

## Insect foraging and pollination activity on the flowers of *Abelmoschus esculentus* (Malvaceae) in the Vina (Ngaoundéré, Cameroon)

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### Abstract

To assess the impact of anthophilous insects on the pod and seed production of *Abelmoschus esculentus*, the foraging and pollination activity of these arthropods was studied on flowers from July 15 to 20, 2023 in Dang. The investigations focused on two treatments, each containing 240 flowers, differentiated by the presence or absence of insect protection. Insect foraging behavior, pollination activity, fruit set, number of seeds per pod, number of normal seeds, pod size, and pod weight were evaluated. The results show that Hymenoptera constitutes the most represented order, accounting for 76.24% of visits (Apidae 35.3%; Halictidae 40.31%; Vespidae 0.63%), followed by Lepidoptera (10.34%) and Coleoptera (3.37%). The insects visited the flowers of this plant throughout the day to collect nectar and pollen, with a peak of activity between 8 a.m. and 9 a.m. Comparing the yields of flowers left to be pollinated freely with those of flowers protected from insects, a significant increase in the fruiting rate (15.25%), the average number of seeds per pod (14.52%), the percentage of normal seeds (2.56%), the average pod size (11.85%), and the average pod weight (25.34%) was observed, all attributed to flower visiting insects. To improve the production of *Abelmoschus esculentus*, it is advisable to protect its flower-visiting insects during the flowering of this Malvaceae.

**Keywords:** *Abelmoschus esculentus*, flowers, insects, pollination, yields, Ngaoundéré, Cameroon

### Introduction

Agriculture is the engine of overall growth for the majority of developing countries (FAO, 2009). It is essential for poverty reduction and strengthening food security (FAO, 2009) [11]. Despite the efforts made by sub-Saharan African countries, approximately 23.2% of the population remains undernourished, primarily due to low agricultural production (FAO, 2016). Okra (*Abelmoschus esculentus* L.) is an annual plant of the Malvaceae family cultivated in tropical and subtropical regions, on very undemanding soils and with a pH between 6 and 7. This species is among the vegetables providing products with significant nutritional value (Hamon *et al.*, 1997) [18]. It is characterized by a diversity of fruit and stem shapes and colors (Seck, 1991) [36]. The stem is cylindrical, hairy, and branched (Charrier, 1983) [6]. The leaves are spirally arranged, simple, and vary in shape and size (Marius *et al.*, 1997) [24]. Okra leaves are consumed for their high protein and mineral content (Martin, 1982) [25]. The fruit is an erect capsule with a round cross-section and 5 to 10 concave angles between its sides (Fondio *et al.*, 2007) [16]. The fruits are used fresh or dried in culinary preparations (Marius *et al.*, 1997) [24]. It is also used in the sugar and pharmaceutical industries (Martin, 1982) [25]. Fresh fruit is rich in vitamin C and calcium, while dried fruit is primarily rich in protein (N'guettia *et al.*, 2017) [29]. India is the world's leading producer, with an estimated production of 6.176.000 tonnes in 2019. It alone accounts for nearly 72% of global production. Nigeria follows with a production of 1.819.018 tonnes (FAOSTAT, 2021). Cameroon, the world's eighth-largest producer of okra, had an annual production of 104.216 tonnes in 2019 (FAOSTAT, 2021). Given this situation, it is important that

agricultural development programs consider all factors that can contribute to increased yields (MINEPAT, 2014), particularly the use of pollinating insects (FAO, 2016), which are responsible for pollinating nearly 85% of flowering plants (Chifflet, 2010). These arthropods alone pollinate more than 65% of cultivated species worldwide (Klein *et al.*, 2007) [21], including *Abelmoschus esculentus* (L.) (Tchuenguem *et al.*, 2009; Djonwangwé *et al.*, 2017) [9, 40]. Despite its importance as a food source, nutritional resource, and economic asset in Cameroon, its production remains low while demand is constantly increasing (MINADER, 2012), primarily due to insufficient knowledge about the relationships between this Malvaceae and anthophilous insects in the different regions of the country (MINADER, 2012) [2]. Data published prior to our work on the relationships between *Ab. esculentus* and flower-visiting insects are those provided by investigations by Angbanyere and Matthew (2012) [2] in Burkina Faso, Azo'o *et al.* (2011), Njoya *et al.* (2005), Pando *et al.* (2020), Kingha *et al.* (2021) [20, 28, 32], Kouayet *et al.* (2021), Pharaon *et al.* (2021), and Adamou *et al.* (2025) [1] in Cameroon and Tébaye *et al.* (2025) [1] in Tchad and Angbanyere and Baidoo (2014) [3] in Ghana. Flower insect fauna and its impact on pollination and plant yields can vary spatially and temporally (Tchuenguem, 2005) [39]. This work contributes to the development of knowledge on the relationships between pollinating insects and *Abelmoschus esculentus*. With a view to their optimal exploitation in Cameroon. It aims at three specific objectives: (i) to identify the flower-visiting insects of *Abelmoschus esculentus*; (ii) to study the activity of these insects on the flowers of this plant; (iii) to assess the impact of flower-visiting insects on pollination and fruit and seed yields of this Malvaceae.

## Materials and methods

### 1. Site, research station and biological materials

The investigations took place from May 4 to August 12, 2023, in Dang, in the Adamawa Region of Cameroon, centered on a point with the following geographic coordinates: latitude = 7° 41'31.49" N; longitude = 13° 54'32.07" E; altitude = 1072 m. These coordinates were obtained using a Garmin II+ Global Positioning System. The climate of the region is of the Sudano-Guinean type, mild and cool, characterized by two seasons: a rainy season

(April to October) and a dry season (November to March) (Yonkeu, 1993) [42]. The plant material consisted of *Abelmoschus esculentus* seeds (Fig. 1) purchased from the agricultural seed shop (SEMAGRI) in Ngaoundéré. The animal material consisted of: (i) three colonies of *Ap. mellifera* from the study station and its surroundings; (ii) of various insect populations present in the experimental environment and which visited the flowers of this mallow. Figure 1 shows the location map of the study site.

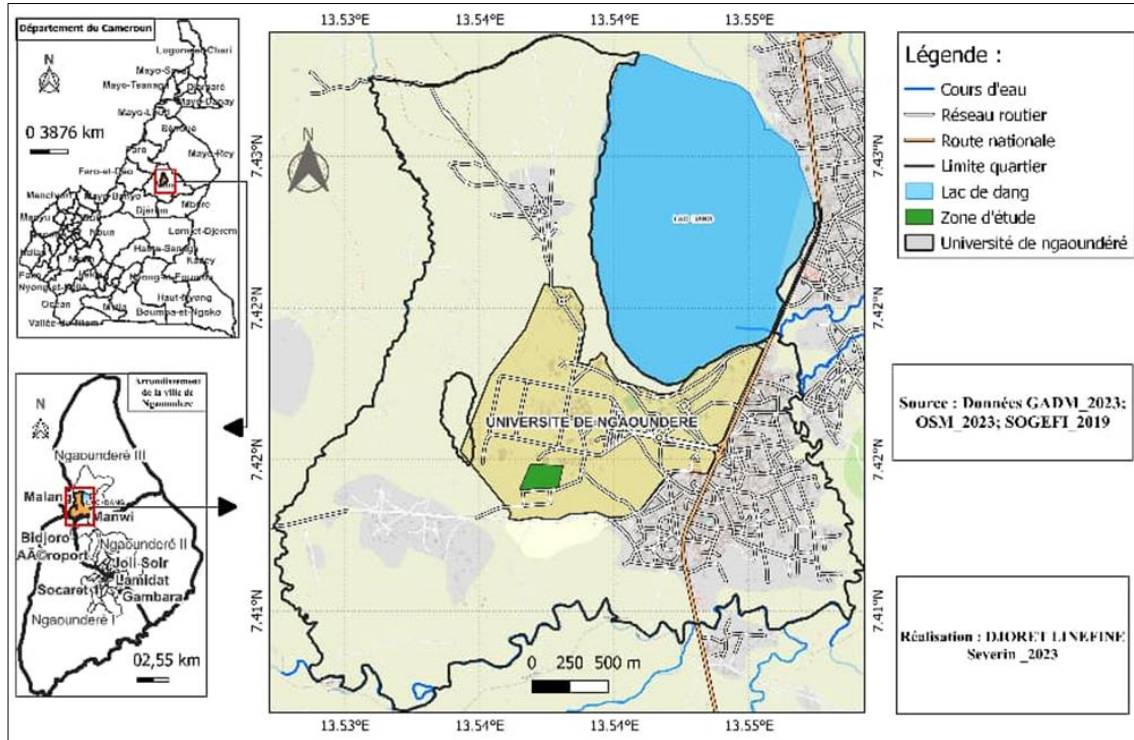


Fig 1: Location map of the study site.

### 2. Preparation, sowing and maintenance of the experimental plot

From May 4 to 15, 2023, the 437 m<sup>2</sup> experimental plot was cleared, plowed, and divided into eight subplots, each 8 m long and 4.5 m wide, separated by 1 m wide paths. A 1 m wide path bordered the perimeter of the experimental site. *Ab. esculentus* seeds were sown on May 18, 2023, in six rows per subplot, with two seeds per planting hole, spaced 50 cm within the rows and 75 cm between rows (Kingha *et al.*, 2021) [20]. From germination until the first flower appeared, the field was regularly hoed every two weeks. Weeding was carried out by hand from the appearance of the first flowers until fruit maturity.

### 3. Determination of the mode of reproduction of *Abelmoschus esculentus*

As soon as the first flowers appeared, 240 of them were tagged at the bud stage on 120 *Ab. esculentus* plants, with 15 plants per subplot, and two treatments were used: - treatment 1: 120 unprotected flowers (Fig. 2); - treatment 2: 120 flowers protected from insects using 1 mm<sup>2</sup> mesh gauze bags (Tchuenguem, 2005) [39] (Fig. 3). Three days after the last tagged flower had withered, the number of fruits formed was counted in each of treatments 1 and 2. For each treatment, the fruiting index (FI) was calculated using the following formula:  $FI = (F2 / F1)$ ; where F2 is the number

of fruits formed and F1 is the number of initially viable flowers (Tchuenguem *et al.*, 2001) [38]. The difference between the fruiting indices of the two treatments made it possible to calculate the rates of allogamy (TC) and autogamy (TA) (Demarly, 1977) [8].

$TC = \{ [(IfrX - IfrY) / IfrX] * 100 \}$ , where IfrX and IfrY are the fruiting indices in the free treatment and in the protected treatment respectively;  $TA = [100 - TC]$ .

### 4. Determination of the place of each insect in the flower-dwelling entomofauna of *Abelmoschus esculentus*

Observations were conducted daily from July 15 to 20, 2023, during six time slots: 6-7 a.m.; 8-9 a.m.; 10-11 a.m.; 12-1 p.m. and 2-3 p.m. Each flower in treatment 1 was visited once during each of these time slots. At each visit, the different insects encountered on the open flowers were identified and counted. Since the insects were not marked, the cumulative results were expressed as the number of visits (Tchuenguem *et al.*, 2005) [39]. The data obtained made it possible to determine the frequency of each insect (Fi) in the flower insect fauna of *Ab. esculentus*, using the following formula:  $Fi = (Vi / VI) * 100$ , with Vi = number of visits of insect i to the flowers of treatment 1 and VI the number of visits of all insects to these same flowers (Tchuenguem *et al.*, 2001) [38].



**Fig 2:** *Abelmoschus esculentus* flower labeled and unprotected



**Fig 3:** *Abelmoschus esculentus* flower labeled and protected from insects with a gauze bag

### 5. Study of the activity insects at the level of the flowers of *Abelmoschus esculentus*

Floral products (nectar or pollen) collected by the visiting insects were noted during the same dates and time slots as for the duration of visits. An insect that plunges its proboscis or head into a flower is a nectar collector; if, using its legs and mandibles, it scrapes the anthers, it is a pollen collector (Tchuenguem, 2005) [39]. The floral products collected were systematically noted, when recording the duration of visits per flower, by a distinctive sign over the corresponding duration (Tchuenguem, 2005) [39].

The durations of pollen collection visits and nectar collection visits were recorded separately using a stopwatch, on the same dates as for the frequency of visits, during the following daily time slots: 7-8 a.m., 9-10 a.m., 11-12 p.m., 1-2 p.m. and 3-4 p.m. (Tchuenguem, 2005) [39].

Pollinator abundance (largest number of individuals simultaneously active on a flower and on 1000 open flowers) (Tchuenguem *et al.*, 2005) [39]; The abundance per 1000 flowers (A1000) was then calculated using the formula:  $A1000 = [(Ax / Fx) * 1000]$ , where Fx and Ax are respectively the number of open flowers and the number of foragers actually counted on Fx at time x (Tchuenguem, 2005) [39]. Forager abundance and foraging speed (number of flowers visited per minute) were recorded on the same dates and time slots as the visit durations.

The foraging speed, which corresponds to the number of flowers visited by an insect in one minute (Jacob-Remacle, 1989) [19], was recorded. As soon as an insect landed on a flower, the timer, previously reset to zero, was started and the number of flowers visited was counted as it moved from one flower to the next. The timer stopped as soon as the forager was lost from sight or left the *Ab. esculentus* flower. The foraging speed (Vb) was calculated according to the following formula:  $Vb = (Fi / di) * 60$  (Tchuenguem *et al.*, 2005) [39], where di is the duration given by the stopwatch (in seconds) and Fi is the number of flowers corresponding to di.

The influence of fauna (interruption of flower visits by competitors or predators) and flora (passage of insects from okra flower to that of another plant species and vice versa) was systematically recorded when timing the duration of visits per flower.

During each day of observation, the temperature and humidity of the study station were recorded every 30

minutes, from 6 a.m. to 6 p.m., using a portable thermohygrometer installed in the shade.

### 6. Estimation of the beekeeping value of *Abelmoschus esculentus*

The beekeeping value of *Ab. esculentus* was assessed using data on flowering intensity, the attractiveness of *Ap. mellifera* to the pollen and nectar of this Malvaceae (Pando *et al.*, 2020; Kingha *et al.*, 2021; Adamou *et al.*, 2025) [1, 20, 32].

### 7. Evaluation of the impact of anthophilous insects on the pollination of *Abelmoschus esculentus*

The frequency of visits was recorded throughout the study. This involved recording the number of times an insect came into contact with the stigma of the visited flower. This allowed researchers to highlight the potential role of insects in self-pollination and cross-pollination of the visited flowers (Delaplaine *et al.*, 2013) [7].

### 8. Evaluation of the impact of flower-visiting insects on fruit and seed production *Abelmoschus esculentus*

It is based on the impact of anthophilous insects on pollination, the impact of pollination on fruiting, the comparison of fruit yields (fruiting rate) and seed yields (average number of seeds per fruit and percentage of normal seeds, i.e. well developed) of the treatment with unprotected flowers to those of the treatment with flowers protected from insects using gauze bags (Tchuenguem *et al.*, 2001) [38].

The fruiting rate due to the influence of flower-visiting insects (Pi) was evaluated using the following formula:  $Pi = \{ [(F1 - F2) / F1] * 100 \}$  where F1 and F2 are the fruiting rates in treatments 1 (unprotected flowers) and 2 (protected flowers), respectively. For a treatment x, the fruiting rate (Fx) is:  $Fx = [(number\ of\ fruits/number\ of\ flowers) * 100]$  (Tchuenguem, 2005) [39].

The percentage of the number of seeds per fruit attributable to the influence of flower insects (Pf) was calculated using the formula:  $Pf = \{ [(f1 - f2) / f1] * 100 \}$  where f1 and f2 are the average number of seeds per fruit in treatments 1 and 2 respectively (Tchuenguem, 2005) [28].

The percentage of normal seeds attributable to the influence of flower insects (Pn) was calculated using the formula:  $Pn = \{ [(Pn1 - Pn2) / Pn1] * 100 \}$  where Pn1 and Pn2 are the

percentages of normal seeds from treatments 1 and 2 respectively (Tchuenguem, 2005) [28].

### Data analysis

Data processing was carried out using descriptive statistics (calculation of means, standard deviations and percentages), the student's t-test for comparing two means, ANOVA for comparing more than two means, the correlation coefficient (r) for studying linear relationships between two variables, and the chi-square ( $\chi^2$ ) for comparing percentages at the thresholds of 5%, 1% and 1%. Excel 2010 software was used for this purpose.

## Results and discussion

### 1. Mode of reproduction of *Abelmoschus esculentus*

**Table 1:** Insects recorded on the flowers of *Abelmoschus esculentus*, number and percentage of visits by different insects

Insect Visits				
Order	Family	Genus, species	n	p (%)
Coleoptera	Meloidae	<i>Coryna</i> sp. (pm)	3	0.63
		(gen. sp. 1) (pm)	3	0.63
		(gen. sp. 2) (pm)	6	1.26
		Total Meloidae	12	2.52
	Pentatomidae	<i>Dysdercus voelkeri</i> (pm)	4	0.85
		Total Pentatomidae	4	0.85
	Total Coleoptera	16	3.37	
Hymenoptera	Apidae	<i>Amegilla</i> sp. (ne, po)	74	15.64
		<i>Apis mellifera</i> (ne, po)	93	19.66
		Total Apidae	167	35.3
	Halictidae	<i>Lasioglossum saegeri</i> (ne)	74	15.64
		<i>Lasioglossum</i> sp. 1 (po)	114	24.10
		<i>Lasioglossum</i> sp. 2 (po)	50	10.57
		Total Halictidae	238	40.31
	Vespidae	<i>Ropalida</i> sp. (pr)	3	0.63
		Total Vespidae	3	0.63
		Total Hymenoptera	408	76.24
Lepidoptera	Hesperiidae	(gen. sp. 1) (ne)	28	5.91
	Pieridae	(gen. sp. 2) (ne)	21	4.43
	Total Lepidoptera		49	10.34
Total		12	473	100.00

n: number of visits on 120 flowers of treatment 1 in 5 days of observation; p: percentage of insect visits in 5 days of observation  $p = (n / 473)$

\* 100; sp.: undetermined species; ne: nectar; po: pollen; pm: petal eater; pr: predator.

This table shows that Hymenoptera are the most represented order, accounting for 76.24% of visits (Apidae 35.3%; Halictidae 40.31%; Vespidae 0.63%), followed by Lepidoptera (10.34%) and Coleoptera (3.37%). These results are similar to those obtained by Kingha *et al.* (2021) [20] on this Malvaceae in Garoua, where they recorded 79.67% Hymenoptera and 15.44% Lepidoptera. In Garoua, Adamou *et al.* (2025) [1], and in Tchad, Tébya *et al.* (2025) [41], found that Hymenoptera were the most represented order (49.08%), followed by Lepidoptera (37.47%). In contrast, Azo'o *et al.* (2011) [4] studies conducted in Maroua on the same plant species found that the order Hymenoptera accounted for the largest share of visits, with 96.6%, followed by Diptera at 1.60%. This observed difference could be explained not only by the needs of the flower-visiting insects of this plant but also by variations in the availability of forage from flowering plants surrounding *Ab. esculentus* during the observation period. These data confirm that the diversity of the flower-visiting insect fauna of a plant species varies over time and space (Tchuenguem, 2005) [39].

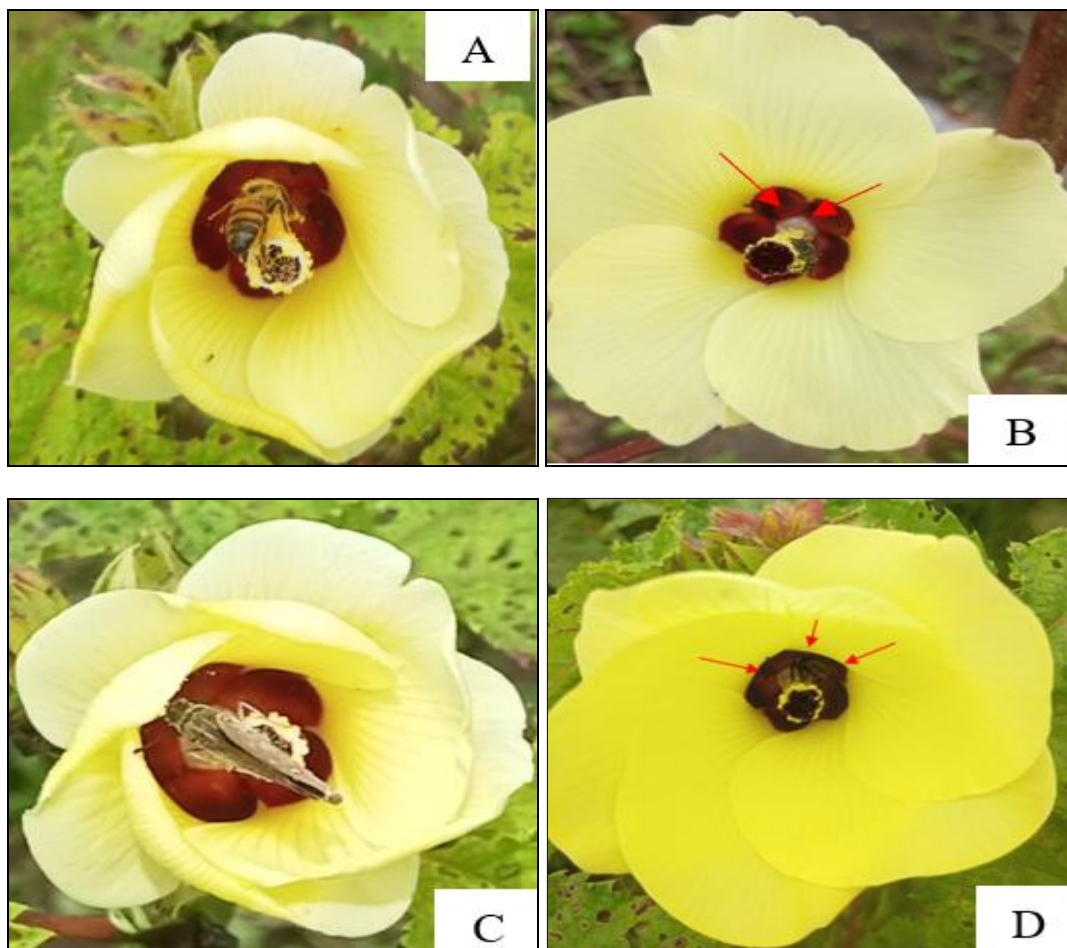
The fruiting index was 0.98 in treatment 1 and 0.83 in treatment 2. Thus, TC = 15.30% and TA = 84.70%. *Abelmoschus esculentus* therefore has a mixed allogamous-autogamous reproductive regime with a predominance of autogamy. This result is consistent with those obtained by Pando *et al.* (2020), Kingha *et al.* (2021), and Adamou *et al.* (2025) [1, 20, 32] in Cameroon on the same plant species. These authors found that TC and TA were 9%, 91%, 9.42%, 90.58%, 20.59%, and 79.41%, respectively.

### 2. Place of each insect species in the flower-dwelling entomofauna of *Abelmoschus esculentus*

From July 15 to 20, 2023, 473 visits of 12 insect species belonging to 3 Orders and 7 Families were recorded on 120 flowers of *Ab. esculentus* from treatment 1. Table 1 presents the list of insects recorded with their percentages of visits.

### 3. Activity of flower-visiting insects at the level of flowers *Abelmoschus esculentus* Floral products picked

The anthophilous insects of this Malvaceae are classified into four categories according to their type of activity: - pollen gatherers: *Lasioglossum* sp. 1, 2; - nectar gatherers: *Lasioglossum saegeri* and Hesperiidae; - nectar and pollen gatherers: *Apis mellifera* and *Amegilla* sp.; - petal eaters: *Corina* sp. and *Dysdercus voelkeri*. Kingha *et al.* (2021), Azo'o *et al.* (2011), Adamou *et al.* (2025) [1, 4, 20] and Tébya *et al.* (2025) have also found that the insects collect nectar and pollen from this tree species. This pollen and nectar collection could be explained by the attractiveness of these floral products to insects, their availability, and their need for these products during the flowering period of *Ab. esculentus*. Figure 4 shows some insect species collecting nectar and/or pollen from the flowers of *Abelmoschus esculentus*.

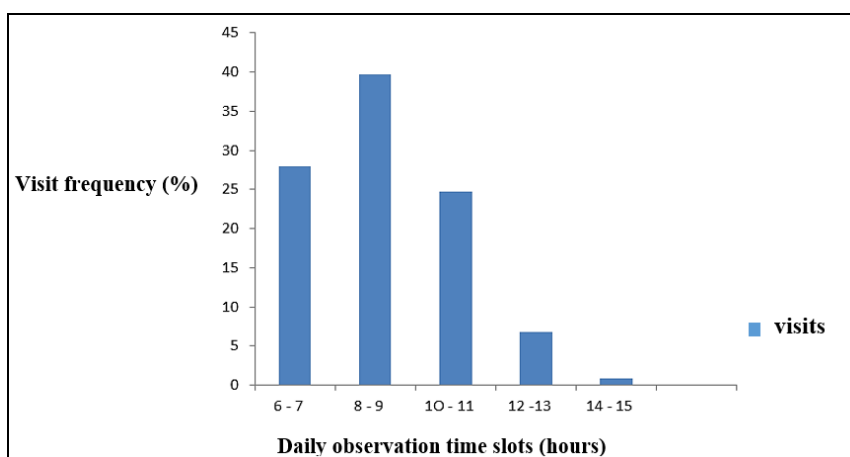


**Fig 4:** *Apis mellifera* collecting nectar (A), *Lasioglossum* sp.1 collecting pollen (B), Pieridae sucking nectar (C) and *Amegilla* sp. collecting pollen (D) on the flowers of *Abelmoschus esculentus*.

#### 4. Insect visit frequency according to daily observation time slots

The visitation pattern varied from one insect to another, as shown in figure 5. This figure indicates that the activity of insects visiting *Ab. esculentus* flowers began around 6:00 a.m. and ended around 3:00 p.m., with a peak in activity between 8:00 a.m. and 9:00 a.m. Low activity was also observed between 2:00 p.m. and 3:00 p.m., followed by no activity after 3:00 p.m. This peak in activity during this time period would coincide with the period of anthesis and the maximum availability of nectar and/or pollen in the flowers of this Malvaceae (Rasn and Karunaratne, 2019) [37]. The lack of activity observed after 3:00 p.m. could be explained

by the closing of the flowers, which makes the floral products of this plant inaccessible to flower-visiting insects. Pando *et al.* (2020) in Maroua, Adamou *et al.* (2025) [1, 32] in Garoua and Tébya *et al.* (2025) [1] in Tchad found a peak of activity on the same plant between 10 a.m. and 11 a.m. This observed difference could be explained simply due to climate variability and by the variation of the agroecological zone. According to Pesson and Louveaux (1984) [23], and this in *Ap. mellifera* particularly when the bounty is no longer easily exploitable or decreases in quantity and/or quality, the foragers reduce their activity on the flowers so that the energy expended for the work of foraging is not greater than that of the bounty.



**Fig 5:** Insect visitation rhythm according to observation time slots.

### 5. Abundance of pollinators

The highest number of individuals simultaneously active on 1000 flowers of *Ab. esculentus* varied from 333.33 in *Lasioglossum* sp.1 to 500 in *Ap. mellifera* and *Amegilla* sp. Table 2 presents the data relating to the abundance of three insect species per 1000 flowers.

**Table 2:** Abundance of three insect species per 1000 flowers of *Abelmoschus esculentus*

Insects	Abundance per 1000 flowers (A1000)				
	n	m	s	mini	maxi
<i>Lasioglossum</i> sp.1	60	241.95	92.73	111	333.33
<i>Apis mellifera</i>	53	176.99	55.05	111	500
<i>Amegilla</i> sp.	43	207.30	90.23	111	500

n: frequency; m: mean; s: standard deviation; mini: minimum; maxi: maximum

*Lasioglossum/Apis*:  $t = 23.41$  ( $df = 111$ ;  $P < 0.001$ ); *Lasioglossum/Amegilla*:  $t = 9.37$  ( $df = 101$ ;  $P < 0.001$ ); *Apis/Amegilla*:  $t = 9.76$  ( $df = 94$ ;  $P < 0.001$ ). The overall comparison of these three means shows that the observed differences are highly significant ( $F = 18.24$ ;  $df1 = 2$ ;  $df2 = 195$ ;  $P < 0.001$ ). Pairwise comparisons of the means reveal that the difference is statistically highly significant between: - *Lasioglossum* sp.1/*Apis mellifera*:  $t = 23.41$  ( $df = 111$ ;  $P < 0.001$ ); - *Lasioglossum* sp.1/*Amegilla* sp.:  $t = 9.37$  ( $df = 101$ ;  $P < 0.001$ ); - *Apis mellifera/Amegilla* sp.:  $t = 9.76$  ( $df = 94$ ;  $P < 0.001$ ). The high abundances per 1000 flowers highlight the strong attractiveness of the nectar and/or pollen of *Ab. esculentus* to the corresponding insects. In *Ap. mellifera*, these abundances are linked to the ability of the workers to recruit a large number of foragers to exploit an interesting food source (Free, 1993) [14].

### 6. Duration of visits per flower

Tables 3 and 4 present data concerning the duration of pollen and nectar collection visits respectively of three insect species on the flowers of *Ab. esculentus*.

**Table 3:** Duration of pollen-collecting visits by three insect species per flower of *Abelmoschus esculentus*

Insects	Duration of a visit per flower (sec)				
	n	m	s	mini	maxi
<i>Lasioglossum</i> sp.1	42	145.71	85.65	55	396
<i>Apis mellifera</i>	46	6.52	2.42	3	13
<i>Amegilla</i> sp.	46	16.71	8.67	2	39

n: number of recorded visit durations; m: mean; s: standard deviation; mini: minimum; maxi: maximum.

**Table 4:** Duration of nectar-collecting visits by three insect species per flower of *Abelmoschus esculentus*

Insects	Duration of a visit per flower (sec)				
	n	m	s	mini	maxi
<i>Lasioglossum</i> sp.1	9	55	25,03	15	92
<i>Apis mellifera</i>	9	6,11	2,26	2	9
<i>Amegilla</i> sp.	12	4,5	2,02	2	9

n: number of recorded visit durations; m: mean; s: standard deviation; mini: minimum; maxi: maximum.

**Globally:**  $F = 100.05$  ( $df 1 = 2$ ;  $df 2 = 122$ ;  $P < 0.001$ ), *Lasioglossum/Amegilla*:  $t = 47.05$  ( $df = 86$ ;  $P < 0.001$ );

*Lasioglossum/Apis*:  $t = 51.03$  ( $df = 86$ ;  $P < 0.001$ ); *Apis/Amegilla*:  $t = 36.41$  ( $df = 90$ ;  $P < 0.001$ ).

**Globally:**  $F = 49.79$  ( $df 1 = 2$ ;  $df 2 = 31$ ;  $P < 0.001$ ), *Lasioglossum/Amegilla*:  $t = 15.01$  ( $df = 19$ ;  $P < 0.001$ ); *Lasioglossum/Apis*:  $t = 11.67$  ( $df = 16$ ;  $P < 0.001$ ); *Apis/Amegilla*:  $t = 3.70$  ( $df = 19$ ;  $P < 0.01$ ). Pairwise comparisons of the means for pollen collection reveal that the difference is statistically very highly significant between *Lasioglossum/Amegilla*:  $t = 47.05$  ( $df = 86$ ;  $P < 0.001$ ); *Lasioglossum/Apis*:  $t = 51.03$  ( $df = 86$ ;  $P < 0.001$ ) and *Apis/Amegilla*:  $t = 36.41$  ( $df = 90$ ;  $P < 0.001$ ).

For nectar collection, the difference is statistically highly significant between *Lasioglossum/Amegilla*:  $t = 15.01$  ( $df = 19$ ;  $P < 0.001$ ); *Lasioglossum/Apis*:  $t = 11.67$  ( $df = 16$ ;  $P < 0.001$ ); and highly significant between *Apis/Amegilla*:  $t = 3.70$  ( $df = 19$ ;  $P < 0.01$ ). These observed differences could be explained by the foraging patterns that characterize each of these insects. Bees spend more time on flowers rich in nectar and/or pollen than on those poor in these resources (Pappers *et al.*, 1999) [33]. The average duration of a visit by *Ap. mellifera* differs from that found by Kingha *et al.* (2021) [20], where this duration was 4.90 sec for nectar collection and 3.15 sec for pollen collection.

### 7. Foraging speed per flower

Data relating to the average foraging speed of *Ab. esculentus* flowers by three insect species are recorded in Table 5.

**Table 5:** Foraging speed of three insect species on the flowers of *Abelmoschus esculentus*

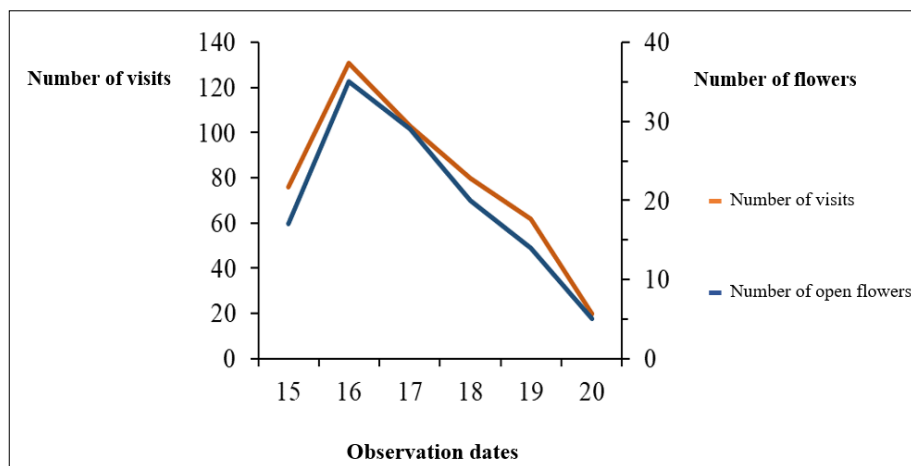
Insects	Foraging speed (flower/min)				
	n	m	s	mini	maxi
<i>Lasioglossum</i> sp.1	56	3.61	3.06	0.50	20.17
<i>Apis mellifera</i>	56	3.12	3.07	0.08	16.75
<i>Amegilla</i> sp.	44	36.40	20.29	5.00	17.00

n: number of recorded foraging speeds; m: mean; s: standard deviation; mini: minimum; maxi: maximum

**Globally:**  $F = 1.57$  ( $df 1 = 2$ ;  $df 2 = 153$ ,  $P > 0.05$ ). This table shows that the average foraging speed varies from 3.12 flowers/min in *Ap. mellifera* to 36.40 flowers/min in *Amegilla* sp.

### 8. Insect visitation patterns in relation to the flowering pattern of *Abelmoschus esculentus*

There figure 6 summarizes the results concerning the frequency of insect visits as a function of the flowering frequency of *Ab. esculentus*. This figure shows that, overall, the number of insect visits is proportional to the number of open *Ab. esculentus* flowers. Statistical analysis reveals a significant positive correlation ( $r = 0.99$ ;  $df = 4$ ;  $P < 0.01$ ) between these two parameters. This significant correlation highlights the high attractiveness of okra flowers to visiting insects. This result confirms the observations of Faegri and Pijl (1979) [10], which indicate that the number of open flowers plays an important role in orienting pollinators towards the flowers. Our data follow the ideal free distribution theory of Fretwell and Lucas (1970) [15], according to which pollinator abundance follows the spatial distribution of flower densities in the field.



**Fig 6:** Variation in the number of open flowers of *Abelmoschus esculentus* and the number of insect visits to the flowers according to the observation days

## Foraging ecology

### 1. Influence of wildlife

During foraging activity on the flowers of *Ab. esculentus*, the insects were disturbed by others that were competitors for pollen and/or nectar from this Malvaceae. Table 6 shows the frequency of interruptions in these insects visits to the flowers of *Abelmoschus esculentus*.

Of 59 recorded visit durations for *Apis mellifera*, 5 (8.47%)

were interrupted by *Lasioglossum* sp.1, 4 (6.77%) by *Apis mellifera* and 3 (5.08%) by *Amegilla* sp. Of 58 recorded visit durations for *Amegilla* sp., 2 (3.44%) were interrupted by *Lasioglossum* sp.1; 5 (8.62%) by *Apis mellifera* and 4 (6.89%) by *Amegilla* sp. These interruptions resulted in shorter visits, forcing these insects to visit a greater number of flowers during a foraging trip to obtain their optimal nectar and/or pollen load (Tchuenguem *et al.*, 2001)<sup>[38]</sup>.

**Table 6:** Frequency of interruptions in insect visits to *Abelmoschus esculentus* flowers

Insects	N	Visits interrupted			Authorities of the interruptions
		n	nt	p (%)	
<i>Lasioglossum</i> sp.1	51	2, 3, 2,3	10	19.60	<i>Lasioglossum</i> sp.1 (3.92) <i>Apis mellifera</i> (5.88) <i>Amegilla</i> sp. (3.92) <i>Lasioglossum saegeri</i> (5.88)
<i>Amegilla</i> sp.	58	2, 5, 4	11	18.96	<i>Lasioglossum</i> sp.1 (3.44) <i>Apis mellifera</i> (8.62) <i>Amegilla</i> sp. (6.89)
<i>Apis mellifera</i>	59	5, 4, 3	12	20.33	<i>Lasioglossum</i> sp.1 (8.47) <i>Apis mellifera</i> (6.77) <i>Amegilla</i> sp. (5.08)
Total	168	33		58.89	

N: total number of visits studied; n: number of interrupted visits; nt: total number of interrupted visits; p: percentage of interrupted visits.

### 2. Influence of the surrounding flora

During the observation period, the flowers of several other plant species near the experimental site were visited by some pollinators of *Ab. esculentus* flowers for their nectar

and/or pollen. Table 7 shows some of these plants and their floral products collected by *Lasioglossum* sp.1 and *Ap. mellifera*.

**Table 7:** Plant species whose floral products attracted *Lasioglossum* sp.1 and *Apis mellifera* during the flowering period of *Abelmoschus esculentus*

Families	Plant species	Animal species	Food samples	
			Nectar	Pollen
Asteraceae	<i>Acanthospermum hispidum</i>	<i>Apis mellifera</i>	+	+
	<i>Ageratum conyzoides</i>	<i>Apis mellifera</i>	+	++
	<i>Bidens pilosa</i>	<i>Apis mellifera</i>	+	+++
Cucurbitaceae	<i>Cucumis melo</i>	<i>Lasioglossum</i> sp.1	+	+++
		<i>Apis mellifera</i>	+	+++
Fabaceae	<i>Vigna unguiculata</i>	<i>Apis mellifera</i>	+	+++
Rubiaceae	<i>Mitracarpus villosus</i>	<i>Apis mellifera</i>	+	+++
Poaceae	<i>Zea mays</i>	<i>Apis mellifera</i>	+	+++

+ : very low harvest; ++ : high harvest; +++ : very high harvest

For all foraging insects, no switching between the flowers of *Ab. esculentus* and those of other plant species was observed, or vice versa. The foragers were thus faithful to the flowers of this Malvaceae during their foraging trips. In *Ap. mellifera*, this phenomenon is called "floral constancy" (Louveaux, 1984)<sup>[23]</sup>. According to Greggers and Menzel (1993)<sup>[17]</sup>, a bee generally forages on only one plant species per foraging trip. It maintains this fidelity to the plant

species during subsequent trips as long as its energy yield remains greater than or equivalent to that offered by foraging on another plant species (Osborne *et al.*, 1999)<sup>[31]</sup>.

### 3. Influence of some climatic factors

The variations in ambient temperature and humidity at the study site during the investigations were noted. Of the 10 days of observation on this Malvaceae, three were sunny,

four were hazy and rainy, two were heavily hazy, and one was dimly sunny and rainy. During sunny days, the abundance of various insects on the plant's flowers was high. On hazy and rainy days, the activity of these insects was low or nonexistent. When it rained and/or there was a strong wind, the activity of these arthropods decreased considerably. It should therefore be noted that rain and strong winds negatively influence insect activity on the flowers of *Ab. esculentus*. Similar observations were made on the same plant by Kingha *et al.* (2021) [20] in Garoua. Indeed, Bolchi *et al.* (1984) [5] had already reported the negative influence of rain and strong wind on insect activity at the level of flowers. The correlations between the number of insect visits and the average temperature ( $r = -0.60$ ;  $df = 3$ ;  $P > 0.05$ ) on the one hand and relative humidity ( $r = 0.69$ ;  $df = 3$ ;  $P > 0.05$ ) on the other hand were found to be non-significant.

#### 4. Beekeeping value of *Abelmoschus esculentus*

During the flowering of *Ab. esculentus*, we recorded high pollen collecting activity and low nectar gathering activity

by *Ap. mellifera* worker bees. These data allow us to classify *Ab. esculentus* among the bee friendly plants that are highly polliniferous and low in nectariferous. These results are consistent with those of Kingha *et al.* (2021) [20] in Garoua, where this plant species was also classified as a bee-friendly plant that is highly polliniferous and low in nectariferous.

#### 5. Impact of flower-visiting insects on the pollination of *Abelmoschus esculentus*

During pollen and/or nectar collection on *Ab. esculentus* flowers, most insects were always in contact with the anthers and stigmas (Table 8). They could therefore directly participate in self-pollination. Some insects transported (actively or passively) pollen from flower to flower on one or more plants of the same species. Consequently, they could participate in cross-pollination. Insect involvement in the pollination of *Ab. esculentus* was reported by Njoya *et al.* (2005) [28] in Cameroon and by Angbanyere and Baidoo (2012) [2] in Ghana.

**Table 8:** Number and frequency of contacts between insects, anthers and stigmas of *Abelmoschus esculentus* flowers

Insects	N	Guided visits with contact with the anthers		Visits with stigmatized contacts	
		n	p (%)	n	p (%)
<i>Lasioglossum</i> sp. 1	137	137	100	137	100
<i>Apis mellifera</i>	93	93	100	93	100
<i>Amegilla</i> sp.	74	15	20.27	3	4.05

N: total number of visits studied; n: number of visits with contacts; p: percentage of visits with contacts.

#### 6. Fruit and seed yields of *Abelmoschus esculentus*

Table 9 gives the values concerning the fruiting rate, the average number of seeds per fruit and the percentage of well-developed seeds in the different treatments of *Ab. esculentus*.

**Table 9:** Fruiting rate, average number of seeds per fruit, percentage of well-developed seeds, average size and average weight of a fruit according to the two treatments of *Abelmoschus esculentus*

Tr	NFE	NFF	TF(%)	NG / F		NTG	NGN	% GN	Length (cm)		Mass (g)	
				m	s				m	s	m	s
1 (FL)	120	118	98.33	76.08	10.16	8926	8795	98.53	7.85	0.99	36.07	5.83
2 (FID)	120	100	83.33	65.03	6.87	6502	6243	96.01	6.92	0.69	26.93	5.30

Tr: treatments; NFE: number of flowers studied; NFF: number of pods formed; TF: fruiting rate; NG/F: number of seeds per fruit; NTG: total number of seeds; NGN: number of well-developed seeds; % GN: percentage of well-developed seeds; m: mean; s: standard deviation; FL: unprotected flowers; FID: protected flowers

Figure 7 shows the well-developed and poorly formed seeds of *Abelmoschus esculentus*.



**Fig 7:** Well-developed (A) and malformed (B) seeds of *Abelmoschus esculentus* collected from the experimental plot

#### 7. Impact of flower-visiting insects on pod and seed production *Abelmoschus esculentus*

Table 9 shows that: a) fruit set rates were 98.33% and 83.33% in treatments 1 and 2, respectively. Comparison of

these percentages shows that the difference between treatments T1 and T2 is highly significant ( $\chi^2 = 16.21$ ;  $df = 1$ ;  $P < 0.01$ ); b) the mean number of seeds per fruit was 76.08 and 65.03 in treatments 1 and 2, respectively. The

differences between these means are also highly significant. Comparison of the means shows that the difference between treatments T1 and T2 is highly significant ( $t = 67.62$ ;  $df = 216$ ;  $P < 0.001$ ); c) the percentages of normal seeds (Figure 8) were 98.53% and 96.01% in treatments 1 and 2, respectively. Comparison of these percentages shows that the difference between treatments T1 and T2 is highly significant ( $\chi^2 = 96.63$ ;  $df = 1$ ;  $P < 0.001$ ); d) the mean fruit sizes were 7.85 cm and 6.92 cm in treatments 1 and 2, respectively. Comparison of the means shows that the difference between treatments T1 and T2 is highly significant ( $t = 57.90$ ;  $df = 216$ ;  $P < 0.001$ ); e) the mean fruit weights were 36.07 g and 26.93 g in treatments 1 and 2, respectively. Comparison of the means shows that the difference between treatments T1 and T2 is highly significant ( $t = 88.05$ ;  $df = 216$ ;  $P < 0.001$ ). The numerical contribution of insects to the different parameters was 15.25% in the fruiting rate, 14.52% in the percentage of the average number of seeds per fruit, 2.56% in the percentage of normal seeds, 11.85% in the percentage of average fruit size, and 25.34% in the percentage of average fruit weight. The influence of anthophilous insects on the yields of plant species in the different agro-ecological zones of Cameroon was noted by Népidé *et al.* (2024).

### Conclusion

In Dang (Ngaoundéré, Cameroon), 473 visits from 12 insect species were recorded on the flowers of *Abelmoschus esculentus*. These insects are distributed among 7 Families and 3 Orders: Hymenoptera, Lepidoptera, and Coleoptera. Insect activity at the flowers of this plant began around 6 a.m. and ended around 3 p.m., with a peak in visits between 8 a.m. and 9 a.m. Anthophilous insects collected a lot of pollen and a little nectar. The most represented order was Hymenoptera with 6 species, followed by Coleoptera with 4 species and Lepidoptera with 2 species. Flower-visiting insects are increasing significant of the fruiting rate of 15.25%, the average number of seeds per pod of 14.52%, the percentage of normal seeds of 2.56%, the average size of a pod of 11.85% and the average weight of a pod of 25.34%. These arthropods positively influence the fruit and seed production of this Malvaceae. Therefore, it is recommended to install and protect the nests of these insects near fields of this tree species. Treating okra plants with chemical pesticides should be avoided during the flowering period in order to benefit from the ecosystem service of pollinating insects.

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