n_t	P_t (%)
Diptera	Calliphoridae	*Chrysomia chloropyga*	-	-	9	1.57	9	0.95
	Syrphidae	(1 sp.)	6	1.60	-	-	6	0.63
Coleoptera	Coccinellidae	(sp. 1)	7	1.87	-	-	7	0.73
Hymenoptera	Apidae	*Apis mellifera*	42	11.22	18	3.14	60	6.33
		Amegilla calens	85	22.72	113	19.7	198	20.90
		Amegilla sp. 1	13	3.47	8	1.39	21	2.21
		Amegilla sp. 2	76	20.32	-	-	76	8.02
		Amegilla sp. 3	-	-	27	4.71	27	2.85
		Amegilla sp. 4	-	-	41	7.15	41	4.32
		Tetralonia sp.	-	-	27	4.71	27	2.85
		Xylocopa sp.	127	33.95	180	31.41	307	32.41
		Xylocapa olivacea	8	2.13	-	-	8	0.84
	Halictidae	*Lasioglossum* sp. 1	5	1.33	12	2.09	17	1.79
		Lasioglossum sp. 2	-	-	36	6.28	36	3.80
		Lasioglossum sp. 3	-	-	45	7.85	45	4.75
		Lipotriches azarensis	-	-	26	4.53	26	2.74
	Vespoidae	(sp. 1)	-	-	15	2.61	15	1.58
		(sp. 2)	-	-	16	2.79	16	1.68
	Pompilidae	(1 sp.)	5	1.33	-	-	5	0.52
Total			**374**	**100**	**573**	**100**	**947**	**100**
			10 species		**14 species**		**19 species**	

n_1 and n_2: number of visits on 120 flowers observed in 7 days in 2019 and 2020, respectively; n_t: number of total visits; **sp.**: undetermined species; P_1, P_2, P_t: percentages of visits in 2019, 2020 and for the two years respectively: $p_1 = (n_1 / 374) * 100$, $p_2 = (n_2 / 573) * 100$, $p_t = (n_t / 947) * 100$.

min = 7; *max* = 82) and 25.22 ± 2.44 sec ($n = 63$; s =19.34; *min* = 3; *max* = 93) respectively, with the difference between these two means being significant ($t = 2.43$; *ddl* = 92; $P < 0.05$). Cumulatively for both years, this visit duration per flower was 32. 32 ± 2.60 sec ($n = 94$; $s = 25.21$; *min* = 3; *max* = 93; $P < 0.05$).

Foraging speed

The number of flowers of *S. aethiopicum* visited by *Xylocopa* sp. individuals varies from 1 to 10 per minute; the average foraging speed was 4.22 flowers/min in 2019 and 5.16 flowers/min in 2020. The difference between both values is not significant ($t = 1.44$; *ddl* = 104; $P > 0.05$). For both years combined, the mean foraging speed was 4.69 flowers/min.

Influence of wildlife on *Xylocopa* sp. activity

In 2019, the frequencies of interrupted visit of *Xylocopa* sp. and their induction factors were 13.33% and 6.66% with *Apis mellifera* and *Amegilla calens* as pollen competitors, respectively. In 2020, these values were 1.58% for *Apis mellifera*, 4.76% for *Amegilla calens,* and 1.58 for *Lasioglossum* sp. The difference between the percentage of interrupted visits for two years was significant ($\chi^2 = 23.41$; *ddl* = 1; $P < 0.001$).

Influence of flora on the activity of *Xylocopa* sp.

During our observations, several plant species were visited by *Xylocopa* sp. foragers for searching pollen and/or nectar: *Solanum lycopersicum* (Solanaceae; pollen); *Solanum nigrum* (Solanaceae; pollen); *Allium cepa* (Liliaceae; pollen and nectar);

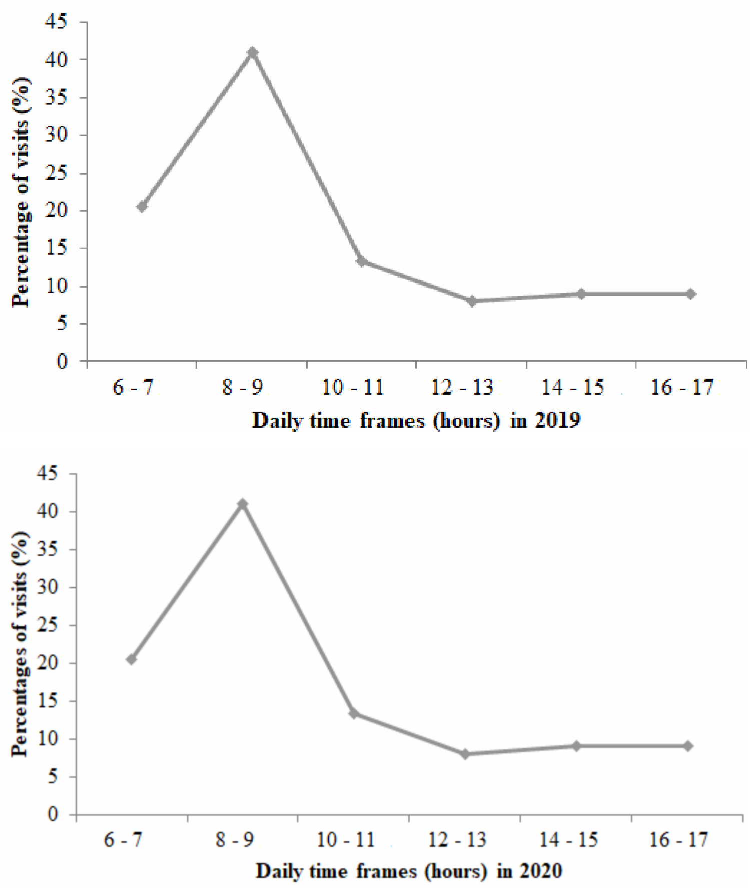

Fig. 1. Variation in the number of *Xylocopa* sp. visits on *Solanum aethiopicum* flowers according to the daily time frames in 2019 and 2020 at Meskine.

Citrus limon (Rutaceae; pollen); *Luffa cylindrica* (Cucurbitaceae; pollen and nectar). In 2019 there were two passages of *Xylocopa* sp. on *S. nigrum* to *A. cepa* flowers and one in 2020 to *C. lemon*.

Influence of meteorological factors on the activity of *Xylocopa* sp.

Ambient temperature, wind speed, and humidity of the area did not influence the activity of *Xylocopa* sp. on *S. aethiopicum* flowers in 2019 and 2020 (Fig. 3).

During the 14 days of observations for both seasons of investigation 100% were sunny. For 31 and 63 visits recorded in 2019 and 2020, 6.45% and 4.76% were interrupted due to wind effects. There was no correlation between the number of visits of *Xylocopa* sp. and the mean temperature in 2019 (r = -0.56; ddl = 4; $P > 0.05$) and 2020 (r = -0.28; ddl = 4; $P > 0.05$); and between the number of visits and the mean relative humidity in 2019 (r = 0.07; ddl = 4; $P > 0.05$) and 2020 (r = 0.62; ddl = 4; $P > 0.05$).

Impact of anthophilous insects including *Xylocopa* sp. on *Solanum aethiopicum* production

From Table 2, it appears that:

a) The mean values of the fruiting rate in treatments 1, 2, 3, 4, 5, 6, 7 and 8, were: 73.33%, 58.33%, 81.98%, 42.58%, 81.66%, 60.83%, 84.00% and 54.60%, respectively. The differences between these values are highly significant (χ^2 = 93.85; ddl = 7; $P < 0.001$). The pairwise comparison shows a significant difference between treatments 1 and 2 (χ^2 = 6; ddl = 1; $P < 0.05$), then 5 and 6 (χ^2 = 12.71; ddl = 1; $P < 0.001$). Consequently, in 2019 and 2020, the fruiting rate of unprotected flowers (treatments 1 and 5) was higher than that of flowers bagged during their flowering period (treatments 2 and 6).

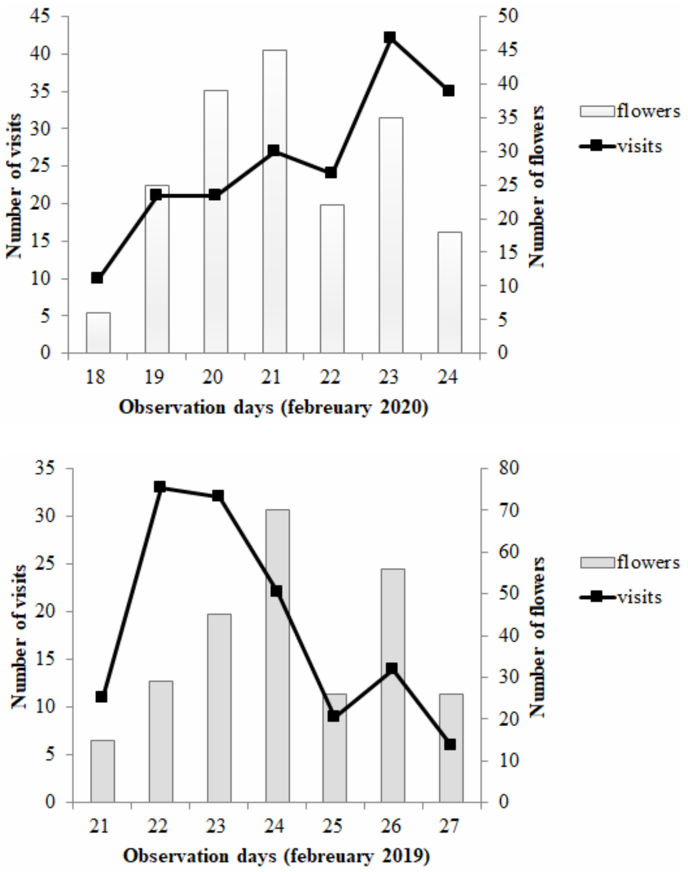

Fig. 2. Seasonal variations of the number of *Solanum aethiopicum* flowers and the number of *Xylocopa* sp. visits in 2019 and 2020 in Meskine.

b) The mean number of seeds per fruit was 240.55, 216.00, 247.41, 213.72, 231.95, 230.11, 242.94 and 226.51 in treatments 1, 2, 3, 4, 5, 6, 7 and 8, respectively. Overall, there was no difference between these means (F = 0.61; ddl_1 = 7; ddl_2 = 497; $P > 0.05$).

c) The percentages of normal seeds in treatments 1, 2, 3, 4, 5, 6, 7 and 8 were 94.09, 82.62, 94.18, 86.47, 89.56, 85.16, 83.46 and 77.11 respectively. The differences between these percentages are highly significant: χ^2_{global} = 3348.16; (ddl = 7; $P <$ 0.001). Pairwise comparisons of these percentages show significant difference between treatments 1 and 2 (χ^2 = 1021.91; (ddl = 1; $P < 0.001$) as well as 5 and 6 (χ^2 = 142.34; (ddl = 1; $P < 0.001$). Thus in 2019, as in 2020, the percentages of normal seeds were higher in treatments with flowers visited by insects (treatments 1 and 5) than in those protected from them (treatments 2 and 6).

The contribution of anthophilous insects including *Xylocopa* sp. on the fruiting rate and the rate of normal seeds of *S. aethiopicum* was 34.52% and 8.44% respectively in 2019. In 2020 the corresponding values were 33.16% and 12.75%. For both years the cumulated values were 33.84% and 10.60% for the fruiting rate and the percentage of normal seeds.

Contribution of *Xylocopa* sp. in the production of *Solanum aethiopicum*

In 2019 and 2020, the fruiting rate due to the influence of a flower visit of *Xylocopa* sp. was 81.98% and 84%, respectively. Cumulatively for both years, the mean value was 82.99%.

For 2019 and 2020, the normal seed rate induced by *Xylocopa* sp. was 94.18% and 83.46%, respectively with a cumulative rate of 88.82%.

This contribution of carpenter bees in the percentage of normal seeds was 8.19% in 2019, 6.61% in 2020, and 7.40% for both years of study.

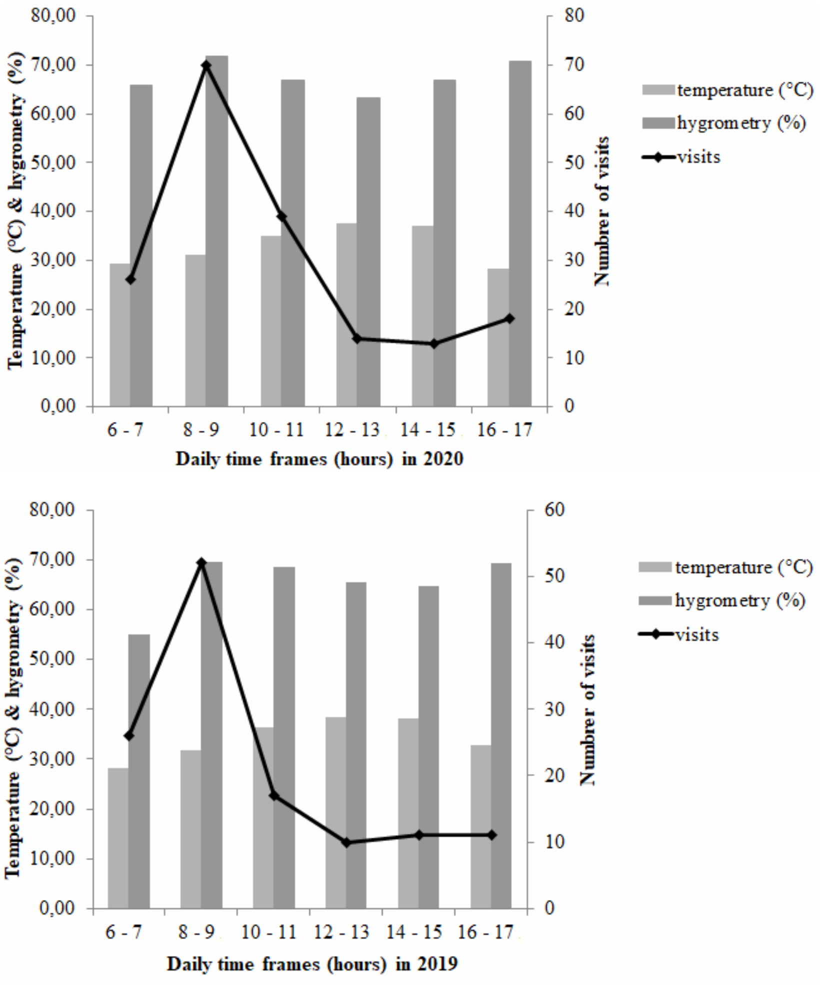

Fig. 3. Influence of temperature and humidity on the number of *Xylocopa* sp. visits on *Solanum aethiopicum* flowers according to the daily time frames in 2019 and 2020 at Meskine.

Table 2. Fruiting rate, average number of seeds per fruit and percentage of normal seeds under different treatments of *Solanum aethiopicum* in 2019 and 2020 in Meskine.

Years	TRM	NF	NFF	FR (%)	Seeds / fruit			TNS	NS	%NS
					Average	*sd*	*n*			
2019	**1**	120	88	73.33	240.55 ± 1.75	75.28	76	18658	17557	94.09
	2	120	70	58.33	216.00 ± 9.63	70.80	54	11664	9637	82.62
	3	111	91	81.98	247.41 ± 9.71	77.04	63	15587	14681	94.18
	4	155	66	42.58	213.72 ± 9.42	78.82	70	14961	12938	86.47
2020	**5**	120	98	81.66	231.95 ± 7.93	71.78	82	19020	17035	89.56
	6	120	73	60.83	230.11 ± 8.81	67.70	59	13577	11563	85.16
	7	100	84	84.00	242.94 ± 9.98	76.03	58	14091	11761	83.46
	8	163	89	54.60	226.51 ± 9.81	79.13	65	14723	11353	77.11

TRM: Treatments; NF: Number of flowers; NFF: Number of fruit formed; FR: Fruiting rate; *sd*: standard deviation; n: number of mature fruit; TNS: Total number of Seeds, NS: Number of normal seeds; %NS: Percentage of normal seeds.

DISCUSSION

Xylocopa sp. was the most frequent visitor on the flowers of *S. aethiopicum* during the studied years 2019 and 2020. This predominance is the result of the good attractiveness of the floral components of this particular species of Solanaceae towards this carpenter bee and their relative abundance in the study site environment. Previous findings have also shown the effect of carpenter bee species in increasing crops yields. This is the case with *Xylocopa calens* which was the most prominent insect on *Phaseolus coccineus* flowers [14], while *Xylocopa olivacea* was the most important on *Vigna unguiculata* [24, 15], *Bixa orellana* [30], and *Phaseolus vulgaris* flowers [19, 28]. Moreover, Azo'o, E. M *et al*. [18] indicated *X. olivacea* as a synergistic and alternative pollinator of *Apis mellifera* on *Citrullus lanatus* flowers in Maroua. Carpenter bees were found as essential visitors of *Calotropis procera* [40] and *Sesamum indicum* [41] in the Sudano-Sahelian region of Cameroon.

The difference in pollen harvesting rates between the two years could be due to the availability of this floral product in the flowers and the food requirements of the carpenter bee. This difference is also reflected in the attractiveness of pollen from other Solanaceae such as *Solanum nigrum* which flowered more intensively in the first year of the study. The exclusive pollen collection by *Xylocopa* sp. could be linked to the absence of nectar production on the flowers of the host plant as already suggested [4].

The optimal activity of *Xylocopa* sp. on *S. aethiopicum* flowers in the morning between 8 and 9 a.m. is the result of the availability of pollen grains of this plant and the favorable ecological conditions for its forager. The regression of the floral activity of *Xylocopa* sp. observed at midday could be related to the decrease in the quantity and/or quality of pollen due to the increase in the ambient temperature of the study site. Indeed when the booty is difficult to access or the quality and quantity are less important, the individuals of *Xylocopa* sp. reduce their activities to avoid energy loss [42, 43]. In fact, in the middle of the days, the average temperature recorded was between 37-38 °C during observation periods which makes the environmental conditions unfavorable for *Xylocopa* sp. foragers. In the same region, for *Cajanus cajan* [44] *Xylocopa* sp. showed peak activities in morning between 9-10 a.m. In Yaounde, the peak of activity of *Xylocopa calens* on *Phaseolus coccineus* flowers was between 9-10 a.m. [14], while, in the Adamawa region the peak of floral activity of *Xylocopa olivacea* was at 8-9 a.m. on *Vigna unguiculata* [24], at 10-11 a.m. on *Phaseolus vulgaris* [28] and 7-8 a.m. on *Bixa orellana* [30].

The one individual bee per flower could be related to the small diameter of the flower whose average size is 2.2 cm. This diameter is less important for larger insects such as carpenter whose individual average length is about 18.45 mm (n = 8; s = 0.89; *mini* = 14.67; *maxi* = 17.04). The high abundances per 1000 flowers highlight the good attractiveness, accessibility, quality, and availability of the pollen of this Solanaceae towards *Xylocopa* sp. The statistical difference observed could be due to the variation of some abiotic ecological factors during the two years of observations that influenced the activity of *Xylocopa* sp. on the flowers of *S. aethiopicum*.

The significant difference observed between the duration of the visits of *Xylocopa* sp. between both years could be explained by the influence of the disturbing agents (*Apis mellifera* in the first year and *Lasioglossum* sp. in the second year) whose percentages were 20% in 2019 and 7.93% in 2020 and strong wind. Wind disturbance on the carpenter bee was evaluated to be 6.45% in 2019 and 4.76% in 2020. Disturbed *Xylocopa* sp. individuals were forced to amplify the number of visited flowers in order to acquire their maximum pollen loads.

The high fruiting rate and normal seeds in treatments 1 and 5 compared to treatments 2 and 6 are due to the positive influence of the floral insect on the pollination of flowers of this Solanaceae. Indeed, during the search for floral products, carpenter bee individuals carry pollen from flower to flower and from plant to plant and increase the probability of pollen deposition on the stigma of the visited flowers. Note that the yield of a flowering plant is mainly dependent on the pollination intensity [45]. Other findings on other Solanaceae species have already shown the upsurge of insect pollinators in improving fruit and seed production. This is the case for *Solanum scabrum*, *Solanum melongena*, *Solanum aethiopicum*, *Solanum anguivi*, *Solanum gilo*, *Solanum erianthum*, and *Solanum torvum* in Nigeria [46]; *Physalis micrantha* [47] and *Physalis minima* [48] in Cameroon.

The differences observed between treatments 3, 4, 7, and 8 are proof of the positive influence of *Xylocopa* sp. in the production of *S. aethiopicum*. This bee intervened in the self-pollination and allopollination of the flowers of the plant studied. Indeed, while looking for pollen on the flowers of this Solanaceae, *Xylocopa* sp., by its very significant weight and by the vibration of its wings, shakes the flower while the thorax and the abdomen are in contact with the anthers and stigma. Thereafter, it scratches the anthers with the help of its posterior legs, mandibles, and abdominal hairs to collect pollen. This leads to the release of pollen by the anthers and increases the probability of fertilization of the visited flowers which is self-compatible. This previous pollination behaviour of carpenter bee species has already been described by other authors working on Solanaceae [49, 50, 20]. Overall, the growth and development of seeds and fruits are the consequences of the important deposition of pollen on the stigma of visited flowers [51]. Previous findings have shown the positive impact of carpenter bee species in increasing production; this is the case for *Xylocopa olivacea* on *Vigna unguiculata* [24], *Phaseolus vulgaris* [27, 28], *Vitellaria paradoxa* [26], and *Xylocopa calens* on *Phaseolus coccineus*.

CONCLUSION

The floral entomofauna of *S. aethiopicum* in Meskine (Soudano-sahélian region of Cameroon) is rich with 19 flower-visiting insect species, with the prominent being *Xylocopa* sp. (32.41%). Individuals of this carpenter bee exclusively collected pollen on the flowers of this Solanaceae during the two studied years, with a peak of floral activity at 8-9 a.m. interval time. Via its foraging and pollinating activities on the plant species studied, *Xylocopa* sp. contributed to the improvement of fruit set rate by 82.99% and the percentage of normal seeds by 7.40%. Farmers have to develop ecofriendly measures for the preservation of carpenter bees such as *Xylocopa* sp. in surrounding fields of *S. aethiopicum* for its sustainable production in the Far-North Region of Cameroon.

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have not conflict of interest.

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