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Comparing the foraging behaviour and pollination efficiency of *Apis mellifera* with *Xylocopa olivacea* (Apidae: Hymenoptera) on *Citrullus lanatus* flowers

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Abstract

Comparing the foraging behaviour and the pollination efficiency of honey bee (*Apis mellifera*) with a carpenter bee (*Xylocopa olivacea*) in the farmer garden of watermelon (*Citrullus lanatus*) was conducted in Maroua (Cameroun) in 2016 and 2017. Several foraging parameters were assessed for each bee species during the blooming period of watermelon and comparisons were made between fruit and seed yields from four pollination treatments on female flowers including the no bee visit treatment (T_0), the one bee visit treatment for *A. mellifera* (T_1) and *X. olivacea* (T_2) and the unrestricted treatment (T_3). Results showed an important difference in the rhythm of activity between the two bee species with a peak of floral activity of *X. olivacea* at 07:00-08:00 a.m. time interval and that of *A. mellifera* at 09:00-10:00 a.m. *A. mellifera* was prominent than *X. olivacea* regarding the frequency of floral visits in 2016 (77.74 and 22.26 %) and in 2017 (81.28 and 18.72 %) and the density of individuals per 1000 flowers in 2016 (442/1000 flowers and 97/1000 flowers) and in 2017 (476/1000 flowers and 88/1000 flowers). Despite the higher foraging intensity of *A. mellifera* compared with that of *X. olivacea*, the carpenter bee was a more efficient pollinator than the honey bee. Indeed, the mean treatments for fruiting rate, mean fruit weight, mean fruit diameter, and mean mature seeds per fruit of watermelon were higher on the one visit basis in T_2 than T_1. Moreover, the unrestricted treatment T_3 produced fruit with the best marketable value than restricted treatments T_2, T_1, and T_0. *X. olivacea* should be associated with *A. mellifera* in a watermelon field to optimize the pollination of this crop for obtaining improved yields. Considering very high pollinating efficiency of *X. olivacea*, the means of conservation must be developed for this solitary bee which appeared in this work as a synergistic or alternative pollinator of the honey bee within a watermelon farm.

Key words: Foraging behaviour, pollination efficiency, *Apis mellifera*, *Xylocopa olivacea*, watermelon, yield.

Introduction

Watermelons (*Citrullus lanatus*) like many other Cucurbit species cannot produce fruits without pollination (Stanghellini *et al.*, 1998). A watermelon plant is monoecious and thus produces both male and female flowers (Adlerz *et al.*, 1966). In order to pollinate the watermelon plant, pollen from the male flowers must be transported to the female flowers by pollen vectors among which insects are the most efficient (Klein *et al.*, 2007). Watermelon in nature is mainly pollinated by bee species that move from flower to flower and distribute pollen (Azo'o *et al.*, 2010). As watermelon farms rely on bees to pollinate the crop, farmers may manage the bee hives to perform this service (Philippe, 1991).

Bee pollination is a vital service for both wild and agricultural systems (Kremen *et al.*, 2004). Without bee pollinators, almost a third of the world's plant species would flower, only to fade and then lie barren (Southwick and Southwick, 1992; Gallai *et al.*, 2009). Bee species are the main service provider along with greater pollinator diversity (Torchio, 1990). Except, bees of the genus *Apis*, all other bee species are known as non-*Apis* bees or wild bees (Aslam *et al.*, 2017).

Utilization of pollinators especially honey bees is considered as one of the cheapest and eco-friendly approach in maximizing the yield of cross-pollinated crops (Free, 1970). Social bee *Apis mellifera* is ranked first amongst the insect species found to visit and pollinate flowers of several crops such as watermelon (Stanghellini *et al.*, 1998; Klein *et al.*, 2007; Azo'o *et al.*, 2010, 2017). Until recently, honey bees have been so easy to manage and pollination by wild bees has largely been ignored in agricultural systems (Brittain *et al.*, 2013). However, with disease, fire, and competing demands reducing honey bee supplies and increasing the cost of hive rentals, the viability of depending on other bees for pollination has become an important factor (Haubruge *et al.*, 2006). Global decline in honey bee populations, and their limited efficiency in pollinating some crops motivate the search for additional pollinators (Sadeh *et al.*, 2007). Indeed, scientists are discovering more and more that unmanaged wild pollinators could also contribute substantially to crop pollination (Faucon *et al.*, 2002; Potts *et al.*, 2010).

Several unmanaged native bees are widely recognized as important pollinators of a range of wild plants and crop species (Kremen *et al.*, 2004); these include carpenter bees. There are more than 730 species of carpenter bees, *Xylocopa* spp. worldwide. They are robust and large, among the largest bee species known, with some reaching 4.5 cm in length (Hurd, 1978). *X. olivacea* is a species of carpenter bee of the family Apidae and the subfamily Xylocopinae (Pauly *et al.*, 2015). Individuals have particular nesting behaviour which consists to burrow into hard plant material such as dead wood or bamboo (Pauly *et al.*, 2015). Female has mesosoma totally covered by yellow pubescence and tergum 1 yellow with a mite pouch while male is totally covered by yellow pubescence (Pauly *et al.*, 2018). Previous results showed the positive impact of *X. olivacea* on the pollination and the increase of seed yields of cultivated legumes such as *Phaseolus vulgaris*, *Pisum sativum*, *Vigna unguiculata* and *Cajanus cajan* in Burundi (Pauly *et al.*, 2015) and in Cameroon (Tchuenguem *et al.*, 2014a,b; Kengni *et al.*, 2015). This wild bee was found among the main flower-visiting insects and pollinators of cucurbit species such as *Cucumis melo* in Israel (Sadeh *et al.*, 2007), *Luffa aegyptiaca* in Ghana (Mensah and Kudom, 2011), *Momordica charantia* in Western Kenya (Oronje *et al.*, 2012), *Cucumeropsis mannii* (Azo'o and Messi, 2012) and *Citrullus lanatus* in Cameroon (Azo'o *et al.*, 2017). Moreover, carpenter bee species are known as the primary pollinators of passion fruit in Brazil (Furlaneto *et al.*, 2011; Giannini *et al.*, 2013). The agronomic significance of this wild bee may even be improving.

For a commercial crop as watermelon, a thorough study of the bee species with a neglected pollination potential appears essential and could allow their knowledge, conservation and optimal use in the biological processes of the host plant production. The present study aimed to determine the foraging and pollination activities of *X. olivacea* that may be valuable as synergistic or alternative pollinator of *A. mellifera* in the watermelon in the study area.

Materials and methods

Study site: The study was carried out in Dengui (10°32'55"N 14°14'48"E, 442 meters), a neighborhood of Maroua (Far-North Region, Cameroon). The field experiments took place in a farmer's garden of about 5000 m^2 during the blooming period of *C. lanatus* for two consecutive cultivating seasons from July until September 2016 and 2017. The climate here is of the Sudano-Sahelian type with two seasons; the dry and rainy seasons. These experiments were conducted during the rainy season; the rainfall recorded stood at a mean of 1004.7 mm and temperatures ranged from 27 to 36 °C.

***A. mellifera* and *X. olivacea* behavioral parameters**: A transect of 4 m^2 was used by the observer along the edge of the garden. Direct observations inside the transect area were done twice a week (Wednesday and Saturday) on bee species targeted at 9 interval periods: 06:00-06:45 a.m., 07:00-07:45 a.m., 08:00-08:45 a.m., 09:00-09:45 a.m., 10:00-10:45 a.m., 11:00-11:45 a.m., 12:00-12:45 p.m., 01:00-01:45 p.m. and 02:00-02:45 p.m. The mean temperature and hygrometry corresponding to each observation interval were recorded using an indoor/outdoor hygro-thermometer HT 9227. The following foraging parameters were registered: the distribution of the two bee species according to the time intervals, the frequency of each bee floral visits, the density of each bee species per 1000 flowers, the foraging preference or floral product harvested, the duration of visit or the time spent by each species on a flower, the foraging speed or number of flowers visited per minute (Jacob-Remacle, 1989) and the percentage of effective visits of each bee species.

Pollination efficiency of *A. mellifera* and *X. olivacea*: The study of the pollination efficiency of *A. mellifera* and *X. olivacea* on watermelon flowers was done daily during 3 weeks. We used random samples of twenty experimental plants for each of the four treatments which were: a control treatment (T_0) with bagged female flowers benefited from no insect visit; two similar treatments where flowers were previously opened to *A. mellifera* (T_1) and *X. olivacea* (T_2) for a single visit. Protection of female flower buds in these treatments was done on the day before their opening using gauze bags; emerged petals were allowed to accurately detect the imminent blossoming of the correspondent flowers the following day (Azo'o *et al.,* 2017). Female flowers here were opened to *A. mellifera* and *X. olivacea* between 07:00-09:00 a.m. After the visit of an individual of a given bee species, each flower was re-bagged to avoid any additional visit of insects. The gauze bag was removed the day after and the young fruit, if any, was flagged for continuous survey until maturity; the unrestricted-visit treatment (T_3), in which plants were tagged at random with open-pollinated flowers that were freely exposed to the foraging activity of anthophilous insects.

To avoid any bias, only the first female flower opened was considered per watermelon flagged plant according to each treatment. All-female flowers that developed after treatments were removed from each test plant using a scissor, insuring that treated flowers were given an optimum chance for development (Stanghellini *et al.*, 1998).

The number of female flowers that set fruit was recorded in each treatment. Fruits were harvested and weighted at physiological maturity. Subsequently, each fruit was cut into the equatorial part with a kitchen knife, allowing the diameter to be measured using a caliper and counting the mature seeds embedded in the fruit flesh. The pollination efficiency of each bee species was estimated in terms of proportion of female flowers which set fruit, the mean weight of fruits, the mean diameter of fruits harvested and the mean number of mature seeds per fruit compared between treatments as a quantitative and qualitative measure of the bees' pollination success.

Statistical analysis: Data collected were keyed into an Excel sheet and analyzed using SPSS software. The data was subjected to the Student's t-test for the comparison of means between two samples. Correlations were established to study the linear relations between two parameters. One-way Analysis of Variance (ANOVA) and post hoc tests (HSD) of Tuckey Kramer with P sets to 0.05 were used for multiple comparisons of means. The mean values were followed by the standard error (SE).

Results

General activity patterns of *A. mellifera* and *X. olivacea* on watermelon flowers: Table 1a and Table 1b showed a divergence in the rhythm of floral activity of the two bee species in 2016 and 2017. In both cases, the number of bee visits was influenced by the time of the day. The floral activity of *X. olivacea* was prominent at dawn; a visitation peak was reached between 07:00-08:00 a.m., which declined to zero by approximately 10 a.m. Meanwhile, the floral activity of *A. mellifera* was effective throughout the daily opening period of the flowers since the dawn (06:00-07:00 a.m.) until around 02:00 p.m. with an important peak observed at 09:00-10:00 a.m. After this peak, the activity decreased with the flower

Table 1a. Variation of bee visits according to interval times, temperature and hygrometry in 2016

Time frames	Abiotic parameters		Number and frequency of bee floral visits			
	Temperature (°C)	RH (%)	Honey bee	FFV	Carpenter bee	FFV
06:00-06:45 a.m.	27.72	76.43	94	4.51	133	22.28
07:00-07:45 a.m.	28.95	71.37	213	10.22	347	58.12
08:00-08:45 a.m.	31.17	67.46	307	14.72	98	16.42
09:00-09:45 a.m.	32.09	64.21	538	25.80	16	2.68
10:00-10:45 a.m.	32.97	62.33	408	19.57	3	0.50
11:00-11:45 a.m.	33.11	59.52	274	13.14	0	0.00
12:00-12:45 a.m.	34.43	55.78	193	9.26	0	0.00
01:00-01:45 p.m.	32.65	51.47	58	2.78	0	0.00
02:00-02:45 p.m.	31.57	48.26	0	0.00	0	0.00
Total			2085	100	597	100

FFV = Frequency of floral visits

Table 1b. Variation of bee visits according to interval times, temperature and hygrometry in 2017

Time frames	Abiotic parameters		Number and frequency of bee floral visits			
	T (°C)	H (%)	Honey bee	FFV	Carpenter bee	FFV
06:00-06:45 a.m.	27.31	73.71	104	4.47	176	32.77
07:00-07:45 a.m.	28.07	69.59	274	11.75	297	55.31
08:00-08:45 a.m.	30.04	65.28	381	16.34	53	9.87
09:00-09:45 a.m.	31.23	62.01	603	25.87	11	2.05
10:00-10:45 a.m.	32.16	60.27	458	19.65	0	0.00
11:00-11:45 a.m.	33.38	58.13	311	13.34	0	0.00
12:00-12:45 a.m.	33.92	54.24	137	5.88	0	0.00
01:00-01:45 p.m.	33.11	50.33	63	2.70	0	0.00
02:00-02:45 p.m.	32.39	47.54	0	0.00	0	0.00
Total			2331	100	537	100

FFV = Frequency of floral visits

wilting and closing. The correlations between the rhythm of floral visits and the temperature corresponding to each daily observation were non-significant for *A. mellifera* (r = 0.25; df = 7; P > 0.05 in 2016; r = 0.07; df = 7; P > 0.05 in 2017) and negative and significant for *X. olivacea* (r = - 0.75; df = 7; P < 0.001 in 2016; r = - 0.86; df = 7; P < 0.001 in 2017). Moreover, our results revealed non-significant correlations between the rhythm of floral visits and the daily variation of the relative humidity for *A. mellifera* (r = 0.33; df = 7; P > 0.05 in 2016; r = 0.37; df = 7; P > 0.05 in 2017) but a significant correlation is the *X. olivacea* floral visits variation which is a function of the variation of the hygrometry according to time intervals (r = 0.68; df = 7; P < 0.001 in 2016; r = 0.75; df = 7; P < 0.001 in 2017).

Table 2 contains results about the foraging parameters of the honey bee and carpenter bee foragers on watermelon flowers in 2016 and 2017. *A. mellifera* and *X. olivacea* were frequent visitors to watermelon flowers where they mostly foraged nectar than pollen. The frequency of *A. mellifera visits* (77.74 % in 2016 and 81.28 % in 2017) was up than that of *X. olivacea* (22.26 % in 2016 and 18.72 % in 2017). Over 100 floral visits studied, 100 % of *X. olivacea* visits were devoted to nectar harvesting during the two experiments, while 92 % and 90 % correspond to the equivalent values dedicated to *A. mellifera* in 2016 and 2017. During their floral activity, both honey bees and carpenter bees came into contact with stigmas when visiting female flowers and anthers on male flowers; that are why the percentage of effective visits was always 100 % for each bee species.

The mean density of forager considerably varied and increased from *X. olivacea* to *A. mellifera* (Table 2); the difference was significant between the two means in 2016 (t = 21.76; df = 98; P < 0.001) and in 2017 (t = 27.32; df = 98; P < 0.001). The density of foragers also varied for a given bee species according to the season, but the difference between the mean values was overall not significant. The foraging speed followed the same evolution as a function of bee species with significant difference between *X. olivacea* and *A. mellifera* in 2016 (t = 7.52; df = 98; P < 0.001) and in 2017 (t = 8.11; df = 98; P < 0.001). Finally, the difference of the mean duration of visit between foragers on male flowers and for a given bee species according to the season was not significant; meanwhile, the difference of the mean duration of *A. mellifera* visit was significant between the sex of the flower in 2016 (t = 5.38; df = 98; P < 0.001) and 2017 (t = 6.06; df = 98; P < 0.001) with the highest value on female flowers than on male flowers; the difference of the mean duration of visit between *A. mellifera* and *X. olivacea* was significant too on female flowers in 2016 (t = 8.16; df = 98; P < 0.001) and 2017 (t = 7.54; df = 98; P < 0.001).

Efficiency of different pollination treatments regarding watermelon yields: Table 3 highlights the variation of the fruit set rate, the mean fruit weight, the mean fruit diameter and the mean number of mature seeds per fruit as a function of years and for a given year according to different treatments. No statistical difference was found during both years between all the four studied parameters from the same level treatment. On the contrary, the difference of the fruiting rate ($F_{3, 76}$ = 13.24; P < 0.001 in 2016 and $F_{3, 76}$ = 11.73; P < 0.001 in 2017); the fruit weight ($F_{3, 76}$ = 21.92; P < 0.001 in 2016 and $F_{3, 76}$ = 18.47; P < 0.001 in 2017); the mean diameter of a fruit ($F_{3, 76}$ = 12.71; P < 0.001 in 2016 and $F_{3, 76}$ = 14.68; P < 0.001 in 2017) and the mean number of seeds per fruit ($F_{3, 76}$ = 20.22; P < 0.001 in 2016 and $F_{3, 76}$ = 16.74; P < 0.001 in 2017) were significant between the four treatments and for a given parameter yearly. It results from the control or no bee visit treatment (T_0) that all-female flowers are aborted and do not produce edible fruit and then any seeds in both years 2016 and

Table 2. Foraging parameters of *Apis mellifera* and *Xylocopa olivacea* on watermelon flowers

Parameters		2016		2017	
		X. olivacea	*A. mellifera*	*X. olivacea*	*A. mellifera*
Foraging preference (n = 100)		100*Ne*; 0*Po*	91*Ne*; 9*Po*	100*Ne*; 0*Po*	90*Ne*; 10*Po*
Frequency of floral visits (%)		22.26	77.74	18.72	81.28
Density of foragers (n =50)		97 ± 11a	442 ± 27b	88 ± 9a	476 ± 31b
Foraging speed (n = 50)		11.17 ± 0.9a	7.62 ± 0.73b	9.98 ± 0.76a	7.01 ± 0.64b
Percentage of effective visits (n = 100)		100 %a	100 %a	100 %a	100 %a
Duration of bee visit	♂ (n = 50)	2.93 ± 0.46a	4.01 ± 0.34a	2.78 ± 0.33a	3.91 ± 0.42a
	♀ (n = 50)	3.07 ± 0.73a	6.73 ± 0.62b	2.98 ± 0.37a	6.48 ± 0.64b

Legend: Means ± SE within a line and/or a column (duration of visit) followed by the same letter are not significantly different. n = sample size; *Ne* = nectar; *Po* = pollen; ♂ = staminate flower; ♀ = pistillate flower

Table 3. Comparison of mean treatments for fruit set rate, fruit weight, mature seeds per fruit and fruit diameter of watermelon

Treatments	Fruiting rate (%)		Fruit weight (g)		Mean number of mature seeds/fruit		Mean fruit diameter (cm)	
	2016	2017	2016	2017	2016	2017	2016	2017
T_0	0a	0a	0a	0a	0a	0a	0a	0a
T_1	40 ± 11b	45 ± 13b	690 ± 480a	570 ± 459a	57.76 ± 20.47a	63.03 ± 21.36a	4.37 ± 4.03a	4.93 ± 4.03a
T_2	85 ± 9c	85 ± 11c	2420 ± 1260c	2370 ± 1420c	234.10 ± 27.60c	228.9 ± 22.41c	14.76 ± 5.44b	13.08 ± 4.03b
T_3	90 ± 3c	90 ± 4c	5360 ± 1050d	5730 ± 1310d	503.94 ± 81.67d	521.17 ± 97.59d	24.81 ± 7.58c	25.34 ± 8.03c
ANOVA	F = 13.24	F = 11.73	F = 21.92	F = 18.47	F = 20.22	F = 16.74	F = 12.71	F = 14.68
	df = 3, 76	df = 3, 76	df = 3, 76	df = 3, 76	df = 3, 76	df = 3, 76	df = 3, 76	df = 3, 76
	P < 0.001	P < 0.001	P < 0.001	P < 0.001	P < 0.001	P < 0.001	P < 0.001	P < 0.001

Mean values in the same column (treatments) or in the same line (for a given parameter as function of the year) but with different letters vary significantly (P < 0.05)

2017. The fruiting rate, the fruit weight, the fruit diameter and the mean number of seeds per fruit were substantially increased for female flowers visited by *X. olivacea* (T_2) than those visited by *A. mellifera* (T_1) at equal pollination level. The differences were significant between mean treatments from pollination efficiency of the two visitors (T_1 and T_2) for these parameters in 2016 and 2017. The low fruiting rate obtained in T_1 justified the insignificant difference observed between this treatment and T_0 with respect to the mean fruit weight, the mean fruit diameter and the average number of mature seeds. Indeed, a single visit of *A. mellifera* seemed clearly insufficient to provide young fruits which could form a marketable value and a high resistance to the destructive activity of Tephritidae found during the field experiment. Finally, female flowers from T_3 produced numerous and bigger fruits with several mature seeds than female flowers issued from T_0, T_1, and T_2 which were under bee visits restriction. Overall, the individual activity of *X. olivacea* allowed for the best fruit set rate, mean fruit weight, mean fruit diameter, and mean number of mature seeds compared with those from *A. mellifera* one female flower visit, although the latter is more frequent in watermelon community than the former. Moreover, the results are maximized when these two bee species, the most prominent of the browsers in the study site work synergically without any external influence on their foraging and pollination activity.

Discussion

Honey bee (*A. mellifera*) and Carpenter bee (*X. olivacea*) were prominent visitors of watermelon flowers in our study site; that is why their foraging and pollinating activities were easily comparable. In the field study, the frequency of *A. mellifera* individuals was up than that of *X. olivacea* and all the measured foraging parameters were more significant for the first bee *A. mellifera* which is a social bee species while *X. olivacea* is solitary. The floral resources constitute both bee species which is an important provision for the perfect growth of their offspring. Unlike carpenter bees, honey bees have large population sizes inside their colony and workers are more empowered to recruit several congeners for exploiting an interesting food resource in terms of nectar and/or pollen (Louveaux, 1984). For this last reason, the density of *A. mellifera* was important than that of *X. olivacea* in our study.

The recrudescence of the carpenter bee activity in the morning appears to be a specific trait of nutrition in this insect group. The intense morning activity of *A. mellifera* on watermelon flowers is synchronized with the higher nectar secretion which occurs 2 to 3 hours after flower opening at dawn (Cervancia and Bergonia, 1991). Indeed, when the watermelon flowers are open, the pollen is dehiscent and the stigma receptive for at least two hours (Philippe, 1991) and a large percentage of fruit results from the deposit of pollen on the stigma between 09:00 and 10:00 a.m. (Adlerz 1966). However, the reduction in honey bee visitation rates after 09:00 and 10:00 a.m. could be explained by the depletion of floral resources and/or adverse abiotic factors. These results are consistent with the findings of Polatto *et al.* (2014) with regard to the influence of abiotic factors and floral resources available in the daily foraging activity of bees. *A. mellifera* and *X. olivacea* were essentially nectarophagous on *C. lanatus* flowers. According to Delaplane and Mayer (2000), nectar is the primary objective of bees that visit flowers of Cucurbitaceae species.

Observed variations in the mean duration of a bee visit according to the sex of flowers are known with Cucurbitaceae species. For instance in California (U.S.A.), the mean duration of a visit of *A. mellifera* on watermelon varied from 5.7 sec. on male flowers to 8.0 sec. on female flowers (Adlerz, 1966); In Constantine (Algeria), Benachour and Louadi (2011) showed that on the flowers of cucumber (*Cucumis sativus*), the mean duration of visit for nectar harvesting varied from female flowers to male flowers according to bee species: 8.4 and 7.2 sec. for *A. mellifera*; 10.5 and 7.5 sec. for *Ceratina cucurbitina*; 11.1 and 6.8 sec. for *Meliponula piliden*. Kaziev and Seidova (1965) reported that female flowers of Cucurbitaceae secreted a lot of energetic nectar than male flowers. The difference in the average duration of a bee visit on both types of flowers is linked to the optimal foraging principle (Frisch, 1969; Heyneman, 1983), which guarantees a net energy gain to honey bees.

Pollinators play a key role in increasing crop yields (Morandin and Winston, 2006). The knowledge of insect pollinators' diversity for a plant is important so that pollination could be made possible in the absence of a particular insect species (Anoosha *et al.*, 2018; Campbell *et al.*, 2019). Watermelon pollination depends on several insect species. Previous results indicated *A. mellifera* and *X. olivacea* among the pollinators of several Cucurbitaceous species, with honey bee as the most representative (Sadeh *et al.*, 2007; Mensah and Kudom, 2011; Azo'o *et al.*, 2010, 2012, 2017). The pollinator diversity on watermelon reduces the risk of lack of pollination service in absence of one insect species during critical period of crop flowering (Kremen *et al.*, 2004).

It is well known that the populations of native bees and honey bees are generally in decline, threatening food production (Kevan and Phillips, 2001). According to our findings, the absence or lack of pollinators in watermelon cultivation represents a major threat to fruit production of this crop. In the watermelon farm, no pollinators represent no-pollination and no fruit set. However, the floral activity of pollinating insects, especially bees, is essential to obtain improved fruit and seed yields of watermelon.

If *A. mellifera* is considered the most important pollinator of watermelon depending on its pollination intensity due to the large size of its colony and the ability of this bee species to recruit several workers during a foraging trip (Frisch, 1969), *X. olivacea* appeared as a more efficient pollinator on an individual basis than *A. mellifera*. Indeed, mean treatments for fruiting rate, fruit weight, fruit diameter and mean of mature seeds per fruit of watermelon in 2016 and 2017 were important for the carpenter bee than the honey bee at equal pollination level. According to Mensah and Kudom (2011), the size of *X. olivacea* has been reported to play a positive role in crop pollination. Furthermore, the low values of the mean duration of a floral visit determine the ability of this carpenter bee species to move swiftly from flower to flower across large areas and suggest that it can cross-pollinate watermelon flowers efficiently.

Apart from the present work-study, other field experiments have shown the importance of other bee species in the pollination of certain crops compared with the honey bee via their pollinating efficiency. For instance, in New-York (eastern U.S.), honey bees (*A. mellifera*) and two native bee species *Bombus impatiens* and *Peponapis pruinosa* were the most abundant species that pollinate *Cucurbita pepo*. Research has shown that *B. impatiens* is an efficient pollinator on individual basis, depositing more pollen per visit and needing fewer overall visits to a flower to produce a large pumpkin fruit compared with equivalent visits by either *A. mellifera* or *P. pruinosa* (Artz and Nault, 2011). Also, in the U.S.A., managed honey bees *A. mellifera* were the most common visitor, but numerous other pollinators (*e.g., Agapostemon splendens* Lepeletier, *Campsomeris plumipes* var. *fossulana* Fabricius) were found to be abundant in field experiment (Campbell *et al.*, 2019). In North Carolina, Stanghellini *et al.* (1998) have shown that watermelon fruit from bumble bee-visited flowers has consistently higher seed sets than did those visited by honey bees when compared at equal bee visit numbers. In Chania region (Greece), the wild bee genus *Lasioglossum* was observed to be the main alternative pollinator to honey bees of watermelon crops (Garantonakis *et al.*, 2016). In Yaounde (Centre region, Cameroon), *Meliponula erythra* was the main pollinator of *Dacryodes edulis* (Tchuenguem *et al.*, 2001) and wild bees were prominent pollinators on *Zea mays* (Tchuenguem *et al.*, 2002). Previous findings in Maroua (Far-North region, Cameroon) showed that two wild bee species *Eucara macrognatha* and *Tetralonia fraterna* (Hymenoptera: Apidae) have outnumbered honey bee *A. mellifera* on Okra (*Abelmoschus esculentus*) pollination (Azo'o *et al.*, 2011) and were more efficient pollinators than this bee species (Azo'o *et al.*, 2012). Hence, maintaining biodiversity in agricultural ecosystems could provide unrecognized benefits (Carvalheiro *et al.*, 2011; Brittain *et al.*, 2013). It is therefore recommended to preserve or restore natural vegetation surrounding watermelon cultivated areas to attract and keep the bees in or near those areas. Such measures may ensure that bees are available to visit the flowers whenever needed.

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