

Research Article

# Diversity, Abundance and the Community Structure of the Flower-Visiting Insects on *Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae) in Bilone (Obala-Cameroon)

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## Abstract

In order to identify flower-visiting insects on sesame plants and characterize the community structure, ecological survey was conducted in Bilone agroecological farm in 2022 and 2023, in 15 experimental plots (6x5.5 m each) each year, created in a 1,600 m<sup>2</sup> area. Insects were captured, stored in papillotes (Lepidoptera) or in vials containing 70 °alcohol (other adults) and identified at the species level in laboratory. A total of 1,703 specimens were captured. They belonged to five orders, 12 families, 18 genera and 19 species. Hymenoptera was mostly collected order (91.5%) followed by Diptera (4.5%), Lepidoptera (1.8%), Neuroptera (0.9%) and Orthoptera (1.3%). Apidae was the most collected family (42.4%) followed by Formicidae (34.1%), Megachilidae (11.6%) while other families were rare: Acrididae (1.3%), Ascalapidae (0.9%), Calliphoridae (0.5%), Eumenidae (0.7%), Halictidae (2.2%), Muscidae (4.0%), Nymphalidae (1.3%), Pieridae (0.5%), and Vespidae (0.6%). *Apis mellifera adansonii* (Apidae: 30.6%) was the most recorded species, followed by *Paratrechina longicornis* (Formicidae: 12.3%), *Pheidole megacephala* (Formicidae: 9.4%), *Myrmicanioa opaciventris* (Formicidae: 8.9%), *Megachile cincta* (Megachilidae: 7.0%), *Amegilla calens* (Apidae: 6.2%), *Xylocopa olivacea* (Apidae: 5.6%), *Megachile kamerunensis* (Megachilidae: 4.6%), *Musca domestica* (Diptera: 4.0%), *Camponotus maculatus* (Formicidae: 3.65%), *Lasioglossum hancocki* (Halictidae: 2.2%), and *Pteropera carnapi* (Acrididae: 1.3%). *Calliphora vicina* (Calliphoridae) was recorded exclusively in 2022. Two exotic Diptera (*Cl. vicina* and *Mu. domestica*) were myiasigenic species. The exotic Eumenidae *Delta* sp. and the afrotropical predator *Ascalaphus africanus* (Ascalapidae) were recorded as well as the phytophagous Acrididae *Pe. carnapi*. Potential pests (Nymphalidae, Pieridae and Acrididae) cumulatively represented 3.1% of the collection. The community was highly diversified

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**Received:** 12 December 2024; **Accepted:** 24 December 2024; **Published:** 21 January 2025



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and lowly dominated by a few species. *Ca. maculatus* was simply abundant in 2023. *Amegilla calens*, *Ap. mellifera adansonii*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Ph. megacephala* and *Xy. olivacea* were simply abundant. *Amegilla calens* and *Me. cincta*, were co-dominants in 2022. *Ca. maculatus* and *Me. kamerunensis* were co-dominants in 2023. *Apis mellifera adansonii*, *Pa. longicornis*, *Ph. megacephala*, *My. opaciventris* and *Xy. olivacea* were co-dominants in each year. *Ca. maculatus* and *Cl. vicina* were rare in 2022. *Bicyclus dorothea* (Nymphalidae), *Delta* sp. and *La. hancocki* were rare in 2023. *Acraea acerata* (Nymphalidae), *Ascalaphus africanus* (Ascalapidae), *Catopsilia florella* (Pieridae), *Pteropera carnapi* (Acrididae) and *Synagris conuta* (Vespidae) were rare. High value of Motomura constant ( $m=0.777$  in 2022) and Preston constant ( $m=0.726$  in 2023) suggested least evolved pioneer assemblages with species competition limited to the physical space. Overall, flower visiting insects exhibited a global positive net association.

## Keywords

Assemblage Composition, Co-Dominant Species, Rare Species, Theoretical Model, Assemblage Functioning, Sesame Plants

## 1. Introduction

*Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae) is an annual herbaceous plant and one of the most cultivated oilseed crops. It is native to Asia (India) and some African countries and was cultivated for over 4,300 years in Babylon and Assyria [1, 2]. It belongs to the division Tracheophyta, class Magnoliopsida, order Scrophulariales or Lamiales, family Pedaliaceae and genus *Sesamum* [3]. According to the Integrated Taxonomic Information System website [3], this genus includes in Africa, three known cultivated valid species: *Se. alatum* Thonn. native to the dry zone of Africa from Western Sahara to Egypt and south to KwaZulu-Natal in South Africa [4], *Se. indicum* L. native to India, and *Sesamum radiatum* Schumacher and Thonn, native to the west and central Africa [5]. *Se. indicum* is mainly grown in tropical and sub-tropical regions of Asia, Africa and South America with a wide diversity of genotypes [6-8]. The plant is erect (0.5-2.5 m tall in optimal growing conditions, presents green stem, rarely purple, basal diameter: one to three centimeters). Upper leaves are lanceolate, while lower leaves are trilobed (7.5-12.7 cm long). The plant can be glabrous, velvety or hairy, the hairy aspect of the stem and branches being used as grouping factor of varieties [9]. The lower leaves are opposite, broad (12 x 8 cm), roughly lobed and with a long petiole (about five centimeters) while the upper leaves are alternate or sub-opposite, or narrow (9 x 2 cm), with a particular phyllotaxis [6, 9]. The leaves are dull green with hairs and stomata on both sides [6]. Zygomorphic flowers (bisexual and then hermaphrodite) with pendulous tubular corolla (3-4 mm in length) and coloring of various shades of purple white (mostly white or pink) hang down from the stem and they can self-pollinate [10]. Flowers occur singly or in groups of two to three in the leaf axils, the androecium consists of four stamens (two long of 1.5-2.0 mm each and two short of 1.0-1.5 mm each) and the gynoecium has superior ovary, multicarpelar and a long style (1.5-2.0 mm) with bifid stigma [10]. The flower produces nectar in a nectary disk surrounding the ovary and in a couple of extrafloral nectaries on both sides of

the pedicel. Anthesis occurs early in the morning when the stigma becomes receptive and senescence can occur six to 12 hours later, depending on the variety and environmental conditions [10]. According the same authors these characteristics of floral biology refer to varieties cultivated especially in warm weather environments, but there is evidence that varieties adapted to tropical conditions behave differently. The genus *Sesamum* includes many varieties which differ in their dimensions, shape, and type of growth, color of flowers, size, color and composition of seeds [11]. The species *Se. indicum* (synonyms: *Se. orientale* Sieber ex C. Presl, 1828, *Se. edule* Steud. (1821), *Se. luteum* Retz., 1791, *Se. oleiferum* Moench, 1802, *Se. africanum* Tod, *Se. foetidum* Afzel. ex Engl.) is presently cultivated in 65 countries across Asia, Africa, Europe, Central and South America [11]. From 2012 to 2016, the global world sesame production was estimated at 12.22 million tons [12] and it was estimated in 2021 at 1,150,714 thousand tons, with the yield of 390 kg.ha<sup>-1</sup> [10, 13]. Asia and Africa hold about 90% of the planted area, Egypt, Central Africa, Israel, Peru, Saudi Arabia and Macedonia being the main producing countries of oil crops [10, 13]. The sesame production ranks 9<sup>th</sup> among the 13 main oilseed crops (90% of global edible oil production in the world) [12, 14]. Global production of sesame seeds was estimated in 2021 by the Food and Agricultural Organization (FAO) at about 6,667,344 tons grown on 12,965,045 ha with an average yield of about 514 kg.ha<sup>-1</sup> [15]. According to the same source of information, in 2022, it was estimated at about 6,741,479 tons grown on 12,836,776 ha with an average yield of about 525 kg.ha<sup>-1</sup>. Which showed in 2021 and 2022, a global decrease in cultivated area of about 128,269 ha, an increase in overall production of 74,136 tons and in the yield production of about 11 kg. ha<sup>-1</sup>. In terms of overall production in 2021, Africa occupied the 1<sup>st</sup> position (3,997,094 tons grown on 8,417,309 ha) followed in the 2<sup>nd</sup> position by Asia (about 2,389,914 tons grown on 4,060,409 ha), the 3<sup>rd</sup> position was occupied by Americas (about 280,295 tons grown on 487,286 ha), and

Europe occupied the 5<sup>th</sup> position (about 41 tons grown on 40 ha) [15]. Based on the production yield, in 2021 it was the highest in Europe (about 1,035 kg.ha<sup>-1</sup>), followed in 2<sup>nd</sup> position by Asia (about 589 kg.ha<sup>-1</sup>), in 3<sup>rd</sup> position by the Americas (about 575 kg.ha<sup>-1</sup>) and Africa occupied the 4<sup>th</sup> position (about 475 kg.ha<sup>-1</sup>) [15]. In 2022, the same source of information reported similar estimates (Africa: about 4,000,119 tons grown on about 8,222,425 ha with an average yield of about 487 kg.ha<sup>-1</sup>; Asia: about 2,401,093 tons grown on 4,010,987 ha with an average yield of about 599 kg.ha<sup>-1</sup>; Americas: about 340,226 tons grown on 603,324 ha with an average yield of 564 kg.ha<sup>-1</sup>; Europe: about 41 tons grown on 40 ha) [15]. In Africa, comparison of the estimation in 2021 (around four million tons) to the amount produced in the preceding years, showed a decreased number by approximately 633,650 tons [16]. The ranking of regions in Africa where sesame is grown showed in 2021 and 2022 that Eastern Africa ranked in the 1<sup>st</sup> position (2021: 1,436,628 tons grown on 2,380,476 ha with a yield of 604 kg.ha<sup>-1</sup>; 2022: 1,375,069 tons, 2,363,960 ha and 582 kg/ha), followed in the 2<sup>nd</sup> position by Northern Africa (2021: 1,285,540 tons, 4,231,280 ha and 304 kg.ha<sup>-1</sup>; 2022: 1,279,981 tons, 4,184,296 ha and 306 kg.ha<sup>-1</sup>), in the 3<sup>rd</sup> position by Western Africa (2021: 814,583 tons, 1,286,685 ha and 633 kg.ha<sup>-1</sup>; 2022: 874,154.85 tons, 1,167,629 ha and 749 kg.ha<sup>-1</sup>) and the Central Africa ranked in the 4<sup>th</sup> position (2021: 460,342 tons, 518,868 ha and 887 kg.ha<sup>-1</sup>; 2022: 470,914 tons, 506,541 ha and 930 kg.ha<sup>-1</sup>) [15]. The first ten African leading sesame producers in 2021 were Sudan (1,119,026 tons), Tanzania (700,000 tons), Nigeria (440,000 tons), Burkina Fasso (270,000 tons), Tchad (196,904 tons), Ethiopia (190,000 tons), South Sudan (182,153 tons), Uganda (146,000 tons), Mozambique (126,000 tons), Niger (85,062 tons) and Cameroon occupied the 11<sup>th</sup> position (70,000 tons) [16].

Seeds are used for the nutritional, medicinal, and industrial purposes in Middle East Asia and in Africa [17]. The high oil-contain of seeds (about 50%) is the main reason for the cultivation for food (for humans and livestock), pharmaceutical and chemical industries [17-19]. In America, Europe, India and Africa, seeds are traditionally used as folk remedy for different disorders such as bowel obstruction, asthma, allergy, and, eye disorders due to its anti-inflammatory, antioxidant and anti-bacterial activities [17, 20-22]. In Chinese medicine, sesame seeds are one of the reputed folk medicine used for cure of most symptoms of aging [17, 20]. In Algeria, the sesame oil supplementation is recommended to conventional frying oil and to commercial margarine, as alternative source of fatty acids, contributing to the diversification of combined oils [23]. Sesame seeds are important grain legume containing high levels of protein, fibres, energy, micronutrients including vitamins B and minerals like copper, iron, calcium, manganese, magnesium, sodium and macro-nutrients whose deficiencies are prevalent in Sub-Saharan African countries and then sesame seeds present a high nutritional value that make it very popular in the diet [7, 13, 14, 17,

18, 20, 22-24]. According to the same authors, sesame seeds are rich in lignan-like active ingredients, antioxidant, suitable for cholesterol reduction, blood lipid regulation, liver and kidney protection, cardiovascular system protection, anti-inflammatory, anti-tumor, and other effects, suitable for the human health and the livestock's nutrition. As an important medicinal and edible homologous food, sesame is used in various aspects of daily life such as food, feed, and cosmetics. The health food applications of sesame are increasing. Sene et al. [24] showed that, in eight sesame varieties, protein's contents ranged from 22.6% to 29.4% whereas that of fats varied from 48.7 to 52.5%, sesame varieties were rich in minerals, calcium being the most representative of all, followed by phosphorus, magnesium, iron, and zinc. The importance of the sesame crop lies in its edible leaves and the seed which is rich in oil (on average 50%), vitamins, proteins (25%), carbohydrates (15%), and minerals. The minerals include calcium, iron, and phosphorus while its vitamin constituents include thiamin, riboflavin and niacin [25]. High oil contents of sesame seeds (35 to 60%) were also reported by El Khier et al. [26], Alyemeni et al. [27], Borchani et al. [28] and Jimoh et al. [29]. Sesame seeds are also a source of essential and sulfur-containing amino acids [30]. They are rich in essential fatty acids from the C18 group (linoleic and linolenic acids) [31]. In addition, sesame seeds contain many mineral elements and vitamins [32, 33]. The strong antioxidant potentials of sesame seeds was highlighted by Dar and Arumugam [34] with lignans (sesamol and sesamin). Sesame seeds are also known to be a source of essential and sulfur-containing amino acids [35]. Given its composition of oil, mineral elements, proteins, and antioxidants, sesame (*Sesamum indicum* L.) is sometimes considered the "queen of oilseeds" and could be used as a food supplement against malnutrition [36, 37].

During the flowering period, flowers of *V. unguiculata* produce nectar and pollen and very often release in nature a scent attractive to useful and/or harmful animals including insects [38]. Harmfull insects on flowers are mostly phytophagous who nibble petals (Hymenoptera, Lepidoptera larvae, Odonata and Orthoptera) and potential pests are sap-sucking insects (Hemiptera and Homoptera) as the case reported in sesame, cowpea, potato and eggplants fields in Cameroon [39-53]. Useful insects are predators of harmful ones (natural enemies Coleoptera, Hymenoptera, Neuroptera and Dictyoptera), true pollinators (Hymenoptera), other pollinators (Diptera, Coleoptera and Lepidoptera) [44]. For example foragers of the useful Hymenoptera bees (case of *Ap. mellifera* and *Xy. olivacea*) face the anthers of the flower, scrape the pollen grains with the metathoracic legs, harvest and carry them in the metathoracic leg baskets (pollen collection). In Cameroon, *Ap. mellifera* is reported the most frequent floricultural insect on *V. unguiculata* blooming flowers [45-53]. In Benin, the most frequent insect on cowpea flowers was reported as *Xy. olivacea* [54] while in Nigeria, *Ap. mellifera* and *Xy. olivacea* predominated on *V. unguiculata* flowers [55]. In Ghana, *Ap. mellifera*

and *Halictus* sp. predominated on cowpea flowers [56]. For the nectar collection, bee foragers spread their wings, introduce entirely their head and the proboscis into the flower base to reach the sweet liquid exudates found deep inside the flower [45]. When entering the flower, foragers come into contact with the anthers; receive inadvertently pollen grains which adhere to their body, and accidentally release them at the bottom of the corolla during the collection of the produced sweet liquid [45]. In the world, similar behavior of the bee foragers was reported in Lepidoptera adults and other Hymenoptera Apidae on flowers of many flowering market garden plant species in India including Indonesia [5-59], Pakistan [60], African countries including Egypt [61], Nigeria [62] and Cameroon [39, 45, 46-53, 62-67]. During the nectar and/or pollen collection, released pollens that escape collection land on the stigma of the flower, facilitating the geitogamy and/or the xenogamy [68].

In Central African countries the sesame production is low compared to the situation in other African Regions and in developing countries and the overall production is insufficient to meet the ever-increasing demand in the cities. Causes of low productions are not fully known but available information points out the influence of abiotic and biotic stresses and socio-economic constraints including the sex and education level of farmers, the lack of improved varieties, insufficient use of fertilizers and low soil fertility, inexperience of farmers, poor access to extension, poor access to credit services, harvesting time, soil conservation, nature of access to land, farmland shortage, access to market, access to irrigation schemes, inadequate phytosanitary control including disease and insect pests, drought, unsuitability of agricultural policies, low soil fertility, the use of infested planting material, high disease and pest infection rates, losses during storage including losses in quality, inappropriate agronomic practices and storage pests. Among the biotic stresses the useful effect of several animal organisms (bacteria and predators that can protect plants against pests) is counterbalanced by pests (borers, phytophagous and sap-sucking insects). In Cameroon, the sesame production is limited by several factors among which the shortage of agricultural land, the low soil fertility, the poor management of pollinating insects, the pressure from insect pests in the fields and the post-harvest losses in warehouses, are frequently reported [42-44]. In natural environments as well as in agro-ecosystems, floricultural insects in general and Apoidea (Hymenoptera) including Apidae *Ap. mellifera*, *Xy. olivacea* and *Amegilla* spp. have a great ecological indirect impact on the yield production [39-52, 59-64]. The lack of yielding amendment and high quality of seed and absence of resistance to pests and diseases, are known as major problems for the vegetables cultivation.

Although the relationships between flowering plant species and their pollinators have been intensively studied in Cameroon [17, 42-44], no published data exist on the diversity of

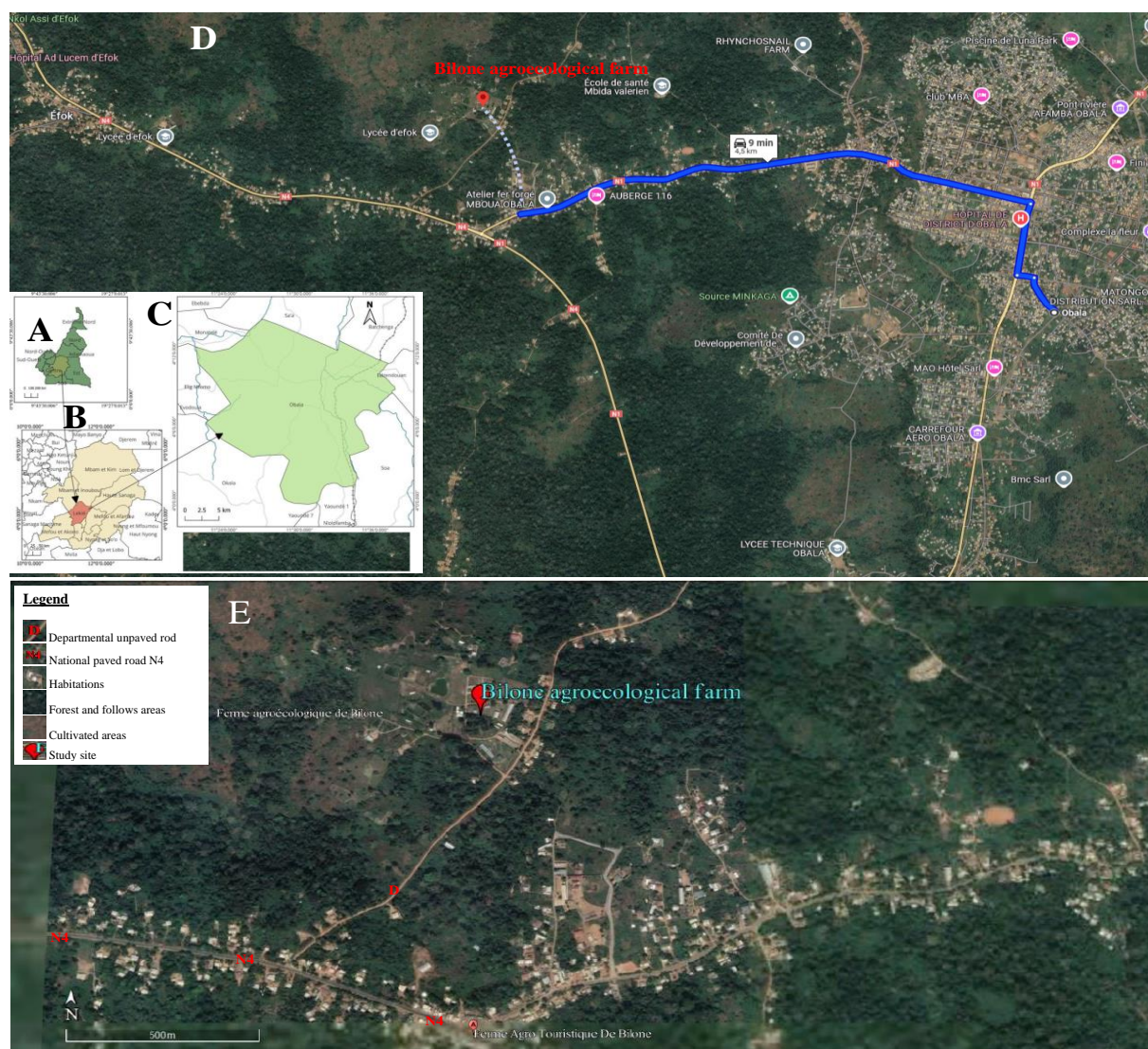
flower-visiting insects in Bilone. Nevertheless, the control of pest insects as well as useful insects is one of the major constraints to be overcome in sesame cultivation. In the rural areas of Cameroon in general and Bilone in particular, market gardening activities are on the rise, but sesame cultivation is little known by small farmers and it remains practiced by agricultural firms and research centres. Farmers are young, little educated, unassisted and each having a fairly low income. Moreover there is no information concerning the community composition and structure of the flower visiting insects on sesame plants in Bilone (Obala-Cameroon). The purpose of this study is to identify active insects on flowers of the sesame plants, able to reinforce the pollination and influence the quality and/or quantity of agricultural yields.

## 2. Material and Methods

### 2.1. Study Site

The study was conducted from May to June 2022 and 2023 at the Bilone agroecological farm (4°10'19.48"N, 11°30'06.53"E; 554 m a.s.l.). Bilone village is located in the northwest of Obala city (Centre Region, Lekie Department) (Figure 1A, 1B and 1C), not far from the N4 national road (Figure 1D). The Obala locality extends between 3°57'0"N, 11°21'0"E and 4°14'0"N, 11°38'0"E, in the forest-savannah ecotone (contact between the Sudanese savannah and the semi-deciduous dense forest) [69, 70]. It belongs to the agroecological zone of dense tropical rainforest [49, 69, 70]. The plant cover is a mosaic of fallows, home gardens, and cocoa plantations of varying sizes and ages [50]. The prevailing climate in Obala and the neighboring areas is a Guinean equatorial savannah [69] with dry winter (type Aw) according to the Köppen-Geiger classification with four seasons [71]: a short rainy season (mid-March to mid-July of the same year), a short dry season (mid-July to mid-August), a long rainy season (mid-August to mid-November) and a long dry season (mid-November to mid-March of the following year) [69]. The rainfall in the Lekie department (around 1,600 mm per year) presents a maximum rainfall in September [69]. In Obala and the neighboring areas, the climate parameters experience strong variability both annually and monthly [69]. According to the same source of information; the wet season is warm and overcast, the dry season is hot and mostly cloudy, and it is oppressive year round. Over the course of the year, the temperature varies from 20 °C in the rainy season to 35 °C in the dry season [69]. The hot season (from mid-January to mid-April), presents a high average daily temperature ( $\geq 31$  °C) and the hottest month of the year is March (maximum: 31 °C; minimum: 22 °C) [69].





**Figure 1.** Localization map of the study site. A: Centre Region in Cameroon [44]; B: Lekie department in the Centre Region [44]; C: Obala in the Lekie department [44]; D: Distance from Obala to the Bilone agroecological farm; E: study site at Bilone agroecological farm (Google Earth Pro for windows version 7.3.4.8642).

The cool season (mid-June to September) presents a high average daily temperature below 27 °C and the coldest month is July (minimum average: 21 °C; maximum: 27 °C) [69]. According to the same source of information, the wetter season lasts 8.0 months (mid-March to mid-November) and the month with most wet days is October, an average of 25.2 days presenting at least 1 mm of precipitation. In the dry season (mid-November to mid-March of the following year), the month with the fewest wet days is January. During 2021 and 2022, the temperature generally ranges from 20 °C to 32 °C and is rarely below 17 °C or above 34 °C. The climate does not show an abnormal variation [69]. Soils are ferrallitic, thick, homogeneous in appearance and formed on altered original material on which uneven vegetation develops [69]. The vegetation is mutilated by humans, notably due to the urban and agricultural development and agricultural operations [69]. The major industrial crops in Obala zone include *Elaeis guineensis* Jacq., 1763 (Arecales: Arecaceae), *Musa x para-*

*disiacal* L., 1753 (Zingiberales: Musaceae), *Theobroma cacao* L., 1753 (Malvales: Sterculiaceae) and *Coffea arabica* L., 1753 (Rubiales: Rubiaceae).

## 2.2. Experimental Device and Procedure

The investigations were carried out during two years (2022 and 2023) within the campus of the Obala Higher Institute of Agriculture and Management (OHAM). The experimental plots were created in 1,600 m<sup>2</sup> area. In the station, several vegetable monoculture plots were created in the vicinity of the sesame plots. Among these neighboring plots were plots of *Abelmoschus esculentus* (L.) Moench, 1794 (Malvales: Malvaceae), *Arachis hypogaea* L., 1753 (Fabales: Fabaceae), *Capsium annuum* L., 1753 (Solanales: Solanaceae), *Citrullus lanatus* (Thunb.) Matsum. & Nakai, 1916 (Cucurbitales: Cucurbitaceae), *Glycine max* (L.) Merr., 1917 (Fabales: Fabaceae), *Oryza* spp. L., 1753 (Poales: Poaceae), *Phaseolus*

*vulgaris* L., 1753 (Fabales: Fabaceae), *Solanum lycopersicum* L., 1753 (Solanales: Solanaceae), *Solanum tuberosum* L., 1753 (Solanales: Solanaceae), *Thebroma cacao* L., 1753 (Malvales: Sterculiaceae), *Solanum* sp. (Solanales: Solanaceae), and *Zea mays* L., 1753 (Cyperales: Poaceae). Seasonal mixed food crop plots were composed with *Colocasia esculenta* (L.) Schott, 1832 (Arales: Araceae), *Mangifera indica* L., 1753 (Sapindales: Anacardiaceae), *Manihot esculenta* Crantz, 1766 (Malpighiales: Euphorbiaceae), *Persea americana* Mill., 1768 (Laurales: Lauraceae), *Psidium guajava* L., 1753 (Myrtales: Myrtaceae), *Gynnanthemum amygdalinum* (Delile) Sch.Bip. ex Walp., 1843 (= *Vernonia amydalina* Delile) (Asterales: Asteraceae), *Xanthosoma sagittifolium* (L.) Schott, 1832 (Alismatales: Araceae), and *Zea mays* L., 1753 (Cyperales: Poaceae). The main wild plants were *Bidens pilosa* L., 1753 (Asterales: Asteraceae), *Lantana camara* L., 1753 (Lamiales: Verbenaceae), *Mimosa invisa* Mart. ex Colla, 1834 (Fabales: Mimosaceae), and *Tithonia diversifolia* (Hemsl.) A. Gray, 1883 (Asterales: Asteraceae).

Packets of *Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae) seeds (White and Smooth variety) were obtained from the Institute of Agricultural Research for Development (IRAD/ARID, Nkolbisson station). After the first rains (mid-March of each year), the experimental plots were cleared; ploughed and 15 plots (6 x 5.5 m each) were formed. Subplots were separated from each other by a two-meter wide path and from neighbouring fallows by a two-meter wide safety space. In each subplot, sowing was done in rows (five rows per subplot) and seeds were sown in pockets (10 to 14 seeds per pocket), the spacing being 100 cm on the lines and between the lines. Two weeks after emergence, weeding was done and two plants (the most vigorous) were kept per pocket. From emergence (occurring at the end of March) to the opening of the first flowers (mid-May each year), weeding operations were carried out regularly with a hoe, twice every two weeks. From the start of the flowering period (mid-May each year) to fruit maturity (end of June each year), manual weeding was regularly carried out. Six bee colonies housed in hives with upper bars were positioned between 20 and 24 m from the experimental plots and other colonies were non-inventoried in the vicinity of the study station. During the flowering period, two *Sesamum* plants were randomly selected each day in each subplot and blooming flowers were checked from 1<sup>st</sup> blooming day to 13<sup>th</sup> day (30 flowers a day).

### 2.3. Capture and Identification of Insects

Throughout the investigation period, 5,241 flowers were monitored in 26 days (13 days in 2022 and 2023 respectively) i.e. in each year, two weeks of the reproductive phase of *Se. indicum* plants (the week of the early blooming stage and the first week of the mid bloom stage). Then in 2022, a total of 2,883 flowers (55.0% of the total monitored flowers) were monitored (56, 125, 268, 356, 389, 450, 426, 352, 216, 110,

85, 35 and 15 flowers during the 1<sup>st</sup> to the 13<sup>th</sup> day respectively). In 2023, a total of 2,358 flowers (45.0%) were monitored (6, 95, 168, 256, 276, 369, 402, 389, 210, 96, 54, 32 and 5 flowers during the 1<sup>st</sup> to 13<sup>th</sup> day respectively). Collection sessions were conducted from 22 May to 15 June of each year. Consecutive session days were separated by two days interval. In each day and each year, the blooming flowers were checked during four time periods (9 to 10 a.m., 11 a.m. to 12 p.m., 1 to 2 p.m. and 3 to 4 p.m.). Insects found on the blooming flowers were captured. Products collected by each insect species were determined. Captures were done with bare hands (case of large non-flying insects), using a pair of soft tweezers or a mouth aspirator for entomologists (case of non-flying small insects) or with an entomological net (case of flying insects), following the procedure described by Tchuenguem Fohouo [42]. Specimens were preserved in glass pill boxes containing each 70% ethanol, except for adults of Lepidoptera and Odonata which were stored dry. The date and time of the captures were noted.

### 2.4. Identification of Insect Specimens

Specimens were identified to the family level using keys of Delvare and Aberlenc [72], and Borror and White [73]. Bees were identified, to the genera level using the key proposed by Eardley et al. [74], Lecoq [75], Brailovsky [76], Tronquet [77], Taylor [78], and Zettler et al. [79]. In order to consider recent developments in the taxonomy, we consulted recent checklists, illustrated catalogues and websites for Diptera [80-83], Hymenoptera [78, 83-93], Lepidoptera [94-97], Neuroptera [98-100], and Orthoptera [101]. Identifications were done in the Laboratory of Applied Zoology, Department of Biological Sciences, Faculty of Science, Ngaoundere University where voucher specimens were deposited.

### 2.5. Data Analysis

Data matrixes of abundance counts of species were constructed in each cultivation campaign and saved using an excel spreadsheet version 2016. Percentages were calculated from the overall total number of specimens or the overall recorded taxa when relevant. Series of abundance counts were presented in terms of mean  $\pm$  standard error (se) and percentages. Two mean values were compared using the Student t-test from SigmaStat software 2.03 (SPSS, Inc., Chicago, IL), when relevant and when normality and equal variance tests passed. Otherwise the non-parametric Wilcoxon test (paired series) or Mann-Whitney test (independent series) was used. Comparison of two frequencies was done using the Fisher's exact-test from StatXact software 3.1. The link between the occurrence of insects and climatic parameters (temperature and air humidity) was evaluated by determining the Pearson correlation. Regression equations were set up when relevant and tested using ANOVA procedure.

Alpha diversity analysis allowed the determination of in-



dices using PAST 3.05 software [102]: the absolute abundance of the  $i^{\text{th}}$  species  $n_i$ , the sample size  $n$  (sum of  $n_i$ ), the maximum abundance  $n_{\text{max}}$ , the relative abundance of the  $i^{\text{th}}$  species  $f_i = n_i/n$ , the observed species richness  $S$  (total number of the collected species), the Shannon-Weaver index  $H'$ , the maximum Shannon-Weaver index  $H'_{\text{max}} = \ln(S)$ , the Simpson's index  $D$  ( $D=0$  for high diversity), the Margalef's index  $Mg = (S-1)/\ln(n)$  with  $0 \leq Mg \leq +\infty$  ( $Mg=0$  for a low species richness). The 'true' theoretical richness  $T$  was determined using six non-parametric estimators from EstimateS software Version 9.1.0 [103]: the Abundance Coverage-based Estimator (ACE), Chao 1, Chao 2, the Incidence Coverage-based Estimator (ICE), Jackknife estimator of order 1 (Jack 1), and Bootstrap Mean. For each estimator, the sampling success was determined as  $SE = (S/T) \times 100$ . Comparison of the species richness was performed using the individual rarefaction procedure and pair wise comparison of diversities ( $H'$  and  $D$ ) was performed using the Student t-test from PAST 3.05 software [102]. The Pielou's evenness index  $J = H'/H'_{\text{max}}$  and the Hill's diversity numbers ( $N_1 = e^{H'}$  and  $N_2 = 1/D$ ) were determined. The richness ratio  $d = S/n$  with  $0 \leq d \leq 1$ , confirmed the quality of the species richness ( $d$  close to null for low species richness and  $d$  close to one for high species richness). The degree of dominance by a few species was evaluated using the Berger-Parker index  $I_{BP} = n_{\text{max}}/n$  with  $0 \leq I_{BP} \leq 1$  ( $I_{BP}$  close to null for equally abundances).

For the beta diversity, the overall species covariance was evaluated using the Schluter's procedure [104] and between species correlations was determined using the Kendall's tau coefficient. The dissimilarity between the two years was evaluated using the Bray-Cutis index [105]. The rank abundance plotting illustrated the shape of the species abundance distributions (SADs). Species were ranged in decreasing order of abundance and the absolute value of the Bravais-Pearson correlation between ranks  $i$  and  $\log_2(n_i)$  made it possible to assess the adjustment of Motomura's law to observed data. We tested five commonly used theoretical models [106] to fit the curves, using the package *vegan* of R 3.4.1 software: Broken-stick (BS), log-linear (LL), Log-normal (LN), Zipf (Z) and Zipf-Mandelbrot (ZM). The best fitted model presented the lowest value of the Akaike Information Criteria (AIC) or the lowest Bayesian Information Criteria (BIC) [107]. For each selected theoretical model, the estimated sample size  $n^*$  was adjusted to the observed sample size  $n$  using the correction factor  $c = n/n^*$ , and the corrected model was given. BS model has a single parameter  $x$  (average abundance). LL or GM model corresponds to the linear regression  $\log_2(n_i) = a(i) + b$  or  $n_i = c \cdot 2^{b \cdot (2^a)^i}$  where  $i$  represents the rank of the species in decreasing order of abundance,  $n_i$  is the abundance of the  $i^{\text{th}}$  species,  $a$  and  $b$  represent the slope and the elevation of the regression respectively. LL model depends on the maximum abundance of the top-ranking species  $n_1$  and the Motomura environmental constant  $m$  (antilogarithm of the regression slope  $a$ ,  $0 \leq m \leq 1$ ) representing the rate of decrease in abundance by rank. The LN model corresponds to the linear

regression  $\log_2(n_i) = a(P_i) + b$  or  $n_i = c \cdot 2^{b \cdot (2^a)^{P_i}}$  where  $P_i$  represents the probit of the  $i^{\text{th}}$  species. For a species of rank  $i$ , the cumulative percentage linked to the rank was determined as  $k_i = 100(i+0.5)/(S+1)$  when  $S$  was odd or  $k_i = 100((i+1)+0.5)/(S+1)$  when  $S$  was even. Probit were determined using the package "Ecotoxicology" from R 3.4.1 software. Parameters of LN were the maximum abundance  $n_1$ , the mean of the lognormal distribution  $x$ , the standard deviation of the lognormal distribution  $\sigma$  and the Preston's environmental constant (rate of decrease in abundance by rank)  $m' = \text{square root of } 1/\sigma$ . Z model is based on the Zipf's law based on two statistics [108]:  $Q$  as the scaling parameter (normalizing constant), and  $\gamma$  (gamma) as the average probability of the appearance of a species [108]. Zipf's law [109] is frequently applied in animal and plant ecology to characterize SADs. ZM is a generalized model in which a new parameter  $\beta$  (beta) is added. Marquardt's nonlinear least squares algorithm [110, 111] was used when relevant to estimate  $\beta$ ,  $\gamma$  and  $1/\gamma$  parameters (fractal dimension of the distribution of individuals among species).

### 3. Results

#### 3.1. Inventory and Abundances of Insects

A total of 1,703 adult insects collected in 2022 and 2023, belonged to five orders, 12 families (1,703 specimens, 8 to 721 specimens, mean  $\pm$  se:  $142 \pm 71$  specimens,  $Me = 22$  specimens), 18 genera and 19 species (Table 1). Orders were Diptera Linnaeus, 1758, Hymenoptera Linnaeus, 1758, Lepidoptera Linnaeus, 1758, Neuroptera Linnaeus, 1758, and Orthoptera Latreille, 1793 (Table 1). Hymenoptera was the most family-rich order (six families) followed by Diptera and Lepidoptera (two families each). Neuroptera and Orthoptera were rare (one Family each) (Table 1). Calliphoridae, Eumenidae and Halictidae were not recorded in 2022. In each year, Hymenoptera was mostly recorded (91.5%). Other orders were rare (Table 1). Apidae Latreille, 1802 was mostly recorded (42.3% of the collection) followed by Formicidae Latreille, 1809 (34.1%), Megachilidae Latreille, 1802 (11.6%). Other families were rare (Table 1). Mean or median occurrences in 2022 (five orders, 10 families, 677 specimens, 4-290 specimens, mean abundance  $\pm$  se:  $68 \pm 33$  specimens, median:  $Me = 11$  specimens) was not different from the records in 2023 (five orders, 11 families, 1,026 specimens, three to 431 specimens,  $93 \pm 46$  specimens,  $Me = 15$  specimens) (Student t-test:  $t = -0.443$ ,  $df = 19$ ,  $p = 0.663$ ; Mann-Whitney test:  $T = 102.500$ ,  $p = 0.622$ ). Calliphoridae (Diptera) and Ascalapidae (Neuroptera) were highly abundant in 2023 campaign than the 2022 one while it was the contrary in Eumenidae, Halictidae, Megachilidae, the pooled data of Hymenoptera and the overall pooled data (Table 1). Between the two years, the difference was not significant in Acrididae, Apidae, pooled Diptera, Formicidae, pooled Lepidoptera, Muscidae, Nymphalidae, Pieridae and Vespidae (Table 1). The most

species-rich family was Formicidae (four species), followed by Apidae (three species), Megachilidae and Nymphalidae were represented each by two species. Acrididae, Ascalapidae, Calliphoridae, Eumenidae, Halictidae, Muscidae, Pieridae, and Vespidae were represented each by one species (Table 2). *Calliphora vicina* Robineau-Desvoidy, 1830 (Diptera: Cal-

liphoridae) was recorded exclusively in 2022 (Table 2). Two useful species: the exotic Eumenidae *Delta* sp. and the afrotropical predator *Ascalaphus africanus* (Ascalapidae) were recorded as well as the phytophagous Acrididae *Pe. carnapi*. Potential pests (Nymphalidae, Pieridae, and Acrididae) cumulatively represented 3.1%.

**Table 1.** Absolute and relative abundance of insect orders and families collected on flowers of *Sesamum indicum* L. (1753) (Pedaliaceae).

Orders / Families	Campaign			
	2022 (%)	2023 (%)	Total (%)	2022 vs. 2023: Fisher's exact test
Diptera Linnaeus, 1758				
Calliphoridae Hough (d), 1899	8 (0.5)	-	8 (0.5)	$\chi^2=8.607$ ; df=1; p=0.008 *
Muscidae Latreille, 1802	29 (1.7)	39 (2.3)	68 (4.0)	$\chi^2=0.273$ ; df=1; p=0.615 ns
Total	37 (2.2)	39 (2.3)	76 (4.5)	$\chi^2=2.645$ ; df=1; p=0.119 ns
Hymenoptera Linnaeus, 1758				
Apidae Latreille, 1802	290 (17.0)	431 (25.3)	721 (42.3)	$\chi^2=0.116$ ; df=1; p=0.764 ns
Eumenidae Leach, 1815	-	12 (0.7)	12 (0.7)	$\chi^2=9.326$ ; df=1; p=0.003 *
Formicidae Latreille, 1809	216 (12.7)	364 (21.4)	580 (34.1)	$\chi^2=2.313$ ; df=1; p=0.130 ns
Halictidae Thomson, 1869	-	37 (2.23)	37 (2.2)	$\chi^2=34.026$ ; df=1; p=9.6x10 <sup>-9</sup> *
Megachilidae Latreille, 1802	97 (5.7)	101 (5.9)	198 (11.6)	$\chi^2=7.878$ ; df=1; p=0.005 *
Vespidae Latreille, 1802	4 (0.2)	7 (0.4)	11 (0.6)	$\chi^2=0.070$ ; df=1; p=1.00 ns
Total	607 (35.6)	952 (55.9)	1,559 (91.5)	$\chi^2=6.101$ ; df=1; p=0.026 *
Lepidoptera Linnaeus, 1758				
Nymphalidae Rafinesque, 1815	9 (0.5)	13 (0.8)	22 (1.3)	$\chi^2=0.045$ ; df=1; p=1.00 ns
Pieridae Swainson, 1820	5 (0.3)	3 (0.2)	8 (0.5)	$\chi^2=1.734$ ; df=1; p=0.278 ns
Total	14 (0.8)	16 (0.9)	30 (1.8)	$\chi^2=0.654$ ; df=1; p=0.456 ns
Neuroptera Linnaeus, 1758				
Ascalapidae Rambur, 1842	12 (0.7)	4 (0.2)	16 (0.9)	$\chi^2=8.075$ ; df=1; p=0.008 *
Orthoptera Latreille, 1793				
Acrididae MacLeay, 1821	7 (0.4)	15 (0.9)	22 (1.3)	$\chi^2=0.532$ ; df=1; p=0.516 ns
Global	677 (39.8)	1,026 (60.2)	1,703 (100.0)	$\chi^2=142.98$ ; df=1; p=5.3x10 <sup>-33</sup> *

ns: not significant difference (p>0.05); \*: significant difference (p<0.05)

### 3.2. Alpha Diversity of the Insects' Assemblages

The numbers of species recorded in 2022 and 2023 were close to each other and revealed in each case, low species richness (richness ratio close to 0) (Table 3A). The species richness was low in 2022 (16 species; Margalef index: Mg=2.301; richness ratio: d=0.024) and high in 2023 (18 species; Mg=2.452; d=0.018) and in the pooled years (19

species; Mg=2.419; d=0.011) (Table 3A). The sampling success was maximal (100.0%), suggesting no rare species escaped (Table 3B). In each year, a high diversity of the assemblage was noted (Shannon index close to the maximum; Table 3C). A low dominance by a few species was noted (Berger-Parker index inferior to the median value; Table 3D).

Based on the Hill's N<sub>1</sub> and N<sub>2</sub> indexes, the number of simply abundant species were close to the number of co-dominants and values of the Hill's ratio were very close to



one (Table 3D), corroborating a low dominance of the assemblages by a few insect species. The number of rare species was 7 species in 2022, eight species in 2023 and nine species in the pooled years (Table 3D). A high even assemblage was noted (Pielou's index close to one; Table 3E). The variation in the diversity indexes was not significant between the two years. The rank-abundance plotting presented in the pooled campaigns, a concave appearance suggesting the presence of co-dominants (Figure 2A). The similar shape was noted in the species distribution of abundances (SADs) recorded in 2022 and 2023 (Figure 2B and 2C). The individual rarefaction curves plotted for the two campaigns and the pooled campaigns approached species saturation plateaus with similar slopes (Figure 2D). The curve observed in 2022 was situated below records in 2023 and the pooled years, suggesting lowest species richness in 2022. A high species richness was noted in 2023 and in the pooled years (Figure 2D). For a standard sample of 661 specimens, the settlement in the pooled years was most diversified ( $E(S_{n=661})=19\pm0$  species), followed by 2023 ( $E(S_{n=661})=18\pm0$  species), and lastly the records in 2022 ( $E(S_{n=661})=16\pm0$  species).

Based on the Hill's first order diversity number  $N_1$  (see Table 3) and the rank-abundance plotting (Figure 2), the number of simply abundant species varied from 9 species (47.4% of the total species richness) in 2022 to 10 species (52.6%) in 2023 and the pooled years respectively. *Camponotus maculatus* was simply abundant in 2023 and in the pooled years. Nine species were simply abundant in each year and in the pooled years. These species were *Am. calens*, *Ap. mellifera*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Ph. megacephala*, and *Xy. olivacea*. Based on the Hill's second order diversity number  $N_2$  (Table 3) and the rank-abundance plotting (Figure 2), seven species were co-dominants (36.8% of the total species richness) in all cases. Two species (*Am. calens* and *Me. cincta*) were co-dominants in 2022 and in the pooled campaign. Two species (*Ca. maculatus* and *Me. kamerunensis*) were co-dominants exclusively in 2023. Five species (*Ap. mellifera*

*adansonii*, *Pa. longicornis*, *Ph. Megacephala*, *My. opaciventris* and *Xy. olivacea*) were co-dominants in each year and in the pooled years. *Camponotus maculatus* was rare exclusively in 2022. *Calliphora vicina* was rare in 2022 and in the pooled years. Three species (*Bi. dorothea*, *Delta* sp. and *La. hancocki*) were rare in 2023 and in the pooled years. Five species (*Ac. acerata*, *As. africanus*, *Ct. florella*, *Pe. carnapi* and *Sy. conuta*) were rare in both years and in the pooled years.

### 3.3. Abundance Distributions (SADs)

Adjustment of the SADs to the five commonly known theoretical models showed that the fit was of excellent quality in 2022 ( $r=-0.990$ ,  $p=3.6\times10^{-13}$ , 16 species), of satisfactory quality in 2023 ( $r=-0.977$ ,  $p=4.1\times10^{-12}$ , 18 species), and of excellent quality in the pooled campaigns ( $r=-0.986$ ,  $p=8.9\times10^{-15}$ , 19 species). On the base of the AIC and BIC values (Table 4) and the SAD plotting (Figure 2A, 2B and 2C), the log-linear model (LL) best fitted the insect assemblage in the 2022 with a high Motomura's environmental constant close to one (maximum abundance:  $n_1=194$  specimens; sample size:  $n=677$  specimens; species richness:  $S=16$  species; log-linear regression slope:  $a=(-0.110\pm0.004)$ ; Student test  $t=-25.638$ ;  $p<0.001$ ); Motomura's environmental constant:  $m=0.777$ ; elevation of the regression:  $b=(2.278\pm0.041)$ ; Student test  $t=55.046$ ;  $p<0.001$ ); ANOVA log-linear regression:  $F_{(1, 14)}=657.291$ ,  $p<0.001$ ; deviance: 23.191; correction factor: 1.045; corrected LL model:  $n_i=198.031*(0.777)^i$  with  $i$  as the rank of species, arranged in descending order of abundance. The settlement in 2023 best fitted the lognormal model (LN) with a high value of the Preston's environmental constant (deviance: 38.368;  $n_1=327$ ; mean of the lognormal distribution:  $x=4.80$ ; standard deviation of the lognormal distribution:  $\sigma=1.896$ ; slope of  $\text{Log}_2(n_i)=f(P_i)$ :  $a=1.207$ ; elevation:  $b=-0.808$ ; Preston's environmental constant:  $m'=0.726$ ; correction factor:  $8.0\times10^{-5}$ ; corrected model:  $n_i=0.810(2.31)^{P_i}$  with  $P_i$  as the probit of the  $i^{\text{th}}$  species.

**Table 2.** Absolute and relative abundance of the insect species collected on flowers of *Sesamum indicum* L. (1753) (Pedaliaceae).

Order/Family	Species name	Product	Origin, references	Campaign		
				2022 (%)	2023 (%)	Pooled (%)
Diptera						
Calliphoridae	<i>Calliphora vicina</i> Robineau-Desvoidy, 1830	Nectar	NA, MS, a	8 (0.5)	-	8 (0.5)
Muscidae	<i>Musca domestica</i> Linnaeus, 1758	Nectar	ME, MS, b, c	29 (1.7)	39 (2.3)	68 (4.0)
Hymenoptera						
Apidae	<i>Amegilla calens</i> (Lepeletier De Saint-Fargeau, 1841)	Nectar, Pollen	AF, d, e	59 (3.5)	46 (2.7)	105 (6.2)
	<i>Apis mellifera adansonii</i> Latreille, 1804	Nectar	AF, e	194 (11.4)	327 (19.2)	521 (30.6)

Order/Family	Species name	Product	Origin, references	Campaign		
				2022 (%)	2023 (%)	Pooled (%)
	<i>Xylocopa olivacea</i> (Fabricius 1778)	Nectar, Pollen	AF, f	37 (2.2)	58 (3.4)	95 (5.6)
Eumenidae	<i>Delta</i> sp. Saussure, 1855	Predator	OW, Useful, g, k	-	12 (0.7)	12 (0.7)
Formicidae	<i>Camponotus maculatus</i> (Fabricius, 1782)	Nectar	AF, h, i	6 (0.4)	53 (3.1)	59 (3.5)
	<i>Myrmicaria opaciventris</i> Emery, 1893	Nectar	AF, h, i	80 (4.7)	71 (4.2)	151 (8.9)
	<i>Paratrechina longicornis</i> (Latreille, 1802)	Nectar	AF, h, i	90 (5.3)	120 (7.0)	210 (12.3)
	<i>Pheidole megacephala</i> (Fabricius, 1793)	Nectar	AF, h, i, j	40 (2.3)	120 (7.0)	160 (9.4)
Halictidae	<i>Lasioglossum hancocki</i> (Cockerell 1945)	Nectar, Pollen	AF, m	-	37 (2.2)	37 (2.2)
Megachilidae	<i>Megachile cincta</i> (Fabricius, 1781)	Nectar	AF, l	81 (4.8)	38 (2.2)	119 (7.0)
	<i>Me. kamerunensis</i> Friese, 1922	Nectar, Pollen	AF, l	16 (0.9)	63 (3.7)	79 (4.6)
Vespidae	<i>Synagris conuta</i> (Linnaeus, 1758)	Nectar, Pollen	AF, n, o	4 (0.2)	7 (0.04)	11 (0.6)
Lepidoptera						
Nymphalidae	<i>Acraea acerata</i> Hewitson, 1874	Nectar	AF, Plant pest, p	9 (0.5)	6 (0.4)	15 (0.9)
	<i>Bicyclus dorothea</i> (Cramer, 1779)	Nectar	AF, p, q, r	-	7 (0.4)	7 (0.4)
Pieridae	<i>Catopsilia florella</i> (Fabricius, 1775)	Nectar	AF, p, s	5 (0.3)	3 (0.2)	8 (0.5)
Neuroptera						
Ascalapidae	<i>Ascalaphus africanus</i> (McLachlan, 1871)	Predator	AF, Useful, t, u, v	12 (0.7)	4 (0.2)	16 (0.9)
Orthoptera						
Acrididae	<i>Pteropera carnapi</i> Ramme, 1929	Phytophagous	AF, Plant pest, w	7 (0.4)	15 (0.9)	22 (1.3)
Total				677 (39.8)	1,026 (60.2)	1,703(100.0)

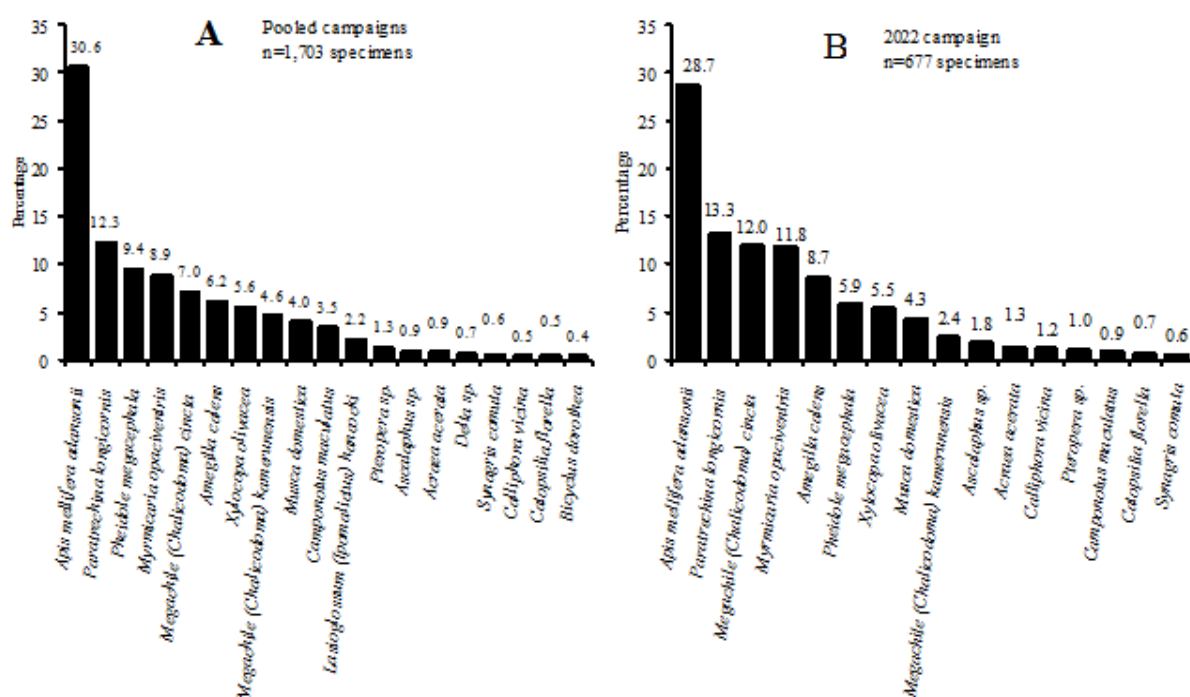
AF: Afrotropical origin; MS: Myiasigenic species; ME: Middle East (Asia); NA: North America origin; OR: oriental origin; OW: Old World; a: [81]; b: [80]; c: [82]; d: [90]; e: [89]; f: [95]; g: [84]; h: [78]; i: [83]; j: [86]; k: [91]; l: [87]; m: [88]; n: [93]; o: [85]; p: [92]; q: [94]; r: [96]; s: [97]; t: [99]; u: [98]; v: [100]; w: [101].

**Table 3.** Alpha diversity indices of the floricultural insects on flowers of *Sesamum indicum* L. (1753) (Pedaliaceae).

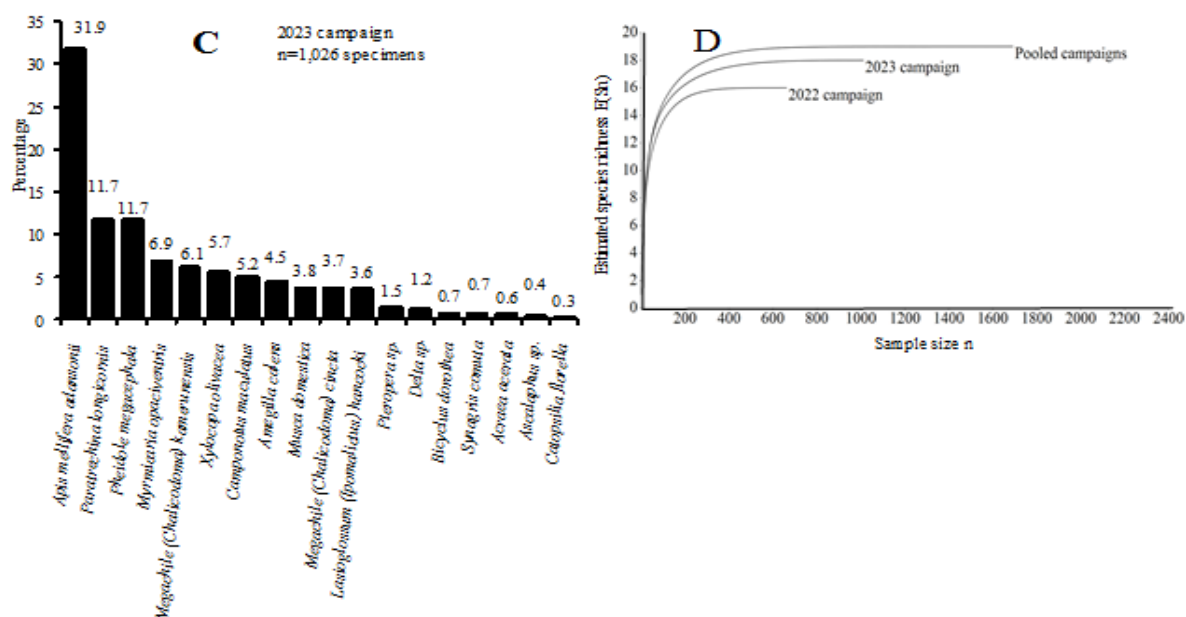
Statistical indices	Campaign		
	I. 2022	II. 2023	III. Pooled years
A. Species richness indices			
Sample size n (%)	677 (39.8)	1,026 (60.2)	1,703 (100.0)
Observed species richness S	16	18	19
Maximum abundance $n_{\max}$	194	327	521
Margalef's index $M_g$	2.301	2.452	2.419
Richness ratio $d=S/n$	0.024	0.018	0.011
B. Non-parametric estimation of the "true" species richness			
ACE (SE=100*S/ACE)	16 (100.0)	18 (100.0)	19 (100.0)
ICE (SE=100*S/ICE)	16 (100.0)	18 (100.0)	19 (100.0)
Chao1 (SE=100*S/Chao1)	16 (100.0)	18 (100.0)	19 (100.0)

Statistical indices	Campaign		
	I. 2022	II. 2023	III. Pooled years
Chao2 ( $SE=(100*S/Chao2)$ )	16 (100.0)	18 (100.0)	19 (100.0)
Jack.1	16 (100.0)	18 (100.0)	19 (100.0)
Bootstrap Mean	16 (100.0)	18 (100.0)	19 (100.0)
C. Species diversity indices			
Shannon-Weaver $H'$	2.232	2.294	2.329
Maximum Shannon-Weaver $H'_{max}=\ln(S)$	2.773	2.890	2.944
Simpson index D	0.145	0.150	0.143
D. Species dominance indices			
Berger-Parker dominance index $IBP=n_{max}/n$	0.287	0.319	0.306
Hill's first order diversity number $N_1=e^{H'}$	9.318	9.914	10.268
Hill's second order diversity number $N_2=1/D$	6.878	6.667	6.983
Hill's ratio: $Hill=N_2/N_1$	0.738	0.672	0.680
Estimated observed rare species: Chao1- $N_1$	7	8	9
E. Evenness index			
Pielou's index $J=H'/H'_{max}$	0.805	0.794	0.791
Comparison of the species diversity indices: I vs. II (Student t-test):	Shannon-Weaver index $H'$ : $t=-1.332$ ; $df=1,532.1$ ; $p=0.183$ ns; Simpson index D: $t=-0.433$ ; $df=1,635.1$ ; $p=0.665$ ns;		

ns: not significant difference ( $p>0.05$ ); SE: sampling effort; ACE: Abundance Coverage-based Estimator; ICE: Incidence Coverage-based Estimator; Chao1: first order Chao index; Chao2: second order Chao index; Jack.1: first order Jackknife estimator.







**Figure 2.** Rank-frequency diagrams of the collected insects in the pooled campaigns (A), in 2022 (B) and 2023 (C) showing species in order of numerical dominance. The species rarefaction curves (D) (estimated species richness as a function of the sample size variation) showed the low species richness variation in 2022 and the high species richness in the pooled campaigns.

The pooled campaigns fitted the LN model with a high value of the Preston's environmental constant (deviance: 53.367;  $n_1=521$ ; mean of the lognormal distribution:  $x=5.43$ ; standard deviation:  $\sigma=1.868$ ; slope of  $\text{Log}_2(n_i)=f(P_i)$ :  $a=1.152$ ; elevation:  $b=0.057$ ; Preston environmental constant:  $m^*=0.732$ ; correction factor: 1.5; corrected model:  $n_i=1.5(2.22)^{P_i}$  with  $P_i$  as the probit of the  $i^{\text{th}}$  species.

### 3.4. Beta Diversity of the Insects Assemblages

Based on the species composition, although a few cosmopolitan species were sampled, a high level of dissimilarity was noted between 2022 and 2023 campaigns (Bray-Curtis index:  $BC=0.694$ ), between 2023 and the pooled campaigns ( $BC=0.752$ ) and it was of median level between 2022 and the pooled campaigns ( $BC=0.569$ ). Species were recorded on 1,066 flowers (5,241 checked flowers: 20.3%): 294 flowers (5.7%) in 2022 and 772 flowers (14.7%) in 2023. Overall, insects exhibited in 2022, a positive net association in presence/absence data ( $VR>1$ ) (variance ratio:  $VR=2.485$ , statistic:  $W=7,165.691$ ,  $df=2,882$ ,  $p<0.001$ ). It was the same in 2023 ( $VR=6.513$ ,  $W=15,357.456$ ,  $df=2,357$ ,  $p<0.001$ ) and in the pooled years ( $VR=8.592$ ,  $W=45,029.530$ ,  $df=5,240$ ,  $p<0.001$ ). A few negatively correlated species (mutual repulsion) and several positively correlated ones (mutual repulsion) were

noted. A negative correlation was noted between Calliphoridae *Cl. vicina* and Apidae *Ap. mellifera adansonii* (Table 5). The Nymphalidae *Ac. acerata* was positively correlated with 16 species: *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta* (Table 5). The Apidae *Am. calens* was positively correlated with 16 species (*Ac. acerata*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta*) (Table 5). *Apis mellifera adansonii* (Apidae) and *Xy. olivacea* were positively correlated (Table 5). *Ascalaphus africanus* (Ascalapidae) was positively correlated with 16 species: *Ac. acerata*, *Am. calens*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta* (Table 5). *Bicyclus dorothea* (Nymphalidae) was positively correlated with 16 species: *Ac. acerata*, *Am. calens*, *As. africanus*, *Ca. maculatus*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, *Sy. cornuta*, and *Xy. olivacea* (Table 5).

**Table 4.** Values of the Akaike Information Criteria and the Bayesian Information Criteria for the adjusted theoretical models of the species abundance distributions.

SAD theoretical model	Deviance; AIC (BIC)		
	I. 2022 campaign 16 species; 677 specimens	II. 2023 campaign 18 species; 1,026 specimens	III. Pooled years 19 species; 1,703 specimens
McArthur's Broken-Stick (BS)	49.920; 129.097 (129.097)	115.881; 209.095 (209.095)	191.935; 298.518 (298.52)
Motomura's Log-linear (LL)	23.191; 104.368 (105.140) *	106.250; 201.464 (202.354)	126.679; 235.261 (236.21)
Preston's Log-normal (LN)	26.090; 109.267 (110.812)	38.368; 135.582 (137.363) *	53.367; 163.95 (165.84) *
Zipf (Z)	70.894; 154.071 (155.616)	91.644; 188.857 (190.638)	155.56; 266.142 (268.03)
Zipf-Mandelbrot (ZM)	21.740; 106.916 (109.234)	79.141; 178.354 (181.025)	103.945; 216.528 (219.36)

AIC: Akaike Information Criteria; BIC: Bayesian Information Criteria; SAD: Species Abundance Distribution; S: observed species richness; n: sample size; \*: the best fitted theoretical model

*Camponotus maculatus* (Formicidae) was positively correlated with 13 species: *Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta* (Table 5). *Calliphora vicina* (Calliphoridae) was positively correlated with 12 species: *Ac. acerata*, *Am. calens*, *As. africanus*, *Ct. florella*, *Me. cincta*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta* (Table 5). Other correlations were not significant (Table 5). *Catopsilia florella* (Pieridae) was positively correlated with 15 species: *Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Cl. vicina*, *Delta* sp., *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta* (Table 5). *Delta* sp. (Eumenidae) was positively correlated with 16 species: *Ac. acerata*, *Am. calens*, *As. africanus*, *Ca. maculatus*, *Ct. florella*, *Bi. dorothea*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, *Xy. olivacea*, and *Sy. conuta* (Table 5). *Lasioglossum (Ipomalictus) hancocki* (Halictidae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Ct. florella*, *Delta* sp., *Me. cincta*, *Me. kamerunensis*, *Mu. do-*

*mestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, *Sy. cornuta*, and *Xy. olivacea*) (Table 5). *Megachile (Chalicodoma) cincta* (Megachilidae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta* sp., *La. hancocki*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta*) (Table 5). *Megachile kamerunensis* (Megachilidae) was positively correlated with 15 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta* sp., *La. hancocki*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta*) (Table 5). *Musca domestica* (Diptera) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta* sp., *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta*) (Table 5). *Myrmecaria opaciventris* (Formicidae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta* sp., *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *Pa. longicornis*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. cornuta*) (Table 5).

**Table 5.** Kendall tau  $\tau$  correlation between 19 species recorded in 1,066 flowers.

Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>Acraea acerata</i>			<i>Apis mellifera adansonii</i>		
<i>Ascalaphus africanus</i>	0.962	$6 \times 10^{-12}$ *	<i>Me. cincta</i>	-0.046	0.739 ns
<i>Bicyclus dorothea</i>	0.622	$8 \times 10^{-6}$ *	<i>Me. kamerunensis</i>	-0.070	0.617 ns
<i>Catopsilia florella</i>	0.593	$2 \times 10^{-5}$ *	<i>My. opaciventris</i>	-0.103	0.463 ns

Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>Pteropera carnapi</i>	0.843	$2 \times 10^{-9}$ *	<i>Pa. longicornis</i>	-0.056	0.689 ns
<i>Amegilla calens</i>			<i>Pe. carnapi</i>	-0.082	0.559 ns
<i>Acraea acerata</i>	0.660	$2 \times 10^{-6}$ *	<i>Ph. megacephala</i>	-0.070	0.617 ns
<i>Apis mellifera adansonii</i>	-0.135	0.335 ns	<i>Sy. conuta</i>	-0.103	0.462 ns
<i>As. africanus</i>	0.655	$3 \times 10^{-6}$ *	<i>Xy. olivacea</i>	0.639	$5 \times 10^{-6}$ *
<i>Bi. dorothea</i>	0.426	0.002 *	<i>As. africanus</i>		
<i>Camponotus maculatus</i>	0.648	$3 \times 10^{-6}$ *	<i>Pe. carnapi</i>	0.786	$2 \times 10^{-8}$ *
<i>Ct. florella</i>	0.403	0.004 *	<i>Bi. dorothea</i>		
<i>Delta sp.</i>	0.449	0.001 *	<i>As. africanus</i>	0.596	$2 \times 10^{-5}$ *
<i>Lasioglossum (Ipomalictus) hancocki</i>	0.449	0.001 *	<i>Ct. florella</i>	0.449	0.001 *
<i>Megachile (Chalicodoma) cincta</i>	0.565	$5 \times 10^{-5}$ *	<i>Pe. carnapi</i>	0.758	$6 \times 10^{-8}$ *
<i>Me. (Chalicodoma) kamerunensis</i>	0.744	$1 \times 10^{-7}$ *	<i>Camponotus maculatus</i>		
<i>Myrmecaria opaciventris</i>	0.958	$7 \times 10^{-12}$ *	<i>Ac. acerata</i>	0.685	$9 \times 10^{-7}$ *
<i>Paratrechina longicornis</i>	0.775	$3 \times 10^{-8}$ *	<i>As. africanus</i>	0.634	$6 \times 10^{-6}$ *
<i>Pe. carnapi</i>	0.570	$5 \times 10^{-5}$ *	<i>Camponotus maculatus</i>		
<i>Pheidole megacephala</i>	0.759	$5 \times 10^{-8}$ *	<i>Bi. dorothea</i>	0.634	$6 \times 10^{-6}$ *
<i>Synagris conuta</i>	0.545	$9 \times 10^{-5}$ *	<i>Ct. florella</i>	0.206	0.139 ns
<i>Xy. olivacea</i>	-0.015	0.915 ns	<i>La. hancocki</i>	0.663	$2 \times 10^{-6}$ *
<i>Apis mellifera adansonii</i>			<i>Me. cincta</i>	0.399	0.004 *
<i>Ac. acerata</i>	-0.197	0.158 ns	<i>Me. kamerunensis</i>	0.885	$2 \times 10^{-10}$ *
<i>As. Africanus</i>	-0.222	0.111 ns	<i>My. opaciventris</i>	0.659	$2 \times 10^{-6}$ *
<i>Bi. dorothea</i>	0.049	0.723 ns	<i>Pa. longicornis</i>	0.709	$4 \times 10^{-7}$ *
<i>Ca. maculatus</i>	0.036	0.798 ns	<i>Pe. carnapi</i>	0.827	$3 \times 10^{-9}$ *
<i>Ct. florella</i>	-0.263	0.059 ns	<i>Ph. megacephala</i>	0.866	$6 \times 10^{-10}$ *
<i>Delta sp.</i>	0.066	0.637 ns	<i>Sy. conuta</i>	0.465	0.001 *
<i>La. hancocki</i>	0.066	0.637 ns			

Table 5. Continued.

Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>Calliphora vicina</i>			<i>La. hancocki</i>		
<i>Ac. acerata</i>	0.652	$3 \times 10^{-6}$ *	<i>Ac. acerata</i>	0.652	$3 \times 10^{-6}$ *
<i>Am. calens</i>	0.472	0.001 *	<i>As. africanus</i>	0.596	$2 \times 10^{-5}$ *
<i>Ap. mellifera adansonii</i>	-0.329	0.018 *	<i>Bi. dorothea</i>	0.959	$6 \times 10^{-12}$ *
<i>As. africanus</i>	0.715	$3 \times 10^{-7}$ *	<i>Ct. florella</i>	0.408	0.003 *
<i>Bi. dorothea</i>	-0.082	0.559 ns	<i>Me. cincta</i>	0.449	0.001 *
<i>Ca. maculatus</i>	0.236	0.091 ns	<i>La. hancocki</i>		
<i>Ct. florella</i>	0.490	$5 \times 10^{-4}$ *	<i>Me. kamerunensis</i>	0.573	$4 \times 10^{-5}$ *



Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>Delta sp.</i>	-0.082	0.559 ns	<i>Pe. carnapi</i>	0.791	$1 \times 10^{-8} *$
<i>La. hancocki</i>	-0.082	0.559 ns	<i>Sy. conuta</i>	0.746	$9 \times 10^{-8} *$
<i>Me. cincta</i>	0.426	0.002 *	<i>Me. cincta</i>		
<i>Me. kamerunensis</i>	0.520	$2 \times 10^{-4} *$	<i>Ac. acerata</i>	0.627	$7 \times 10^{-6} *$
<i>Musca domestica</i>	0.359	0.010 *	<i>As. africanus</i>	0.622	$8 \times 10^{-6} *$
<i>My. opaciventris</i>	0.393	0.005 *	<i>Bi. dorothea</i>	0.426	0.002 *
<i>Pa. longicornis</i>	0.474	0.001 *	<i>Ct. florella</i>	0.403	0.004 *
<i>Ph. megacephala</i>	0.546	$9 \times 10^{-5} *$	<i>Me. kamerunensis</i>	0.518	$2 \times 10^{-4} *$
<i>Pe. carnapi</i>	0.320	0.022 *	<i>Pe. carnapi</i>	0.532	$1 \times 10^{-4} *$
<i>Sy. comuta</i>	0.373	0.008 *	<i>Sy. conuta</i>	0.545	$9 \times 10^{-5} *$
<i>Xy. olivacea</i>	-0.265	0.057 ns	<i>Me. kamerunensis</i>		
<i>Ct. florella</i>			<i>Ac. acerata</i>	0.822	$4 \times 10^{-9} *$
<i>As. africanus</i>	0.670	$2 \times 10^{-6} *$	<i>As. africanus</i>	0.797	$1 \times 10^{-8} *$
<i>Pe. carnapi</i>	0.286	0.040 *	<i>Bi. dorothea</i>	0.546	$9 \times 10^{-5} *$
<i>Delta sp.</i>			<i>Ct. florella</i>	0.493	$4 \times 10^{-4} *$
<i>Ac. acerata</i>	0.652	$3 \times 10^{-6} *$	<i>Pe. carnapi</i>	0.725	$2 \times 10^{-7} *$
<i>As. africanus</i>	0.596	$2 \times 10^{-5} *$	<i>Sy. conuta</i>	0.653	$3 \times 10^{-6} *$
<i>Bi. dorothea</i>	0.959	$6 \times 10^{-12} *$	<i>Mu. domestica</i>		
<i>Delta sp.</i>			<i>Ac. acerata</i>	0.648	$4 \times 10^{-6} *$
<i>Ca. maculatus</i>	0.663	$2 \times 10^{-6} *$	<i>Am. calens</i>	0.758	$6 \times 10^{-8} *$
<i>Ct. florella</i>	0.408	0.003 *	<i>Ap. mellifera adansonii</i>	-0.131	0.348 ns
<i>La. hancocki</i>	1.000	$8 \times 10^{-13} *$	<i>As. africanus</i>	0.609	$1 \times 10^{-5} *$
<i>Me. cincta</i>	0.449	0.001 *	<i>Bi. dorothea</i>	0.487	$5 \times 10^{-4} *$
<i>Me. kamerunensis</i>	0.573	$4 \times 10^{-5} *$	<i>Ca. maculatus</i>	0.636	$5 \times 10^{-6} *$
<i>My. opaciventris</i>	0.462	0.001 *	<i>Ct. florella</i>	0.359	0.010 *
<i>Pa. longicornis</i>	0.439	0.002 *	<i>Delta sp.</i>	0.510	$3 \times 10^{-4} *$
<i>Pe. carnapi</i>	0.791	$1 \times 10^{-8} *$	<i>La. hancocki</i>	0.510	$3 \times 10^{-4} *$
<i>Ph. megacephala</i>	0.573	$4 \times 10^{-5} *$	<i>Me. cincta</i>	0.346	0.013 *
<i>Sy. conuta</i>	0.746	$9 \times 10^{-8} *$	<i>Me. kamerunensis</i>	0.688	$8 \times 10^{-7} *$

Table 5. Continued.

Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>My. opaciventris</i>	0.734	$1 \times 10^{-7} *$	<i>Ph. megacephala</i>		
<i>Pa. longicornis</i>	0.702	$5 \times 10^{-7} *$	<i>Ac. acerata</i>	0.803	$9 \times 10^{-9} *$
<i>Pe. carnapi</i>	0.602	$2 \times 10^{-5} *$	<i>As. africanus</i>	0.797	$1 \times 10^{-8} *$
<i>Ph. megacephala</i>	0.673	$1 \times 10^{-6} *$	<i>Bi. dorothea</i>	0.546	$9 \times 10^{-5} *$
<i>Sy. conuta</i>	0.529	$2 \times 10^{-4} *$	<i>Ct. florella</i>	0.520	$2 \times 10^{-4} *$

Species 1/species 2	tau $\tau$	p-value	Species 1/species 2	tau $\tau$	p-value
<i>Xy. olivacea</i>	0.005	0.971 ns	<i>La. hancocki</i>	0.573	$4 \times 10^{-5}$ *
<i>My. opaciventris</i>			<i>Me. cincta</i>	0.534	$1 \times 10^{-4}$ *
<i>Ac. acerata</i>	0.604	$2 \times 10^{-5}$ *	<i>Me. kamerunensis</i>	0.983	$2 \times 10^{-12}$ *
<i>As. africanus</i>	0.598	$2 \times 10^{-5}$ *	<i>Pe. carnapi</i>	0.703	$5 \times 10^{-7}$ *
<i>Bi. dorothea</i>	0.439	0.002 *	<i>Sy. conuta</i>	0.675	$1 \times 10^{-6}$ *
<i>Ct. florella</i>	0.393	0.005 *	<i>Sy. conuta</i>		
<i>My. opaciventris</i>			<i>Ac. acerata</i>	0.751	$8 \times 10^{-8}$ *
<i>La. hancocki</i>	0.462	0.001 *	<i>As. africanus</i>	0.804	$8 \times 10^{-9}$ *
<i>Me. cincta</i>	0.547	$9 \times 10^{-5}$ *	<i>Bi. dorothea</i>	0.780	$2 \times 10^{-8}$ *
<i>Me. kamerunensis</i>	0.754	$7 \times 10^{-8}$ *	<i>Ct. florella</i>	0.814	$6 \times 10^{-9}$ *
<i>Pa. longicornis</i>	0.784	$2 \times 10^{-8}$ *	<i>Pe. carnapi</i>	0.573	$4 \times 10^{-5}$ *
<i>Pe. carnapi</i>	0.524	$2 \times 10^{-4}$ *	<i>Xy. olivacea</i>		
<i>Ph. megacephala</i>	0.769	$4 \times 10^{-8}$ *	<i>Ac. acerata</i>	0.039	0.783 ns
<i>Sy. conuta</i>	0.537	$1 \times 10^{-4}$ *	<i>As. africanus</i>	0.013	0.926 ns
<i>Pa. longicornis</i>			<i>Bi. dorothea</i>	0.309	0.027 *
<i>Ac. acerata</i>	0.654	$3 \times 10^{-6}$ *	<i>Ca. maculatus</i>	0.198	0.156 ns
<i>As. africanus</i>	0.649	$3 \times 10^{-6}$ *	<i>Ct. florella</i>	-0.009	0.949 ns
<i>Bi. dorothea</i>	0.416	0.003 *	<i>Delta sp.</i>	0.327	0.019 *
<i>Ct. florella</i>	0.404	0.004 *	<i>La. hancocki</i>	0.327	0.019 *
<i>La. hancocki</i>	0.439	0.002 *	<i>Me. cincta</i>	0.205	0.143 ns
<i>Pa. longicornis</i>			<i>Me. kamerunensis</i>	0.098	0.482 ns
<i>Me. cincta</i>	0.534	$1 \times 10^{-4}$ *	<i>My. opaciventris</i>	0.020	0.886 ns
<i>Me. kamerunensis</i>	0.814	$6 \times 10^{-9}$ *	<i>Pa. longicornis</i>	0.115	0.410 ns
<i>Ph. megacephala</i>	0.829	$3 \times 10^{-9}$ *	<i>Pe. carnapi</i>	0.160	0.250 ns
<i>Pe. carnapi</i>	0.562	$6 \times 10^{-5}$ *	<i>Ph. megacephala</i>	0.098	0.482 ns
<i>Sy. conuta</i>	0.537	$1 \times 10^{-4}$ *	<i>Xy. olivacea</i>		
			<i>Sy. conuta</i>	0.140	0.317 ns

ns: not significant correlation ( $p \geq 0.05$ ); \*: significant correlation ( $p < 0.05$ ). Significant correlations are in bold.

*Paratrechina longicornis* (Formicidae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pe. carnapi*, *Ph. megacephala*, and *Sy. conuta*) (Table 5). *Pteropera carnapi* (Acrididae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Ph. megacephala*, and *Sy. conuta*) (Table 5). *Pheidole megacephala* (Formicidae) was positively

correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, and *Sy. conuta*) (Table 5). *Synagris cornuta* (Vespidae) was positively correlated with 16 species (*Ac. acerata*, *Am. calens*, *As. africanus*, *Bi. dorothea*, *Ca. maculatus*, *Cl. vicina*, *Ct. florella*, *Delta sp.*, *La. hancocki*, *Me. cincta*, *Me. kamerunensis*, *Mu. domestica*, *My. opaciventris*, *Pa. longicornis*, *Pe. carnapi*, and *Ph. megacephala*) (Table 5). *Xyloxopa olivacea* (Apidae) was positively correlated with four species (*Ap. mellifera adansonii*, *Bi. dorothea*, *Delta sp.*, and

*La. hancocki*) (Table 5).

## 4. Discussion

### 4.1. Species Richness, Diversity, Abundances

The study carried out on the flower-visiting insects fauna revealed that on *Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae) plant flowers these insects belonged to five orders, 12 families, 18 genera, and 19 species. Hymenoptera represented more than 91.5% of the collected insects. Other orders were rare and represented each by less than 5% of the total collection: Diptera (4.5%), Lepidoptera (1.8%), Neuroptera (0.9%), and Orthoptera (1.3%). Apidae was the most recorded (42.4%) followed by Formicidae (34.1%), Megachilidae (11.6%). Other families were rare and represented each by less than 5%: Acrididae (1.3%), Ascalapidae (0.9%), Calliphoridae (0.5%), Eumenidae (0.7%), Halictidae (2.2%), Muscidae (4.0%), Nymphalidae (1.3%), Pieridae (0.5%), and Vespidae (0.6%). The most recorded species was *Apis mellifera adansonii* (Apidae) (30.6%), followed very far by *Paratrechina longicornis* (Formicidae) (12.3%), *Pheidole megacephala* (Formicidae) (9.4%), *Myrmicaria opaciventris* (Formicidae) (8.9%), *Megachile cincta* (Megachilidae) (7.0%), *Amegilla calens* (Apidae) (6.2%), *Xylocopa olivacea* (Apidae) (5.6%), *Megachile kamerunensis* (Megachilidae) (4.6%), *Musca domestica* (Muscidae) (4.0%), *Camponotus maculatus* (Formicidae) (3.65%), *Lasioglossum hancocki* (Halictidae) (2.2%), and *Pteropera carnapi* (Acrididae) (1.3%) while other species were rare and represented each by less than 1.0%. Amongst these insects, two exotic Diptera (*Calliphora vicina* and *Mu. domestica*) were known as human health pests causing myiasis infections [80-82]. Two useful species (the exotic Eumenidae *Delta* sp. and the afrotropical Ascalapidae predator *Ascalaphus africanus*) were able to be used as biological control agents against phytophagous pest insects such as the Acrididae pest *Pe. carnapi* [101, 112]. The diversity of the recorded flower visiting insects is reminiscent of the reports from several countries including Cameroon on several plant species in market gardens [47, 66, 67, 112-120]. Potential pest insects with phytophagous larvae were Lepidoptera (Nymphalidae and Pieridae) and Orthoptera (Acrididae), cumulatively representing 3.1% of the total collection. Sap-feeding insects were not recorded contrary to the case in other market garden crops in Cameroon [39]. Our results were contrary to those reported in *Se. indicum* plants in Egypt, India [123, 124] and in other market garden plants such as cowpea, potato and eggplant in Cameroon [66, 67]. For illustration, it is the case in cowpea fields in Indonesia, Egypt, Nigeria [47, 116, 125, 126], in cowpea fields in Cameroon [39], in potato and eggplants fields in Cameroon [39, 45, 46-53, 63-67] where Homoptera Aphididae was highly recorded. The recorded number of species was low compared to the situation reported in Egypt where 31 insect species collected on *Se. indicum* plants were divided into four groups,

true pollinators (Hymenoptera), other pollinators (Diptera, Coleoptera and Lepidoptera), pests (Orthoptera, Odonata, Hemiptera and Homoptera) and natural enemies (Coleoptera, Hymenoptera, Neuroptera and Dictyoptera) [120]. It was the same in India where *Sesamum* flowers attracted 24 species belonging to 17 families under eight orders in Odisha locality [121] and 34 insect species belonging to 18 families from four orders in Haryana locality [124]. The species richness of the flower-visiting insects was quite close to the observations made in cowpea fields in India where a list of 19 insect species was reported [65]. Similar results were reported in cowpea plantations in Cameroon where flowers were visited by insects belonging to six orders, 13 families, 19 genera and 19 species and where Coleoptera, Hemiptera and Hymenoptera were species-rich orders (five species each i.e. 26.3%) and Hemiptera was mostly abundant (40.0%) followed by Coleoptera (27.6%), Hymenoptera (21.9%), Lepidoptera (0.9%). Heteroptera and Orthoptera (0.8% respectively) [39]. The peculiarity of our results was the absence of five main taxa frequently recorded in market garden fields (Coleoptera, Dictyoptera, Hemiptera, Homoptera, and Odonata) certainly due to the short time period of our study (13 consecutive days from the first day of the flowering period: the week of the early blooming stage and the first week of the mid bloom stage) and probably due to a low production of the attractive scent by the blooming flowers since plants were not at their optimal flowering period. It is well known that flowers progressively appear on mature plants (reproductive period) and each blooming flower remain on the plants for ten days. The blooms do not open all at once, but gradually from the base of the stem upwards to the top of the plant [125, 126]. Due to the non uniform, indeterminate nature of the blooming period, the reproductive, ripening, and drying phases of the seed tend to overlap, seed lowest on the plant being mature first, even as the upper part of the plant is still flowering or has just formed seed capsules [126]. The duration of the early blooming stage of the mature plants (not all flowers set capsules) is one week, the duration of the mid bloom stage is four weeks (over 70% of flowers occur in first two weeks of this stage) and the duration of the last blooming stage is one week (leaves in light start to fall off), making a total of six weeks for the reproductive phase of the mature plants [125-127]. Even though the reproductive stage can go on for six weeks, weeks two and three produce 70-75% of the flowers and it is the most important two weeks of the cycle [127]. Thus, our study period would certainly only concern a few cohorts of flowers produced. In the localities of Bilone (Obala-Cameroon), natural enemies were the most recorded (Hymenoptera, and Neuroptera with one family: 92.4% of the total collection) followed by the true pollinators (Hymenoptera with six families: 91.5%) while rare taxa were other pollinators (Diptera and Lepidoptera with two families each: 6.3%), and pests (Orthoptera with one family: 1.3%), suggesting that flowers of *Se. indicum* were widely and frequently visited by beneficial insects (pollinators). Nevertheless, the low rate of visited



flowers (20.3% during the two campaigns: 5.7% in 2022 and 14.7% in 2023) suggested either flowers did not necessarily need pollinating insects because they are hermaphrodite with facultative allogamy, producing both nectar and pollen attractive to insects [128] or the scarcity of associated entomofauna in neighboring sites. Moreover it was demonstrated in the locality of Bambui (North-West of Cameroon) that *Se. indicum* presented a mixed allogamous-autogamous reproduction regime with the predominance of autogamy [43]. Blooming flowers of *Se. indicum* produce nectar attractive to pollinator and non-pollinators, which allowed this plant species to be classified in the category of highly nectar-producing plants and weekly pollen-producing bee plants. Therefore it is necessary to preserve plants of *Se. indicum* and/or cultivate them not far from the hives. Consequently, bee foragers could play a positive role on geitogamy [64] by depositing the pollen of one flower on the stigma of another flower of the same plant. Foragers that passed from flower to flower could transport pollen from one plant to another and thus allow xenogamy by putting the pollen from one plant on the stigma of a flower belonging to another plant. Apoides are known as pollinators of *Se. indicum* in Egypt [129] and in Bambui (North-West Cameroon) [43] and even pollinators of cowpea in Yaounde, Maroua and Ngaoundere [39, 44]. Rare species included a native phytophagous Orthoptera (one family: 1.3%) known as pest for plants and two exotic Diptera (*Calliphora vicina* native to North America and *Mu. domestica* native to the Palearctic Region) known as responsible of human myiasis infections. These phytophagous insects and myiasigenic species are frequently recorded in anthropized areas [61, 101]. The damage caused by phytophagous insects (Coleoptera Chrysomelidae, Hymenoptera, Lepidoptera and Orthoptera) is greater on leaves and pods because at the fruiting stage, plants emit volatile compounds which attract insects (pollinators, predators and pests including phytophagous insects). The situation found in the localities of Bilone (Obala-Cameroon) in *Se. indicum* plots is therefore not surprising. In market garden crops (example of the reports from Ivory Coast, Egypt, Nigeria [47, 116, 125, 126], and Cameroon [39, 45, 46-53, 63-67, 130]), aerial plant organs such as leaves, flowers and pods can be more attacked than other plant organs, depending on the high production periods. Our study is the first step in evaluating the species richness of flower visiting native and non-native insects on *Se. indicum* flowers. In *Se. indicum*, pollen is produced by the anthers which are easily accessible to the foragers, while, the nectar produced in the corollary tube, is difficult to access as already noted in Bambui (West-Cameroon) [43]. Plots of *Se. indicum* showed low species richness (richness ratio close to null), high species diversity (Shannon-Weaver index close to the maximum value), a low dominance level of a few species (Berger-Parker index inferior to the median value) and a high level of the species evenness (Pielou index close to one). Similar results are reported in ground-dwelling ants in anthropized environments [113, 131, 132], in the assemblages of insects as-

sociated with potato plants [67] or eggplants [66], in the assemblage of the floricultural insects associated with cowpea plants [39]. Recent reports show that the same orders and families damage chili pepper plants (*Piper nigrum* L.) in the locality of Penja-Cameroon [133]. The low diversity of the flower visiting insects was associated with a high abundance in native species, resulting in the high exploitation of resources. The exploitation of both food and nest sites was rarely achieved by non-native species (15.8% of the total species richness and 5.2% of the total abundance). These results were contrary to the reports in cowpea, egg-plant and potato fields in Cameroon [39, 66, 67]. Based on the reports on the harmful activity of non-native species in the localities of introduction, they would carry out in Bilone a similar activity in sesame plots. The low representation of exotic species could be the result either of the regulation of their populations by local enemies or of unsuitable environmental conditions in the study location.

## 4.2. Community Structure and Functioning

Assemblage of flower-visiting insects in Bilone best fitted in 2022, the LL model with a Motomura environmental constant close to one ( $m=0.777$ ). In 2023 and the pooled campaigns, settlements best fitted the LN model (Preston niche partitioning model) with in each case a Preston environmental constant close to one ( $m'=0.726$  and  $m'=0.732$  respectively). LL model reflects a community where the majority of species show moderate abundance (a community in which a reduced number of species is largely dominant, or a pioneer assemblage) [134]. High values of the Motomura or the Preston parameters suggest a high decay rate of abundance per rank of the species, as reported in pioneer assemblages (elementary interspecies relations with competition limited to the physical space) [135]. LL (niche partitioning model) is reported fitting SADs of ground-dwelling ants in France [136] and in Cameroon [120], the dung beetles in the Southern Alps [137], sand flies in Congo [138], the Carabidae and Heteroptera in Finland [139], grasshoppers in Cameroon [140], insects associated with potato plants, eggplants and cowpea plants in Cameroon [66, 67, 132]. LN is reported fitting SADs of invertebrates [138, 140, 141] and characterizes open or less disturbed environments. It is well known that human activities in general, resulting in large deforestation, urbanization and growing cities affect ecosystem functioning and contribute to the loss of biodiversity [142]. A similar situation occurs in Bilone. LL niche partitioning and LN models reflect communities with moderately abundant majority of species. It is well known that nomocenosis are associations of species subject to the influence of the same factors and whose species profile is sufficiently close to be assimilated to LL or LN representation (open or more or less disturbed environments) with a strong competition between pioneer species for exploitation of available resources [142].

## 5. Conclusion

The purpose of this study was to determine the biodiversity of the flower-visiting insects on *Sesamum indicum* and characterize their community structure. Specimens belonged to five orders, 12 families, 18 genera and 19 species. Hymenoptera was the most recorded (91.5% of the collected insects). Other orders were rare: Diptera (4.5%), Lepidoptera (1.8%), Neuroptera (0.9%), and Orthoptera (1.3%). Apidae was the most recorded family (42.4%) followed by Formicidae (34.1%), Megachilidae (11.6%) and other families were rare: Acrididae (1.3%), Ascalapidae (0.9%), Calliphoridae (0.5%), Eumenidae (0.7%), Halictidae (2.2%), Muscidae (4.0%), Nymphalidae (1.3%), Pieridae (0.5%), and Vespidae (0.6%). *Apis mellifera* (Apidae) was the most recorded species (30.6%), followed by *Paratrechina longicornis* (Formicidae) (12.3%), *Pheidole megacephala* (Formicidae) (9.4%), *Myrmecaria opaciventris* (Formicidae) (8.9%), *Megachile cincta* (Megachilidae) (7.0%), *Amegilla calens* (Apidae) (6.2%), *Xylocopa olivacea* (Apidae) (5.6%), *Me. kamerunensis* (Megachilidae) (4.6%), *Musca domestica* (Mus-

cidae) (4.0%), *Camponotus maculatus* (Formicidae) (3.65%), *Lasioglossum hancocki* (Halictidae) ((2.2%), and *Pteropera carnapi* (Acrididae) (1.3%). Two exotic Diptera (*Calliphora vicina* and *Mu. domestica*) were myiasogenic species. Two useful species were recorded (the exotic Eumenidae *Delta* sp. and the Ascalapidae predator *Ascalaphus africanus*). Assemblages showed low species richness, high species diversity, a low dominance of a few species and the community was highly even. The sampling success was maximal. The number of simply abundant species was close to the number of co-dominants. Overall, insects exhibited in 2022 and 2023, a positive net association in presence/absence data. A few negative correlations (mutual repulsion) and several positive correlations (mutual tolerance) were noted. *Calliphora vicina* (Calliphoridae) was negatively correlated with *Ap. mellifera* (Apidae). Positive correlation was recorded in several combinations and the community functioned on the base of niche partitioning models (LL in 2022, LN in 2023 and the pooled years), suggesting a more or less disturbed environment with a strong competition between pioneer species for the available resources.

## Abbreviations

<i>Ac. acerata</i>	<i>Acraea acerata</i> Hewitson. 1874
ACE	Abundance Coverage-based Estimator
AIC	Akaike Information Criteria
<i>Am. calens</i>	<i>Amegilla calens</i> (Lepeletier De Saint-Fargeau.1841)
<i>Ap. mellifera adansonii</i>	<i>Apis mellifera adansonii</i> Latreille. 1804
<i>As. africanus</i>	<i>Ascalaphus africanus</i> (McLachlan. 1871)
<i>Bi. dorothea</i>	<i>Bicyclus dorothea</i> (Cramer. 1779)
BC	Bray-Curtis Index
BIC	Bayesian Information Criteria
BS	Broken-Stick Theoretical Model
<i>Ca. maculatus</i>	<i>Camponotus maculatus</i> (Fabricius. 1782)
<i>Cl. vicina</i>	<i>Calliphora vicina</i> Robineau-Desvoidy. 1830
<i>Ct. florella</i>	<i>Catopsilia florella</i> (Fabricius. 1775)
CRC	Central Regional Council
FAOSTAT	Food and Agricultural Organization Statistics
GBIF	Global Biodiversity Information Facility
GM	Geometric Theoretical Model
IRAD/ARID	Institut de Recherche Agricole Pour le Développement/Agricultural Research Institute for Development
ICE	Incidence Coverage-based Estimator $\hat{c}$
ITIS	Integrated Taxonomic Information System
OHIAM	Obala Higher Institute of Agriculture and Management
<i>La. hancocki</i>	<i>Lasioglossum (Ipomalictus) hancocki</i> (Cockerell 1945)
LL	Loglinear Theoretical Model
LN	Lognormal Theoretical Model
<i>Me. kamerunensis</i>	<i>Megachile (Chalicodoma) kamerunensis</i> Friese. 1922
<i>Me. cincta</i>	<i>Megachile (Chalicodoma) cincta</i> (Fabricius. 1781)
<i>Mu. domestica</i>	<i>Musca domestica</i> Linnaeus. 1758
<i>My. opacivenyrtis</i>	<i>Myrmecaria opaciventris</i> Emery. 1893
<i>Pa. longicornis</i>	<i>Paratrechina longicornis</i> (Latreille. 1802)
<i>Pe. carnapi</i>	<i>Pteropera carnapi</i> Ramme. 1929

<i>Ph. megacephala</i>	<i>Pheidole megacephala</i> (Fabricius. 1793)
POWO	Plant of the World Online
SAD	Species Abundance Distribution
sp.	Undetermined Species
<i>Se. alatum</i>	<i>Sesamum alatum</i> Thonn.
<i>Se. indicum</i>	<i>Sesamum indicum</i> L. (1753)
<i>So. tuberosum</i>	<i>Solanum tuberosum</i> L., 1753
SPSS	Statistical Package for the Social Sciences
<i>Sy. conuta</i>	<i>Synagris conuta</i> (Linnaeus. 1758)
VR	Variance Ratio
<i>Xy. olivacea</i>	<i>Xylocopa olivacea</i> (Fabricius 1778)
Z	Zipf Model
ZM	Zipf-Mandelbrot Model

## Acknowledgments

The authors acknowledge the Cameroonian Ministry of Higher Education for providing funds through the research support program. They thank the elders of the Laboratory of Applied Zoology of University of Ngaoundere for assistance in the insect identification and the manuscript preparation.

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## Data Availability Statement

The data is available from the corresponding author upon reasonable request.

## Conflicts of Interest

The authors declare no conflicts of interest.

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## Research Field

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