Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

A stingless bee in activity: Meliponula bocandei (Hymenoptera: Apidae) and pollination of Ceratotheca sesamoides (Pedaliaceae) in Bertoua (East, Cameroon)

Aminou Mohamadou
aminidool3@gmail.com

University of Ngaoundéré
Beaudelaine Stéphanie Kengni
University of Ngaoundéré
Christèle Carole Egono Ndemé
University of Bertoua
Njoya Moses Tita Mogho
University of Bamenda
Fadoul Mahamat Fadoul
University of Ngaoundéré
Fernand-Nestor Tchuenguem Fohouo
University of Ngaoundéré

Research Article

Keywords: Ceratotheca sesamoides, Meliponula bocandei, pollination, production, Koumé-Bonis

Posted Date: November 18th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10779782/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

A stingless bee in activity: *Meliponula bocandei* (Hymenoptera: Apidae) and pollination of *Ceratotheca sesamoides* (Pedaliaceae) in Bertoua (East, Cameroon)

Mohamadou Aminou,[1] Kengni Beaudelaine Stephanie,[3] Egono Ndemé Carole Christèle,[2] Njoya Moses Tita Mogho,[4] Fadoul Mahamat Fadoul,[1] and Tchuenguem Fohouo Fernand-Nestor [1]

[1] Department of Biological Sciences, Faculty of Science, University of Ngaoundere, P.O. Box 454 Ngaoundere, Cameroon

[2] Department of Environmental Sciences, Higher Institute of Agriculture, Wood, Water Resources and Environment, P.O. Box 60 Belabo, University of Bertoua, Cameroon

[3] Department of Sciences and Technics of Biological Agriculture, Faculty of Science, University of Ngaoundere, P.O. Box 454 Ngaoundere, Cameroon

[4] Department of Biological Sciences, Faculty of Science, University of Bamenda, Cameroon

Corresponding author: Mohamadou Aminou (aminidool3@gmail.com)

Abstract

To assess the impact of *Meliponula bocandei* on the fruit and seed production of *C. sesamoides*, the foraging and pollination activities of worker bees of this stingless bee species were investigated on the flowers of *C. sesamoides* during August 2023 and August 2024 in Koumé-Bonis, Eastern Region, Cameroon. Total of 540 flowers were assigned to four treatments: (1) unprotected flowers, freely exposed to floral visitors; (2) protected flowers, excluding all floral visitors; (3) flowers protected before anthesis, uncovered at anthesis to allow a single visit by *M. bocandei*, and then re-protected; and (4) flowers protected before anthesis, uncovered at anthesis and immediately re-protected by human intervention without receiving any visits from insects or any other flower-visiting organisms. Foraging activity and pollination effectiveness of *M. bocandei* on flowers were assessed. Results showed that 44 insect species were recorded on the flowers of *C. sesamoides*, with *Meliponula bocandei* being the most frequent floral visitor, accounting for 34.44% of the 1,724 recorded visits. This bee primarily collected nectar and only small quantities of pollen. Activity of the stingless bee started around 6 a.m. and ended around 5 p.m., with a peak of visits between 10 and 11 a.m. Average number of foragers simultaneously active was 246.06 per 1000 flowers. Mean foraging speed was 8.9 flowers per minute. *C. sesamoides* is a highly nectariferous and slightly polliniferous stingless bee plant. Through its pollinating efficiency on *C. sesamoides*, *M. bocandei* increased the fruiting rate, the mean number of seeds per fruit, and the weight of 100 normal seeds by 20.15%, 8.21%, and 4.93%, respectively. However, no significant effect was observed on the germination rate of normal seeds. Therefore, installing stingless bee nests near or within false sesame (*Ceratotheca sesamoides*) fields is recommended to enhance honey production and improve seed yield and quality.

Keywords

Ceratotheca sesamoides, *Meliponula bocandei*, pollination, production, Koumé-Bonis

INTRODUCTION

Pollination is a critical ecosystem service for global food production, food security, and the economy (FAO 2018). Honey bees are considered essential crop pollinators that meet agricultural needs and provide hive products (Chen et al. 2007). Honey bees are currently experiencing dramatic population declines in several regions of the world (Bauer and Wing 2010; Potts et al. 2010; Roubik 1995), prompting the search for locally available alternative pollinators to help ensure food security (FAO 2018). Furthermore, the use of native pollinators, other than honey bees, can be part of a conservation strategy to preserve species diversity in the region where they occur (Nkoba et al. 2022). In Africa, other groups of social bees, such as stingless bees, also live in perennial colonies (Nkoba et al. 2022). They are also frequent floral visitors in both natural ecosystems and agroecosystems (Roubik et al. 1992; Heard et al. 1999; Meléndez et al. 2002) and are recognized as effective pollinators of numerous crop species (Slaa et al. 2006; Eka et al. 2014).
Research on stingless bees as pollinators of food crops is more advanced in South and Central America than in other regions of the world. For example, the pollination efficiency of stingless bee species was demonstrated in crops, such as habanero pepper (*Capsicum chinense*) (Cauich et al. 2006), bell pepper (*Capsicum annuum*) (Oliveira et al. 2005), and tomato (*Solanum lycopersicum*) (Santos Dos et al. 2009). Despite the increasing effort in America and Asia to study stingless bees as pollinators, their pollination effectiveness remains largely unknown for many crops (Cruz et al. 2005; Mélendez et al. 2018). The pollination behavior and efficiency of African stingless bees remain largely unstudied. Stingless bee species are not yet used for crop pollination on the African continent due to knowledge gaps in the domestication of African stingless bee species (Raina et al. 2011). Therefore, this study aimed to gain insights into the foraging behavior and pollination efficiency of *Meliponula bocandei* in relation to false sesame production.

Ceratotheca sesamoides (commonly known as false sesame) is an annual herb native to Africa, found in the wild in most countries south of the Sahara (Josina et al. 1990). It originates from West Africa and grows in fields, fallow lands, and forests (Sinébou et al. 2012). *Ceratotheca sesamoides* is also found in Florida (Josina et al. 1990), Australia, and the Indo-Himalayan region (Ariharan et al. 2014). In Cameroon, the species is mainly found in the North, in Adamaoua and on the South Cameroonian plateau (Josina et al. 1990). This plant is one of the most consumed leafy vegetables in West and Central Africa, due to its dietary, medicinal (Dansi et al. 2012), and cultural (Dansi et al. 2008) virtues. Leaf macerates are traditionally used to treat conjunctivitis and to facilitate childbirth in humans (Noura et al. 2014). The aqueous extract of the leaves is used to treat amoebic dysentery, jaundice, and skin infections (Ariharan et al. 2014). In Burkina Faso, an infusion of the leaves or stem of this Pedaliaceae is used to combat head lice.

The oil extracted from the seeds contains sesamin, a polyphenolic compound with antioxidant, antihypertensive, anti-inflammatory, antitumor, and insecticidal activity (Grubben et al. 2004). This oil can also be used as fuel for diesel engines, reducing environmental pollution (Ariharan et al. 2014).

Despite its attributes, *C. sesamoides* remains in the wild or cultivated on small areas, with low yields (Thiégang and Aissatou 2004). Prior to the present study, the only in-depth investigations of the entomophilous pollination of this plant were those conducted in Dang by Tchuenguem et al. (2018), Djakbé et al. (2020), and Deli et al. (2023). However, to our knowledge, there are no published data on the relationships between *C. sesamoides* and flower-visiting insects in Koumé-Bonis, a locality in East Cameroon. Moreover, the flower-visiting entomofauna and the impact of insects on pollination and plant production can vary with space and time (Roubik

2000; Tchuenguem 2005), hence the need to conduct further studies to complement existing data.

The general aim of this investigation was to contribute to a better understanding of the interactions between *C. sesamoides* and *M. bocandei* in order to promote their optimal management in Cameroon. The specific objectives were to determine the place of that stingless bee in the entomofauna, study its foraging activity on flowers of *C. sesamoides*, determine the meliponicultural value of this plant, evaluate the impact of flower-visiting insects on pod and seed production, and measure the pollinating efficiency of a floral visit of this stingless bee on the Pedaliaceae.

MATERIAL AND METHODS

Study site

The experiments were conducted from 7 to 14 August 2023 and from 15 to 21 August 2024 at Koumé-Bonis (latitude: 4°32′35″ N; longitude: 13°39′21″ E; altitude: 636 m), located in the Bertoua I Subdivision, Lom and Djerem Division, Eastern Region of Cameroon. This region is part of the agro-ecological zone known as the forest zone with a bimodal rainfall pattern. It is located between latitudes 2° and 6° N and longitudes 12° and 16° E, covering an area of 109,002 km² (MINEPAT 2010). The climate is equatorial of the Guinean type, characterized by the alternation of four seasons: a long dry season from mid-November to mid-March; a short rainy season from mid-March to mid-June; a short dry season from mid-June to mid-August; and a long rainy season from mid-August to mid-November (ONACC 2018). The rainfall is relatively abundant, with annual totals ranging from 1,500 to 2,000 mm. Temperatures remain high throughout the year, ranging from a minimum of 18°C to a maximum of 30°C. The average temperature ranges from 23°C to 25°C (ONACC 2018).

Biological materials

The plant material consisted of *C. sesamoides* seeds purchased at "Petit marché de Ngaoundéré". The animal material included *M. bocandei* foragers and other insects naturally present in the environment.

In the experimental station, the number of *M. bocandei* nests recorded was 2 in 2023 and 1 in 2024. The nearest nest to the study area was found approximately 190 meters away.

Methods

Preparation of the experimental plot, sowing, and crop maintenance

An experimental plot of 437 m^2 was delimited, fenced, plowed, and divided into 8 subplots of 8*4.5 m^2 each. The subplots consisted of 8 rows per subplot and 16 planting holes per row. On April 28th, 2023, and May 7th, 2024, ten seeds of *C. sesamoides* were sown per planting hole in all the subplots (Sinébou et al. 2012). The spacing between planting holes was 50 cm, between and within rows (Sinébou et al. 2012). The experimental plot was weeded every two weeks using a hoe to prevent weeds from competing with the germinating seedlings. Three weeks after emergence, thinning was performed, leaving two plants per planting hole. From blooming to pod maturation, weeding was done by hand (Tchuenguem et al. 2018).

Determination of the reproduction mode of *Ceratotheca sesamoides*

For each study year, when the first flowers appeared, 240 floral buds were marked and assigned to two treatments: - treatment X (1 in 2023 or 5 in 2024): 120 flowers left opened and exposed to all visitors (Tchuenguem et al. 2001); - treatment Y (2 in 2023 or 6 in 2024): 120 flowers bagged with gauze mesh of 1 mm^2 to exclude insect visitors (Tchuenguem et al. 2001). After

the fruiting period for each year, the number of fruits developed in both treatments was counted. For each treatment, the fruiting index (Fri) was then calculated using the following formula:

$Fri = Fb/Fa$ (1) where Fa was the number of flowers and Fb the number of formed fruits (Tchuenguem et al. 2001). For each year, the allogamy rate (*Alr*) from which determines the autogamy rate (*Atr*) was communicated as the variation in fruiting indices between treatment X (unprotected flowers) and treatment Y (sacked flowers) (Tchuenguem et al. 2004):

$Atr = (FriX - FriY/FriX) \times 100$ (2) where *FriX* and *FriY* were the fruiting indices in treatments X and Y respectively; $Alr = 100 - Atr$ (3) (Demarly 1977).

Measurement of total sugar concentration in the nectar of *Ceratotheca sesamoides*

The total sugar concentration in the nectar was evaluated using a portable refractometer (range: 0-50% Brix), while the ambient temperature during sampling was taken using a mini thermometer. The nectar content of the flowers was determined by capturing *Apis mellifera* workers actively engaged in nectar collection and then anesthetizing them with chloroform, following the method described by Tchuenguem et al. (2007). Subsequently, gentle pressure was applied to the abdomen of each anesthetized bee to expel nectar from the crop. The extracted nectar was deposited onto the prism of a refractometer, and its total sugar concentration was measured according to the method described by Tchuenguem et al. (2007). The values obtained were corrected according to the ambient temperature using the correction table provided in the refractometer manufacturer's instructions (Tchuenguem et al. 2007). The data were collected during the same dates and time periods used in measuring visit duration (Tchuenguem et al. 2001).

Determination of the position of *Meliponula bocandei* in *Ceratotheca sesamoides* entomofauna

From 7th to 14th August 2023 and from 15th to 21st August 2024, observations were made every day on flowers of treatments 1 and 5, at 6:00–7:00 a.m,, 8:00–9:00 a.m,, 10:00–11:00 a.m,, 12:00 a.m.–1:00 p.m., 2:00–3:00 p.m. and 4:00–5:00 p.m.. For each of these time frames, the different insects encountered on the blooming flowers were recorded (Tchuenguem 2005). Cumulative results were expressed as the number of visits (Tchuenguem et al. 2018). Data on the frequency of visits of the various identified flowering insects made it possible to determine the place of *M. bocandei* in the anthophilous entomofauna of *C. sesamoides*. The frequency of visits of the insect on *C. sesamoides* flowers (*Fi*) was calculated using the following formula:

$Fi = \{[Vi / Vt] * 100\}$ (4)

Where *Vi* is the number of visits for insect i on unprotected flowers and *Vt* the number of visits of all insects on the same flowers (Tchuenguem 2005).

Foraging activity of *Meliponula bocandei* on *Ceratotheca sesamoides* flowers

Floral product harvested

This observation aimed to determine whether *M. bocandei* foragers collected nectar, pollen, or both during their floral visits on *C. sesamoides*. A bee is considered a nectar forager when it inserts its proboscis into the corolla to access floral nectar. In contrast, a forager that actively scraped the anthers using its mandibles or legs was considered a pollen collector (Jean-Prost 1987). The presence of pollen loads in the corbiculae (pollen baskets) on the hind legs further confirmed pollen collection activity (Jean-Prost 1987). For each visit, the type of floral resource harvested was recorded (Tchuenguem et al. 2007).

Duration of visit per flower

This refers to the time a *M. bocandei* worker takes to collect a product (either pollen or nectar) from a flower during a visit (Tchuenguem 2005). The time spent by each *Meliponula bocandei* forager on a flower was recorded using a stopwatch reset to zero at the beginning of each observation, with timing starting upon landing and ending at take-off. The duration of the visit thus corresponds to the value read on the stopwatch (Tchuenguem 2005). This parameter was recorded on the same dates and during the same time intervals as those used to assess the abundance of foragers, with at least five measurements obtained per time interval whenever possible (Tchuenguem et al. 2001).

Rhythm of visits according to the flowering stages

The number of open flowers in the unprotected treatment was counted during the same observation periods used to record the frequency of visits, from the onset of flowering until the last tagged flower had wilted (Tchuenguem 2005). The data obtained were compared with the number of visits of *M. bocandei* on the corresponding flowers (Tchuenguem 2005).

Rhythm of visits according to time frames and observation days

For each year of the study, data on the frequency of floral visits were used for the analysis (Tchuenguem et al. 2001).

Abundances of foragers per flower and per 1000 flowers

It is expressed by the highest number of *M. bocandei* workers simultaneously active per flower and per 1000 opened flowers *(A1000*) (Tchuenguem et al. 2004). The first parameter was recorded by direct counting (Tchuenguem et al. 2004). For the abundance per 1000 flowers, foragers of *M. bocandei* were counted on a known number of opened flowers, and *A1000* was determined utilizing the accompanying equation:

$$A1000 = [(Ax/Fx) * 1000] \quad (5)$$

Where *Fx* and *Ax* were, respectively, the number of flowers and the number of foragers effectively counted on these flowers at time x (Tchuenguem et al. 2004).

The data were recorded on the same dates as the visit duration and according to the six daily time slots (7:00–8:00 a.m,, 9:00–10:00 a.m,, 11:00–12:00 a.m,, 1:00 a.m.–2:00 p.m., 3:00–4:00 p.m. and 5:00–6:00 p.m.), with at least five values for each parameter and per time slot, when the activity of the worker allowed it (Tchuenguem et al. 2001).

Foraging speed (*Fs*)

The foraging speed is the number of flowers visited by a single bee per minute (Jacob-Remacle 1989). Data on foraging speed were collected on the same dates, during the same time intervals, and over the same observation periods as those used for recording the duration of floral visits. The stopwatch, reset before each use, was turned on when an individual bee arrived at a flower and the number of visited flowers was correspondingly counted. The stopwatch was halted when the visitor was out of sight or when it left *C. sesamoides* flowers for another flower. The foraging speed was determined using the following formula:

$$Fs = [(Nf/dv) * 60] \quad (6)$$

Where dv was the time (sec) given by a stopwatch and *Nf* the number of flowers visited during *dv*. During the observation period, when a forager returned to a previously visited flower, it was counted as two distinct flowers (Tchuenguem 2005).

Foraging ecology

The influence of the associated fauna was systematically recorded while measuring the duration of floral visits. Each interrupted visit was marked with a superscript symbol indicating the type

of fauna responsible for the interruption (e.g., honey bees, other Apoidea, other competitors, or predators) (Tchuenguem 2005). The influence of the flora surrounding *C. sesamoides* on the activity of *M. bocandei* at the flowers of this plant was assessed through direct observations: the number of times *M. bocandei* workers switched from a *C. sesamoides* flower to other nearby flowers of other plant species and vice versa was noted (Tchuenguem 2005). During each observation day, temperature and hygrometry were recorded every 30 minutes from 6 am to 6 pm using a portable thermo-hygrometer installed in the shade (Tchuenguem 2005). The effect of wind on the foraging activity of *Meliponula bocandei* was recorded, primarily during the measurement of floral visit duration. The duration of each visit interrupted by wind was marked with a distinctive sign (Tchuenguem 2005).

Estimation of the meliponicultural value of *Cerathoteca sesamoides*

The meliponicultural value of *C. sesamoides* was estimated mainly using data on flowering intensity and the attractiveness to *M. bocandei* workers to nectar and pollen (Tchuenguem et al. 2001).

Assessment of the impact of *Meliponula bocandei* on *Cerathoteca sesamoides* pollination

The impact of *M. bocandei* on pollination was assessed while measuring the duration of visits during nectar or pollen collection: the number of times a forager came into contact with the stigma of the visited flower was noted (Tchuenguem et al. 2001). This approach makes it possible to assess the potential contribution of stingless bees to both self-pollination and cross-pollination (Tchuenguem et al., 2001).

Evaluation of the impact of flowering insects including *Meliponula bocandei* on the production of *Ceratotheca sesamoides*

Along with the implementation of treatments X and Y, 300 flowers at bud stage were labeled to constitute two treatments:

• treatment M (3 or 7): 200 flowers protected using gauze bags, then unprotected, intended to be visited once by *M. bocandei* before being protected again. As soon as each flower bud opened, the gauze bag was carefully removed during the period of peak daily foraging activity. The exposed flower was then observed for 1 to 10 minutes to determine whether it was visited by an individual *M. bocandei* worker. After this operation, the flower was protected again and was no longer handled.

• treatment Z (4 or 8): 100 flowers protected, then uncovered and protected again, without insect or any other organism visits. As soon as each flower bud opened, the gauze bag was carefully removed, and the exposed flower was observed for 1 to 10 minutes while preventing visits by insects or any other flower-visiting organisms. After this operation, the flower was again protected and was no longer handled (Djakbé et al. 2017). One week after fruit set, the bags were removed from all treatment groups. At maturity, the pods were harvested and counted in the different treatments. The mean number of seeds per pod, the percentage of normal (well developed) seeds (Tchuenguem et al. 2009), the weight of 100 seeds and the germination rate of normal seeds were then evaluated for each treatment. The estimation of the impact of flowering insects including *M. bocandei* on the production of *C. sesamoides* was based on the impact of flowering insects on pollination, the impact of pollination on fruiting and the comparison of production (fruiting rate, mean number of seeds per pod, percentage of normal seeds, weight of 100 normal seeds and germination rate of normal seeds) in treatments X, Y and Z. For each year of study, the fruiting rate due to anthophilous insects (*Fri*) is calculated using the formula below:

$$Fri = \{[(Fx - Fz)/Fx + Fy - Fz] *100\} \quad (7)$$

where *Fx*, *Fy* and *Fz* are the fruiting rates in treatments X (unprotected flowers), Y (flowers protected from insects) and Z (flowers protected, then uncovered and protected again, without insect visits or any other organism) respectively (Diguir et al. 2020). For one treatment, the fruiting rate (*Tf*) is:

$$Tf = [b/a] * 100 \quad (8)$$

Where *a* is the number of flowers initially borne and *b* the number of pods formed (Tchuenguem et al. 2001). The mean number of seeds per pod, the percentage of normal seeds, the weight of 100 normal seeds and the germination rate of normal seeds (measured using a JA-203H brand electronic scale with an accuracy of 1/100) attributable to anthophilous insects were calculated using the method as mentioned for the fruiting rate.

Estimation of the pollination efficiency of *Meliponula bocandei* on *Ceratotheca sesamoides*

The contribution of *Meliponula bocandei* to the fruit set, mean number of seeds per pod, percentage of normal seeds, 100-seed weight, and seed germination rate of *C. sesamoides* was assessed using data from treatment M and treatment Z. For each year of study, the fruiting rate due to *M. bocandei* (*Frm*) was calculated using the formula below:

$$Frm = \{[(Fm - Fz) / Fm] * 100\} \quad (9)$$

where *Fm* is the fruiting rate in treatment M (flowers protected, then uncovered, visited once by *M. bocandei*) (Djakbé et al. 2017). The mean number of seeds per pod, the percentage of normal seeds, the weight of 100 normal seeds, and the germination rate of normal seeds due to *M. bocandei* were evaluated using the method mentioned for the fruiting rate.

Data analysis

Data analysis was performed using descriptive statistics to calculate means, standard deviations, and percentages. Inferential statistical tests included analysis of variance (ANOVA, *F*-test) to appreciate differences among multiple group means; Student's t-test for pairwise mean comparisons; chi-square (χ^2) tests to assess two percentages; and Pearson's correlation coefficient (*r*) to examine linear relationships between continuous variables. All statistical computations, as well as the generation of graphs and histograms, were performed using Microsoft Excel 2016. We also used STATGRAPHICS software.

RESULTS AND DISCUSSION

Reproduction mode of *Ceratotheca sesamoides*

The fruiting indexes of *C. sesamoides* were 0.88, 0.54, 0.9 and 0.58 for treatments 1, 2, 5 and 6 respectively. Thus in 2023, the allogamy rate was 38.64 % whereas the autogamy rate was 61.36 %. In 2024, the corresponding figures were 35.56 % and 64.44 %. For the two cumulated years, the allogamy rate was 35.56 % and the autogamy rate was 64.44 %. It appears that *C. sesamoides* has a mixed reproduction mode, allogamous and autogamous, with the predominance of autogamy over allogamy. Our outcome is in accordance with those got by Tchuenguem et al. (2018) who found that at Dang (Ngaoundéré), on the same plant species, autogamy rate (68.06 %) was higher than the allogamy rate (31.93 %).

Total sugar concentration in the nectar of *Ceratotheca sesamoides*

The mean concentration of total sugars in *C. sesamoides* nectar was 34.66% ($n = 45$; $sd = 5.54$) in 2023 and 34.38% ($n = 30$; $sd = 4.38$) in 2024. The difference between these means is not significant ($t = 0.04$; $df = 73$; $P>0.05$). For the two years, the mean concentration for total sugars

in *C. sesamoides* nectar was 34.52%. This value was higher than the range of 5 to 80% reported for several plant species (Philippe 1991), which may explain the greater attractiveness of the flowers of this Pedaliaceae species to *Meliponula bocandei*.

Functional role of *Meliponula bocandei* in *Ceratotheca sesamoides* entomofauna

In total, 44 insect species belonging to twenty families and five orders visiting the *C. sesamoides* flowers were recorded during the two studied periods (**Table 1**). Out of these, twenty-nine species were Hymenoptera (65.91%), eight Lepidoptera (18.18%), four Diptera (9.09%), two Coleoptera (4.55%), and one Hemiptera (2.27%). Amongst the 824 and 900 visits of 28 and 34 insect species recorded on *C. sesamoides* flowers in 2023 and 2024, respectively, *M. bocandei* ranked first, accounting for 30.46 % and 38,00 % of all visits following by *Dactylurina staudingeri* and *Meliponula ferruginea* (**Table 1**). The difference between these two percentages is not significant ($\chi 2 = 1.26$; $df = 1$; $P > 0.05$).

In Dang, Deli et al. (2023) identified 28 insect species visiting *C. sesamoides* flowers, with *Apis mellifera* and *Megachile cincta* being the most frequent visitors. Our findings show higher numbers than these figures. Consequently, the abundance and diversity of flower-visiting insects associated with a plant species may vary among regions (Roubik 2000).

Activity of *Meliponula bocandei* on *Ceratotheca sesamoides* flowers

Floral product harvested

During each flowering period, individuals of *M. bocandei* were found to harvest nectar intensively (**Fig 1a**) while pollen was marginally reaped from *C. sesamoides* flowers (**Fig 1b**). For 264 and 337 visits enrolled in 2023 and 2024, respectively, 209 (79.17%) and 279 (82.79%) were devoted to nectar collection, while 55 (20.83%) and 58 (17.21%) were to pollen harvest. For the two cumulated years, 80.98% of visits were devoted to nectar harvest while 19.02% were devoted to pollen reap. The difference between the two last percentages is highly significant ($\chi 2 = 76.78$ ($df = 1$; $P < 0.001$). This difference may be attributed to the accessibility of the floral resources as well as the nutritional requirements of the colony (Tchuenguem et al. 2009; Tchuenguem et al. 2010).

Actually, *M. bocandei* foragers obtained nectar from flowers by piercing or creating a hole in the flower's corolla or by exploiting existing perforations made by other insects. This enabled the bees to access nectar more easily than pollen, the collection of which required the foragers to come into close contact with the floral reproductive structures. This finding is consistent with that of Nkoba et al. (2022), who reported that *M. bocandei* collected only nectar from greenhouse cucumber (*Cucumis sativus*) flowers.



Fig 1: *Meliponula bocandei* collecting nectar (a) and pollen (b) on *Ceratotheca sesmoides* flowers at Koumé-Bonis in 2023.

Table 1: Insects recorded on *Ceratotheca sesamoides* flowers in 2023 and 2024, number and percentage of visits of different insects.

Insects			**2023**		**2024**		**Total**	
Order	**Family**	**Genus and Species**	***n1***	***p1* (%)**	***n2***	***p2* (%)**	***nt***	***pt* (%)**
Coleoptera	Lycidae	*Lycus latissimus* (ne)	-	-	9	1.00	9	0.52
	Scarabeidae	(gen. sp.) (ne)	6	0.73	-	-	6	0.35
Diptera	Calliphoridae	*Calliphora* sp. (ne)	23	2.79	10	1.11	33	1.91
	Sarcophagidae	*Sarcophaga* sp. (ne)	15	1.82	10	1.11	25	1.45
	Syrphidae	(2 sp.) (ne)	16	1.94	16	1.78	32	1.86
Hemiptera	Alydidae	*Riptortus dentipes* (ne)	11	1.33	-	-	11	0.64
Hymenoptera	Apidae	*Apis mellifera* (ne, po)	27	3.28	15	1.67	42	2.44
		Amegilla acraensis (ne, po)	-	-	10	1.11	10	0.58
		Amegilla callens (ne, po)	-	-	20	2.22	20	1.16
		Amegilla sp. (ne)	10	1.21	10	1.11	20	1.16
		Dactylurina staudingeri (po)	73	8.86	150	16.67	223	12.94
		Meliponula bocandei (ne, po)	251	30.46	342	38.00	593	34.44
		Meliponula ferruginea (ne, po)	129	15.66	73	8.11	202	11.72
		Pachymelus sp. (ne)	6	0.73	-	-	6	0.35
		Xylocopa albiceps (ne)	14	1.70	10	1.11	24	1.39
		Xylocopa inconstans (ne)	13	1.58	-	-	13	0.75
		Xylocopa nigrita (ne)	-	-	5	0.56	5	0.29
		Xylocopa olivacea (ne)	-	-	15	1.67	15	0.87
		Xylocopa sp. (ne)	13	1.58	10	1.11	23	1.33
	Crabronidae	*Philanthus triangulum* (ne)	14	1.70	22	2.44	36	2.09
	Formicidae	*Camponotus* sp. (ne)	-	-	28	3.11	28	1.62
	Halictidae	*Lasioglossum* sp. 1 (ne, po)	30	3.64	15	1.67	45	2.61
		Lasioglossum sp. 2 (ne)	15	1.82	-	-	15	0.87
		Lipotriches collaris (po)	10	1.21	10	1.11	20	1.16
		*Euaspis abdominalis (*ne)	-	-	16	1.78	16	0.93
		Halictus sp. (ne, po)	56	6.80	-	-	56	3.25
		(gen. sp.) (ne, po)	-	-	9	1	9	0.52
	Megachilidae	*Chalicodoma* (sp. 1 and sp. 2) (ne)	-	-	3	0.33	3	0.17
	Vespidae	*Belanogaster juncea* (ne)	10	1.21	10	1.11	20	1.16
		Synagris sp. (ne)	22	2.67	8	0.89	30	1.74
		(gen. sp. 1) (ne)	12	1.46	4	0.44	16	0.93
	Vespoidea*	(3 fam. gen. sp.) (ne)	_-	-	16	1.78	16	0.93
Lepidoptera	Acraeidae	*Acraea* sp. (ne)	18	2.18	18	2	36	2.09
	Erebidae	*Amata amoena* (ne)	12	1.46	-	-	12	0.70
	Hesperiidae	(gen. sp.) (ne)	8	0.97	-	-	8	0.46
	Lycaenidae	(gen. sp.) (ne)	-	-	18	2	18	1.04
	Nymphalidae	*Hypolimnas misippus* (ne)	-	-	8	0.89	8	0.46
		Neptis sp. (ne)	8	0.97	8	0.89	16	0.93
	Papillionidae	(gen. sp.) (ne)	2	0.24	-	-	2	0.12
	Zygenidae	(gen. sp.) (ne)			2	0.22	2	0.12
Total		**Visits**	**824**	**100**	**900**	**100.00**	**1724**	**100.00**
		Species	**28**		**34**		**44**	

n1 and *n2*: number of visits on 120 flowers in 2023 and 2024 respectively; *p1* and *p2*: percentages of visits in 2023 and 2024 respectively; fam.: undetermined family, gen.: undetermined genus, sp.: undetermined species; *p1* = (*n1* / 824) x 100; *p2* = (*n2* / 900) x 100; ne: nectar collection; po: pollen collection; *nt*: total number of visits, *pt*: total percentage of visits.

Duration of visits per flower

The duration of a *M. bocandei* visit to a *C. sesamoides* flower varied according to the floral resource harvested. The mean duration of a visit per flower for nectar harvesting was 6.58 sec (n = 218; sd = 2.22) in 2023 and 6.29 sec (n = 464; sd = 2.41) in 2024. The difference between these two means is not significant (t = 1.50; df = 680; P > 0.05). For the two years, the mean duration of a nectar harvesting visit was 6.44 sec (n = 682; sd = 2.31). The corresponding durations for the pollen harvesting were 43.97 sec in 2023 (n = 82; sd = 19.05) and 29,70 sec in 2024 (n = 92; sd = 10,65). The difference between these last two means was highly significant (t = 6.18; df = 172; P <0.001). For the two years, the mean duration of a pollen harvesting visit was 36.84 sec (n = 174; sd =14.85). The duration of a visit for pollen harvesting was significantly higher than that of nectar in 2023 (t=28.54; df=298; P <0.001) and in 2024 (t=42.33; df=554; P <0.001). This difference seems to be related to how easily the stingless bee can access each floral resource. Nectar, produced at the base of the standard petal in the corolla tube, is readily accessible to the foragers through corolla perforations. In contrast, pollen is produced by anthers situated above the stamen filaments, which are fully covered by the petals, making accessibility by foragers difficult. The duration of visit also depended on floral resource availability, with bees lingering longer on nectar- or pollen-rich flowers (Djakbé et al. 2020).

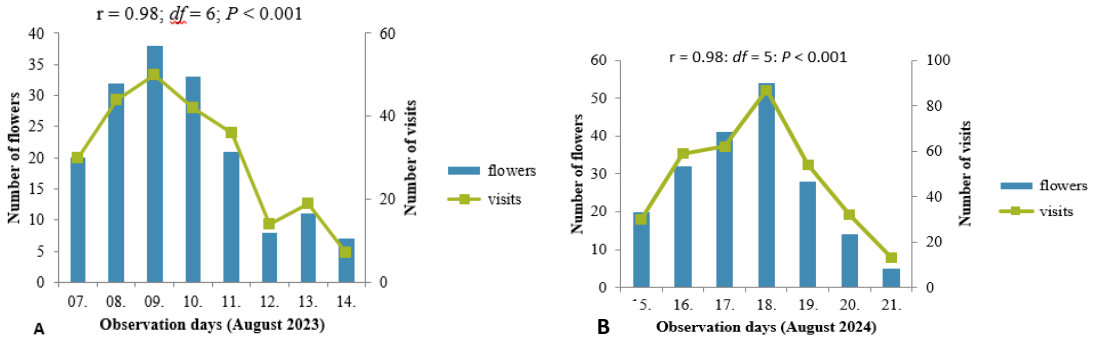
The mean duration for nectar collection was higher than that of 2.97 sec (n = 150; sd = 0.95) recorded by Deli et al. (2023) for the harvesting of nectar by *Megachile cincta*. The difference between the two means was very highly significant (t = 18.06; df = 830; P <0.001). This difference could be explained by the availability of nectar on flowers of this Pedaliaceae.

Rhythm of visits according to the flowering stages

In both 2023 and 2024, *M. bocandei* visits were more frequent when the number of open *C. sesamoides* flowers was higher within the study plots. The correlation between the number of blooming flowers and the number of visits was very highly significant (r = 0.98; df = 6; P < 0,001) for 2023 (**Fig 2, A**), as for 2024 (**Fig 2, B**) (r = 0.98; df = 5; P < 0.001).

These correlations highlight the greater attractiveness of the nectar and/or pollen of *C. sesamoides* towards *M. bocandei* workers.

According to Guérin (2014), flowers emit chemical cues that can be detected by insects from distances of up to approximately 100 m. These stimuli are olfactory substances such as pheromone analogues and taste substances released by flowers. They are detected by the olfactory sensilla located on the palps and antennae of insects (Guérin 2014).



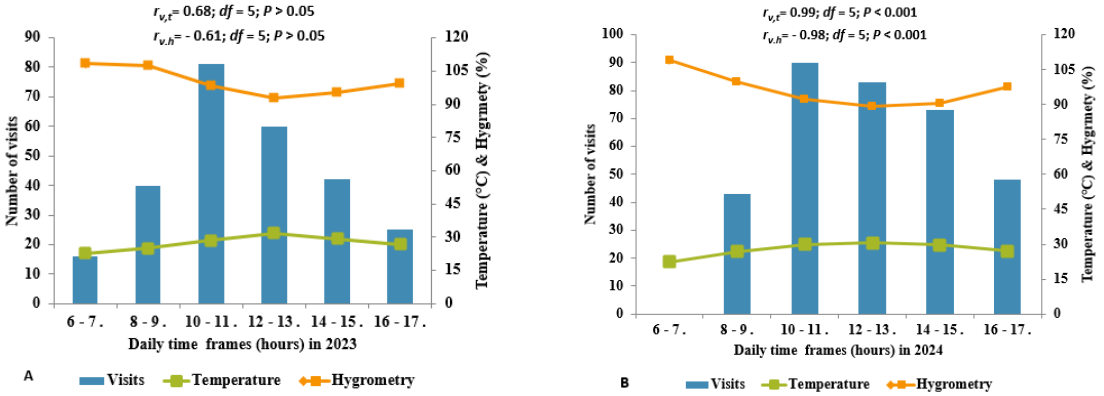
rv,t: Correlation coefficient between the number of visit of *M. bocandei* and the number of blooming flowers; *df*: degrees of freedom; *P*: significance threshold.

Fig 2: Variations in the number of blooming flowers on *Ceratotheca sesamoides* and the number of visits by *Meliponula bocandei* to these organs according to the observation dates in Koumé-Bonis in 2023 (A) and 2024 (B).

Rhythm of visits according to time frames and observation days

Meliponula bocandei was active on *C. sesamoides* flowers from 6 am to 5 pm in 2023 (**Fig 3, A**) and from 8 am to 5 pm in 2024 (**Fig 3, B**) and throughout its blooming period, with a peak of visits between 10 and 11 am in both years.

This figure illustrates the variations in ambient temperature, relative humidity, and the number of visits by *M. bocandei* to *C. sesamoides* flowers across the different daily observation periods.



rv,t: Correlation coefficient between visit frequency of *M. bocandei* and humidity; *df*: degrees of freedom; *P*: significance threshold.

Fig 3: Variations in ambient temperature, atmospheric humidity, and visit frequency of *M. Bocandei* to *C. Sesamoides* flowers according to observation time slots at Koumé-Bonis in 2023 (A) and 2024 (B).

This peak in foraging activity between 10:00 and 11:00 h may be associated with the period of greatest nectar or pollen availability in the flowers of *Ceratotheca sesamoides*.

This figure shows that the correlation between ambient temperature and the number of visits by *M. bocandei* to *C. sesamoides* flowers was not significant in 2023 ($r = 0.68$; $df = 5$; $P > 0.05$), but was very highly significant in 2024 ($r = 0.99$; $df = 5$; $P < 0.001$). A similar pattern was observed for the correlation between the number of *M. bocandei* visits and relative humidity. The correlation was not significant in 2023 ($r = -0.61$; $df = 5$; $P > 0.05$), but was very highly significant in 2024 ($r = -0.99$; $df = 5$; $P < 0.001$).

Abundance of workers per flower and per 1000 flowers

The mean abundance of *M. bocandei* foragers per *C. sesamoides* flower was one in both 2023 and 2024. This low abundance may be attributed to the small diameter of the corolla tube (2.48 cm; $n = 46$; $sd = 0.04$), which may have limited the simultaneous access of more than one forager to a flower (Deli et al. 2023).

The mean abundance per 1000 flowers was 254.58 in 2023 and 237.54 in 2024. The difference between these two means is not significant ($t = 1.39$; $df = 282$; $P > 0.05$). For the two cumulative years, the mean abundance of *M. bocandei* per 1000 flowers of *C. sesamoides* was 246.06 ($n = 224$; $sd = 89{,}09$) (Table 2). This mean abundance is higher than that found by Deli *et al*. (2023) on the same plant species, which was 160.64 ($n = 179$; $sd = 106.58$) individuals of *Megachile cincta* per 1000 flowers ($t = 8.76$; $df = 401$; $P < 0.001$).

The high abundance of *M. bocandei* per 1000 flowers highlights the good attractiveness of the nectar of *C. sesamoides*. Moreover, this high abundance may be attributed to the high total sugar concentration of *Ceratotheca sesamoides* nectar, which averaged 34.52% ($n = 45$, $sd = 4.97$, range = 29.15–46.16%). Indeed, nectar is a very attractive substance for flowering insects (Floriane 2016).

According to Krausa et al. (2017), foragers of *M. bocandei* recruit their nestmates to exploit valuable food sources by using thoracic vibrational signals produced during trophallaxis with their nestmates. These signals activate the foraging force and facilitate the exploitation of food resources (Krausa et al. 2017).

Table 2: Abundance of *Meliponula bocandei* per 1000 flowers of *Ceratotheca sesamoides* in Koumé-Bonis in 2023 and 2024.

Years	**Abundance per 1000 flowers**				
	n	***m***	***sd***	***min***	***max***
2023	107	254.58	60.71	100	450
2024	177	237.54	117.46	20	525
Total	284	246.06	89.09	20	450

n: number of visits studied; *m*: mean; *sd*: standard deviation; *min*: minimum; *max*: maximum

It is well known that foragers of many species of stingless bees guide their nestmates to food sources by means of trail pheromones (Hexyl decanoate, Octyl octanoate) deposited on solid substrates between the food source and the nest (Jarau et al. 2006). Secreted by the labial gland extract of the foragers, these trail pheromones facilitate the recruitment of their nestmates to valuable food sources (Jarau et al. 2006).

Foraging speed

Meliponula bocandei foragers visited between 1 and 23 flowers per minute, with average foraging rates of 7.39 flowers/minute (n=125; sd=3.17) in 2023, 10.41 flowers/minute (n=210; sd=3.50) in 2024, and an average of 8.9 flowers/minute over the two years. The difference between the means of the two years was highly significant ($t = 7.92$; $df = 333$; $P < 0.001$). This difference may be explained by the accessibility and availability of nectar and pollen, the frequency of interruptions during foraging visits, the distance between consecutively visited flowers, and the number of hovering flights performed during foraging.

The foraging speed recorded in the present study differed significantly from that reported by Djakbé et al. (2020), who observed that *Megachile cincta* visited 14.35 flowers per minute ($t = 6.00$; $df = 395$; $P < 0.001$). These differences may be attributed to the availability, accessibility, and type of floral resources harvested from *Ceratotheca sesamoides* flowers, as well as to differences in bee species. Indeed, when the floral product is not easily accessible to the forager, it visits a large number of flowers during a foraging trip to obtain its maximum load of food. According to Potts et al. (2003), insects spend more time on a flower to maximize their nectar intake when nectar is readily accessible and abundant.

Foraging ecology

In 2023 and 2024, out of 231 and 508 *M. bocandei* visits recorded on *C. Sesamoides* flowers, respectively, 45 and 86 were interrupted. The causes of interruption in 2023 included visits by other *M. bocandei* workers (25), *M. ferruginea* workers (10), *Calliphora* sp. (8), and wind (2) In 2024, interruptions were attributed to *M. bocandei* (56), *D. staudingeri* (20), and *Camponotus* sp. (10). Consequently, the frequencies of visit interruptions were 19.48% in 2023, 16.93% in 2024, and 18.20% for both years. The difference between the percentage of visit interruptions in 2023 and 2024 was not significant ($\chi 2 = 0.22$; $df = 1$; $P > 0.05$). Interruptions occurred due to collisions between *M. bocandei* workers and other individuals or when approaching a flower already occupied by another forager. The direct effects of these interruptions on the foraging activity of *M. bocandei* workers included a reduction in the duration of some visits, the loss of part of the pollen load, and an increase in foraging speed. These interruptions forced the affected foragers to visit a greater number of flowers during each foraging trip to maximize their nectar

and/or pollen loads, as also reported by Tchuenguem et al. (2007) for *Apis mellifera* foraging on *Callistemon rigidus* flowers. During the flowering period of *C. sesamoides*, several other flowering plant species in the experimental station were also visited by *M. bocandei* foragers for their nectar and pollen, including *Croton hirtus*, *Sida rhombifolia*, *Bidens pilosa,* and *Tithonia diversifolia*. No transition of *M. bocandei* foragers from *C. Sesamoides* to another plant was observed. The fidelity of this stingless bee to *C. sesamoides* flowers could be partly explained by the fact that its nectar is rich in sugars.

Meliponicultural values of *Ceratotheca sesamoides*

During the flowering period of *C. sesamoides*, *M. bocandei* foragers exhibited intensive foraging activity on its flowers. In particular, *M. bocandei* exhibited a high daily and seasonal frequency of visits, a high abundance of foragers per 1,000 flowers, substantial nectar collection, which was readily accessible to the workers, limited pollen collection, and strong floral constancy during foraging bouts. Furthermore, *Ceratotheca sesamoides* exhibited prolific flowering, with each plant producing between 20 and 120 flowers. In addition, the nectar of *Ceratotheca sesamoides* had a high sugar concentration, averaging 34.52%. These data highlight the high attractiveness of the nectar and the slight attractiveness of the pollen of this plant for *M. bocandei*. Therefore, *C. sesamoides* is a highly nectariferous and slightly polliniferous stingless bee plant. This Pedaliaceae could thus be grown to help stabilize *M. bocandei* colonies and enhance meliponiculture.

Assessment of the impact of *Meliponula bocandei* on *Cerathoteca sesamoides* pollination

When harvesting pollen from *C. sesamoides* flowers, *M. bocandei* workers were frequently in contact with the anthers and stigma. In both 2023 and 2024, all 88 recorded pollen-foraging visits (100%) by *Meliponula bocandei* involved contact with both the anthers and the stigma. In contrast, visits for nectar collection were not accompanied by any contact with the reproductive organs of the flower. The difference between these two percentages is highly significant ($\chi 2 = 200$; $df = 1$; $P < 0.001$). This difference may be explained by the fact that, during all nectar-foraging visits, *Meliponula bocandei* workers obtained nectar by piercing the corolla or by exploiting perforations previously made by other insects, thereby avoiding contact with the anthers and stigma.

Production of *Ceratotheca sesamoides*

The fruit and seed production of *Ceratotheca sesamoides* under the different treatments is presented in Table 3.

Table 3: Fruiting rate, mean number of seeds per pod, percentage of normal seeds, weight of 100 seeds and germination rate in the different treatments of *Ceratotheca sesamoides* in 2023 and 2024 at Koumé-Bonis.

Treatments	Years	NFS	NPF	FR (%)	Number of seeds/pod		TNS	NNS	% NS	SW_{100} (g)	GR(%)
					m	*sd*					
1 (UF)	**2023**	120	105	87.50	54.04	12.77	5350	5037	94.15	0.166	72
2 (PF)		120	65	54.17	45.34	9.27	1859	1635	85.00	0.145	58
3 (FPVM)		150	114	77.00	49.49	7.71	5642	5198	92.13	0.158	45
4 (FPWV)		100	64	64.00	45.42	7.62	2963	2646	85.72	0.150	44
5 (UF)	**2024**	120	108	90.00	53.17	12.14	5264	4866	92.44	0.178	88
6 (PF)		120	70	58.33	46.00	10.19	2070	1656	80.00	0.158	77
7 (FPVM)		155	122	78.71	50.28	10.21	4777	4064	85.07	0.167	86
8 (FPWV)		100	60	60.00	46.16	9.60	3244	2695	80.15	0.159	83

NFS: number of flowers studied; NPF: number of pods formed; FR: fruiting rate; *m*: mean; *sd*: standard deviation; TNS: total number of seeds; NNS: number of normal seeds; % NS: percentage of normal seeds; SW: 100-normal seed weight; GR: germination rate of 100 normal seeds; UF: unprotected flowers; PF: protected flowers, excluding all floral visitors; FPVM: flowers protected, then uncovered, visited once by *Meliponula bocandei* and protected again; FPWV: flowers protected then uncovered and protected again, without visits from insects or any other organism

This table shows that:
(a) the fruiting rates were 87.50 %, 54.17 %, 77 %, 64 %, 90 %, 58.33 %, 78.71 % et 60 % in treatments 1 to 8, respectively. Overall, the differences among these percentages were highly significant ($\chi^2 = 217.02$, $df = 7$, $P < 0.001$). The two to two comparisons show that the difference observed is highly significant between treatments 1 and 2 ($\chi^2 = 26.89$; $df = 1$; $P < 0.001$), 5 and 6 ($\chi^2 = 26.17$; $df = 1$; $P < 0.001$), then 7 and 8 ($\chi 2 = 8.24$; $df = 1$; $P < 0.01$) and significant between treatments 3 and 4 ($\chi^2 = 4.01$; $df = 1$; $P < 0.05$).

(b) The mean numbers of seeds per pod were 54.04, 45.34, 49.49, 45.42, 53.17, 46.00, 50.28, and 46.16 for treatments 1 to 8, respectively. Overall, the differences among these means were highly significant ($F = 7.79$, $df1 = 7$, $df2 = 618$, $P < 0.001$). The two to two comparisons show that the difference observed is highly significant between treatments 1 and 2 ($t = 4.49$; $df = 138$; $P < 0.001$) and 5 and 6 ($t = 3.45$; $df = 142$; $P < 0.001$) significant between treatments 3 and 4 ($t = 2.66$; $df = 176$; $P < 0.05$), then 7 and 8 ($t = 2,08$; $df = 162$; $P < 0.05$).

(c) The percentages of normal seeds were 94.15 %, 85 %, 92.13 %, 85.72 %, 92.44 %, 80 %, 85.07%, and 80.15% in treatments 1 to 8 respectively. Overall, the differences among these percentages were highly significant ($\chi^2 = 352.95$, $df = 7$, $P < 0.001$). The two to two comparisons show that the difference observed is significant between treatments 1 and 2 ($\chi 2 = 4,48$; $df = 1$; $P < 0.05$), then 5 and 6 ($\chi 2 = 6.51$; $df = 1$; $P < 0.05$) and not significant between treatments 3 and 4 ($\chi 2 = 2.09$; $df = 1$; $P > 0.05$), then 7 and 8 ($\chi 2 = 0.84$; $df = 1$; $P > 0.05$).

(d) the mean weights of 100 normal seeds were 0.166 g, 0.145 g, 0.158 g, 0.150 g, 0.178 g, 0.158 g, 0.167 g and 0.159 g in treatments 1 to 8, respectively. The difference between these eight means is highly significant ($F = 25.30$; $df1 = 7$; $df2 = 238$; $P < 0.001$. The two to two comparisons show that the difference observed is highly significant between treatments 1 and 2 ($t = 6.68$; $df = 62$; $P < 0.001$), 5 and 6 ($t = 6.87$; $df = 59$; $P < 0.001$), 7 and 8 ($t = 3.47$; $df = 59$; $P < 0.001$), and significant between treatments 3 and 4 ($t = 2.28$; $df = 58$; $P < 0.05$).

(e) The germination rates of normal seeds were 72%, 58%, 45%, 44%, 88%, 77%, 86% and 83% in treatments 1 to 8, respectively. Overall, the differences among these percentages were highly significant ($\chi^2 = 260.99$; $df = 7$; $P < 0.001$). The two to two comparisons show that the difference observed is significant between treatments 1 and 2 ($\chi 2 = 4.31$; $df = 1$; $P < 0.05$), 5 and 6 ($\chi 2 = 4.19$; $df = 1$; $P < 0.05$), and not significant between treatments 3 and 4 ($\chi 2 = 0.02$; $df = 1$; $P > 0.05$), then 7 and 8 ($\chi 2 = 0.34$; $df = 1$; $P > 0,05$).

In summary, the unprotected flower treatments generally resulted in higher fruiting rates, greater mean numbers of seeds per pod, higher percentages of normal seeds, greater mean weight of 100 normal seeds, and higher germination rates of normal seeds than those of the protected flower treatments. Besides, the treatments in which flowers received a single visit by *Meliponula bocandei* generally resulted in higher fruiting rates, greater mean numbers of seeds per pod, and greater mean weight of 100 normal seeds than the treatments in which flowers were protected, temporarily uncovered, and then re-protected without being visited by insects or any other organisms.

Impact of flower-visiting insects including *M. bocandei* on *Cerathoteca sesamoides* production

In 2023, the contributions of flower-visiting insects, including *M. bocandei*, to the fruiting rate, mean number of seeds per pod, percentage of normal seeds, mean weight of 100 normal seeds, and germination rate of normal seeds of *C. sesamoides* were 30.26%, 15.97%, 9.02%, 9.94%, and 32.56%, respectively.

In 2024, the fruiting rate, percentage of average number of seeds per pod, percentage of normal seeds, percentage of average weight of 100 normal seeds, and germination rate of normal seeds due to flower-visiting insects including *M. bocandei* were 33.96%, 13.22%, 13.32%, 10.73%, and 6.09%, respectively.

For the two years combined, the numerical contribution of flower-visiting insects, including *M. bocandei,* to the fruiting rate, percentage of average number of seeds per pod, percentage of normal seeds, percentage of average weight of 100 normal seeds, and germination rate of normal seeds was 32.11%, 14.60%, 11.17%, 10.34%, and 19.33%, respectively.

The positive contribution of anthophilous insects, including *M. bocandei,* to the improvement of fruit and seed production of *C. sesamoides* can be explained by the action of insects on the pollination of exploited flowers.

The fruiting rate and mean number of seeds per pod attributable to anthophilous insects on *Ceratotheca sesamoides* were lower than those reported by Deli et al. (2023) for the same plant species, who recorded corresponding values of 31.75% and 18.74%, respectively. This difference may be explained by the fact that, although we recorded a greater number of insect species (44) than Deli et al. (2023) (18 species), 35 of these species collected nectar exclusively and therefore did not make contact with the stigma, resulting in a limited contribution to pollination.

Pollination efficiency of a single visit by *Meliponula bocandei* on *Ceratotheca sesamoides*

In 2023, the contributions of *M. bocandei* to the fruiting rate, mean number of seeds per pod, and mean weight of 100 normal seeds of *C. sesamoides* were 16.53%, 8.22%, and 5.06%, respectively.

In 2024, the contributions of *M. bocandei* to the fruiting rate, mean number of seeds per pod, and mean weight of 100 seeds of *C. sesamoides* were 23.77%, 8.19%, and 4.79%, respectively.

For the two years combined, the contributions of *M. bocandei* to the fruiting rate, mean number of seeds per pod, and mean weight of 100 normal seeds of *C. sesamoides* were 20.15%, 8.21%, and 4.93%, respectively. Deli et al. (2023) found that *M. cincta* increased the fruiting rate by 21.22 %, the mean number of seeds per pod by 20.61%, and the percentage of normal seeds by 6.47% in the even Pedaliaceae. Regarding these figures, this contribution is higher than that recorded during our investigations. This difference could be explained by differences in the foraging strategies of these two bee species. Indeed, our investigations on visit effectiveness revealed a low frequency of stigmatic contacts over the two years, with only 34.75% of 305 visits, whereas the aforementioned authors reported a frequency of 92.56%. This discrepancy accounts for the lower contributions we observed compared to their findings. Nkoba et al. (2022) reported that in Kenya, on cucumber flowers, *M. bocandei* was associated with the best fruit quality. This was reflected by an increase of the fruit weight and the seed germination rate close to 90%.

The increase in the reproductive output of *C. sesamoides* attributable to the pollination efficiency of *M. bocandei* may be explained by the deposition of large quantities of pollen on the stigma (Pashte et al. 2015). Moreover, stingless bees are known to enhance pollination

efficiency by increasing auxin concentrations in developing fruits, thereby promoting fruit development (Wietzke et al. 2018).

CONCLUSION

At Koumé-Bonis, among 44 species of insects recorded on the flowers of *C. sesamoides*, *M. bocandei* ranked first with 34.44% of 1724 visits. The workers of this stingless bee collected more nectar than pollen from this Pedaliaceae. The foraging activity of *Meliponula bocandei* on *Ceratotheca sesamoides* flowers began at approximately 6:00 a.m. and ended around 5:00 p.m., with a peak in visitation occurring between 10:00 a.m. and 11:00 a.m. *Ceratotheca sesamoides* is a highly nectariferous and slightly polliniferous plant for stingless bees. Flower-visiting insects, including *M. bocandei*, greatly increase the pollination possibilities of *C. sesamoides*. Through the pollination efficiency of a single floral visit, *Meliponula bocandei* increased the fruiting rate, mean number of seeds per pod, and mean weight of 100 normal seeds of *Ceratotheca sesamoides* by 20.15%, 8.21%, and 4.93%, respectively. The cultivation of false sesame in this area is recommended to promote meliponiculture. The conservation of *M. bocandei* nests near *C. sesamoides* crops is recommended to improve fruit and seed production of this Pedaliaceae.

Author contributions This manuscript was prepared through a collective effort between the listed co-authors; all the listed authors contributed to the research design, collection of data, data analysis, literature review, and revision of the manuscript. All the listed authors played a significant role in completing this manuscript.

Funding No funding was received for conducting this study.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethics approval and consent to participate Not applicable to this manuscript.

Consent for publication All authors have read the final manuscript approved the submission

Competing interests The authors declare no competing interests.

Clinical trial Not applicable

References

Ariharan VN, Meena DVN, Prasad PN (2014) False sesame (*Ceratotheca sesamoides*) oil: a potential biodiesel source, J Chem Pharm Res 6(2):284–287

Bauer DM, Wing IS (2010) Economic consequences of pollinator declines: A synthesis. Agric Resour Econ Re 39(3):368-383. https://doi.org/10.1017/S1068280500007371

Cahuich O, Quezada-Euan JJG, Meléndez RV, Valdovinos NO, Moo-Valle H (2006) Pollination of habanero pepper (*Capsicum chinense*) and production in enclosures using stingless bee *Nannotrigona perilampoides*. J Apic Res 45:125-130

Chen YP, Siede R (2007) Honey bee viruses. Adv Virus Res 70:33–80. https://doi.org/10.1016/S0065-3527(07)70002-7

Cruz DO, Freitas BM, Silva LA, Silva SEM, Bomfim IGA (2005) Use of the stingless bee *Melipona subnitida* to pollinate sweet pepper (*Capsicum annuum* L.) flowers in greenhouse. Pesquisa Agropecuária Brasileira 40:1197–1201

Dansi A, Adjatin A, Adoukonou-Sagbadja H, Adéoti K, Faladé V, Yédomonhan P, Vodouhè R, Agbangla C, Sanni A, Akouegninou A, Akpagana K (2008) Biodiversité des légumes-feuilles traditionnels consommés au Bénin. Sci. World J (1):1–19

Dansi A, Vodouhé R, Azokpota P, Yedomonhan H, Assogba P, Adjatin A, Loko YL, Dossou-Aminon I, Akpagana K (2012) Diversity of the neglected and underutilized crop species of importance in Benin. Sci. World J (1):1–19

Deli KP, Adamou M, Tchuenguem FF-N (2023) Pollination efficiency of *Megachile cincta* (Megachilidae) and its impact on the production of pods and seeds of *Ceratotheca sesamoides* (Pedaliaceae) in Dang (Ngaoundéré, Cameroon). J Chem Biol Phys Sci 13(2):247–266. https://DOI:10.24214/jcbps.B.13.2.24766

Diguir BB, Pando BJ, Fameni TS, Tchuenguem FF-N (2020) Pollination efficiency of *Dactylurina staudingeri* (Hymenoptera: Apidae) on *Vernonia amygdalina* (Asteraceae) florets at Dang (Ngaoundéré, Cameroon). Int J Res Stu 6(2):22–31

Djakbé JD, Ngakou A, Wékéré C, Faibawa E, Tchuenguem FF-N (2017) Pollination and yield components of *Physalis minima* (Solanaceae) as affected by the foraging activity of *Apis mellifera* (Hymenoptera: Apidae) and compost at Dang (Ngaoundéré - Cameroon). Int J Agron & Agric Res 11(3):43–60

Djakbé JD, Wékéré C, Djonwangwé D, Tchuenguem FF-N (2020) Impact of single visit of *Chalicodoma cincta* Fabricius, 1871 (Hymenoptera: Megachilidae) on *Ceratotheca sesamoides* Endlicher, 1832 (Pedaliaceae) flowers at Ngaoundéré (Cameroon). J Chem Biol Phys Sci 10(4):687–696

Eka PR, Dana PA, Kinasih I (2014) Application of Asiatic honey bees (*Apis cerana*) and stingless bees (*Trigona laeviceps*) as pollinator agents of hot pepper (*Capsicum annuum* L.) at local Indonesia farm system. Psyche 1–5. http://dx.doi.org/10.1155/2014/687979

Floriane F (2016) Influence des interactions entre espèces végétales sur les relations plantes - pollinisateurs : cas de la compétition induite par la présence d'espèces anémophiles sur l'attractivité aux pollinisateurs d'espèces entomophiles. Thèse de Doctorat/Ph.D, Université Pierre et Marie Curie, Paris, France

Food and Agriculture Organization (2018) Why Bees Matter: The importance of bees and other pollinators for food and agriculture. Rome

Grubben GJH, Denton OA (2004) *Plant Resources of Tropical Africa 2* : Vegetables. PROTA Foundation / CTA, Wageningen.

Guérin M (2014) Attractivité des plantes pour les auxiliaires : synthèse sur les interactions plantes/insectes. Institut technique de l'agriculture biologique

Heard TA (1999) The role of stingless bees in crop pollination. Annu Rev of Entomol 44:183–206

Jacob-Remacle A (1989) Comportement de butinage de l'abeille domestique et des abeilles sauvages dans des vergers de pommiers en Belgique. Apidologie 20(4):271–285

Jarau S, Schulz C, Hrncir M, Francke W, Zucchi R, Barth FG, Ayasse M (2006) Hexyl decanoate, the first trail pheromone compound identified in a stingless bee, *Trigona recursa*. J Chem Ecol 32:1555–1564

Jean-Prost P (1987) *Apiculture : connaître l'abeille - conduire le rucher*. (6th ed.). Lavoisier, Paris, France

Josina MCS (1990) Légumes traditionnels du Cameroun, une étude agro-botanique. Thèse de Doctorat/Ph.D, Université de Waginegen.

Krausa K, Hager FA, Niatoko N, Kirchner WH (2017) Vibrational signals of African stingless bees. Insect. Soc 64:415–424. https://DOI:10.1007/s00040-017-0564-9

Meléndez RV, Ayala R, Delfın Gonzalez H (2018) Crop pollination by stingless bees. In: Vit P., Pedro S, Roubik D. (Eds.), Pot-pollen in stingless bee melittology. Springer, pp 139–153. https://doi.org/10.1007/978-3-319-61839-5_11

Meléndez RV, Maga~na RS, Parra TV, Ayala R, Navarro J (2002) Diversity of native bee visitor of cucurbita crops (Cucurbitaceae) in Yucatan, Mexico. J Insect Conserv 6(3):135–147. https://doi.org/10.1023/A:1023219920798

Meyer S, Reb C, Bosdeveix R (2008) Botanique, biologie et physiologie végétale. Méloine.

MINEPAT (2010) Rapport régional de progrès des objectifs du millénaire pour le développement. Région de l'Est, Cameroun.

Nkoba K, Maria IP, Annette VO, Maurice M, Kika J, Wäckers F, Langevelde FV, Hundt B, Jaramillo J (2022) African endemic stingless bees as an efficient alternative pollinator to honey bees in greenhouse cucumber (*Cucumis sativus* L.), J Apic Res 62(5):1017–1029. DOI: 10.1080/00218839.2021.2013421

Nura S, Adamu AK, Mu'Azu S, Dangora DB, Shehu K, Mahamud FM, Mansur K (2014) Assessment of the growth responses of sesame (*Sesamum indicum* L.) and false sesame (*Ceratotheca sesamoides* Endlicher) to Colchicine treatments. Am J Exp Agric 4(8):902–912.

Oliveira CD de, Freitas BM, Da Silva LA, Sarmento da SEM, Abrahão BIG (2005) Pollination efficiency of the stingless bee *Melipona subnitida* on greenhouse sweet pepper. Pesquisas Agropecuria Brasileira, Brasilia 40:1197–1201.

ONACC (2018) Pluviométrie et température au Cameroun. Analyse de la pluviométrie et de températures pour la période allant de 1950 à 2015 et projection à l'horizon 2090 : Cas de la région de l'Est, Cameroun

Pashte VV, Shylesha AN, Badge AS (2015) Effect of honey bee pollination, bee attractants and scents on yield of Sesamum. Int J Ecol Environm Sci 41(2):87–93

Philippe JM (1991) La pollinisation par les abeilles : pose des colonies dans les cultures en floraison en vue d'accroître les rendements des productions végétales. éd. Edisud, Aix-en-Provence, France ISBN : 2-85744-514-4

Potts GS, Vulliamy B, Dafni A, Ne'eman G, Willmer P (2003) Linking bees and flowers: how do flower communities structure pollinator communities? Ecology 84(10):2628–2642.

Potts SG, Roberts SPM, Dean R, Marris G, Brown MA, Jones R, Neumann P, Settele J (2010) Declines of managed honey bees and beekeepers in Europe. J Apic Res 49(1):15–22. https://doi.org/10.3896/IBRA.1.49.1.02

Radovića A, Nikolić D, Milatović D, Zivković & Stevanović NB (2017) The effect of plant hormones on pollen germination and pollen tube growth of almond cultivars. Acta Horticulturae 1(39):375–379.

Raina SK, Kioko E, Zethner O, Wren S (2011) Forest habitat conservation in Africa using commercially important insects. Annu Rev Entomol 56:465–485. https://doi.org/10.1146/annurev-ento-120709-144805

Roubik WD (1992) Ecology and natural history of tropical bees. Cambridge University Press, New York, USA.

Roubik WD (1995) Pollination of cultivated plants in the tropics: Stingless bee colonies for pollination. FAO Agricultural Services Bulletin.

Roubik WD (2000) Pollination system stability in tropical America. Conserv Biol 14(5):1235–1236. https://doi.org/1046/j.1523-1739.2000.99436.x

Santos SAB dos, Roselino AC, Hrncir M, Bego LR (2009) Pollination of tomatoes by the stingless bee *Melipona quadrifasciata* and the honey bee *Apis mellifera* (Hymenoptera, Apidae). Genet Mol Res 8:751–757.

Savadogo S, Sambare O, Sereme A, Thiombiano A (2016) Méthodes traditionnelles de lutte contre les insectes et les tiques chez les Mosée au Burkina Fasso. J Appl Biosci 105:10120–10133.

Sinébou V, Ahoton LE, Ahohuendo BC, Etèka CA, Amadji G, Dansi A, Ahanchédé A, Hounhouigan DJ, Vodouhè RS, Sanni A (2012**)** Biologie florale de *Ceratotheca sesamoides* Endlicher, un légume feuille traditionnel en voie de domestication au Bénin. J Appl Biosci 58:4251–4261.

Slaa EJ, Sanchez CLA, Malagodi BKS, Hofstede FE (2006) Stingless bees in applied pollination: practice and perspectives. Apidologie 37:293–315.

Tchiégang C, Aissatou K (2004) Données éthno-nutritionnelles et caractéristiques physico-chimiques des légumes-feuilles consommés dans la savane de l'Adamaoua (Cameroun). Tropicultura 22(1):11–18.

Tchuenguem FF-N (2005) Activité de butinage et de pollinisation de *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae, Apinae) sur les fleurs de trois plantes à Ngaoundéré (Cameroun): *Callistemon rigidus* (Myrtaceae), *Syzygium guineense* var. *macrocarpum* (Myrtaceae) et *Voacanga africana* (Apocynaceae). Thèse de Doctorat d'Etat, Université de Yaoundé I.

Tchuenguem FF-N, Djakbé JD, Ngakou A, Wékéré C, Louabe S, Faïbawa E (2018) Impact de l'activité de butinage de *Apis mellifera* Linné (Hymenoptera: Apidae) sur la pollinisation et les rendements de *Ceratotheca sesamoides* Endlicher (Pedaliaceae) à Dang (Ngaoundéré, Cameroun). Cameroon J Exp Biol 2(1):22–31. https://doi.org/10.4314/cajeb.v12i1.3

Tchuenguem FF-N, Djonwangwé D, Messi J, Brückner D (2009) Activité de butinage et de pollinisation de *Apis mellifera adansonii* Latreille (Hymenoptera: Apidae, Apinae) sur les fleurs de *Helianthus annuus* (Asteraceae) à Ngaoundéré (Cameroun). Cameroon J Exp Biol 5(1):1–9. https://doi.org/10.4314/cajeb.v5i1.44442

Tchuenguem FF-N, Djonwangwé D, Messi J, Brückner D. (2007) Exploitation des fleurs de *Entada africana*, *Eucalyptus camaldulensis*, *Psidium guajava* et *Trichilia emetica* par *Apis mellifera adansonii* à Dang (Ngaoundéré, Cameroun). Cameroon J Exp Biol 3:50–60. https://doi.org/10.4314/cajeb.v3i1.52612

Tchuenguem FF-N, Fameni TS, Pharaon MA, Messi J, Brückner D. (2010) Foraging behavior of *Apis mellifera adansonii* (Hymenoptera: Apidae) on *Combretum nigricans, Erythrina sigmoidea, Lannea kerstingii* and *Vernonia amygdalina* flowers at Dang (Ngaoundéré, Cameroon). Int J Trop Ins Sci 30(1):40–47. https://doi.org/10.1017/S1742758409990484

Tchuenguem FF-N, Messi J, Brückner D, Mbofung G, Hentchoya JH (2004) Foraging and pollination behaviour of *Apis mellifera adansonii* on *Callistemon rigidus* flowers at Ngaoundéré (Cameroon). J Cameroon Acad Sci 4(2):133–140.

Tchuenguem FF-N, Messi J, Pauly A (2001) Activité *de Meliponula erythra* sur les fleurs de *Dacryodes edulis* et son impact sur la fructification. *Fruits* 56:179–188. https://doi.org/10.1051/fruits:2001121