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# INSERT ACTIVITIES AND THEIR IMPACT ON THE YIELD OF *Abelmoschus esculentus L* ( MALVACEAE) IN BAMBILI ( MEZAM - CAMEROON)

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## *ABSTRACT*

Experiments were made to evaluate the impact of the flowering insect activity on *Abelmoschus esculentus* (L.) pod and seed yields. Their foraging and pollination activities were examined in Bambili from September 2019 to February 2020. Treatments included open floral access to all visitors (treatment 1) and bagging of flowers to avoid all visits (treatment 2). Observations were made on 30 flowers per treatment. The Insect foraging behavior, their rhythm of activity, the fruiting rate and the mean number of seeds per pod were recorded. The results show that three insect species visited *A. esculentus* flowers. *Lipotriches collaris* was the most common species with 76.40 %, followed by *Apis mellifera* (19.10%) and *Musca domestica* (4.49%). Insects foraged throughout the day light period. Their activity was highest between 9 am and 12 pm Insect species foraged the flowers for pollen and nectar. Comparing the yields of the two treatments, it appeared that insect visits increase the number of fruits per plant, the average number of seeds per fruit and the percentage of normal seeds by 42.27%, 17.39% and 22.88%. The maintenance of insect nest close to *A. esculentus* field is recommended to improve the seed production of okra.

**Contribution/Originality:** The paper's primary contribution is finding that the insect associated with *A. esculentus* flowers can be exploited in Cameroon agricultural program to increase the agricultural outputs especially in bambili area.

## 1. INTRODUCTION

*Abelmoschus esculentus* (commonly known as "okra or gumbo") is an annual plant native to Africa (Kochhar, 1986). The crop is grown in many parts of the world, especially in tropical including Asia, Central and South America (Fao, 2008) and sub-tropical countries (Kumar et al., 2010). The crop is cultivated for its edible leaves, buds, flowers and fruits and easy to farm (Angbanyere & Baidoo, 2014). The crop has duration of 90-100 days with continuous flowering (Joshi, Gadwal, Hardas, & Hutchinson, 1974). According to Angbanyere (2012) Okra is an erect robust annual herb of up to two meters high, having a deep taproot system; its stem is semi woody with many short branches. The leaves are large, alternate, cordate and are divided into three to seven lobes with toothed margins. The flowers are yellow with brown centers with shorter stamen and style. Flowers open only once in the morning and close after pollination on the same day. *Abelmoschus esculentus* flowers structure combines hermaphroditism and self-compatibility (Al-Ghzawi, Zaittoun, Makadmeh, & Al-Tawaha, 2003). Passive self pollination characterizes *A. esculentus* flowers (Chandra & Bhatnagar, 1975) despites the fact that the flowers are insect pollinated (Al-Ghzawi et al., 2003). The fruits are long (10-30 cm), beaked, ridged, oblong hairy capsules with the colour ranges from green to red Angbanyere (2012). Seeds are tuberculate (Kochhar, 1986) with about 30 -100 seeds per fruit (Messiaen, 1992). *Abelmoschus esculentus* is a rich source of water, protein, carbohydrates, fibre, calcium, zinc iron and vitamin A, B and C Norman (1992); Justo (2005); Angbanyere (2012).The crop is sometimes grown purposely for the seeds because of their high amounts of edible oil Oyolu (1983); Norman (1992). The plant species is of considerable economic importance (Njoya, Wittmann, & Schindler, 2005); Sawadogo, Zombre, and Balma (2006) in that the global demand for okra is increasing because of the growing health consciousness and high nutritional qualities of okra as an excellent source of food and bio medicine (Reddy, Chandra, Pooni, & Bramel, 2004) and high financial value Sawadogo et al. (2006). According to FAO (2018) the world production of gumbo is 9872826 tons with India ranks first (72%). The Africa accounts 3277076 tons of okra produced; Nigeria is the largest producer (2,033,129 t) followed by Ivory Coast (160.250 t). Production of okra in Cameroon stands at 100,025 tons FAO (2018) with the Far North Region being the highest producer followed by North West, West and the South Region. The production of okra in that country is low and the demand is high, mean while one of the key objectives of agricultural research in Cameroon is to obtain high and sustainable yields to feed the growing population (DSCE, 2009). This low production is because, okra crop is suffering from number of biotic and abiotic factors, including lack of knowledge on the importance of flowering insect in increasing yields of vegetable crops. The exploitation of pollinating insects is rarely included in the agricultural programs of several African countries. According to the farmers; higher yields are rather obtained through the application of fertilizers and pesticides (Kumar, 1991). Few published data do exist on the relationships between insect foragers and *A. esculentus* flowers. In India for instance, honeybees *Apis cerana* and solitary bees *Halictus* spp. appeared as the main okra pollinators Crane (1991); Free (1993); Nandhini, Padmini, Venugopalan, Anjanappa, and Lingaiah (2018) at Bengaluru in India show that the foraging population of *Apis* spp, *Lasius niger* and *Solenopsis invicta* was the main pollinators of okra flowers. Khan (2019) at Gazipur in Bangladesh found that *Papilio demoleus* was the most abundant pollinator followed by *Apis mellifera*, *Papilio cresphontes* and *Phoebis sennae* on *A. esculentus* flowers. A positive impact of wild bees on the yields of eight okra genotypes was shown in Jordan, but the list of the bees concerned was unpublished (Al-Ghzawi et al., 2003). In Cameroon: Njoya et al. (2005) in Yaounde observed on preliminary trials that *Megachile* spp., *Halictus* spp., *Xylocopa* spp. and *Apis mellifera* were the main okra anthophilous insects, but till-date there exist no precise data on their foraging activities; (Azo'o, Fohouo, & Messi, 2011) in Maroua found that *Eucara macrognatha* and *Tetralonia fraterna* were the two main visitors and were effective okra pollinators; (Amada et al., 2018) in Yaounde found out that *Xylocopa olivacea*, *Synagris cornuta* and the ants were the most frequently insect species pollinators of *A. esculentus*. Following the lack of complete data on the relationship between *A. esculentus* and its floral entomofauna; the emergency to know the crop-plant pollinators for their conservation; and the necessity to produce a higher quantity of seeds to meet their various uses, it is important to further research on okra in order to complete the useful available data thus, the necessity to conduct investigations on the relationships between *A. esculentus* and their flowering insects in Bambili, North West Region of Cameroon, to increase the data that exists for Cameroon. The main objective of this work is to recognize the flowering insects and determine the importance of their activities on the yield of this crop plant for its optimal management.

## 2. MATERIALS AND METHODS

### *2.1. Study Site*

This experiment was carried out from September 2019 to February 2020. The study was carried out in Bambili (6.0029115 N 10.2590745 E and 1430 above sea level), Tubah Sub Division, Mezam Division, in the North West

Region of Cameroon during the dry season. The climate is of the tropical monsoon type with two seasons, namely, the long rainy season (mid-March to mid-October) and the short dry season (mid-October to mid-March) (Neba & Eze, 2004). The annual average precipitation ranges from 1770 mm to 2824 mm, the mean annual temperature is 20°C and the mean annual relative humidity is above 85% (Abdoul, Moise, & Akoulong, 2008).

### *2.2. Biological Material*

#### *2.2.1. Animal Material*

The animal material was represented by;

- The population of *A. mellifera* which came from non-inventoried colonies around the study site. According to Louveaux (1984) the range of *A. mellifera* foragers may exceed 12 km around the hive.
- The population of *L. collaris* which came from the nests present on the study site.
- Other insect species naturally present in the experimental environment.

#### *2.2.2. Plant Material*

The plant material was made up of seeds of *A. esculentus* bought from "Farmers Pharmacy" located at "Three corners" Bambili.

### *2.3. Experimental Plot*

The experimental plot was 7 m long and 6.5 m wide. It was cleared and cleaned with a cutlass 20 September, 2019. Then using a digger and a hoe, the soil was tiled and 10 ridges of 3 m long by 1 m wide and 0.3 m high were formed. The distance between bridges was 0.5 m. The vegetation near *A. esculentus* field had various spontaneous and cultivated species.

### *2.4. Sowing and Monitoring the Crop*

Prior to planting, fowl droppings were mixed with the ground and put in holes destined for each okra plant. Okra seeds were then deposited in each hole on a row of 3 lines while maintaining a gap of 0.5 m between two holes. Watering was done daily between 4-6 pm to prevent drying. From germination (13$^{th}$ October, 2019) to the opening of the first flowers (27$^{th}$ December, 2019), weeding was done manually every two weeks to maintain ridge weeds-free.

### *2.5. Determination of the Reproduction Mode of Abelmoschus esculentus*

Ten ridges carrying 60 plants with 60 flowers at the bud stage were labeled. Five ridges carrying 30 plants with 30 flowers were left un-attended (treatment 1) and five ridges carrying 30 plants with 30 flowers were bagged delicately using the gauze bags to prevent visitors (treatment 2).

After the last labeled flower had withered, the number of fruits formed was counted in each treatment. The fruiting index (*FI*) was calculated as described by Tchuenguem, Messi, and Pauly (2001).

$$FI = (Ff / Fv)$$

Where $Ff$ is the number of fruit formed and $Fv$ is the number of viable flowers initially borne.

The allogamy rate (*RAl*) from which derives the autogamy rate (*RAu*) was expressed as the difference in fruiting indexes between treatment 1 (unprotected flowers) and treatment 2 (bagged flowers) as follows (Demarly, 1977).

$$RAl = [(FI_1 - FI_2) / FI_1] \times 100$$

Where $FI_1$ and $FI_2$ are the fruiting average indices obtained in treatment 1 and 2 respectively.

$$RAu = 100 - RAl.$$

### *2.6. Study of the Foraging Activity of Insects on Abelmoschus esculentus Flowers*

The frequency of flowering insects were determined based on observations of flowers in treatment 1 every day, from December 27, 2019 to February 11, 2020 at 7 - 8 am, 9 - 10 am, 11 - 12 pm, 1 - 2 pm , 3 - 4 pm and 5 - 6 pm. In a slow walk along all flowers of treatment 1, the characteristics of all insects that visited *A. esculentus* flowers were recorded. Specimens of all insect taxa were caught with an insect net on unlabeled plant. For each species, three to five insect specimens were captured. These insects were conserved in 70% ethanol for subsequent taxonomy determination except for Lepidoptera which were conserved in wrapper following (Borror & White, 1991) recommendations. All insects encountered on flowers were registered and the cumulated results expressed in number of visits to determine the relative frequency ($Fi$) of each insect species in the pollinator fauna of *A. esculentus*, where,

$$Fi = Vi / VI \times 100,$$

With $Vi$ = number of visits of the insect $i$ on the flowers of the free treatment and $VI$ the number of visits of all the insects on these same flowers Tchuenguem et al. (2001).

Direct and careful observations of the foraging activity on flowers were made on insect pollinator fauna in the experimental field. The difference between the collection of pollen and nectar was recorded. The floral products (nectar or pollen) harvested by each insect species during each floral visit were registered based on its foraging behavior. Nectar foragers extend their proboscis to the base of the corolla and the stigma, while pollen gatherers scratch the anthers with their mandibles or legs. Harvested pollen can be observed on transport organs, especially in the baskets of the hind legs in Apidae, the collecting hairs of the legs in Halictidae and the ventral brush in Megachilidae (Borror & White, 1991). Pollen harvesting can be active (if pollen is collected) or passive (if by taking the nectar, the pollen accumulates on the insect's tegument and then collects it in its organs storage (Jousselin & Kjellberg, 2001). The floral products collected were systematically noted during the recording of the floral insect's frequency.

In the morning of each sampling day, the number of blooming flowers carried by each ridge of treatment 1 was counted. During the same time that insect species encountered on flowers were registered.

During the same days as for the frequency of visits, the duration of the individual flower visits was recorded (using a stopwatch). It is the time that an insect takes to collect a product (nectar and / or pollen) on a flower. The duration of pollen harvest visits and that of nectar collection were recorded separately and according to five daily periods (8-9 am, 10-11 am, 12-1 pm, 2-3 pm and 4-5 pm).

During each daily period of observations, the temperature and relative humidity of the study station were regularly recorded using a mobile thermo-hygrometer installed in the shade, every one hour.

### *2.7. Evaluation of the Impact of Insects on Pollination of Abelmoschus esculentus Yield*

This evaluation was based on the impact of insect visiting flowers on pollination, the impact of pollination on fructification of *A. esculentus* and the comparison of yields (fruiting rate, mean number of seed per fruit and percentage of normal seeds) of treatment 1 (unprotected flowers) and treatment 2 (bagged flowers). The fruiting rate due to the influence of foraging insects ($Fri$) was calculated as follows (Tchuenguem et al., 2004).

$$Fri = ([(Fr_1 - Fr_2) / Fr_1] \times 100)$$

Where $Fr_1$ and $Fr_2$ were the fruiting rate in treatment 1 and treatment 2. The fruiting rate of a treatment (Fr) is:

$$Fr = [(F_2 / F_1) \times 100]$$

Where $F_2$ is the number of fruits formed and $F_1$ the number of viable flowers initially set. At maturity, fruits were harvested from each treatment and the number of seeds per fruit counted. The mean number of seeds per fruit and the percentage of normal (well developed) seeds were then calculated for each treatment. The percentage of the number of seeds per fruit (*Ps*) due to the influence of foraging insects was calculated as follows (Tchuenguem et al., 2004):

$$Ps = ([(s_1 - s_2) / s_1] \times 100)$$

Where $s_1$ and $s_2$ were the mean number of seeds per fruit in treatment 1 and 2. The percentage of normal seeds (*Pns*) due to the influence of foraging insects was calculated as follows (Tchuenguem et al., 2004):

$$Pns = ([(ns_1 - ns_2) / ns_1] \times 100)$$

Where $ns_1$ and $ns_2$ were the percentage of normal seeds in treatment 1 and 2.

### *2.8. Data Analysis*

The data was processed using descriptive statistics (calculation of means, standard deviations and percentages) and three tests: Correlation coefficient (r) for studying the linear relationships between two variables, Student's (t) for the comparison of means of two samples and Chi-square ($x^2$) for the comparison of percentages and Microsoft Excel 2010.

## 3. RESULTS

### *3.1. Mode of Reproduction of Abelmoschus esculentus*

The fruiting index was 0.97 for treatment 1 and 0.56 for treatment 2; the rate of allogamy (*RAl*) was 42.42% and the rate of autogamy (*RAu*) was 57.58%; Consequently, *A. esculentus* has a mixed mode of reproduction that is allogamous - autogamous, with a predominance of autogamy.

### *3.2. Frequency of Insects in the Floral Fauna of Abelmoschus esculentus*

Eighty nine visits of three insect species were recorded on 30 flowers of *A. esculentus*. Table 1 presents the list of these insects and the percentages of visits made. It appears that two orders of insects visited the flowers of *A. esculentus* during the study period; these were Diptera and Hymenoptera. The Hymenoptera order being the most present. *Lipotriches collaris* was the most frequent insect (76.40%) followed by *Apis mellifera* (19.10%) and *Musca domestica* with a visit rate of less than 5%.

**Table-1.** Insect species recorded on *Abelmoschus esculentus* flowers from december 27, 2019 to february 11, 2020, number and percentage of visits of different insects.

| Order | Family | Genus or Species | *n* | *p* (%) |
|---|---|---|---|---|
| Diptera | Muscidae | *Musca domestica* | 4 | 4.49 |
| Hymenoptera | Apidae | *Apis mellifera* | 17 | 19.10 |
| Hymenoptera | Halictidae | *Lipotriches collaris.* | 68 | 76.40 |

**Note:** ***n***: number of visits on 30 flowers in 25 days; *p*: percentage of visits; $p = (n / 89) \times 100$.

### *3.3. Insect Activities on the Flowers of Abelmoschus esculentus*

#### *3.3.1. Floral Products Harvested*

Each of the individuals of *A. mellifera*, *L. collaris* and *M. domestica* selectively visited the open flowers of *A. esculentus* for the collection of pollen and/or nectar. The foraging behaviour of these insect species varies with the food harvested. Nectar foragers were seen extending their proboscis to the base of the corolla while pollen gatherers scratched anthers with the mandibles or the legs. Table 2 shows the floral products harvested from the plant studied.

It appears that: out of 17 *A. mellifera* visits recorded, 41.18% were devoted to the nectar harvest and 58.82% to the pollen harvest; out of 68 visits by *L. collaris* recorded, 57.35% were spent on nectar harvesting and 42.65% on pollen harvesting. All the 4 recorded *M. domestica* visits were devoted to a nectar harvest. The difference between the percentages of pollen harvest visits and the percentages of nectar collection is not significant ($\chi^2 = 4.71$; $df = 1$; $p > 0.05$).

**Table-2** Product harvested by different insect species on the flowers of *Abelmoschus esculentus* from December 27, 2019 to February 11, 2020 at Bambili.

| Insect species | Total number of visits | Nectar harvest | | Pollen harvest | |
|---|---|---|---|---|---|
| | | Visits | | Visits | |
| | Studied | Number | % | Number | % |
| *Apis mellifera* | 17 | 7 | 41.18 | 10 | 58.82 |
| *Lipotriches collaris.* | 68 | 39 | 57.35 | 29 | 42.65 |
| *Musca domestica* | 4 | 4 | 100 | 0 | 0 |

**Note:** The data is obtained by direct observation during the registration of the number of insect visits.

### *3.3.2. Rhythm of Visits According to the Flowering Stages*

The daily visits of the different species of insects were more numerous when the number of open flowers was high Figure 1. Furthermore, a positive and significant correlation was found between the number of open flowers and the number of visits of *A. mellifera* in one hand ($r = 0.53$; $df = 23$; $p < 0.001$) and between the number of open flowers and the number of visits of *L. collaris* on the other hand ($r = 0.91$; $df = 23$; $p < 0.001$).

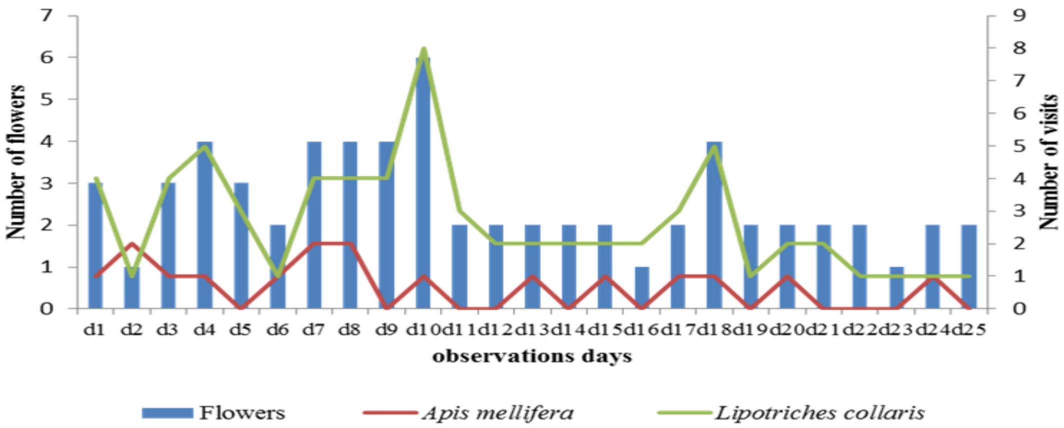


**Figure-1.** Daily variation in the number of visits of *Apis mellifera* and *Lipotriches collaris* influenced by the number of open flowers of *Abelmoschus esculentus* from December 27, 2019 to February 11, 2020.

### *3.3.3. Daily Rhythm of Visits*

In general *L. collaris* visited the flowers of *A. esculentus* throughout the period of the day when they were open, while *A. mellifera* visited these same flowers from 7 am to 12 pm and *M. domestica* from 9 am to 4 pm. For *A. mellifera* the peak for visits was between 9 am and 10 am with 82.35 % of visits; during this time slot, the average humidity was 33.43% and the average temperature was 28.30°C. *L. collaris* and *M. domestica* have a peak of activity between 11 am and 12 pm with 60.29% and 50 % of visits respectively Table 3; during this time slot, the average relative humidity was 27.38% and the average temperature was 30.64°C. We found a positive and not significant correlation between the temperature and the number of insect visits ($r = 0.28$; $df = 4$; $p > 0.05$) and negative and not significant ($r = - 0.26$; $df = 4$; $p > 0.05$) between the relative humidity and the number of insect visits.

**Table-3.** Frequency of daily visits by the different insects from December 27, 2019 to February 11, 2020.

| Insect species | Daily period (hours) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 7 - 8 | | 9 - 10 | | 11 - 12 | | 13 - 14 | | 15 - 16 | |
| | *n* | *p* (%) | *n* | *p* (%) | *n* | *p* (%) | *n* | *p* (%) | *n* | *p* (%) |
| *Apis mellifera* | 1 | 5.88 | 14 | 82.35* | 2 | 11.76 | 0 | 0 | 0 | 0 |
| *Lipotriches collaris* | 3 | 4.41 | 14 | 20.59 | 41 | 60.29* | 9 | 13.24 | 1 | 1.47 |
| *Musca domestica* | 0 | 0 | 1 | 25 | 2 | 50* | 1 | 25 | 0 | 0 |
| T (°C) | 25.39 | | 28.3 | | 30.64 | | 31.5 | | 30 | |
| H (%) | 40.82 | | 33.43 | | 27.38 | | 25.19 | | 28.5 | |

**Note:** ***n***: number of visits; *P*: percentage of visits = (*n* / A) × 100; *: daily peak of visits; T:Temperature; H: Relative humidity.

### *3.3.4. Duration of Visits to Abelmoschus esculentus Flower*

The duration of visits to a flower varies with the insect species. Table 4 shows that:

- For *A. mellifera*, the average duration of a visit to a flower was 14.69 sec for the collection of pollen and 16.35 sec for the collection of nectar. The difference between these two means is very highly significant. The average duration for both pollen and nectar collection is 22.64 sec.
- For *L. collaris*, the average duration of a visit to a flower was 12.77 sec for the sampling of pollen and 11.73 sec for the sampling of nectar. The difference between these two means is very highly significant. The average duration for both pollen and nectar collection is 21.36 sec.
- For *M. domestica*, the average duration of a visit to a flower for the collection of nectar was 18.53 sec.
- The difference is very highly significant between the average duration of visit of *A. mellifera* and *L. collaris*.

**Table-4.** Duration of nectar and pollen harvests from *Abelmoschus esculentus* recorded for different insects from December 27, 2019 to February 11, 2020.

| Insect species | Harvested product | Harvest time per flower (sec) | | | | |
|---|---|---|---|---|---|---|
| | | ***n*** | ***M*** | ***S*** | ***mini*** | ***Max*** |
| *Apis mellifera* | Pollen | 70 | 14,69 | 7,18 | 5 | 56 |
| | Nectar | 40 | 16,35 | 6,9 | 8 | 36 |
| | Pollen + Nectar | 84 | 22,64 | 8,43 | 9 | 54 |
| | Total | 194 | 17,89 | 7,5 | 5 | 56 |
| *Lipotriches collaris.* | Pollen | 69 | 12,77 | 4,97 | 2 | 27 |
| | Nectar | 168 | 11,73 | 4,27 | 3 | 27 |
| | Pollen + Nectar | 177 | 21,36 | 8,1 | 6 | 51 |
| | Total | 414 | 15,29 | 5,78 | 2 | 51 |
| *Musca domestica* | Nectar | 118 | 18,53 | 9,88 | 2 | 56 |
| | Total | 118 | 18,53 | 9,88 | 2 | 56 |

**Note:** Comparison of the average duration of visit by: -*Apis mellifera* devoted to the collection of pollen and nectar: $t_{(nectar\ /\ pollen)} = 5.91$, $df = 108$, $p<0.001$, VHS); -*Lipotriches collaris* devoted to the collection of pollen and nectar: $t_{(nectar\ /\ pollen)} = 11.29$, $df = 235$, $p<0.001$, VHS); -*Apis mellifera* and *Lipotriches collaris*: $t_{(Apis\ mellifera\ /\ Lipotriches\ collaris.)} = 5.52$, $df = 310$, $p < 0.001$, VHS. *n* = number, *m* = mean, *S* = Standard deviation, *mini* = minimum, *Max* = Maximum.

### *3.4. Impact of Insect Activities on Seed Yields of Abelmoschus esculentus*

During nectar and pollen harvest from *A. esculentus*, foraging insects were always regularly made contact with the anthers and stigma, increasing the possibility of *A. esculentus* pollination. From Table 5, we documented the following:

a) The Fruiting rate or fruit formation was higher in flowers left unprotected for unlimited visits (where high diversity of insects was observed) than in the bagged flowers. The percentage of fruiting rate attributed to insect activity was 42.27%. The comparison of the fruiting rates were very highly significant between opened flowers (treatment 1) and bagged flowers (treatment 2) ($\chi^2 = 14.39$, $df = 1$, $p<0.001$).

b) The mean number of seeds per fruit was higher in flowers left unprotected for unlimited visits than in the bagged flowers. The comparison of the mean number of seeds per pod was very highly significant between treatments 1 and 2($t = 31.39$, $df = 58$, $p<0.001$). Thus, the number of seed per pod was higher in opened flowers than bagged flowers. The percentage of the number of seeds per pod due to insect activity was 53.33%.

c) Normal seed yield in flowers left unprotected for unlimited visits was higher than that in the bagged flowers. The comparison of the percentage of normal seeds were very highly significant between treatment 1 and treatment 2 ($\chi^2 = 60.00$; $df = 1$; $p < 0{,}001$). The percentage of normal seeds in opened flowers was higher than that of protected flowers. The percentage of normal seeds attributed to the influence of insects was 17.39%.

The impact of pollinating insects on pod and seed yields was positive and significant.

**Table-5.** Fruiting rate, average number of seeds per fruit and percentage of normal seeds according to *Abelmoschus esculentus* treatments from September 2019 to February 2020 in Bambili.

| Treatment | NFS | NFF | FR (%) | Seed / fruit | | TNS | NNS | % NS |
|---|---|---|---|---|---|---|---|---|
| | | | | *M* | *S* | | | |
| 1 (Ff) | 30 | 28 | 89,55 | 30 | 8 | 889 | 811 | 91,23 |
| 2 (Pf) | 30 | 21 | 51,22 | 14 | 7 | 418 | 315 | 75,36 |
| Comparison of fruiting rates: Ff / Pf: $\chi^2 = 14.39$ ($df = 1$, $p<0.001$, VHS). | | | | | | | | |
| Comparison of the average number of seeds / fruit: Ff / Pf: $t = 31.39$ ($df = 58$, $p<0.001$, VHS). | | | | | | | | |
| Comparison of the percentages of normal seeds: Ff / Pf: $\chi^2 = 60.00$ ($df = 1$, $p<0.001$, VHS). | | | | | | | | |

**Note: NFS:** number of flowers studied; NFF: number of fruits formed; FR: fruiting rate; TNS: total number of seeds; NNS: number of normal seeds; % NS: percentage of normal seeds. Ff: free flowers; Pf: protected flowers.

## 4. DISCUSSION

A mixed reproduction regime with the predominance of autogamy over allogamy could be explained by the structure of the flower (George, 1989). The flowers are self-compatible and usually self-pollinated but may nevertheless benefit from pollinator visitation (Al-Ghzawi et al., 2003).

The studies revealed that three insect species were recorded on *A. esculentus* with two species belonging to Hymenoptera and one to Diptera. Our results corroborate other report that Hymenoptera, mainly bees, are the most important foragers for *A. esculentus* Nandhini et al. (2018); Azo'o et al. (2011); Amada et al. (2018); McGregor (1976); Klein et al. (2007); Hasnat, Sarkar, Hossain, Chowdhury, and Matin (2015); Pando, Djonwangwé, Moudelsia, Fohouo, and Tamesse (2020). *L. collaris* was the main floral visitor of *A. esculentus* flowers (76.40%) during the observation period. The species have been reported among the floral visitor of *A. esculentus* Pando et al. (2020) *Gossypium hirsutum* (Dounia & Tchuenguem Fohouo, 2013) *Allium cepa* (Tchindebe & Fohouo, 2014) *Phaseolus vulgaris* (Douka, Tamesse, & Tchuenguem, 2017) *Glycine max* (Dounia & Tchuenguem, 2016); Pando, Djonwangwé, Moudelsia, Fohouo, and Tamesse (2019) *Arachis hypogaea* (Tchindebe, Douka, Tope, & Fohouo, 2018) in Maroua. *Apis mellifera* rank second insect species (19.10%) visiting *A. esculentus* flowers during the studied period. *A. mellifera* was already mentioned in the okra floral entomofauna in Yaounde (Cameroon) (Njoya et al., 2005); Azo'o et al. (2011); Amada et al. (2018) in Rosehill (Australia) (Tanda, 2019). Moreover, the genus Apis was identified as the main *A. esculentus* pollinator in India (Crane, 1991) at Bengaluru in India Nandhini et al. (2018) at Gazipur in Bangladesh (Khan, 2019). *Musca domestica* species were mentioned on okra flowers besides bee species with a visit rate of less than 5%. Similar results have been obtained to the same plant by Amada et al. (2018). *Musca domestica* is known in Cameroon as insect visiting the flowers of other plant species such as *G. hirsutum* in Maroua (Dounia & Tchuenguem Fohouo, 2013) *P. vulgaris* in Ngaoundere (Kingha, Fohouo, Ngakou, & Bruuml, 2012) *P. vulgaris* in Maroua (Douka & Fohouo, 2013) *Ricinus communis* in Maroua (Douka & Fohouo, 2014) *Physalis micrantha* in Bamenda (Atibita, Fohouo, & Djieto-Lordon, 2015).

During the flowering periods of *A. esculentus*, those insects intensely and regularly harvested nectar or pollen. For *A. mellifera*, the collection of pollen was higher than the collection of nectar in contrary to *L. collaris* who's the harvesting of nectar was higher than the harvesting of pollen. *M. domestica* visits were devoted to a nectar harvest. This could be attributed to the needs of individual insect species (Tchuenguem Fohouo, 2005). Insect visited *A. esculentus* throughout the day when the flowers were open and the daily foraging period varied with the insect species. The peaks in activity could be explained by the optimal foraging strategy adopted by foragers during the morning. It is characterized by an increased exploitation of floral product which is more available and easily collected in the morning, as George (1989) had already indicated. Furthermore, Kasper, Reeson, Mackay, and Austin (2008) mentioned that in wild and solitary bees that primarily visited the flowers of *A. esculentus*, the predominant morning activity being a survival instinct. The drop in flower activity after 12 pm would be linked to the decrease in the quality and / or quantity of floral products firstly and the gradual closure of flowers on the other hand. According to Kasper et al. (2008) when the booty is no longer easily exploitable or it is reduced in quantity and / or mediocre in quality, the insects reduce their activity on the flowers.

The significant difference between the duration of visits of *A. mellifera* and *L. collaris* could be attributed to the diversity of flowering insects and the needs of individuals at flowering period (Tchuenguem Fohouo, 2005). They intensely and regularly harvested nectar and pollen because these species have a high aptitude in collecting nectar and pollen when available.

During the collection of nectar and pollen on each flower, flowering insects regularly come into contact with the stigma. This increases pollinating efficiency in the completely opened flower. They could thus enhance auto-pollination (Delaplane et al., 2013). By doing so, flowering insects could provide allogamous pollination through carrying of pollen with their furs, legs and mouth accessories, which is deposited on another flower belonging to the same plant (geitogamy) or to a different plant of the same species (xenogamy) (Lobreau-Callen & Coutin, 1987). The significant contribution of pollinating insects in pods and seed yield of *A. esculentus* was found by Al-Ghzawi et al. (2003) in Jordanie, Azo'o et al. (2011) at Domayo (Maroua), Amada et al. (2018) at Yaounde, Pando et al. (2020) at Wourndé and Palar (Maroua), These authors show that *A. esculentus* flowers produce fewer seeds per pod in the absence of pollinating insects. The weight of insect pollinators played a positive role during the collection of floral products; those insects shook flowers, facilitating the liberation of pollen by anthers for the optimal occupation of the stigma (Klein et al., 2007).

The Higher productivity of fruits and seeds in unlimited visits when compared with bagged flowers showed that insect foraging activity on okra flowers were effective in increasing cross-pollination. Our results confirmed those of Al-Ghzawi et al. (2003) in Jordanie, Azo'o et al. (2011) at Domayo (Maroua), Amada et al. (2018) at Yaounde, Pando et al. (2020) at Wourndé and Palar (Maroua). Fruiting being mainly dependent on the intensity of pollination (McGregor, 1976) the significant increase in yields of *A. esculentus* in the presence of flowering insects is the consequence of the foraging activity of these insect species on the pollination of the flowers of the plant studied.

## 5. CONCLUSION

In Bambili, Cameroon, three species of insects distributed in three families and two orders visited the flowers of *A. esculentus* to harvest nectar and/or pollen. The orders were representing by Diptera and Hymenoptera with the hymenopterans being the most present. *Lipotriches collaris* was the most frequent insect (76.40%) followed by *Apis mellifera* (19.10%) and *Musca domestica* with a visit rate of less than 5%. These insects foraged the flowers of this plant species from 7 am to 6 pm, with a peak activity located between 9 am and 12 pm. *A. esculentus* is plant that benefits from pollination by insects. Comparing the yield of unprotected flowers with insect-protected flowers, it is observed that insect visits increase the number of fruits per plant, the average number of seeds per fruit and the percentage of normal seeds 42.27%, 17.39% and 22.88% respectively. Installation and preservation of insect nests near the population of *A. esculentus* should be recommended in order to benefit from the ecosystem service of pollinating insects thus increase in fruit and seed yield of *A. esculentus.*

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## REFERENCES

Abdoul, A. S., Moise, H., & Akoulong, C. (2008). Diagnosis of Cameroon's national agricultural research and extension system and capacity building strategy for the dissemination of agricultural knowledge and technologies. CEMAC Project Report (p. 143). TCP / RAF / 2913.

Al-Ghzawi, A., Zaittoun, S. T., Makadmeh, I., & Al-Tawaha, A.-R. M. (2003). The impact of wild bees on the pollination of eight okra genotypes under semi-arid Mediterranian conditions. *International Journal of Agriculture and Biology, 5*(4), 409-411.

Amada, B., Dounia, C., D., Ningatoloum, C., Guiffo, G. A. A., Angoula, B. S., Ngonaïna, J. P., . . . Tchuenguem, F. F.-N. (2018). Diversity of flowering insects and their impact on yields of Abelmoschus esculentus (L.) Moench, 1794 (Malvaceae) in Yaoundé (Cameroon). *Journal of Entomology and Zoology Studies, 6*(6), 945-949.

Angbanyere, M. A. I. (2012). *The effect of pollinators and pollination on fruit set and fruit yields of okra (Abelmoschus esculentus (L) Moench) in the forest region of Ghana*. Doctoral Dissertation.

Angbanyere, M. A., & Baidoo, P. K. (2014). The effect of pollinators and pollination on fruit set and fruit yield of Okra (Abelmoschus esculentus (L.) Moench) in the Forest Region of Ghana *Journal of Experimental Agriculture International, 4*(9), 985-995.

Atibita, E. N. O., Fohouo, F.-N. T., & Djieto-Lordon, C. (2015). Foraging and pollination behavior of Apis mellifera adansonii (Hymenoptera: Apidae) on Physalis micrantha (Solanales: Solanaceae) flowers at Bambui (Nord West, Cameroon). *Journal of Entomology and Zoology Studies, 3*(6), 250-256.

Azo'o, M. E., Fohouo, F.-N. T., & Messi, J. (2011). Influence of the foraging activity of the entomofauna on okra (Abelmoschus esculentus) seed yield. International Journal of Agriculture and Biology. *International Journal of Agriculture & Biology, 13*(5), 761-765.

Borror, D. J., & White, R. E. (1991). North America insects (North of Mexico). Broquet (Eds) (pp. 408): The Prairie-Quebec.

Chandra, S., & Bhatnagar, S. (1975). Reproductive biology of Abelmoschus esculentus. 1.-Reproductive behaviour, floral morphology, anthesis and pollination mechanism. *Acta Botanica Indica, 3*, 104–113.

Crane, E. (1991). Apis species of tropical Asia as pollinators, and some rearing methods for them. *Acta horticulturae, 288*, 29-48.

Delaplane, K. S., Dag, A., Danka, R. G., Freitas, B. M., Garibaldi, L. A., Goodwin, R. M., & Hormaza, J. I. (2013). Standard methods for pollination research with Apis mellifera. *Journal of Apicultural Research, 52*(4), 1-28.

Demarly, Y. (1977). Plant Genetics and plant breeding (pp. 285). Masson - Paris (France).

Douka, C., & Fohouo, F. H. T. (2013). Foraging and pollination behavior of Apis mellifera adansonii L.(Hymenoptera, Apidae) on Phaseolus vulgaris (Fabaceae) flowers at Maroua (Cameroon). *International Research Journal of Plant Science, 4*(2), 45-54.

Douka, C., & Fohouo, F. N. T. (2014). Foraging and pollination activity of Musca domestica L.(Diptera: Muscidae) on flowers of Ricinus communis L.(Euphorbiaceae) at Maroua, Cameroon. *Journal of Biodiversity and Environmental Sciences (JBES), 4*(3), 63-76.

Douka, C., Tamesse, J. L., & Tchuenguem, F. F. N. (2017). Impact of single visit of Lipotriches collaris Vachal 1903 (Hymenoptera: Halictidae) on Phaseolus vulgaris (Fabaceae) flowers at Maroua (Cameroon). *Journal of Applied Biology & Biotechnology, 5*(2), 072-076.

Dounia, T. F. F., & Tchuenguem Fohouo, E. (2013). Foraging and pollination activity of Apis mellifera adansonii Latreille (Hymenoptera: Apidae) on flowers of Gossypium hirsutum L.(Malvaceae) at Maroua, Cameroon. *International Research Journal of Plant Science, 4*(2), 33-44.

Dounia., T. J. L., & Tchuenguem, F. F.-N. (2016). Foraging and pollination activity of Lipotriches collaris Vachal 1903 (Hymenoptera: Halictidae) on flowers of Glycine max (L.) (Fabaceae) in Maroua-Cameroon. *Journal of Animal &Plant Sciences, 29*(1), 4515-4525.

DSCE. (2009). *Growth and employment strategy paper*. Yaoundé, Cameroon: MINEPAT.

FAO. (2018). The state of food and agriculture 2018. Migration, agriculture and rural development (pp. 199). Rome: Licence: CC BY-NC-SA 3.0 IGO.

Fao, F. A. O. S. T. A. T. (2008). Food and agricultural organization of the United Nations. Retrieved on,15.

Free, J. B. (1993). Insect pollination of crops (pp. 684). London, UK: Academic Press.

George, R. A. T. (1989). Vegetable seed production (pp. 330). Spanish: Mundi-Prensa.

Hasnat, M., Sarkar, S., Hossain, M., Chowdhury, I., & Matin, M. (2015). Relative abundance of pollinators, foraging activity of bee species and yield performance of okra at Dhaka (Bangladesh). *Journal Crop and Weed, 11*(2), 34-37.

Joshi, A. B., Gadwal, V. R., Hardas, M. W., & Hutchinson, J. B. (1974). Evolutionary studies in world crops. Diversity and change in the Indian Sub–Continent (pp. 99-105). London: Cambridge University Press.

Jousselin, E., & Kjellberg, F. (2001). The functional implications of active and passive pollination in dioecious figs. *Ecology Letters, 4*(2), 151-158.Available at: https://doi.org/10.1046/j.1461-0248.2001.00209.x.

Justo, V. P. (2005). Okra: Integrated pest management an ecological guide (pp. 50). Laguna – Philippines.

Kasper, M., Reeson, A., Mackay, D., & Austin, A. (2008). Environmental factors influencing daily foraging activity of Vespula germanica (Hymenoptera, Vespidae) in Mediterranean Australia. *Insectes Sociaux, 55*(3), 288-295.Available at: https://doi.org/10.1007/s00040-008-1004-7.

Khan, R. (2019). Diversity of insects in Okra agro-ecosystem at Gazipur in Bangladesh. *Indian Journal of Ecology, 46*(1), 214-216.

Kingha, B. M. T., Fohouo, N. T., Ngakou, A., & Bruuml, D. (2012). Foraging and pollination activities of Xylocopa olivacea (Hymenoptera, Apidae) on Phaseolus vulgaris (Fabaceae) flowers at Dang (Ngaoundere-Cameroon). *Journal of Agricultural Extension and Rural Development, 4*(10), 330-339.Available at: https://doi.org/10.24214/jcbps.b.10.4.65972.

Klein, A.-M., Vaissiere, B. E., Cane, J. H., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., & Tscharntke, T. (2007). Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences, 274*(1608), 303-313.Available at: https://doi.org/10.1098/rspb.2006.3721.

Kochhar, S. L. (1986). Tropical crops: A textbook of economic botany (pp. 467). Hong Kong: Macmillan.XI.

Kumar, R. (1991). The fight against insect pests: The state of African agriculture: Ctakarthala (Eds) (pp. 231). Paris: Wageningen.

Kumar, S., Dagnoko, S., Haougui, A., Ratnadass, A., Pasternak, D., & Kouame, C. (2010). Okra (Abelmoschus spp.) in West and Central Africa: Potential and progress on its improvement. *African Journal of Agricultural Research, 5*(25), 3590-3598.

Lobreau-Callen, D., & Coutin, R. (1987). Floral resources exploited by a few Apoids in cultivated areas in the Senegalese savannah during the rainy season. *Agronomy, 7*(4), 231-246.

Louveaux, J. (1984). Domestic bee and their relation with grown plants «Pollination and plant production» (pp. 527-555). Paris, France: Pesson P, Louveaux J, INRA.

McGregor, S. E. (1976). Insect pollination of cultivated crop plants (pp. 496). Washington: Agricultural Research Service, US Department of Agriculture.

Messiaen, C. M. (1992). The tropical vegetable garden. Principles for improvement and increased production with application to the main vegetable types (pp. 528). London: Macmillan Press Ltd.

Nandhini, E., Padmini, K., Venugopalan, R., Anjanappa, M., & Lingaiah, H. (2018). Flower-visiting insect pollinators of okra [Abelmoschus esculentus (L.) Moench] in Bengaluru region. *Journal of Pharmacognosy and Phytochemistry, 7*(2), 1406-1408.

Neba, N. E., & Eze, E. (2004). Geomorphic and anthropogenic factors influencing landslides in the Bameda Highlands, NW province, Cameroon. *Journal of Applied Social Sciences (Buea, Cameroon), 4*(1), 15-26.

Njoya, M. T., Wittmann, D., & Schindler, M. (2005). *Effect of bee pollination on seed set and nutrition on okra (Abelmoschus esculentus) in Cameroon. The Global Food and Product Chain--Dynamics, Innovations, Conflicts, Strategies.* Germany: Hohenheim.

Norman, J. C. (1992). Tropical vegetable crops: Arthur H. Stockwell (pp. 252): University of Wisconsin-Madison.

Oyolu, C. (1983). *Okra seeds, potential source of high quality vegetable oil.* Paper presented at the In Proceedings, 5th Annual Conference, Horticulture Society. Nigeria, Nsukka.

Pando, J. B., Djonwangwé, D., Moudelsia, O. B., Fohouo, F.-N. T., & Tamesse, J. L. (2019). Insect pollinators and productivity of soybean [Glycine max (L.) Merr. 1917] at Maroua, Far North, Cameroon. *World Journal of Advanced Research and Reviews, 4*(2), 117-129.

Pando, J., Djonwangwé, D., Moudelsia, O., Fohouo, F.-N., & Tamesse, J. L. (2020). Diversity of flower-growing insects of Abelmoschus esculentus (Malvaceae) and their impact on fruit and grain yields in Maroua-Cameroon. *Journal of Animal & Plant Sciences, 43*(1), 7350-7365.

Reddy, L. J., Chandra, S., Pooni, H., & Bramel, P. J. (2004). Rate of out crossing in pigeon pea under intercropped conditions. Assessing the Risk of Losses in Biodiversity in Traditional Cropping Systems: A Case Study of Pigeon pea in Andhra Pradesh.(Bramel PJ, ed.). *Patancheru, 502*(324), 133-141.

Sawadogo, M., Zombre, G., & Balma, D. (2006). Expression of different ecotypes of okra (Abelmoschus esculentus L.) with water deficit occurring during budding and flowering. *Biotechnology, Agronomy, Society and Environment, 10*(1), 43-54.

Tanda, A. (2019). Entomofauna enhance the quality and quantity in Okra. *Indian Journal of Entomology, 81*(1), 16-17.Available at: https://doi.org/10.5958/0974-8172.2019.00073.7.

Tchindebe, G., & Fohouo, F.-N. T. (2014). Foraging and pollination activity of Apis mellifera adansonii Latreille (Hymenoptera: Apidae) on flowers of Allium cepa L.(Liliaceae) at Maroua, Cameroon. *International Journal of Agronomy and Agricultural Research, 5*(2), 139-153.

Tchindebe, G., Douka, C., Tope, S., & Fohouo, F. (2018). Diversity of flowering insect and its impact on fruit and seed yields of Arachis hypogaea L.(Fabaceae) at Maroua (Far North, Cameroon). *Journal of Applied Biosciences, 129*(2018), 13075-13087.

Tchuenguem, F. F. N., Messi, J., & Pauly, A. (2001). Activity of Meliponula erythra on dacryodes edulis flowers and its impact on fruiting. *Fruits, 56*(3), 179-188.

Tchuenguem Fohouo, F. N. (2005). *Foraging and pollination activity of Apis mellifera adansonii Latreille (Hymenoptera: Apidae, Apinae) on the flowers of three plants in Ngaoundéré (Cameroon): Callistemon rigidus (Myrtaceae), Syzygium guineense var. macrocarpum (Myrtaceae) and Voacanga africana (Apocynaceae).* These doctoral studies, University of Yaoundé I, Yaoundé, Cameroon.

Tchuenguem, F., FN, Messi, J., Brüchner, D., Bouba, B., Mbofung, G., & Hemo, J. H. (2004). Foraging and pollination behaviour of the African Honey bee (Apis mellifera adansonii) on Callistemon rigidus flowers in Ngaoundere (Cameroon). *Journal of the Cameroon Academy of Sciences, 4*(2), 133-140.