



Exploring the Pollinator Community: Diversity and Abundance of Flower- Visiting Insects on Cowpea in Bilone, Obala, Cameroon

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Authors' contributions

This work was carried out in collaboration among all authors. Authors' PAM, FNTF and MK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors' ASKT, SJT and MK managed the analyses of the study. Authors' MM, Taimanga, JBP, AVTI, XANO, NEOA, CD managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Investigations in cowpea fields allowed the characterization of the community structure of flower-visiting insects.

Study Design: Seeds were sown in 15 plots (6x5.5 m each).

Place and Duration of Study: Campus of Obala Higher Institute of Agriculture and Management (OHIAM), Bilone agroecological farm (Obala-Cameroon), from May to June 2016 and 2017.

Methodology: Insects were identified *in-situ* or captured and stored in papillotes (Lepidoptera adults) or labelled vials containing 70° ethanol (other insects). Abundances allowed the determination of 11 alpha diversity indices. Beta diversity was tested using Bray-Curtis dissimilarity index and the correlation between species occurrences.

Results: A total of 929 specimens belonged to five orders, 10 families, 13 species were recorded. Hymenoptera was the most family-rich and abundant (four families, 94.3% of the collection) followed by Diptera and Lepidoptera (two families each). Neuroptera and Orthoptera (one family each). Apidae was the most species-rich and abundant (three species; 72.9%), then Formicidae (one, 10.1%), Megachilidae (two; 9.8%). *Apis mellifera* (Apidae) was the most abundant (35.5%), then *Xylocopa olivacea* (Apidae) (22.3%), *Amegilla calens* (Apidae) (15.1%), *Myrmecaria opaciventris* (Formicidae) (10.1%), and *Megachile (Chalicodoma) cincta* (Megachilidae) (8.2%). The afro-tropical useful predator *Ascalaphus africanus* (Ascalapidae) and the phytophagous pest *Pteropera carnapi* (Acrididae) were recorded. Exotic myasigenic species *Calliphora vicina* (Calliphoridae) and *Musca domestica* (Muscidae) were recorded. Acrididae, Nymphalidae and Pieridae cumulatively represented 3.1% pest species in the collection. Assemblages showed low species richness, high species diversity, and highly even community. Numbers of simply abundant species were close to that co-dominants. A negative correlation was noted between *Acraea acerata* (Nymphalidae) and *Apis mellifera adansonii* (Apidae), *Ap. mellifera* and *Calliphora vicina* (Calliphoridae), *Ap. mellifera* and *Synagris conuta* (Vespidae). Several positive correlations were recorded.

Conclusion: In Bilone, results highlighted the importance of flower-visiting insects for the cowpea pollination and crop yield. Species were moderately abundant and assemblages functioned on the base of niche partitioning nomocenosis (log-linear model) of more or less disturbed environments with strong competition between pioneer species for the available resources.

Keywords: *Assemblage composition; Co-dominant species; rare species; theoretical model; assemblage functioning; cowpea plants.*

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Ac. acerata: *Acraea acerata* Hewitson. 1874; AIC: Akaike Information Criteria; *Am. calens*: *Amegilla calens* (Lepeletier De Saint-Fargeau.1841); *Ap. mellifera*: *Apis mellifera* Linnaeus. 1758; *As. africanus*: *Ascalaphus africanus* (McLachlan. 1871); *Bi. dorothea*: *Bicyclus dorothea* (Cramer. 1779); BC: Bray-Curtis index; BIC: Bayesian Information Criteria; BS: Broken-Stick theoretical model; *Ca. vicina*: *Calliphora vicina* Robineau-Desvoidy. 1830; *Ct. florella*: *Catopsilia florella* (Fabricius. 1775); FAOSTAT: Food and Agricultural Organization Statistics; GBIF: Global Biodiversity Information Facility; IRAD/ARID: Institut de Recherche Agricole pour le Développement / Agricultural Research Institute for Development; ITIS: Integrated Taxonomic Information System; OHIAM: Obala Higher Institute of Agriculture and Management; LL: Log-linear theoretical model;

Me. kamerunensis: *Megachile (Chalicodoma) kamerunensis* Friese. 1922; *Me. cincta*: *Megachile (Chalicodoma) cincta* (Fabricius. 1781); *Mu. domestica*: *Musca domestica* Linnaeus. 1758; *My. opacivenytrtis*: *Myrmecaria opaciventris* Emery. 1893; *Pe. carnapi*: *Pteropera carnapi* Ramme. 1929; POWO: Plant of the World Online; SAD: Species Abundance Distribution; sp.: undetermined species; SPSS: Statistical Package for the Social Sciences; *Sy. conuta*: *Synagris conuta* (Linnaeus. 1758); VR: Variance Ratio; *Xy. olivacea*: *Xylocopa olivacea* (Fabricius 1778); Z: Zipf model; ZM: Zipf-Mandelbrot model.

1. INTRODUCTION

Vigna unguiculata (L.) Walp., 1843 (Fabales: Fabaceae) is an annual seed legume (herbaceous plant) and one of the most cultivated in the world. Some authors report that it is native to South Africa and secondary spread

throughout the world (Edeh & Igberi, 2012, Badiane, et al., 2014, Abebe, et al., 2022). Cowpea seeds are highly rich in protein, fibres, energy, micronutrients including iron and vitamin A, C and E and minerals like copper, iron, calcium, manganese, magnesium, sodium and macro-nutrients whose deficiencies are prevalent in Sub-Saharan African countries (Horn & Shimelis, 2020, Owade, et al., 2020, Abebe, et al., 2022). In sub-Saharan Africa, cowpea is cultivated for the leaves and seeds because they play a crucial role in feeding humans and livestock and the creation of income for farmers as well as sellers of food products (Omoigui, et al., 2018, Horn & Shimelis, 2020, Owade, et al., 2020, Abe, et al., 2022). Bisexual flowers produce nectar, pollen and indehiscent pods (Abebe, et al., 2022). Seeds are highly rich in proteins ($\geq 25\%$) (lysine: 427 mg.g^{-1} of azotes, and tryptophan: 68 mg.g^{-1} of azotes although poorly rich in sulfur amino-acids) (Singh, et al., 2003). The consumption of cowpea seeds helps fight against malnutrition and much more, the folic acid content is of importance in pregnant women (protection against malformation of the newborn) (Amougou & Breuil, 2018). It is also an excellent source of antioxidants for the body (Amougou & Breuil, 2018). Global cowpea production is estimated as 6.4 million tons per year, of which Sub-Saharan Africa accounts for approximately 95.0% (FAO, 2022). Nigeria is the main producer and consumer with production estimated as 3.2 million tons per year (FAOSTAT, 2021, 2024). In Cameroon, the cowpea annual production is low and this country occupies the eighth position among the main African cowpea producing countries, with an annual production estimated as 156.2 tons per year (FAOSTAT, 2021). Then 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 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 reported (Horn & Shimelis, 2020). Other reports point out the 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, 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 (Mengui, et al., 2019, Horn & Shimelis, 2020, Goac, et al., 2021). The relationships between floricultural plants and their pollinators have been intensively studied in the world. In Cameroon as reported in the literature, many plant species depend on the pollination by insects. Efficient pollination by insects increases fruit yield in tomato fields in Dang (Adamaoua-Cameroon) (Kingha, et al., 2021), cowpea fields in Bockle and Dang (North and Adamaoua respectively) (Mohammadou, et al., 2023a, 2023b), eggplant fields in the West (Fouelifack-Nitidem, et al., 2021), potato fields in the West (Ngamaleu-Siewe, et al., 2021) and sesame fields in the North-West (Otiobo, et al., 2016). Via the pollinating efficiency, the installation of Apoidea's nests around plantations is recommended to improve fruit and seed yields (Tchuenguem, et al., 2009, Djonwangwe, et al., 2017, Adamou, et al., 2020, Mazi, et al., 2020; Kingha, et al., 2021, Mohammadou, et al., 2023a). As reported by Potts, et al. (2010), pollinators are a key component of global biodiversity, providing vital ecosystem services to crops and wild plants and there is clear evidence of recent declines in both wild and domesticated pollinators, and parallel declines in the plants that rely upon them. Indeed, in natural environments as well as in agro-ecosystems, floricultural insects in general and Apoidea (Hymenoptera) including *Apis mellifera* Linnaeus, 1758 (Hymenoptera: Apidae) in particular have great ecological and economic importance as pollinators, because they positively influence agro-food production (Tchuenguem, et al., 2009, Pharaon, et al., 2019). Hence the preservation of pollinator insects, particularly *Ap. mellifera*, in cultivated plots, is nowadays recommended (Mohammadou, et al., 2023a, 2023b). In the rural area of Cameroon, market gardening activities are on the rise, but they are practiced by young farmers, little educated, unassisted and each having a fairly low income. In market garden crops, the beneficial activity of pollinators is widely reported (Garibaldi, et al. 2013, Srinivasa, et al., 2018, Ba, et al., 2020, Zra, et al., 2020, Ekka, et al., 2020). Despite the diversified flora and a flourishing market gardening activity in Bilone (Obala-Cameroon), there is no information concerning the community composition and structure of the flower-visiting insects on cowpea

plants, able to boost the plant yield. The purpose of this study is to identify insects active on flowers of cowpea and thus those which influence the quality and/or quantity of agricultural yields. These works should make it possible to characterize the flower-visiting insects in the field condition in Bilone (Obala-Cameroon).

2. MATERIALS AND METHODS

2.1. Study Site

The study was carried from May to June 2016 and 2017 at Bilone agroecological farm (4°10'19.48"N, 11°30'06.53"E; 554 m a.s.l.), campus of the Obala Higher Institute of Agriculture and Management (OHIAM). Bilone village is located northwest of Obala city (Central Region, Lekie Department) (Fig. 1A, 1B and 1C), not far from the national N4 road (Fig. 1D and 1E) (Djimarbeye, et al., 2024). The Obala locality is located in the forest-savannah ecotone and belongs to the dense tropical rainforest agroecological zone (Manfo, 2018; Djimarbeye et al., 2024). It presents a mosaic of fallows, home gardens, and cocoa plantations of varying sizes and ages (Manfo, et al., 2015). The prevailing climate in Obala locality is a Guinean equatorial savannah type with dry winter (type Aw) according to the Köppen-Geiger classification with four seasons (Kottek, et al., 2006): a short rainy season (mid-March to mid-July), 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). The rainfall in the Lekie department (around 1600 mm per year) is maximal in September. Soils are ferralitic, thick, homogeneous in appearance and are formed on altered original material on which uneven vegetation develops. In the Central Region of Cameroon, the forest (characterized by the abundance of leguminous plants) is mutilated by human activities, notably the urban and agricultural development. The major cultivated industrial crops include *Coffea arabica* L., 1753 (Rubiales: Rubiaceae), *Elaeis guineensis* Jacq., 1763 (Arecales: Arecaceae), *Musa x paradisiacal* L., 1753 (Zingiberales: Musaceae), and *Theobroma cacao* L., 1753 (Malvales: Sterculiaceae).

In OHIAM, the main cultivated plant species were *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), *Gymnanthemum amygdalinum* (Delile) Sch.Bip. ex Walp., 1843 (= *Vernonia amygdalina* Delile) (Asterales: Asteraceae), *Lantana camara* L., 1753 (Lamiales: Verbenaceae), *Mangifera indica* L., 1753 (Sapindales: Anacardiaceae), *Manihot esculenta* Crantz, 1766 (Malpighiales: Euphorbiaceae), *Oryza* spp. L., 1753 (Poales: Poaceae), *Persea americana* Mill., 1768 (Laurales: Lauraceae), *Phaseolus vulgaris* L., 1753 (Fabales: Fabaceae), *Psidium guajava* L., 1753 (Myrtales: Myrtaceae), *Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae), *Solanum lycopersicum* L., 1753 (Solanales: Solanaceae), *Solanum tuberosum* L., 1753 (Solanales: Solanaceae), *Solanum* sp. (Solanales: Solanaceae), *Theobroma cacao* L., 1753 (Malvales: Sterculiaceae), and *Zea mays* L., 1753 (Cyperales: Poaceae). The main wild plants were *Bidens pilosa* L., 1753 (Asterales: Asteraceae), *Mimosa invisa* Mart. ex Colla, 1834 (Fabales: Mimosaceae), and *Tithonia diversifolia* (Hemsl.) A. Gray, 1883 (Asterales: Asteraceae).

2.2. Experimental Device and Procedure

In OHIAM, experimental plots are of similar dimensions (6x5.5 m each), surrounded by market gardening plots and old fallows. Seeds of *Vigna unguiculata* (L.) Walp., 1843 (Fabales: Fabaceae) (small and brown 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 15 experimental plots were delimited, cleared, and plowed. Plots were separated from each other by a two meters wide path and from neighbouring non-experimental plots as well as fallows by a safety space of two meters. In each plot, sowing was done in rows (five rows per plot) 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.



Fig. 1. Localization map of the study site. A: Centre Region in Cameroon (Djimarbeye, et al., 2024); B: Lekie department in the Centre Region (adapted from Djimarbeye, et al., 2024); C: Obala in the Lekie department (adapted from Djimarbeye, et al., 2024); D: Distance from Obala to the Bilone agroecological farm (Google Earth Pro for windows version 7.3.4.8642; from Pharaon, et al., 2024); E: study site at Bilone agroecological farm (Google Earth Pro for windows version 7.3.4.8642; from Pharaon, et al., 2024)

From the start of the flowering period (mid-May in 2016 and 2017) to fruit maturity (end of June in 2016 and July in 2017), manual weeding was regularly carried out. Six hives with colonies of *Apis mellifera* Linnaeus, 1758 (Hymenoptera: Apidae) were positioned between 20 and 24 m from the experimental plots, other colonies being non-inventoried in the vicinity of the study station.

Nests of *Xylocopa olivacea* (Fabricius, 1778) (Hymenoptera: Apidae) were inventoried in the wood of the framework of buildings at OHIAM station, located nearly 200 m from the plots and whose number varied from 9 in 2016 to 15 in 2017 and other unidentified nests were naturally present in the experimental environment. Apart from *Ap. mellifera* and *Xy. olivacea* whose nests were found in the station, other insect species found on cowpea flowers came naturally from the environment. During the flowering period, one or two cowpea plants were randomly selected in nine and six plots respectively each monitoring day and blooming flowers were checked on the selected plants.

2.3. Sampling Design: Capture and Determination of the Flower-Visiting Insects

Throughout the investigation period a total of 2730 flowers were checked in 25 days during the flowering period of the cowpea plants in 2016 (13 first days of the flowering period, 1,380 flowers checked, eight to 213 flowers a day, 126±19 flowers in average) and in 2017 (12 first days of the flowering period, 1,333 flowers checked, 23 to 222 flowers a day, 111±20 flowers in average). Then in 2016, 46 flowers, 75, 102, 146, 186, 198, 213, 156, 124, 57, 46, 23, and 8 were checked from the 1st to the 13th day respectively and in 2017, 30 flowers, 56, 102, 146, 186, 198, 222, 156, 111, 57, 46 and 23 were checked from the 1st to the 12th day respectively. Collection sessions were conducted from 8th June to 2nd July in 2016 and from 7th June to 29th June in 2017. Consecutive session days were separated by two days. Flowers were checked each day, in five time slots (6-8 a.m., 9-10 a.m., 11 a.m.-12 p.m., 1-2 p.m. and 3-4 p.m.). Insects visiting the blooming flowers were identified *in-situ* when

possible or captured with bare hands (large non-flying insects), a pair of soft tweezers or a mouth aspirator (non-flying small insects) or with a sweeping net (flying insects). Specimens were stored in labeled glass pill boxes containing 70% ethanol, except adults of Lepidoptera and Odonata which were stored dry in papillotes.

2.4. Identification of Insect Specimens

In the laboratory, collected specimens were identified to the family level using the identification keys of Delvare & Aberlenc (1989). Bees were identified to the species level using keys of Eardley et al. (2010), Lecoq (2010), Brailovsky (2014), Tronquet (2014), Taylor (2015), and Zettler et al. (2016). Recent checklists, illustrated catalogues and websites were consulted for recent developments in the taxonomy of Diptera (Nihei & De Carvalho, 2009, Whitworth, 2010, Hewitt, 2011), Hymenoptera (Carpenter, 2008; Gusenleitner & Madl, 2012; Taylor, 2015, Pauly, 2015, 2001; Oyerinde, 2017; Madl, 2020; GBIF Secretariat, 2023, Selis, 2023), Lepidoptera (Aduse-Poku, et al., 2015; Pauly, 2016, Dongmo et al., 2017, Kioko, et al. 2021, GBIF Secretariat, 2023), Neuroptera (Tjeder & Hansson, 1992; Prost, 2013, Oswald, 2024), and Orthoptera (Yetchom, et al., 2014). Identifications were done in the Laboratory of Applied Zoology, Department of Biological Sciences, Faculty of Science, University of Ngaoundere where voucher specimens were deposited.

2.5. Data Analysis

Abundance counts were stored each year in a species matrix constructed using an excel spreadsheet version 2016. Percentages were calculated from the overall total number of captured specimens. 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), since normality and equal variance tests passed. Comparison of two frequencies was done using the Fisher's exact-test from StatXact software 3.1. The correlation between occurrences of insects was evaluated by determining the Kendall coefficient. Regression equations were set up when relevant and tested using ANOVA procedure.

Absolute abundance of all recorded i species n_i allowed the determination using PAST 3.05 software (Hammer, et al., 2001) of 11 alpha diversity indices: the sample size n (sum of n_i),

the maximum abundance n_{max} , the relative abundance of the i^{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 $H'_{max}=\ln(S)$, 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 first order non-parametric estimator Chao 1 ('true' theoretical species richness), Pielou's evenness index $J=H'/H'_{max}$, and Berger-Parker index $I_{BP}=n_{max}/n$ with $0 \leq I_{BP} \leq 1$. The sampling success was determined as $SE=(S/Chao\ 1)*100$. Comparison of the species richness was performed using the individual rarefaction procedure and pairwise comparison of diversities (H' and D) was performed using the Student t-test from PAST 3.05 software (Hammer, et al., 2001). Hill's diversity numbers were determined as $N_1=e^{H'}$ (estimator of the number of simply abundant species) and $N_2=1/D$ (estimator of the number of co-dominant species). 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} close to 0 for equally abundance).

For the beta diversity evaluation, the dissimilarity between records in 2016 and those obtained in 2017 was done using the Bray-Cutis's index (Chao, et al., 2005). Overall species covariance was evaluated using the Schluter's procedure (Schluter, 1984) and between species correlations was determined using the Kendall's tau coefficient. Rank abundance plotting was used to illustrate the shape of the species abundance distributions (SADs). Species were first ranged in decreasing order of abundance. Value of the Bravais-Pearson correlation coefficient between ranks i and the logarithmic transformed abundance series $\text{Log}(n_i)$ make it possible to adjust the observed Species Abundance Distributions (SADs) to five theoretical models (McGill, et al., 2007), 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 was selected using the Akaike Information Criteria (AIC) or the lowest Bayesian Information Criteria (BIC) (Johnson & Omland, 2004) as the one with the lowest value of AIC or BIC. For each selected theoretical model, the estimated sample size n^* was adjusted to the observed sample size n using the correction factor $c=n/n^*$. Parameters

and the corrected model were given. BS model has a single parameter x (average abundance). LL corresponds to the linear regression $\text{Log}_2(n_i)=a(i)+b$ where i is the rank of the species in decreasing order of abundance, n_i is the abundance of the i^{th} species, a and b represent the slope and the elevation of the regression respectively. LL depends on the maximum abundance of the top-ranking species n_1 and the Motomura's environment constant m (antilogarithm of the regression slope a , with $0 \leq m \leq 1$). The m parameter gives the rate of decrease in abundance by rank. LN corresponds to the linear regression $\text{Log}_2(n_i)=a(\text{Pi})+b$ or $n_i=c \cdot 2^b \cdot (2^a)^{\text{Pi}}$ where Pi represents the probit of the i^{th} species. For a species of rank i , the cumulative percentage linked to the rank $k_i=100(i+0.5)/(S+1)$ when S was odd or $k_i=100((i+1)+0.5)/(S+1)$ when S was even, was calculated and the probit was 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 σ 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 (Li, 2002; Kopleinig, 2015) and parameters are Q as the scaling parameter (normalizing constant), and γ (gamma) as the average probability of the appearance of a species (Li, 2002). ZM is a generalized model in which a new parameter β (beta) is added. Marquardt's non-linear least squares algorithm (Le, et al., 2012, Murthy (2014), was used when relevant to estimate β , γ and $1/\gamma$ parameters (fractal dimension of the distribution of individuals among species).

3. RESULTS

3.1. Inventory and Abundances of the Flower Visiting Insects

A total of 929 adult insects (411 in 2016 and 518 in 2017) collected belonged to five orders (three in 2016 and five in 2017), 10 families (seven in 2016 and 2017 respectively), and 13 species (10 in 2016 and nine in 2017). Abundances varied from three to 330 specimens (mean \pm se: 71 \pm 8 specimens; median: Me=15 specimens) (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 (four families) followed by Diptera and

Lepidoptera (two families each). Neuroptera and Orthoptera were rare (one family each) (Table 1). Globally, flower visiting insects were mostly collected in 2017 than 2016 (Table 1). Acrididae, Ascalapidae, and Muscidae were not recorded in 2016. Diptera, Hymenoptera were mostly collected in 2017 (Table 1). Families were Acrididae MacLeay, 1821 (Orthoptera), Apidae Latreille, 1802 (Hymenoptera), Ascalapidae Rambur, 1842 (Neuroptera), Calliphoridae Hough (d), 1899 (Diptera), Formicidae Latreille, 1809 (Hymenoptera), Megachilidae Latreille, 1802 (Hymenoptera), Muscidae Latreille, 1802 (Diptera), Nymphalidae Rafinesque, 1815 (Lepidoptera), Pieridae Swainson, 1820 (Lepidoptera), Vespidae Latreille, 1802 (Hymenoptera) (Table 1). Calliphoridae, Nymphalidae, and Vespidae were not recorded in 2017 (Table 1). Apidae, Formicidae, Megachilidae, and Pieridae were commonly recorded in 2016 and 2017 (Table 1). Hymenoptera was mostly recorded (94.3%). Other orders were rarely represented each by less than 3% of the total collection (Table 1). Apidae was the most collected (72.9%) followed by Formicidae (10.1%), Megachilidae (9.8%) and other families were rare (less than 2% of the collection) (Table 1). Apidae was mostly collected in 2017 while it was the contrary in Formicidae in 2016 (Table 1). Mean or median occurrences in 2016 (four to 109 specimens, mean \pm se: 41 \pm 4 specimens, median abundance: Me=24 specimens) was not statistically different from the records in 2017 (three to 221 specimens, 58 \pm 8 specimens, Me=15 specimens) (Student t-test: $t=-0.617$, $df=17$, $p=0.5463$; Mann-Whitney rank sum test: $T=92.00$, $p=0.902$) (Table 1). In each year, Apidae (Hymenoptera) was the most abundant (26.9%, 46.0% and 72.9% in 2016, 2017 and the pooled years respectively) (Table 1). It was followed very far by Formicidae (8.8%, 1.3% and 10.1% in 2016, 2017 and the pooled years respectively) and Megachilidae (5.1%, 4.7% and 9.8% in 2016, 2017 and the pooled years respectively) (Table 1). Other families were rare and represented each by less than 2% of the collection (Table 1). The most species-rich family was Apidae (three species), followed by Megachilidae (two species). Other families were rare (one species each) (Table 2). The most recorded species was *Apis mellifera* Linnaeus, 1758 (Apidae) (11.7%, 23.8% and 35.5% in 2016, 2017 and the pooled years respectively), then *Xylocopa olivacea* (Fabricius 1778) (Apidae) (10.3%, 12.0% and 22.3% in 2016, 2017 and the pooled years respectively).

Table 1. Absolute and relative abundance of insect orders and families collected on flowers of *Vigna unguiculata* (Fabales: Fabaceae)

| Orders / Families | Campaign | | | I vs. II: Fisher's exact test |
|-------------------------------|--------------------|--------------------|---------------------|--|
| | I. 2016 (%) | II. 2017 (%) | Total (%) | |
| Diptera Linnaeus, 1758 | | | | |
| Calliphoridae Hough (d), 1899 | 6 (0.65) | - | 6 (0.65) | - |
| Muscidae Latreille, 1802 | - | 15 (1.61) | 15 (1.61) | - |
| Total | 6 (0.65) | 15 (1.61) | 21 (2.26) | $\chi^2=7.614$; df=1; p=0.013 * |
| Hymenoptera Linnaeus, 1758 | | | | |
| Apidae Latreille, 1802 | 250 (26.91) | 427 (45.96) | 677 (72.87) | $\chi^2=93.496$; df=1; p= 6.5×10^{-22} * |
| Formicidae Latreille, 1809 | 82 (8.83) | 12 (1.29) | 94 (10.12) | $\chi^2=115.43$; df=1; p= 2.0×10^{-26} * |
| Megachilidae Latreille, 1802 | 47 (5.06) | 44 (4.74) | 91 (9.80) | $\chi^2=0.204$; df=1; p=0.767 ns |
| Vespidae Latreille, 1802 | 14 (1.51) | - | 14 (1.51) | - |
| Total | 393 (42.30) | 483 (51.99) | 876 (94.29) | $\chi^2=18.505$; df=1; p=2.1×10^{-5} * |
| Lepidoptera Linnaeus, 1758 | | | | |
| Nymphalidae Rafinesque, 1815 | 8 (0.86) | - | 8 (0.86) | - |
| Pieridae Swainson, 1820 | 4 (0.43) | 8 (0.86) | 12 (1.29) | $\chi^2=2.559$; df=1; p=0.220 ns |
| Total | 12 (1.29) | 8 (0.86) | 20 (2.15) | $\chi^2=1.569$; df=1; p=0.343 ns |
| Neuroptera Linnaeus, 1758 | | | | |
| Ascalapidae Rambur, 1842 | - | 3 (0.32) | 3 (0.32) | - |
| Orthoptera Latreille, 1793 | | | | |
| Acrididae MacLeay, 1821 | - | 9 (0.97) | 9 (0.97) | - |
| Global | 411 (44.24) | 518 (55.76) | 929 (100.00) | $\chi^2=24.677$; df=1; p=8.5×10^{-7} * |

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

Table 2. Absolute and relative abundances of the insect species collected on flowers of *Vigna unguiculata* (Fabales: Fabaceae)

| Order/Family | Species | Product | Origin, Ref. | Campaign | | |
|---------------|--|----------|------------------|--------------------|--------------------|---------------------|
| | | | | 2016 (%) | 2017 (%) | Pooled (%) |
| Diptera | | | | | | |
| Calliphoridae | <i>Calliphora vicina</i> Robineau-Desvoidy, 1830 | Ne. | NA,WS, MS, a | 6 (0.65) | - | 6 (0.65) |
| Muscidae | <i>Musca domestica</i> Linnaeus, 1758 | Ne. | ME,WS, MS, b, c | - | 15 (1.61) | 15 (1.61) |
| Hymenoptera | | | | | | |
| Apidae | <i>Amegilla calens</i> (Lepelletier De Saint-Fargeau,1841) | Ne., Po. | AF, d, e | 45 (4.84) | 95 (10.23) | 140 (15.1) |
| | <i>Apis mellifera</i> Linnaeus, 1758 | Ne., Po. | AF, e | 109 (11.7) | 221 (23.8) | 330 (35.5) |
| | <i>Xylocopa olivacea</i> (Fabricius 1778) | Ne., Po. | AF, f | 96 (10.3) | 111 (12.0) | 207 (22.3) |
| Formicidae | <i>Myrmecaria opaciventris</i> Emery, 1893 | Ne. | AF, h | 82 (8.8) | 12 (1.3) | 94 (10.1) |
| Megachilidae | <i>Megachile cincta</i> (Fabricius, 1781) | Ne. | AF, l | 22 (3.4) | 44 (4.7) | 66 (8.18) |
| | <i>Me. kamerunensis</i> Friese, 1922 | Ne., Po. | AF, l | 15 (1.6) | - | 15 (1.61) |
| Vespidae | <i>Synagris conuta</i> (Linnaeus, 1758) | Ne., Po. | AF, n, o | 14 (1.5) | - | 14 (1.51) |
| Lepidoptera | | | | | | |
| Nymphalidae | <i>Acraea acerata</i> Hewitson, 1874 | Ne. | AF, p | 8 (0.86) | - | 8 (0.86) |
| Pieridae | <i>Catopsilia florella</i> (Fabricius, 1775) | Ne. | AF, s | 4 (0.43) | 8 (0.86) | 12 (1.29) |
| Neuroptera | | | | | | |
| Ascalapidae | <i>Ascalaphus africanus</i> (McLachlan, 1871) | Pr. | AF, Us., t, u, v | - | 3 (0.32) | 3 (0.32) |
| Orthoptera | | | | | | |
| Acrididae | <i>Pteropera carnapi</i> Ramme, 1929 | Ph. | AF, Pest, w | - | 9 (0.97) | 9 (0.97) |
| Total | | | | 411 (44.24) | 518 (55.76) | 929 (100.00) |

AF: Afrotropical origin; MS: Myiasigenic species; ME: Middle East (Asia); NA: North America origin; Ne.: Nectar; OR: oriental origin; OW: Old World; Ph.: Phytophagous species; Po.: Pollen; Pr.: Predator species; Ref.: References; Us.: Useful species; WS: widespread; a: Whitworth, (2010); b: Nihei & De Carvalho, (2009); c: Hewitt, (2011); d: Madl, (2020); e: Oyerinde, (2017); f: Pauly, (2016); g: Carpenter, (2008); h: Taylor, (2015); l: Pauly (2015); n: Selis (2023); o: Gusenleitner & Madl (2012); p: GBIF Secretariat, (2023); s: Kioko, et al. (2021); t: Prost, (2013); u: Tjeder & Hansson, (1992); v: Oswald, (2024); w: Yetchom, et al. (2024)

They were followed by *Amegilla calens* (Lepeletier De Saint-Fargeau, 1841) (Apidae) (4.8%, 10.2% and 15.1% in 2016, 2017 and the pooled years respectively). *Myrmecaria opaciventris* Emery, 1893 (Formicidae) (8.8%, 1.3% and 10.1% in 2016, 2017 and the pooled years respectively), and *Megachile (Chalicodoma) cincta* (Fabricius, 1781) (Megachilidae) (3.4%, 4.7% and 8.2% in 2016, 2017 and the pooled years respectively) (Table 2). Other species were rare and represented each by less than 2% of the total collection (Table 2).

Four species were recorded exclusively in 2016: *Acraea acerata* Hewitson, 1874 (Nymphalidae), *Calliphora vicina* Robineau-Desvoidy, 1830 (Calliphoridae), *Megachile kamerunensis* Friese, 1922 (Megachilidae), and *Synagris conuta* (Linnaeus, 1758) (Vespidae) (Table 2). Three species were recorded exclusively in 2017: *Ascalaphus africanus* (McLachlan, 1871) (Ascalapidae), *Musca domestica* Linnaeus, 1758 (Muscidae), *Pteropera carnapi* Ramme, 1929 (Acrididae) (Table 2). Six species were commonly recorded in both years: *Am. calens* (Apidae), *Ap. mellifera* (Apidae), *Catopsilia florella* (Fabricius, 1775) (Pieridae), *Me. cincta* (Megachilidae), *My. opaciventris* (Formicidae), *Xy. olivacea* (Apidae) (Table 2). Making a total of 10 species in 2016 and nine species in 2017. The useful predator species native to the afro-tropical region *As. africanus* (Ascalapidae) was recorded as well as the phytophagous Acrididae *Pe. carnapi*. Two exotic myasigenic species were recorded: *Ca. vicina* (Calliphoridae) native to the Northern America, and *Mu. domestica* (Muscidae) native to the Middle East Asia. Other species were in their native range. Potential pests Lepidoptera (Nymphalidae and Pieridae), and Orthoptera (Acrididae) cumulatively represented 1.29%, 1.83% and 3.12% in 2016, 2017 and the pooled years respectively.

3.2. Alpha Diversity of the Floricultural Insects' Assemblages

In 2016 and 2017, the species richness was low (richness ratio d close to 0) (13 species; $Mg=1.756$; $d=0.014$) (Table 3). The species richness was high in 2016 (10 species; Margalef index: $Mg=1.495$; richness ratio: $d=0.024$) and low in 2017 (nine species; $Mg=1.280$; $d=0.017$) (Table 3). Considering the non-parametric estimator of the "true" species richness, the sampling success was maximal (100.0%),

suggesting that no rare species escaped (Table 3). In each year a high diversity was noted (Shannon-Weaver index very close to the maximum value; Table 3). The species diversity was significantly high in 2016 than 2017. In each year and the pooled years the community was highly even (Pielou's index close to 1) (Table 3) and a low dominance by a few species was noted in 2016 and in the pooled years (Berger-Parker index inferior to the median value) while a median level of dominance was detected in 2017 (Table 3). Based on the Hill's N_1 and N_2 indexes, the number of simply abundant species were in all cases close to the number of co-dominants (Hill's ratio close to the unity) (Table 3), corroborating the low dominance of the studied assemblages by a few insect species. The number of the observed rare species was three species in 2016, four species in 2017 and seven species in the pooled years (Table 3). The rank-abundance plotting of the pooled data suggested the presence of co-dominants (concave appearance of the plotting) (Fig. 2A). The similar shape was noted in 2016 and 2017 (Fig. 2B and 2C). The individual rarefaction curves plotted for both years and the pooled years approached species saturation plateaus with similar slopes (Fig. 2D). The curve observed in 2017 was situated below that recorded in 2016 and the pooled years, suggesting the lowest species richness in 2017. For a standard sample of 441 specimens, the settlement in the pooled campaign appeared most diverse with $E(S_{n=441})=13\pm 0$ species, followed by the settlement recorded in 2016 [$E(S_{n=441})=10\pm 0$ species, and lastly by the settlement in 2017 with $E(S_{n=441})=9\pm 0$ species.

Based on the Hill's first order diversity number N_1 (Table 3) and the rank-abundance plotting (Fig. 2), the number of simply abundant species varied from five species (38.5% of the total species richness) in 2017 to seven species (53.8%) in 2016 and six species (46.2%) in the pooled years. Three species were simply abundant exclusively in 2016: *My. opaciventris* (Formicidae), *Me. kamerunensis* (Megachilidae), and *Sy. conuta* (Vespidae). *Musca domestica* (Muscidae) was simply abundant exclusively in 2017. Four species were simply abundant in both years: *Am. calens* (Apidae), *Ap. mellifera* (Apidae), *Me. (Chalicodoma) cincta* (Megachilidae), and *Xy. olivacea* (Apidae).

The number of co-dominant species was five species in 2016 (38.5% of the total species richness), four species in 2017 (30.8%) and five

species in the pooled years (38.5%). *Myrmecaria opaciventris* (Formicidae) was dominant exclusively in 2016. Four species were commonly codominants in 2016 and 2017: *Am. calens* (Apidae), *Ap. mellifera* (Apidae), *Me. (Chalicodoma) cincta* (Megachilidae), and *Xy. olivacea* (Apidae). The five listed species were co-dominants in the pooled years. Two species *Ac. acerata* (Lepidoptera: Nymphalidae) and *Ca. vicina* (Diptera: Calliphoridae) were rare exclusively in 2016.

Three species *My. opaciventris* (Hymenoptera: Formicidae), *Pe. carnapi* (Orthoptera: Acrididae) and *As. africanus* (Neuroptera: Ascalapidae) were rare exclusively in 2017. Two species *Me. (Chalicodoma) kamerunensis* (Hymenoptera: Megachilidae) and *Sy. conuta* (Hymenoptera:

Vespidae) were rare exclusively in the pooled years. *Catopsilia florella* (Lepidoptera: Pieridae) was rare in 2016, 2017 and in the pooled years respectively.

3.3. Adjustment of Species Abundance Distributions (SADs) to the Theoretical Models

Adjustment of the SADs to the five commonly used theoretical models showed that the fit was of excellent quality in 2016 ($r=-0.991$, $p=2.3 \times 10^{-8}$, 10 species), of satisfactory quality in 2017 ($r=0.982$, $p=2.4 \times 10^{-6}$, nine species), and of approximate quality in the pooled campaigns ($r=-0.967$, $p=7.3 \times 10^{-8}$, 13 species).

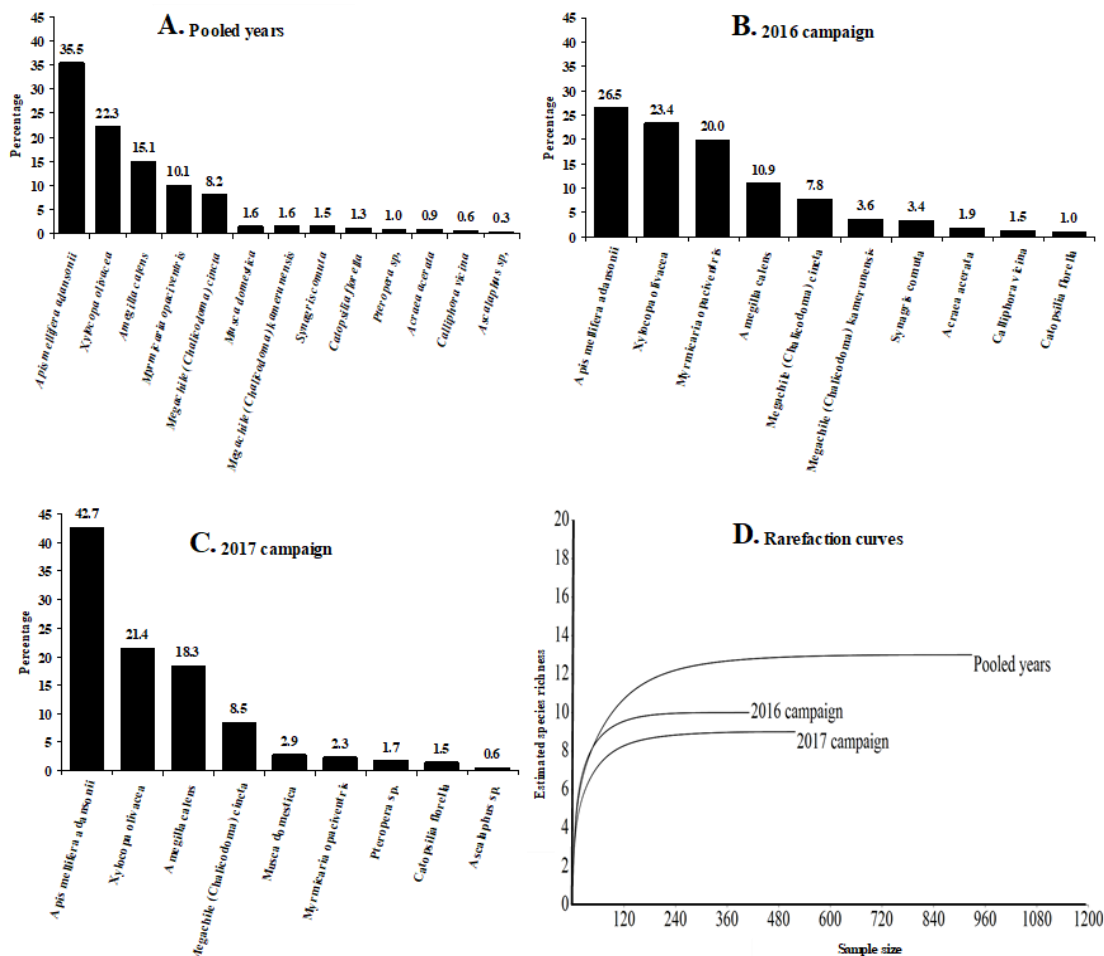


Fig. 2. Rank-frequency diagrams of the collected insects in the pooled campaigns (A), in 2016 (B) and 2017 (C) showing species in order of numerical dominance. The species rarefaction curves (D) showed the low species richness in 2017 and the high species richness in the pooled campaigns

Table 3. Alpha diversity indexes of the floricultural insects on flowers of *Vigna unguiculata* (Fabales: Fabaceae)

| Indexes | Campaign | | |
|-----------------------------|---|-------------|-------------------|
| | I. 2016 | II. 2017 | III. Pooled years |
| A. Richness indexes | | | |
| n (%) | 411 (44.24) | 518 (55.76) | 929 (100.00) |
| S (%) | 10 (76.92) | 9 (69.23) | 13 (100.00) |
| n_{max} | 109 | 221 | 330 |
| Mg | 1.495 | 1.280 | 1.756 |
| $d=S/n$ | 0.024 | 0.017 | 0.014 |
| Chao1 (SE=100*S/Chao1) | 10 (100.0) | 9 (100.0) | 13 (100.0) |
| B. Diversity indexes | | | |
| H' | 1.874 | 1.568 | 1.814 |
| $H'_{max}=\ln(S)$ | 2.303 | 2.197 | 2.565 |
| D | 0.186 | 0.271 | 0.217 |
| C. Evenness indexes | | | |
| $J=H'/H'_{max}$ | 0.814 | 0.714 | 0.707 |
| D. Dominance indexes | | | |
| $I_{BP}=n_{max}/n$ | 0.265 | 0.427 | 0.355 |
| $N_1=e^{H'}$ | 6.512 | 4.800 | 6.132 |
| $N_2=1/D$ | 5.379 | 3.694 | 4.617 |
| $HR=N_2/N_1$ | 0.826 | 0.770 | 0.753 |
| Chao1- N_1 | 3 | 4 | 7 |
| I vs. II: Student t-test | H': $t=5.587$; $df=924.69$; $p=3.0 \times 10^{-8}$ *; D: $t=-5.594$; $df=847.88$; $p=3.0 \times 10^{-8}$ * | | |

Chao1: non-parametric estimator of the "TRUE" species richness; Chao1- N_1 : Observed rare species; d: Richness ratio; D: Simpson diversity index; H': Shannon-Weaver diversity index; H'_{max} : Maximum Shannon-Weaver diversity index; HR: Hill's ratio; I_{BP} : Berger-Parker dominance index; J: Pielou's evenness index; Mg: Margalef's species richness index; n: Sample size; N_1 : Hill's first order diversity number; N_2 : Hill's second order diversity number; n_{max} : Maximum abundance; S: Observed species richness; SE: Sampling effort; %: percentage; *: significant difference ($p < 0.05$)

Base on the AIC and BIC values (Table 4) and the SAD plotting (above Fig. 2A, 2B and 2C), the log-linear nomocenosis model (LL) best fitted the insect assemblage in 2016 (maximum abundance $n_1=109$ specimens; sample size $n=411$ specimens; species richness $S=10$ species; log-linear regression slope $a=(-0.171 \pm 0.008$; Student test $t=-21.533$; $p < 0.001$); elevation of the regression $b=(2.311 \pm 0.049$; Student test $t=46.850$; $p < 0.001$); ANOVA regression: $F_{(1, 8)}=463.675$, $p < 0.001$; deviance=12.494; correction factor=0.989; corrected LL model: $n_i=202.551 \cdot (0.674)^i$ with i as the rank of species, arranged in descending order of abundance). Similar result was obtained in 2017 ($n_1=221$ specimens; $n=518$ specimens; $S=9$ species; $a=(-0.225 \pm 0.016$; $t=-13.843$; $p < .001$); $b=(2.526 \pm 0.092$; $t=27.598$; $p < .001$); $F_{(1, 7)}=191.618$, $p < .001$; deviance=14.529; correction factor=1.059; corrected LL model: $n_i=355.200 \cdot (0.596)^i$) and the pooled years ($n_1=330$ specimens; $n=929$ specimens; $S=13$ species; $a=(-0.163 \pm 0.013$; $t=-12.552$; $p < .001$); $b=(2.563 \pm 0.103$; $t=24.926$; $p < .001$); $F_{(1,$

$11)=157.552$, $p < .001$; deviance=34.379; correction factor=1.162; corrected LL model: $n_i=425.253 \cdot (0.688)^i$). The Motomura environmental constant values were close to 0.5 (0.674, 0.596, and 0.688 in 2016, 2017 and the pooled years respectively).

3.4 Beta diversity of the assemblages and Correlation between Insects

Based on the species composition, although a few cosmopolitan species were sampled, a dissimilarity close to the median level (0.5) was noted between 2016 and 2017 campaigns (Bray-Curtis index: $BC=0.642$), between 2016 and the pooled years ($BC=0.613$) and it was of high level (BC close to 1) between 2017 and the pooled years ($BC=0.716$).

A total of 2,713 flowers were checked in 24 days (13 days in 2016 and 11 days in 2017) and the 13 insect species were recorded visiting 628 flowers (23.1% of the total checked flowers): 253 flowers (9.3%) visited in 2016 and 375 flowers (13.8%) visited in 2017. Overall, the community

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. 2016 campaign 10 species; 411 specimens | II. 2017 campaign 9 species; 518 specimens | III. Pooled years 13 species; 929 specimens |
| McArthur's Broken-Stick (BS) | 24.439; 74.485 (74.485) | 81.155; 126.837 (126.837) | 218.940; 285.663 (285.663) |
| Motomura's Log-linear (LL) | 12.494; 64.540 (64.842) * | 14.529; 62.211 (62.409) * | 34.379; 103.103 (103.668) * |
| Preston's Log-normal (LN) | 32.892; 86.938 (87.543) | 26.363; 76.045 (76.440) | 76.976; 147.700 (148.829) |
| Zipf (Z) | 69.808; 123.854 (124.459) | 58.860; 108.542 (108.937) | 140.893; 211.617 (212.746) |
| Zipf-Mandelbrot (ZM) | 12.220; 68.265 (69.173) | 14.447; 66.129 (66.721) | 34.365; 107.089 (108.783) |

*AIC: Akaike Information Criteria; BIC: Bayesian Information Criteria; SAD: Species Abundance Distribution; *: the best fitted theoretical model (lowest AIC or BIC value)*

Table 5. Kendall tau (τ) correlation coefficient between the 13 insect species recorded on 628 cowpea flowers

| Species 1/species 2 | tau | p-value | Species 1/species 2 | tau | p-value |
|--------------------------------|--------|-----------------------|-------------------------|--------|-----------------------|
| <i>Acraea acerata</i> | | | <i>As. africanus</i> | | |
| <i>Amegilla calens</i> | 0.110 | .453 ns | <i>Pe. carnapi</i> | 0.653 | 8x10 ⁻⁶ * |
| <i>Apis mellifera</i> | -0.337 | .021 * | <i>Sy. conuta</i> | -0.062 | .670 ns |
| <i>Ascalaphus africanus</i> | -0.063 | .667 ns | <i>Xy. olivacea</i> | -0.052 | .722 ns |
| <i>Calliphora vicina</i> | 1.000 | 8x10 ⁻¹² * | <i>Ca. vicina</i> | | |
| <i>Catopsilia florella</i> | 0.342 | .019 * | <i>Ct. florella</i> | 0.342 | .019 * |
| <i>Megachile cincta</i> | 0.559 | 1x10 ⁻⁴ * | <i>Me. cincta</i> | 0.559 | 1x10 ⁻⁴ * |
| <i>Megachile kamerunensis</i> | 0.472 | .001 * | <i>Me. kamerunensis</i> | 0.472 | .001 * |
| <i>Musca domestica</i> | -0.063 | .667 ns | <i>Mu. domestica</i> | -0.063 | .667 ns |
| <i>Myrmicaria opaciventris</i> | 0.715 | 1x10 ⁻⁶ * | <i>My. opaciventris</i> | 0.715 | 1x10 ⁻⁶ * |
| <i>Pteropera carnapi</i> | -0.090 | .538 ns | <i>Pe. carnapi</i> | -0.090 | .538 ns |
| <i>Synagris conuta</i> | 0.989 | 1x10 ⁻¹¹ * | <i>Sy. conuta</i> | 0.989 | 1x10 ⁻¹¹ * |
| <i>Xylocopa olivacea</i> | -0.169 | .247 ns | <i>Xy. olivacea</i> | -0.169 | .247 ns |
| <i>Am. calens</i> | | | <i>Ct. florella</i> | | |
| <i>Ap. mellifera adansonii</i> | -0.015 | .918 ns | <i>Me. cincta</i> | 0.430 | .003 * |
| <i>As. africanus</i> | 0.219 | .134 ns | <i>Me. kamerunensis</i> | -0.113 | .440 ns |
| <i>Ca. vicina</i> | 0.110 | .453 ns | <i>Mu. domestica</i> | 0.552 | 2x10 ⁻⁴ * |
| <i>Ct. florella</i> | 0.285 | .051 ns | <i>My. opaciventris</i> | 0.774 | 1x10 ⁻⁷ * |
| <i>Me. cincta</i> | 0.379 | .010 * | <i>Pe. carnapi</i> | 0.789 | 7x10 ⁻⁸ * |
| <i>Me. kamerunensis</i> | 0.446 | .002 * | <i>Sy. conuta</i> | 0.357 | .015 * |
| <i>Mu. domestica</i> | 0.388 | .008 * | <i>Xy. olivacea</i> | 0.008 | .957 ns |
| <i>My. opaciventris</i> | 0.392 | .007 * | <i>Me. cincta</i> | | |
| <i>Pe. carnapi</i> | 0.446 | .002 * | <i>Me. kamerunensis</i> | 0.538 | 2x10 ⁻⁴ * |
| <i>Sy. conuta</i> | 0.096 | .509 ns | <i>Mu. domestica</i> | 0.468 | .001 * |
| <i>Xy. olivacea</i> | 0.187 | .201 ns | <i>My. opaciventris</i> | 0.610 | 3x10 ⁻⁵ * |
| <i>Ap. mellifera adansonii</i> | | | <i>Pe. carnapi</i> | 0.276 | .058 ns |
| <i>Ascalaphus africanus</i> | -0.104 | .478 ns | <i>Sy. conuta</i> | 0.538 | 2x10 ⁻⁴ * |
| <i>Ca. vicina</i> | -0.337 | .021 * | <i>Xy. olivacea</i> | 0.237 | .104 ns |
| <i>Ct. florella</i> | -0.117 | .421 ns | <i>Me. kamerunensis</i> | | |
| <i>Me. cincta</i> | -0.067 | .648 ns | <i>Mu. domestica</i> | -0.062 | .670 ns |
| <i>Me. kamerunensis</i> | -0.204 | .163 ns | <i>My. opaciventris</i> | 0.322 | .028 * |
| <i>Mu. domestica</i> | 0.143 | .329 ns | <i>Pe. carnapi</i> | -0.089 | .543 ns |
| <i>My. opaciventris</i> | -0.241 | .099 ns | <i>Sy. conuta</i> | 0.444 | .002 * |
| <i>Pe. carnapi</i> | 0.037 | .800 ns | <i>Xy. olivacea</i> | 0.074 | .611 ns |
| <i>Sy. conuta</i> | -0.333 | .022 * | <i>Mu. domestica</i> | | |
| <i>Xy. olivacea</i> | 0.562 | 1x10 ⁻⁴ * | <i>My. opaciventris</i> | 0.427 | .003 * |
| <i>As. africanus.</i> | | | <i>Pe. carnapi</i> | 0.715 | 1x10 ⁻⁶ * |
| <i>Ca. vicina</i> | -0.063 | .667 | <i>Sy. conuta</i> | -0.062 | .670 ns |
| <i>Ct. florella</i> | 0.552 | 2x10 ⁻⁴ * | <i>Xy. olivacea</i> | 0.299 | .041 * |
| <i>Me. cincta</i> | -0.102 | .486 ns | <i>My. opaciventris</i> | | |
| <i>Me. kamerunensis</i> | -0.062 | .670 ns | <i>Pe. carnapi</i> | 0.595 | 5x10 ⁻⁵ * |
| <i>Mu. domestica</i> | -0.043 | .766 ns | <i>Sy. conuta</i> | 0.691 | 2x10 ⁻⁶ * |
| <i>My. opaciventris</i> | 0.382 | .009 * | <i>Xy. olivacea</i> | 0.007 | .963 ns |
| <i>Sy. conuta</i> | -0.089 | .543 ns | <i>Xy. olivacea</i> | -0.177 | .226 ns |
| <i>Xy. olivacea</i> | 0.186 | .203 ns | | | |

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

of flower-visiting insects exhibited in 2016, a positive net association in presence/absence data with $VR > 1$ (Schluter's variance ratio: $VR = 2.321$, Schluter's statistic: $W = 3,202.426$, $df = 1,329$, $p < .001$). It was the same in 2017 ($VR = 2.273$, $W = 3,029.953$, $df = 2,016$, $p < .001$) and

in the pooled years ($VR = 6.440$, $W = 17,472.783$, $df = 2,712$, $p < .001$). Kendall correlation coefficient allowed the identification of negative correlated species (they repelled each other) and positive correlated ones (they were mutually tolerant).

A negative correlation was noted between *Acraea acerata* (Nymphalidae) and *Apis mellifera* (Apidae), between *Ap. mellifera* and *Calliphora vicina* (Calliphoridae), between *Ap. mellifera* and *Synagris conuta* (Vespidae) (Table 5). Positive correlation was recorded in several combinations. *Acraea acerata* (Nymphalidae) was positively correlated with six species: *Ca. vicina*, *Catopsilia florella* (Pieridae), *Megachile (Chalicodoma) cincta* (Megachilidae), *Me. (Chalicodoma) kamerunensis* (Megachilidae), *Myrmecaria opaciventris* (Formicidae) and *Sy. conuta* (Table 5). *Amegilla calens* (Apidae) was positively correlated with five species: *Me. (Chalicodoma) cincta*, *Me. (Chalicodoma) kamerunensis*, *Musca domestica* (Muscidae), and *Pteropera carnapi* (Acrididae) (Table 5). *Apis mellifera adansonii* was positively correlated with *Xylocopa olivacea* (Apidae) (Table 5). *Ascalaphus africanus* (Ascalapidae) was positively correlated with three species: *Catopsilia florella* (Pieridae), *My. opaciventris*, and *Pe. carnapi* (Table 5). *Calliphora vicina* (Nymphalidae) was positively correlated with five species: *Ct. florella*, *Me. (cincta)*, *Me. kamerunensis*, *My. opaciventris*, and *Sy. comuta* (Table 5). *Catopsilia florella* was positively correlated with five species: *Me. (Chalicodoma) cincta*, *Mu. domestica*, *My. opaciventris*, *Pe. carnapi* and *Sy. conuta* (Table 5). *Megachile (Chalicodoma) cincta* was positively correlated with four species: *Me. (Chalicodoma) kamerunensis*, *Mu. domestica*, *My. opaciventris*, and *Sy. conuta* (Table 5). *Megachile (Chalicodoma) kamerunensis* was positively correlated with two species: *My. opaciventris* and *Sy. conuta* (Table 5).

Musca domestica was positively correlated with three species: *My. opaciventris*, *Pe. carnapi* and *Xy. olivacea* (Table 5). *Myrmecaria opaciventris* was positively correlated with two species: *Pe. carnapi* and *Sy. conuta* (Table 5).

4. DISCUSSION

4.1 Species Richness, Diversity, Abundance and Dominance

The studied assemblage of flower visiting insects on *Vigna unguiculata* (Fabaceae) in Bilone (Obala-Cameroon) revealed the presence of five orders, 10 families, 12 genera, and 13 species. Hymenoptera was the most family-rich order (four families) and the most recorded (94.3%) followed by Diptera and Lepidoptera (two families each). Neuroptera and Orthoptera were rare (one

family each). Apidae was the most collected and the most species-rich family (72.9% and three species) followed by Formicidae (10.1% and one species), Megachilidae (9.8% and two species) and other families were rare (less than 2% of the collection and one species each). *Apis mellifera* (Apidae) was the most recorded species (35.5% of the total collection), followed by *Xylocopa olivacea* (Apidae) (22.3%), *Amegilla calens* (Apidae) (15.1%), *Myrmecaria opaciventris* (Formicidae) (10.1%), and *Megachile (Chalicodoma) cincta* (Megachilidae) (8.2%). Two myiasogenic exotic Diptera (*Cl. vicina* and *Mu. domestica*) were recorded (Whitworth, 2010; Nihei & De Carvalho, 2009; Hewitt, 2011). The afro-tropical predator *Ascalaphus africanus* (Yetchom, et al., 2024) was recorded. The diversity of the flower-visiting insects recorded on *V. unguiculata* in Bilone was low compared to the situation reported in several other plants in the world. For example coffee flowers in Colombia were visited by 566 species (90 bees being the most abundant) and potential pollinators were *Apis mellifera*, *Nannotrigona gaboii*, *Tetragonisca angustula*, *Geotrigona cf. tellurica*, and *Partamona cf. peckolti* (Maldonado-Cepeda, et al., 2024). In Indonesia, flowers of market gardens plant species in general, were visited by insects belonging to eight orders, 54 families, 186 genera, 186 species, where Hymenoptera and Lepidoptera represented 84% of the recorded species, 50% were pollinators and other insects were herbivores, predators and parasitoids (Ferdian & Buchori, 2022). In Brazil, flowers of five tree species, including *Acacia polyphylla* (Fabaceae), *Aegiphila sellowiana* (Lamiaceae), *Croton floribundus*, *Croton urucurana* (Euphorbiaceae) and *Schinus terebinthifolius* (Anacardiaceae) were visited by five orders, Hymenoptera being the most diverse order and from 37 families, Vespidae (15 species), Crabronidae (12), Apidae (10), Halictidae (10), Syrphidae (12), Tachinidae (six species) and Hesperidae (seven species) were recorded (Fragazo & Varanda, 2011). As for the insects that visit cowpea flowers, our results were reminiscent of the reports from the United States of America (USA) where cowpea flowers were visited by five pollinator types (honey bees, bumble bees, carpenter bees, wasps, and butterflies and moths) and where 11 and 16 pollinator families were recorded from direct visual counts, pan and sticky traps (Dingha, et al., 2021). In Athens (Portugal), the main pollinators recorded on cowpea flowers belonged to the genus *Xylocopa*, the floral traits related to pollinators abundance and foraging activity being

flower colour, inflorescence position and the hours that the flowers per plant remained open during the day (Lazaridi, et al., 2023). In Ghana, insects observed on the flowers of *V. unguiculata* were *Apis mellifera*, *Ceratina* sp., thrips, crickets, flies, butterflies/moths, *Megachile* sp., *Lasioglossum* sp., ants, wasps, *Xylocopa calens*, and beetles, the most prevalent insects being butterflies moths and the most abundant being thrips (Hordzi, 2024). In Cameroon, our results were high compared to the reports from Dang (Ngaoundere-Cameroon) on cowpea flowers where seven insect species were recorded, belonging to Diptera (49.02% of the total collection) Hymenoptera (11.3%), Lepidoptera (39.4%), *Paragus borbonicus* being the most frequent insect species, followed by *Eurema eximia* (Farda, et al., 2017). The high occurrence of Hymenoptera and Lepidoptera is therefore not surprising because these taxa are very frequently cited in the literature. Several taxa listed in the literature were not recorded in our study, yet the duration of our controls (13 days) covered most of the flowering period of cultivated cowpea. In deed, it is well known that the average number of days to first flower initiation ranged from 29.16 to 41.37 days, days to 50% flowering range between 33.11 and 44.29 days, days to first pod maturity range from 43.73 to 56.07 days, days to 90% pod maturity range from 49.33 to 69.00 days (Owusu, et al., 2018). In all the cowpea varieties, it is known that flower opening is initiated between 6:00 a.m. - 6:30 a. m. and they are closed between 11:30 a. m. -12:00 p. m. (Ige et al., 2011). According to the same authors, when the weather is hot and dry, the flowers close earlier compared to when the weather is cold and humid and after about one or two days of flower opening and closing, the flower wilts and fall off from the cowpea plant. This signifies that cowpea flowers does better or bloom under a cool and humid condition but the onset of hot and dry weather initiates flower closing. The stigmas are receptive over a short period of time and unfertilized flowers drop off within 24 hours after anthesis and the fertilized ovary may remain attached for 48 hours after anthesis (Ige et al., 2011). Flowers progressively appear on mature plants (reproductive period) and each blooming flower remain opened on the plants for few hours a day and for few days. In the localities of Bilone (Obala-Cameroon), natural enemies were the most recorded (Hymenoptera, and Neuroptera with one family: 94.6% of the total collection) followed by the true pollinators (Hymenoptera with four families: 94.3%) while other pollinators were rare (Diptera and Lepidoptera with two

families each: 4.4%), and pests (Orthoptera with one family: 0.97%), suggesting that flowers of *V. unguiculata* were widely and frequently visited by beneficial insects. Nevertheless, the low rate of visited flowers (20.1% during the pooled years: 9.3% in 2016 and 13.8% in 2017) was certainly due to the hermaphrodite state of flowers; with facultative allogamy and producing both nectar and pollen attractive to insects (Ahohuendo, et al., 2012) or the scarcity of associated entomofauna in neighboring sites. Given that the flower-dwelling insects came naturally from the surrounding savannah vegetation and that very few of them were attracted to the plants grown in our plots, it is obvious that the majority of floricultural insects were busy exploiting several other nectar-producing plants in neighboring fallows, more productive than the young flowering cowpea plants. It is therefore likely that during the period of intense flowering, cowpea plants would attract many more insects compared to the present situation. But our main objective in Bilone (Central Region of Cameroon) was just to identify the main pollinating insects of the locality and compare the assemblage structure to the situation reported by Taïmanga et al. (2024) in cowpea fields located in Bockle (North-Cameroon) and Dang (Adamaoua-Cameroon). It was demonstrated in the localities of Dang, Nkolbisson (Yaounde-Cameroon) and Bilone (Obala-Cameroon) that flowers of *V. unguiculata* present a mixed allogamous-autogamous reproduction regime with the predominance of autogamy (Tchuenguem, et al., 2009; Pando et al., 2014; Pharaon Mbianda et al., 2019). Blooming flowers of *V. unguiculata* produce nectar attractive to pollinator and non-pollinator insects. Therefore it is necessary to make *V. unguiculata* plots not far from the hives, since bee foragers play a positive role on geitogamy by depositing the pollen of one flower on the stigma of another flower of the same plant and 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 (Klin-khamer & de Jong, 1993). Indeed Apoides are known as the main pollinators of market garden plants in the world (Mahfouz, et al., 2012) and this is the case in agricultural areas of Cameroon, such as Bambui (North-West Cameroon) (Otiobo, et al., 2016), Yaoundé, Maroua and Ngaoundere (Pando, et al. 2013; Djonwangwé, et al., 2017, Mohammadou, et al., 2023a). Rare species included a native phytophagous Orthoptera *Pteropera carnapi* (0.97%) and the two

myiasigenic Diptera of exotic origin (*Cl. vicina* native to North America and *Mu. domestica* native to the Palearctic Region). Phytophagous and myiasigenic species are frequently recorded in anthropized areas (Whitworth, 2010, Hussein & John, 2014, Grzywacz, et al., 2017a, 2017b, Khamesipour, et al., 2018; Yetchom Fodjo et al., 2024). The damage caused by phytophagous insects (Coleoptera Chrysomelidae, Hymenoptera, Lepidoptera and Orthoptera) is usually recorded on leaves and pods. The situation would be the same in cowpea fields in Bilone. Indeed in market gardens as it is the case in Adamaoua and North Cameroon, cowpea aerial plant organs (flowers, fruits, leaves, pods; stems) can be more attacked than other parts of the plant, depending on the high production periods (Mohammadou et al., 2023). Our study is the first step in evaluating the species richness of flower-visiting native and non-native insect species on *V. unguiculata* flowers in Bilone (Obala-Cameroon). Cowpea plots showed low species richness (richness ratio close to 0), a high species diversity (Shannon-Weaver index close to the maximum value), the assemblage was lowly dominated by a few species in 2016 (Berger-Parker index inferior to the median value) while in 2017 a median level of the dominance was noted and a high level of species evenness (Pielou index close to one) was noted. Similar results are reported in ground-dwelling ants in anthropized environments (Uno, et al., 2010, Solar, et al., 2016, Biawa-Kagmegni, et al., 2021), in the assemblages of insects associated with potato plants (Ngamaleu-Siewe et al., 2021) or eggplants (Fouelifack-Nintidem, et al., 2021), in the assemblage of the floricultural insects associated with cowpea plants (Mohammadou, et al., 2023b). The low diversity of the flower visiting insects was associated with a high abundance in native species, resulting in the high exploitation of resources by native species (two non-native species i.e. 15.4% of the total species richness). The low representation of exotic species (2.26%) is contrary to the situation described in cowpea fields located in Bockle and Dang (Adamaoua and North Cameroon respectively) where flowers were reported mainly explored by introduced species (Mohammadou, et al., 2023b), in egg-plant and potato fields in Balessing (Cameroon) (Fouelifack-Nintidem, et al., 2021; Ngamaleu-Sewe et al., 2021). During the day, occurrences of *Ap. mellifera adansonii* and *Xy. olivacea* foragers were in each year and in the pooled years, not correlated with the air temperature and the air humidity. Their activity would undoubtedly be correlated with other

climatic conditions prevailing in open fields (which remain to be verified) such as sunshine, brightness, rainfall and wind speed, as demonstrated in several pollinating insects. Generally, climatic conditions, such as low temperature, strong wind, and rainfall, minimize the flower-visiting activity of honey bees, limiting pollination in orchard crops (Webster, 2003; Ige et al., 2011). Based on the reports concerning the harmful activity of non-native species in the localities of introduction, they would carry out a similar activity in cowpea plots in Bilone (Obala-Cameroon). The low representation of exotic species could be the result either of the regulation of their populations by local natural enemies, either due to hostile environmental conditions. Pollinator declines could result in loss of pollination services which have important negative ecological and economic impacts that could significantly affect the maintenance of wild plant diversity, wider ecosystem stability, crop production, food security and human welfare (Protts, et al., 2010). A similar situation could occur in Bilone if no measures are taken to preserve and promote pollinators in agricultural land in order to conserve them and ensure sustainable crop production.

4.2 Community Structure and Functioning Model

Assemblage of flower-visiting insects in cowpea field located in Bilone (Obala-Cameroon), best fitted in 2016, 2017 and in the pooled years, the log-linear nomocenososis model (LL) with a median value of the Motomura environmental constant (close to 0.5) ($m=0.674$, $m=0.596$, $m=0.688$ in 2016, 2017 and the pooled years respectively). The LL model reflects a community where the majority of species shows moderate abundances and corresponds to a community in which a reduced number of species is largely dominant (pioneer assemblages) (Motomura, 1932, Carpentier & Leprêtre, 1999). Then in Bilone, assemblage of flower-visiting insects on cowpea functions as pioneer community. High value of the Motomura parameter m suggests a high decay rate of abundance per rank of the recorded species, and then the presence of a few highly dominant species in the community as reported in least evolved pioneer assemblages (elementary interspecies relations and competition limited to the physical space) (Iganaki, 1967). LL niche partitioning model is reported fitting SADs of several insect communities such as the ground-dwelling ants in forest and grasslands in France and in

Cameroon (Cagnant, 1989, Biawa-Kagmegni, et al., 2021), the dung beetles in the Southern Alps (Errouissi, et al., 2004), sand flies in Congo (Trouillet & Vattier-Bernard, 1983), the Carabidae and Heteroptera in managed grasslands located in Finland (Komonen & Elo, 2017), the grasshoppers in the littoral zone of Cameroon (Yetchom-Fondjo, et al., 2020), the insects associated with eggplants, potato plants and cowpea in Cameroon (Fouelifack-Nintidem, et al., 2021, Ngamaleu-Siewe, et al., 2021, Mohamadou, et al., 2023) and aquatic microarthropod assemblage in the Memve'ele Dam (South-Cameroon) (Kemgue, et al., 2024). It is well known that human activities in general are resulting in large deforestation, urbanization and growing cities affect ecosystem functioning and contribute to the loss of biodiversity (McDonald, et al., 2013). A similar situation occurs in Bilone (Obala-Cameroon). LL niche partitioning model reflects communities with moderately abundant majority of species and characterizes stands of open forests and/or disturbed environments where there is a strong competition between pioneer species for the exploitation of available resources (Daget, 1976).

5. CONCLUSION

The purpose of this study in Bilone (Obala-Cameroon) was to determine the biodiversity of the flower-visiting insects on *Vigna unguiculata* and characterize the community structure. Collected specimens belonged to five orders, 10 families, 12 genera, and 13 species. Hymenoptera was the most recorded (94.3% of the collection) and the most family-rich order (four families), followed by Diptera and Lepidoptera (two families each). Neuroptera and Orthoptera were rare (one family each). Apidae was the most abundant and species-rich (72.9%; three species) followed by Formicidae (10.1%; one species), Megachilidae (9.8% and two species) and other families were rare (less than 2%; one species each). *Apis mellifera* (Apidae) was the most abundant (35.5% of the collection), followed by *Xylocopa olivacea* (Apidae) (22.3%), *Amegilla calens* (Apidae) (15.1%), *Myrmecaria opaciventris* (Formicidae) (10.1%), and *Megachile (Chalicodoma) cincta* (Megachilidae) (8.2%). Two myiasogenic exotic Diptera (*Calliphora vicina* (Calliphoridae) and *Musca domestica* (Muscidae)) and the afro-tropical native predator *Ascalaphus africanus* (Ascalapidae) were recorded. Assemblages showed low species richness, high species diversity, a low dominance level of a few species in 2016 and a median level of dominance in 2017

and was highly even. The number of simply abundant species was close to the number of co-dominants. Three species were simply abundant exclusively in 2016: *My. opaciventris*, *Megachile (Chalicodoma) kamerunensis* (Megachilidae), and *Synagris conuta* (Vespidae). *Musca domestica* was simply abundant exclusively in 2017. Four species were simply abundant in both years: *Am. calens*, *Ap. mellifera*, *Me. cincta*, and *Xylocopa olivacea* (Apidae). *Myrmecaria opaciventris* was dominant exclusively in 2016. Four species were codominants in 2016 and 2017: *Am. calens*, *Ap. mellifera*, *Me. cincta*, and *Xy. olivacea*. The four listed species were co-dominants in the pooled years' assemblage. Two species *Acraea acerata* (Nymphalidae) and *Ca. vicina* were rare exclusively in 2016. Three species *My. opaciventris*, *Pteropera carnapi* (Acrididae) and *As. africanus* were rare exclusively in 2017. Two species *Me. kamerunensis* and *Sy. conuta* were rare exclusively in the pooled years. *Catopsilia florella* (Pieridae) was rare in 2016, 2017 and the pooled years. Overall, the community of flower-visiting insects exhibited in 2016, a positive net association in presence/absence data. A negative correlation was noted between the *Ac. acerata* and *Ap. mellifera*, between *Ap. mellifera* and *Ca. vicina*, between *Ap. mellifera* and *Sy. conuta*. Several positive correlations were recorded. In Bilone, flower-visiting insects presented on cowpea plants, a moderately abundant majority of species and the community functioned on the base of log-linear niche partitioning nomocenososis model (more or less disturbed environment) with a strong competition between pioneer species for the available resources. In the future, studies of the activity rhythm of foraging pollinators, the effects of environmental changes on the diversity and behaviour of pollinating insects and the interactions between different pollinator species, would provide valuable information to other researchers and farmers.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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