

Diversity and Abundance of Pest Insects Associated with *Vigna unguiculata* (L.) Walp., 1843 (Fabales: Fabaceae) in Bockle and Dang Localities (North-Cameroon)

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Abstract: Cowpea plants are damaged by insects in North-Cameroon. During ecological survey (2021 and 2022) in 44 plots of 4x3.5 m each, insects were captured on stems, leaves, flowers and pods, stored in vials containing 70° alcohol, identified in laboratory and the community structure was characterized. We captured 26,015 adults belonging to six orders, 13 families, 19 genera and 19 species. Coleoptera, Hemiptera and Hymenoptera were species-rich orders [five species each (26.3%)]. Hemiptera was mostly abundant (40.0%) followed by Coleoptera (27.6%), Hymenoptera (21.9%), Lepidoptera (0.9%). Heteroptera and Orthoptera were least abundant (0.8% respectively). We recorded five (26.3%) useful species [the West African predator species *Cheilomenes sulphurea* (Coleoptera: Coccinellidae), and four (21.1%) afrotropical Apidae species [*Apis mellifera adamsonni*, *Amegilla calens*, *Amegilla* sp. and *Xylocopa olivacea*]], seven (36.8%) phytophagous species [the indomalayan native *Aulacophora indica* (Coleoptera: Chrysomelidae), Nearctic native *Danaus plexippus* (Lepidoptera: Nymphalidae), Palaearctic native *Dolerus* sp. (Hymenoptera: Tenthredinidae), afrotropical native *Hypolimnas misippus* (Lepidoptera: Nymphalidae), afrotropical native *Monolepta marginella* (Coleoptera: Chrysomelidae), Palaearctic native *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae) and the Eurasian native *Tettigonia viridissima* (Orthoptera: Tettigoniidae)]. We recorded seven (36.8%) sap-feeding species [the afrotropical native *Anoplocnemis curvipes* (Hemiptera: Coreidae), cosmopolitan Palaearctic native *Aphis crassivora* (Hemiptera: Aphididae), old world native *Bothrogonia* sp. (Hemiptera: Cicadellidae), subtropical native *Dysdercus cingulata* (Hemiptera: Pyrrhocoridae), western Palaearctic native *Lagria hirta* (Coleoptera: Tenebrionidae), North American native *Poecilocapsus* sp. (Hemiptera: Miridae) and the Palaearctic native *Riptortus dentipes* (Heteroptera: Alydidae)]. Giving up eight (42.1%) native species, 11 (57.9%) non-native species and 14 (73.7%) pest species [three natives species (15.8%) and 11 non-natives species (57.9%)]. The abundant species were *M. marginella* (39.9%), *Poecilocapsus* sp. (14.4%), *Au. indica* (11.4%), *Ph. cruciferae* (10.4%), *C. sulphurea* (4.6%), *H. misippus* (3.7%), *L. hirta* (3.4%), *Ah. crassivora* (2.4%) while 11 species (57.9%) were rare (<2.2% each). Insects associated with cowpea consisted mostly of non-native species and the situation calls for more research on the bio-ecology of recorded pests. Cowpea plants' insect assemblage mostly presented in

Bockle and Dang, a fairly significant regeneration force (Zipf and Zipf-Mandelbrot functioning models) and all conditions combine to soar. Due to the numerical and behavioural dominance of non-native insects, a significant number of resources are potentially exploitable. In due course, once the invaders would monopolize available resources and saturate the localities, they would not allow native species the niche opportunities to re-establish themselves. The consequences of loosing native species, which may well interact with the endemic flora and fauna, will be of extreme concern.

Keywords: *Vigna unguiculata*, Pest Insects, Biodiversity, North-Cameroon

1. Introduction

Cowpea *Vigna unguiculata* (L.) Walp., 1843 (Fabales: Fabaceae) originated in South Africa and secondary spread throughout the world including Europe, Latin America and Southeast Asia [1, 2], is one of the most cultivated plants for the leaves and seeds used for the nutrition of man and livestock [3]. It is an important grain legume containing high levels of 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 [3-5]. In Sub-Sahara African countries the cowpea production is low compared to the situation in developing countries although nowadays, the adaptability of this crop to a wide range of environmental conditions and the overall production is insufficient to meet the ever-increasing demand in the cities. Considering the limitation of seasonal availability, preservation techniques have been adopted to enhance availability with little success [4]. Causes of low productions are not fully known but available information from African countries 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 [5-9]. Among the biotic stresses the harmful action of insects that feed and/or lodge in the tissues of stems and pods or that suck plant sap, or that nibble and pierce the foliage surface, reduce the photosynthetic potential of the plants and consequently cause the drop in vegetable quality and seed yield. Many animal organisms such as bacteria and predators can protect plants against pests [10, 11] while several useful Apidae and Halictidae facilitate the plant pollination [12, 13]. In market garden crops, it is known that the beneficial activity of pollinators is counterbalanced by that of harmful phytophagous, borers and sap-sucking insects [14-17]. Cowpea plant organs are target of several attacks such as micro organisms (fungi, viruses and bacteria) and metazoan organisms (phytophagous and xylophagous agents). Several

animal species use them either as a nesting site (e.g. insects that drill stems and tubers such as larvae of beetles, wasps that can build their nests at the bottom of the leaves), or as a feeding site and thus as a foraging site (termites that rob the plant from the roots, nectarivorous insects including adults of ants and butterflies who feed on sweet liquids secreted by the plant), or both as nesting and feeding site (cases of Hemipterans such as aphids and mealy bugs that pump the plant's sap to exploit proteins and a little sugar and discard the remaining enriched sugar called honeydew [18]. When Insects feed on plant organs, the saliva injected during food intake can be toxic to the plant as it is the case with Thrips [19]. Then these insects directly damage the plants and indirectly cause the drastic decrease that affect productivity of the attacked plants [20, 21]. 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 in Cameroon. These insects reduce the photosynthetic potential of the plants, the quality of the seed and negatively affect yield. Nevertheless more than 70% of agricultural production would suffer colossal on-farm and post-harvest losses without proactive and preventive measures [22]. To improve yield and meet the ever-increasing market demand, producers generally use synthetic chemicals in abusive and inadequate manner, leading to harmful effects on humans, environment, flower insects, pest resistance and this is expected to be further amplified by the impacts of climate change [23, 24]. The negative consequences related to the inappropriate overuse of synthetic chemicals have necessitated the need of alternative methods of pest management among which is the search for genetic varieties resistant to pests [25]. Nowadays, there is a greater focus on botanical pesticides as new effective alternative of crop pest control, preserving useful pollinators. For this purpose, many natural additives from plants have been reported effective in controlling pest insects. For example leaf aqueous extract of several plant species were reported effective against pest insects [26]. The relationships between floricultural plants and their pollinators have been intensively studied in Cameroon [12, 26]. Studies on the entomofauna associated with cowpea plants have been conducted in several countries including USA, India, Indonesia, Egypt, Malaysia, Sudan and Tchad where authors pointed out the negative effect of insect pests [13, 27-32]. Although cowpea is widely cultivated in Cameroon, no published data exist on the diversity of associated insects. Nevertheless, the control of pest insects is one of the major constraints to be overcome in cowpea cultivation. In the northern savannah region of Cameroon, several reports have

shown the importance of the use of botanical pesticides in agriculture as an alternative to synthetic pesticides for the eradication of target enemies of crops [33-36]. In the rural area of Garoua and Ngaoundere (North-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. Physical damages are still recorded in chemically treated plantations. Despite the diversified flora and a flourishing market gardening activity, there is no information concerning the community composition and structure of insects associated with cowpea plants. The purpose of this study is to identify insects active on cowpea aerial plant organs, likely to damage or protect plants grown in the region and thus those which influence the quality and/or quantity of agricultural yields. These works should make it possible to characterize the insect community structure associated with cowpea in the field condition in Garoua and Ngaoundere (North-Cameroon).

2. Material and Methods

2.1. Study Sites

The study was conducted in 2021 and 2022, during the rainy seasons, in the North Cameroon. Two sites were selected due to the collaboration of landowners and the availability of cultivable plots. Georeference coordinates were taken using a Garmin GPS. The plots were delimited in Bockle (9°17'29.81"N, 13°25'4.39"E, and 169 m a.s.l.) Bockle and in Dang (7°25'26.42"N, 13°32'24.46"E, and 1107.40 m a.s.l.). Bockle is a third suburb district of Garoua (North region) and Dang is a third suburb district of Ngaoundere (Adamaoua Region). Both localities are situated in the high Guinean wooded tropical savannah [37] and correspond to the sudano-Sahelian agro-ecological zone, with a semi-arid and a unimodal rainfall [38, 39]. The prevailing climate both localities is globally tropical Sudano-Guinean with two seasons: a rainy season (from April to October of the same year) and a dry season (from November to March of the following year) [40]. The temperature averages 22.9°C and the precipitation is about 2,248 mm per year. The lowest relative humidity is in February (21.7%), and the average annual hygrometry is 70% [38, 39]. Frequently observed plants were *Cosmos sulphureus* Cav., 1791 (Asterales: Asteraceae), *Helianthus annuus* L., 1753 (Asterales: Asteraceae), *Tithonia diversifolia* (Hemsley) Gray, 1883 (Asterales: Asteraceae), *Cajanus cajan* (L.) Huth, 1893 (Fabales: Fabaceae), *Phaseolus vulgaris* L., 1753 (Fabales: Fabaceae) and *Sesamum indicum* L. (1753) (Scrophulariales: Pedaliaceae). The floristic species encountered along the waterways consisted of *Bombax costatum* Pellegr. and Vuillet, 1914 (Malvales: Malvaceae), *Borassus aethiopicum* Mart., 1838 (Arecales: Arecaceae), *Boswellia dalzielii* Hutch., 1910 (Sapindales: Burseraceae), *Commiphora africana* (A. Rich.) Engl., 1883 (Sapindales: Burseraceae), *Hyparrhemia rufa* (Nees) Stapf, 1919 (Poales: Poaceae), *Lannea microcarpa* Engl. and K. Krause, 1911 (Sapindales: Anacardiaceae), *Prosopis africana* (Guill. and Perr.) Taub., 1893 (Fabales: Fabaceae) and

Vittellaria paradoxa C.F. Gaertn., 1807 (Ebenales: Sapotaceae). Plantations of *Azadirachta indica* (Sapindales: Meliaceae), *Eucalyptus camaldulensis* (Myrtales: Myrtaceae), *Cassia occidentalis* (Fabales: Caesalpinaceae) and *Hyptis suaveolens* (Lamiales: Lamiaceae) are found. Cultivated areas were small plots of polycultures family farms.

2.2. Sample Design

Cowpea plants were categorized into three types: (1) four untreated plots, (2) four treated plots using the synthetic insecticide Parastar 40EC 535/10/IN (20 g/l Imidacloprid and 20 g/l lambda-cyhalothrin, one l p.c./ha) approved in Cameroon and usually used by farmers [23, 24] and (3) 36 treated plots using aqueous leave extract of three plant species [*Calotropis procera* (Aiton) Aiton, 1811 (Gentianales: Apocynaceae), *Eucalyptus camaldulensis* Dehnh., 1832 (Myrtales: Myrtaceae) both from Bockle, and *Tithonia diversifolia* (Hemsl.) A. Gray (1883) (Asterales: Asteraceae) from Dang]. Giving up a total of 44 open-field plots of 4x3.5 m each spaced 1 m apart were delimited in the field according to the randomized complete block procedure with four replications. At least three-meter space separated plots from neighbouring fallows and plots of subsistence farming. Plots were subjected to the same climate. Three packets of cowpea seeds (variety Fenkem) were obtained from IRAD Garoua. After the first rains, sowing was done in rows (at 36.4 cm intra-row spacing and 50 cm inter-row spacing and thinned 14 days after sowing to two plants per hill. Six rows were formed per plot and each row consisted of eight bunches. Ten seedlings were positioned per plot (total: 440 seedlings). Two weeks after sowing, from germination to the appearance of the first flowers, weeding was carried out with bare hands and a hoe. Farmers carried out 21 days after planting, one to two early chemical treatments applied on plants. Chemical treatments were done between 7 and 9 a.m. and/or between 12 and 5 p.m., some treatments being carried out during the hottest hours of the day (from 12 to 2 p.m.). After the last chemical treatment, we cleared the plots during one week, of all scarified stems, damaged flowers and leaves. Thirty two plants were labelled and inspected once a week for insect collection using a sweep net from 6:00 a.m. to 10:30 a.m. on the aerial plant organs (stem, leaves, flowers and pods). Capture of insects began the 14th day after sowing and continued until the harvest of pods. Plants were inspected during two days a week from 7 a.m. to 3 p.m. each day and insects found on stems, branches, leaves and flowers, were captured using brushes for small insects or soft forceps for large non-flying insects or a vacuum cleaner. Flying insects were sampled using a sweep net or after neutralizing them using an aerosol insecticide spray. Adults of butterflies were conserved in A4 size paper devices folded to keep the wings intact while other insect adults were kept in labelled vials containing 70° alcohol. During the harvest period, insects found on tubers were collected. The scarified pods were collected and checked every day in laboratory until the release of adult insects. Butterfly caterpillars and other insect larvae were collected and reared in laboratory.

2.3. Identification of Insect Specimens

Insects were identified to the species level using a magnifying glass, keys and illustrated catalogues [41-47] in the Laboratory of Applied Zoology, Department of Biological Sciences, Faculty of Science, University of Ngaoundere, where voucher specimens were deposited. In order to consider recent developments in the taxonomy of we consulted recent reports and illustrated catalogues.

2.4. Data Analysis

Data were stored in an excel spreadsheet version 2016. Data matrixes of abundance counts of species for each site and each year were constructed. Percentages were calculated from the overall total number of the collected specimens. Abundance counts were presented in terms of mean \pm standard error (se). Two means were compared using the Student t-test when relevant and when normality and equal variance tests passed. In other hand we used the non-parametric test (Wilcoxon for paired series or Mann-Whitney for independent ones). Non-parametric comparison of several abundance series was set up using the Kruskal-Wallis test from SigmaStat software 2.0® and the pairwise comparison was set up using Dunn's procedure. Comparison of two frequencies was done using Fisher's exact-test and simultaneous comparison of several frequencies was done using Fisher-Freeman-Halton test from StatXact software 3.1 and appropriate probabilities were adjusted for the number of simultaneous tests using the sequential Bonferroni procedure [48]. Regression equations were set up and tested using ANOVA procedure. Statistics of the insect assemblages were determined using PAST 3.05 software. These statistics were the absolute abundance of i^{th} species n_i , the sample size n (sum of n_i), the relative abundance of i^{th} species $f_i = n_i/n$, the species richness S , the Shannon-Weaver index H' , the maximum Shannon-Weaver index $H'_{\text{max}} = \ln(S)$ and 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 richness) indicated the species' richness quality. The Pielou's evenness index J and the Hill's diversity numbers $N_1 = e^{H'}$ and $N_2 = 1/D$ were determined. The richness ratio $d = S/n$ confirmed the species richness ($d = 0$ for low species richness). The theoretical richness T was determined using the abundance based non-parametric estimator Chao1 and the sampling success $(S/T)*100$ were estimated. The degree of dominance by a few species was evaluated using Berger-Parker index $I_{BP} = n_{\text{max}}/n$ ($I_{BP} = 0$ for equally presence of taxa).

The overall species covariance was evaluated using Schluter's procedure [49]. Between species correlations was evaluated using Kendall's *tau* coefficient. The dissimilarity between plots and between plant stages was evaluated using Bray-Cutis's index and was confirmed using the classical Hierarchical Cluster Analysis based on Jaccard's similarity index. The cluster was constructed using UPGMA algorithm [50]. The rank abundance plotting was used to illustrate the shape of the SADs and the goodness of fit of each SAD to a theoretical model was assessed by calculating the Pearson's

correlation coefficient and interpreting as summarized by Biawa-Kagmegni *et al.* [51]. We tested five commonly used theoretical SADs [52] to fit the curves: the Broken-stick model (BS), the Geometric model (GM), the Lognormal model (LN), the Zipf model (Z) and the Zipf-Mandelbrot (ZM) model. The best fitted model was selected using AIC procedure summarized by Johnson and Omland [20]. The package *vegan* of R 3.4.1 software [53] helped us to adjust the SADs. BS model has a single parameter x which represents the mean abundance of species [54]. We determined the parameters of GM or LM on which the studied insects' communities depended. GM depends on the maximum abundance of the first-rang species n_1 and the Motomura's environment constant m . The m parameter gives the decay rate of the abundance per rank [55]. Z model is based on the ZL model [56], abundances being ranked in decreasing order. Z model is based on two statistics: Q is the scaling parameter (normalizing constant), and γ (gamma) is the decay coefficient or the average probability of the appearance of a species [56, 57]. ZM is a generalized model in which β (beta) is added. Marquardt's nonlinear least squares algorithm summarized by Le *et al.* [58] and Murthy [59], was used to estimate β and γ . We calculated $1/\gamma$ (fractal dimension of the distribution of individuals among species) [60, 61].

3. Results

3.1. Inventory of Insect Species

A total of 26,015 specimens were collected (10,201 specimens i.e. 39.2% in Bockle and 15,814 specimens i.e. 60.8% in Dang). These specimens belonged to six orders, 13 families, 19 genera and 19 species. Seven families (53.8%) [Aphididae Latreille, 1802 (Hemiptera Linnaeus, 1758), Apidae Latreille, 1802 (Hymenoptera Linnaeus, 1758), Chrysomelidae Latreille, 1802 (Coleoptera Linnaeus, 1758), Cicadellidae Latreille, 1802 (Hemiptera Linnaeus, 1758), Coccinellidae Latreille, 1807 (Coleoptera Linnaeus, 1758), Miridae Hahn, 1831 (Hemiptera Linnaeus, 1758) and Tenebrionidae Latreille, 1802 (Coleoptera Linnaeus, 1758)] occurred during 2021 and 2022 in both sites (Bockle and Dang). Alydidae Amyot & Serville, 1843 (Heteroptera Latreille, 1810) was not recorded during 2021 in Bockle. Coreidae Leach, 1815 (Hemiptera Linnaeus, 1758) and Tettigoniidae Krauss, 1902 (Orthoptera Latreille, 1793) were not recorded during 2022 in Bockle. Pyrrhocoridae Amyot & Serville, 1843 (Hemiptera Linnaeus, 1758) was not recorded during 2021 in both sites. Nymphalidae Rafinesque, 1815 (Lepidoptera Linnaeus, 1758) and Tenthredinidae Latreille, 1802 (Hymenoptera Linnaeus, 1758) were not recorded during 2022 in Dang. According to the recorded families' data (Table 1), the differences in the mean or the median values amongst the two sites (Bockle and Dang) and the two years (2021 and 2022), were globally statistically not significant [Bockle in 2021: 11 families; 4,617 specimens; min. = 68 specimens; max. = 1475 specimens; mean \pm se = 420 ± 155 specimens; median value $Me = 199$ specimens; Dang in 2021: 12 families, 6251 specimens, min = 11, max = 3851; $521 \pm$

311 specimens, Me = 153 specimens; pooled data in 2021: 12 families; 10,868 specimens, min = 66, max = 5,326; 906 ± 438 specimens; Me = 341 individuals; Bockle in 2022: 11 families; 5,584 specimens collected; min = 65 specimens; max = 3,179 specimens; 508 ± 278 specimens; Me = 154 individuals; Dang in 2022: 11 families; 9,563 specimens; min = 19 specimens; max = 7,551 specimens; 869 ± 669 specimens; median = 198 individuals; pooled data in 2022: 13 families, 45,147 specimens, min = 53 specimens, max = 7,381 specimens; 1,165 ± 604 specimens; median = 141 individuals; simultaneous comparisons of median values using Kruskal-Wallis non-parametric one way ANOVA: $H = 6.137$; $df = 8$; $p = 0.632$; simultaneous comparisons of mean values using the parametric one way ANOVA: $F(8; 100) = 0.699$; $p = 0.692$. However, in each year and in each site of the study, the variation in the percentage of occurrence of families is statistically significant on the Fisher-Freeman Halton test. However, in each year and in each site of the study, the global variation in the percentage of occurrence of families was statistically significant (Table 1). Pairwise comparisons showed that in Bockle and 2021 study year, three families groups were recognized within which groups differences between involved families were not significant [group 1 of five families (Aphididae, Cicadellidae, Coreidae, Tenebrionidae and Tettigoniidae), group 2 of two families (Apidae and Coccinellidae) and group 3 of two families (Chrysomelidae and Miridae)] (Table 1) while the same site showed in 2022, four families groups [group 1 of four families (Aphididae, Apidae, Cicadellidae and Tenthredinidae), group 2 of three families (Coccinellidae, Nymphalidae and Tenebrionidae), group 3 of two families (Alydidae and Pyrrhocoridae) and group 4 of two families (Coreidae and Tettigoniidae)] (Table 1). In Dang and 2021 study year, three families groups were recognized [group 1 of three families (Aphididae, Aphididae and Chrysomelidae), group 2 of three families (Alydidae, Coreidae and Tenthredinidae) and group 3 of two families (Nymphalidae and Tenebrionidae)] (Table 1) while the same site showed in 2022, three families groups [group 1 of three families (Alydidae, Coreidae and Pyrrhocoridae), group 2 of three families (Apidae, Coccinellidae and Tenebrionidae), and group 3 of two families (Nymphalidae and Tenthredinidae)] (Table 1). Based on the percentages of overall occurrences recorded during the two years and in the two study sites, three families were highly recorded, the ranking in descending order placing Aphididae in first position (39.9%) followed by Chrysomelidae (26.4%) and by Apidae (21.4 %). The other families were rarely recorded (Alydidae: 0.8%; Cicadellidae: 1.7%; Coccinellidae: 0.9%; Coreidae: 2.4%; Miridae: 0.5%; Nymphalidae: 0.9%; Pyrrhocoridae: 3.4%; Tenebrionidae: 0.3%; Tenthredinidae: 0.5% and Tettigoniidae: 0.8%).

Data analysis according to insect species (Table 2) showed that eight species (42.1%) occurred during the two study years in the two sampling sites. These species were *Aphis crassivora* Koch, 1854 (Hemiptera: Aphididae), *Aulacophora indica* Gmelin, 1790 (Coleoptera: Chrysomelidae), *Bothrogonia* sp. Melichar, 1926 (Hemiptera: Cicadellidae), *Cheilomenes*

sulphurea Olivier, 1791 (Coleoptera: Coccinellidae), *Lagria hirta* Linnaeus, 1758 (Coleoptera: Tenebrionidae), *Monolepta marginella* Weise, 1903 (Coleoptera: Chrysomelidae), *Phyllotreta cruciferae* Goeze, 1777 (Coleoptera: Chrysomelidae) and *Poecilocapsus* sp. Reuter, 1876 (Hemiptera: Miridae). Two species (10.5%) [*Amegilla* sp. Friese, 1897 (Hymenoptera: Apidae) and *Riptortus dentipes* Fabricius, 1787 (Heteroptera: Alydidae)] did not occurred in Bockle site during the 2021 campaign. Two other species (10.5%) [*Amegilla calens* Le Peletier, 1841 (Hymenoptera: Apidae) and *Dysdercus cingulata* Fabricius, 1775 (Hemiptera: Pyrrhocoridae)] were not recorded during the 2021 campaign in both sites. Three species (15.8%) [*Danaus plexippus* Linnaeus, 1758 (Lepidoptera: Nymphalidae), *Dolerus* sp. Panzer, 1801 (Hymenoptera: Tenthredinidae) and *Hypolimnas misippus* Linnaeus, 1764 (Lepidoptera: Nymphalidae)] were not recorded in Dang during the 2022 campaign, the first species being absent in the same site in 2021. Four species (21.1%) [*Anoplocnemis curvipes* Fabricius, 1781 (Hemiptera: Coreidae), *Apis mellifera adansonii* Latreille, 1804 (= *Apis mellifera* Linnaeus, 1758) (Hymenoptera: Apidae), *Tettigonia viridissima* Linnaeus, 1758 (Orthoptera: Tettigoniidae) and *Xylocopa (Kopthortosoma) olivacea* Fabricius, 1778 (Hymenoptera: Apidae)] were not recorded in Bockle during the 2022 campaign (Table 2).

Based on the pooled data, *M. marginella* was the most represented (39.9%), followed by *Poecilocapsus* sp. (14.4%), *Au. indica* (11.4%) and *Ph. cruciferae* (10.4%) while 15 other species (78.9%) [*Ah. crassivora* (2.4%), *Am. calens* (0.5%), *Amegilla* sp. (0.8%), *An. curvipes* (0.9%), *Ap. mellifera adansonii* (0.3%), *Bothrogonia* sp. (1.7%), *C. sulphurea* (4.6%), *Dolerus* sp. (2.1%), *Da. plexippus* (0.5%), *Dy. cingulata* (0.5%), *H. misippus* (3.7%), *L. hirta* (3.4%), *R. dentipes* (0.8%), *X. (Kopthortosoma) olivacea* (1.2%) and *T. viridissima* (0.4%)] were each poorly represented. Insect species less than 5.0% could be classified as rare (Table 2). *Da. plexippus* occurred exclusively in Bockle during the two years while *Ap. mellifera adansonii* was recorded exclusively during the 2022 campaign in Dang. During the 2021 campaign, between sites variation of percentages was not significant in five species (26.3%) [*Am. calens* (Fisher's exact test: $p = 1.00$), *An. curvipes* ($p = 0.800$), *Ap. mellifera adansonii* ($p = 1.00$), *Bothrogonia* sp. ($p = 0.129$) and *Dy. cingulata* ($p = 1.00$)].

In contrast, eight species (42.1%) presented significantly high percentage of occurrence in Bockle [*Da. plexippus* ($p = 9.3 \times 10^{-29}$), *Dolerus* sp. ($p = 6.2 \times 10^{-45}$), *H. misippus* ($p = 1.6 \times 10^{-23}$), *M. marginella* ($p = 6.3 \times 10^{-274}$), *Ph. cruciferae* ($p = 1.8 \times 10^{-8}$), *Poecilocapsus* sp. ($p = 2.8 \times 10^{-15}$), *X. (Kopthortosoma) olivacea* ($p = 5.3 \times 10^{-19}$) and *T. viridissima* ($p = 2.0 \times 10^{-11}$)]. Finally percentages of six species were significantly high in Dang [*Amegilla* sp. ($p = 1.6 \times 10^{-21}$), *Ah. crassivora* ($p = 2.8 \times 10^{-5}$), *Au. indica* ($p = 6.9 \times 10^{-113}$), *C. sulphurea* ($p = 5.4 \times 10^{-6}$), *L. hirta* ($p = 2.0 \times 10^{-10}$) and *R. dentipes* ($p = 2.6 \times 10^{-20}$)]. During the 2022 campaign, between sites percentage variation was not significant in five species (26.3%) [*Amegilla* sp. (Fisher's exact test: $p = 0.399$), *Bothrogonia* sp. ($p = 0.070$), *Dy. cingulata* ($p = 0.446$) and *R.*

dentipes (p = 0.613)].

Table 1. Occurrences and percentages of collected insects by family. Percentages are calculated from the total number of specimens.

| Family | Year 2021 | | | Year 2022 | | | Both years (2021 and 2022) | | |
|---|--|--|---------------------|--|--|---------------------|--|---|---------------------|
| | A. Bockle (%) | B. Dang (%) | C. Global (%) | A. Bockle (%) | B. Dang (%) | C. Global (%) | A. Bockle (%) | B. Dang (%) | C. Global (%) |
| I. Alydidae | - | 66 (0.3) | 66 (0.3) | 67 (0.3) | 74 (0.3) | 141 (0.5) | 67 (0.3) | 140 (0.5) | 211 (0.8) |
| II. Aphididae | 106 (0.4) | 177 (0.7) | 283 (1.1) | 154 (0.6) | 198 (0.8) | 7,381 (28.4) | 260 (1.0) | 375 (1.4) | 10,384 (39.9) |
| III. Apidae | 199 (0.8) | 129 (0.5) | 328 (1.3) | 130 (0.5) | 270 (1.0) | 1,853 (7.1) | 329 (1.3) | 399 (1.5) | 5,556 (21.4) |
| IV. Chrysomelidae | 1,475 (5.7) | 3,851 (14.8) | 5,326 (20.5) | 3,179 (12.2) | 7,551 (29.0) | 4,004 (15.4) | 4,654 (17.9) | 11,402 (43.8) | 6,869 (26.4) |
| V. Cicadellidae | 94 (0.4) | 117 (0.4) | 211 (0.8) | 106 (0.4) | 135 (0.5) | 241 (0.9) | 200 (0.8) | 252 (1.0) | 452 (1.7) |
| VI. Coccinellidae | 218 (0.8) | 324 (1.2) | 542 (2.1) | 285 (1.1) | 370 (1.4) | 93 (0.4) | 503 (1.9) | 694 (2.7) | 233 (0.9) |
| VII. Coreidae | 68 (0.3) | 72 (0.3) | 140 (0.5) | - | 93 (0.4) | 352 (1.4) | 68 (0.3) | 165 (0.6) | 635 (2.4) |
| VIII. Miridae | 1,338 (5.1) | 967 (3.7) | 2,305 (8.9) | 975 (3.7) | 457 (1.8) | 140 (0.5) | 2,313 (8.9) | 1,424 (5.5) | 140 (0.5) |
| IX. Nymphalidae | 595 (2.3) | 234 (0.9) | 829 (3.2) | 264 (1.0) | - | 53 (0.2) | 859 (3.3) | 234 (0.9) | 227 (0.9) |
| X. Pyrrhocoridae | - | - | - | 65 (0.2) | 75 (0.3) | 533 (2.0) | 65 (0.2) | 75 (0.3) | 886 (3.4) |
| XI. Tenebrionidae | 117 (0.4) | 236 (0.9) | 353 (1.4) | 212 (0.8) | 321 (1.2) | 78 (0.3) | 329 (1.3) | 557 (2.1) | 78 (0.3) |
| XII. Tenthredinidae | 338 (1.3) | 67 (0.3) | 405 (1.6) | 147 (0.6) | - | 137 (0.5) | 485 (1.9) | 67 (0.3) | 137 (0.5) |
| XIII. Tettigoniidae | 69 (0.3) | 11 (0.0) | 80 (0.3) | - | 19 (0.0) | 141 (0.5) | 69 (0.3) | 30 (0.1) | 207 (0.8) |
| Total | 4,617 (17.7) | 6,251 (24.0) | 10,868 (41.8) | 5,584 (21.5) | 9,563 (36.8) | 15,147 (58.2) | 10,201 (39.2) | 15,814 (60.8) | 26,015 (100.0) |
| FFHT (df = 12) | $\chi^2=6,764.9$ * | $\chi^2=15,054.0$ * | $\chi^2=20,774.0$ * | $\chi^2=12,139.0$ * | $\chi^2=33,128.0$ * | $\chi^2=35,258.0$ * | $\chi^2=18,063.0$ * | $\chi^2=49,506.0$ * | $\chi^2=57,641.0$ * |
| FFHT (2021 vs. 2022). Bockle: $\chi^2=1,226.9$ *; Dang: $\chi^2=1,291.4$ *; Global: $\chi^2=13,544.0$ *. 2021: Bockle vs. Dang: $\chi^2=1,501.7$ *; 2022: Bockle vs. Dang: $\chi^2=1,767.6$ *; Global: $\chi^2=2,862.6$ * | | | | | | | | | |
| Pairwise comparisons using the Bonferroni procedure in 2021 | | | | | | | | | |
| | Bockle: $\alpha'(p)$ | Dang: $\alpha'(p)$ | 2021 | Bockle: $\alpha'(p)$ | Dang: $\alpha'(p)$ | 2021 | Bockle: $\alpha'(p)$ | Dang: $\alpha'(p)$ | |
| I vs. II | 1.3x10 ⁻³ (2.2x10 ⁻³²)* | 0.002 (6.0x10 ⁻¹³)* | II vs. VIII | 7.8x10 ⁻⁴ (1.9x10 ⁻²⁷⁸)* | 0.003 (5.5x10 ⁻⁶)* | IV vs. VI | 8.1x10 ⁻⁴ (5.5x10 ⁻²³⁶)* | 7.0x10 ⁻⁴ (0)* | |
| I vs. III | 1.6x10 ⁻³ (3.2x10 ⁻²¹)* | 0.003 (7.3x10 ⁻⁶)* | II vs. IX | 1.0x10 ⁻³ (2.0x10 ⁻⁸⁴)* | 0.007 (5.5x10 ⁻³)* | IV vs. VII | 6.9x10 ⁻⁴ (0)* | 7.1x10 ⁻⁴ (0)* | |
| I vs. IV | 6.6x10 ⁻⁴ (0)* | 6.7x10 ⁻⁴ (0)* | II vs. X | 1.4x10 ⁻³ (2.2x10 ⁻³²)* | 0.001(7.7x10 ⁻⁵⁴)* | IV vs. VIII | 0.006 (0.008)ns | 7.2x10 ⁻⁴ (0)* | |
| I vs. V | 1.5x10 ⁻³ (9.3x10 ⁻²⁹)* | 0.004 (2.0x10 ⁻⁴)* | II vs. XI | 0.017 (0.502)ns | 0.006(4.1x10 ⁻³)* | IV vs. IX | 1.0x10 ⁻³ (3.7x10 ⁻⁸⁹)* | 6.8x10 ⁻⁴ (0)* | |
| I vs. VI | 1.1x10 ⁻³ (3.0x10 ⁻⁶⁶)* | 0.001 (2.9x10 ⁻⁴²)* | II vs. XII | 1.4x10 ⁻³ (1.6x10 ⁻²⁹)* | 0.002(1.1x10 ⁻¹²)* | IV vs. X | 7.0x10 ⁻⁴ (0)* | 7.3x10 ⁻⁴ (0)* | |
| I vs. VII | 1.8x10 ⁻³ (6.5x10 ⁻²¹)* | 0.013 (0.670)ns | II vs. XIII | 0.005(0.006)ns | 0.001(8.0x10 ⁻⁴⁰)* | IV vs. XI | 7.5x10 ⁻⁴ (2.0x10 ⁻³⁰⁷)* | 7.4x10 ⁻⁴ (0)* | |
| I vs. VIII | 6.7x10 ⁻⁴ (0)* | 8.0x10 ⁻⁴ (1.5x10 ⁻²⁰⁹)* | III vs. IV | 8.0x10 ⁻⁴ (1.1x10 ⁻²⁴⁷)* | 6.6x10 ⁻⁴ (0)* | IV vs. XII | 8.8x10 ⁻⁴ (1.5x10 ⁻¹⁷⁴)* | 7.5x10 ⁻⁴ (0)* | |
| I vs. IX | 8.5x10 ⁻⁴ (5.0x10 ⁻¹⁸¹)* | 0.001 (2.6x10 ⁻²³)* | III vs. V | 2.7x10 ⁻³ (7.4x10 ⁻¹⁰)* | 0.010 (0.482)ns | IV vs. XIII | 7.1x10 ⁻⁴ (0)* | 7.7x10 ⁻⁴ (0)* | |
| I vs. X | 0.025 (1.00)ns | 0.002 (2.6x10 ⁻²⁰)* | III vs. VI | 0.010 (0.376)ns | 0.002 (1.4x10 ⁻²⁰)* | V vs. VI | 2.4x10 ⁻³ (1.5x10 ⁻¹²)* | 0.001 (9.9x10 ⁻²⁴)* | |
| I vs. XI | 1.3x10 ⁻³ (1.1x10 ⁻³⁵)* | 0.001 (1.0x10 ⁻²³)* | III vs. VII | 2.2x10 ⁻³ (3.8x10 ⁻¹⁶)* | 0.003 (6.8x10 ⁻⁵)* | V vs. VII | 0.006 (0.049)ns | 0.006 (1.3x10 ⁻³)* | |
| I vs. XII | 9.5x10 ⁻⁴ (1.2x10 ⁻¹⁰²)* | 0.050 (1.00)ns | III vs. VIII | 8.3x10 ⁻⁴ (6.9x10 ⁻²¹³)* | 8.5x10 ⁻⁴ (3.0x10 ⁻¹⁶²)* | V vs. VIII | 7.7x10 ⁻⁴ (7.7x10 ⁻²⁸⁹)* | 8.4x10 ⁻⁴ (4.4x10 ⁻¹⁷⁰)* | |
| I vs. XIII | 1.7x10 ⁻³ (3.2x10 ⁻²¹)* | 0.002 (1.0x10 ⁻¹⁰)* | III vs. IX | 1.1x10 ⁻³ (2.9x10 ⁻⁴⁷)* | 0.003 (3.5x10 ⁻⁸)* | V vs. IX | 9.9x10 ⁻⁴ (5.9x10 ⁻⁹¹)* | 0.002 (3.6x10 ⁻¹⁰)* | |
| II vs. III | 3.2x10 ⁻³ (1.0x10 ⁻⁷)* | 0.009 (6.9x10 ⁻³)* | III vs. X | 1.7x10 ⁻³ (3.2x10 ⁻²¹)* | 0.001 (2.5x10 ⁻³⁹)* | V vs. X | 1.5x10 ⁻³ (9.3x10 ⁻²⁹)* | 0.001 (1.1x10 ⁻³⁵)* | |
| II vs. IV | 6.7x10 ⁻⁴ (0)* | 6.7x10 ⁻⁴ (0)* | III vs. XI | 3.7x10 ⁻³ (4.3x10 ⁻⁶)* | 0.002 (2.1x10 ⁻⁸)* | V vs. XI | 0.009 (0.129)ns | 0.002 (2.0x10 ⁻¹⁰)* | |
| II vs. V | 0.013 (0.436)ns | 0.005 (5.4x10 ⁻⁴)* | III vs. XII | 2.8x10 ⁻³ (1.8x10 ⁻⁹)* | 0.003 (1.1x10 ⁻⁵)* | V vs. XII | 1.3x10 ⁻³ (1.24x10 ⁻³³)* | 0.004 (2.7x10 ⁻⁴)* | |
| II vs. VI | 2.6x10 ⁻³ (4.2x10 ⁻¹⁰)* | 0.002 (4.1x10 ⁻¹¹)* | III vs. XIII | 2.3x10 ⁻³ (7.4x10 ⁻¹⁶)* | 0.001 (9.3x10 ⁻²⁷)* | V vs. XIII | 0.007 (0.059)ns | 0.001 (1.4x10 ⁻²³)* | |
| II vs. VII | 0.005(0.006)ns | 0.002 (2.0x10 ⁻¹¹)* | IV vs. V | 6.8x10 ⁻⁴ (0)* | 6.9x10 ⁻⁴ (0)* | VI vs. VII | 2.0x10 ⁻³ (1.4x10 ⁻¹⁹)* | 0.001 (1.6x10 ⁻³⁹)* | |

| 2021 | Bockle: α' (p) | Dang: α' (p) | 2021 | Bockle: α' (p) | Dang: α' (p) | 2021 | Bockle: α' (p) | Dang: α' (p) |
|---|--|--|---------------|--|---|--------------|---|---|
| VI vs. VIII | 2.0x10 ⁻³ (2.9x10 ⁻¹⁹)* | 9.3x10 ⁻⁴ (2.3x10 ⁻⁷⁶)* | VII vs. XI | 3.9x10 ⁻³ (3.8x10 ⁻⁴)* | 0.001 (1.2x10 ⁻²¹)* | IX vs. XI | 1.0x10 ⁻³ (7.1x10 ⁻⁷⁹)* | 0.025 (0.963)ns |
| VI vs. IX | 1.2x10 ⁻³ (8.7x10 ⁻⁴²)* | 0.003 (1.5x10 ⁻⁴)* | VII vs. XII | 1.2x10 ⁻³ (1.9x10 ⁻⁴⁴)* | 0.017 (0.734)ns | IX vs. XII | 2.1x10 ⁻³ (1.7x10 ⁻¹⁷)* | 0.001 (5.8x10 ⁻²³)* |
| VI vs. X | 1.1x10 ⁻³ (3.0x10 ⁻⁶⁶)* | 9.0x10 ⁻⁴ (2.1x10 ⁻⁹⁸)* | VII vs. XIII | 0.050 (1.00)ns | 8.3x10 ⁻⁴ (3.0x10 ⁻²⁰⁴)* | IX vs. XIII | 9.3x10 ⁻⁴ (1.6x10 ⁻¹⁰⁶)* | 0.001 (8.8x10 ⁻⁵⁶)* |
| VI vs. XI | 3.0x10 ⁻³ (3.4x10 ⁻⁸)* | 0.004 (2.1x10 ⁻⁴)* | VIII vs. IX | 1.1x10 ⁻³ (6.5x10 ⁻⁶⁸)* | 8.7x10 ⁻⁴ (1.9x10 ⁻¹⁰⁸)* | X vs. XI | 1.3x10 ⁻³ (1.1x10 ⁻³⁵)* | 9.5x10 ⁻⁴ (1.1x10 ⁻⁷¹)* |
| VI vs. XII | 3.4x10 ⁻³ (3.5x10 ⁻⁷)* | 0.001 (8.4x10 ⁻⁴²)* | VIII vs. X | 7.3x10 ⁻⁴ (0)* | 7.8x10 ⁻⁴ (1.7x10 ⁻²⁹⁵)* | X vs. XII | 9.7x10 ⁻⁴ (1.2x10 ⁻¹⁰²)* | 0.002 (1.3x10 ⁻²⁰)* |
| VI vs. XIII | 8.4x10 ⁻⁴ (6.8x10 ⁻²⁰²)* | 9.2x10 ⁻⁴ (1.5x10 ⁻⁸¹)* | VIII vs. XI | 7.9x10 ⁻⁴ (2.1x10 ⁻²⁶⁹)* | 8.8x10 ⁻⁴ (1.3x10 ⁻¹⁰⁷)* | X vs. XIII | 1.8x10 ⁻³ (3.2x10 ⁻²¹)* | 0.005 (9.8x10 ⁻⁴)* |
| VII vs. VIII | 7.2x10 ⁻⁴ (0)* | 0.002 (3.8x10 ⁻¹²)* | VIII vs. XII | 9.0x10 ⁻⁴ (7.7x10 ⁻¹⁴⁵)* | 8.1x10 ⁻⁴ (1.2x10 ⁻²⁰⁸)* | XI vs. XII | 1.6x10 ⁻³ (3.8x10 ⁻²⁶)* | 0.001 (2.4x10 ⁻²³)* |
| VII vs. IX | 9.2x10 ⁻⁴ (3.3x10 ⁻¹⁰⁷)* | 0.002 (2.1x10 ⁻²¹)* | VIII vs. XIII | 7.4x10 ⁻⁴ (0)* | 7.9x10 ⁻⁴ (1.9x10 ⁻²⁷³)* | XI vs. XIII | 4.3x10 ⁻³ (5.2x10 ⁻⁴)* | 9.9x10 ⁻⁴ (2.4x10 ⁻⁵⁶)* |
| VII vs. X | 1.9x10 ⁻³ (6.5x10 ⁻²¹)* | 0.001 (4.0x10 ⁻²²)* | IX vs. X | 8.7x10 ⁻⁴ (5.0x10 ⁻¹⁸¹)* | 9.7x10 ⁻⁴ (4.3x10 ⁻⁷¹)* | XII vs. XIII | 1.2x10 ⁻³ (5.6x10 ⁻⁴⁴)* | 0.002 (5.9x10 ⁻¹¹)* |
| Pairwise comparisons using the Bonferroni procedure in 2022 | | | | | | | | |
| | Bockle: α' (p) | Dang: α' (p) | 2022 | Bockle: α' (p) | Dang: α' (p) | 2022 | Bockle: α' (p) | Dang: α' (p) |
| I vs. II | 0.002 (4.3x10 ⁻⁹)* | 2.0x10 ⁻³ (2.7x10 ⁻¹⁴)* | II vs. XIII | 0.001 (7.0x10 ⁻⁴⁷)* | 1.2x10 ⁻³ (7.0x10 ⁻³⁹)* | V vs. VIII | 8.3x10 ⁻⁴ (8.6x10 ⁻¹⁸⁰)* | 1.1x10 ⁻³ (2.7 x10 ⁻⁴²)* |
| I vs. III | 0.003 (8.1x10 ⁻⁶)* | 1.4x10 ⁻³ (1.7x10 ⁻²⁷)* | III vs. IV | 6.6x10 ⁻⁴ (0)* | 6.6x10 ⁻⁴ (0)* | V vs. IX | 0.002 (8.8x10 ⁻¹⁷)* | 1.1x10 ⁻³ (3.9 x10 ⁻⁴¹)* |
| I vs. IV | 6.7x10 ⁻⁴ (0)* | 6.7x10 ⁻⁴ (0)* | III vs. V | 0.007 (0.133)ns | 2.4x10 ⁻³ (1.5x10 ⁻¹¹)* | V vs. X | 0.004 (2.1x10 ⁻³)* | 4.3x10 ⁻³ (4.0x10 ⁻⁵)* |
| I vs. V | 0.005 (3.7x10 ⁻³)* | 3.9x10 ⁻³ (2.8x10 ⁻⁵)* | III vs. VI | 0.002 (1.6x10 ⁻¹⁴)* | 4.7x10 ⁻³ (8.0x10 ⁻⁵)* | V vs. XI | 0.002 (2.5x10 ⁻⁹)* | 1.9x10 ⁻³ (1.1x10 ⁻¹⁸)* |
| I vs. VI | 0.001 (2.5x10 ⁻³³)* | 1.0x10 ⁻³ (9.1 x10 ⁻⁴⁹)* | III vs. VII | 0.001 (1.3x10 ⁻³⁹)* | 1.8x10 ⁻³ (2.9x10 ⁻²¹)* | V vs. XII | 0.006 (0.012)ns | 1.1x10 ⁻³ (3.9 x10 ⁻⁴¹)* |
| I vs. VII | 0.001 (1.3x10 ⁻²⁰)* | 0.013 (0.163)ns | III vs. VIII | 8.4x10 ⁻⁴ (1.2x10 ⁻¹⁶³)* | 2.3x10 ⁻³ (2.9x10 ⁻¹²)* | V vs. XIII | 0.001 (2.2x10 ⁻³²)* | 1.7x10 ⁻³ (8.4x10 ⁻²³)* |
| I vs. VIII | 8.1x10 ⁻⁴ (7.0x10 ⁻²¹¹)* | 9.3x10 ⁻⁴ (5.4x10 ⁻⁶⁹)* | III vs. IX | 0.002 (1.1x10 ⁻¹¹)* | 9.0x10 ⁻⁴ (5.2 x10 ⁻⁸²)* | VI vs. VII | 9.3x10 ⁻⁴ (1.5x10 ⁻⁸⁶)* | 1.2x10 ⁻³ (1.8 x10 ⁻⁴⁰)* |
| I vs. IX | 0.001 (5.9x10 ⁻²⁹)* | 1.7x10 ⁻³ (1.0x10 ⁻²²)* | III vs. X | 0.003 (8.1x10 ⁻⁶)* | 1.4x10 ⁻³ (3.9x10 ⁻²⁷)* | VI vs. VIII | 9.2x10 ⁻⁴ (1.3x10 ⁻⁹⁰)* | 6.4x10 ⁻³ (2.6x10 ⁻³)* |
| I vs. X | 0.025 (1.00)ns | 0.025 (1.00)ns | III vs. XI | 0.003 (1.0x10 ⁻⁵)* | 0.009 (0.039)ns | VI vs. IX | 0.013 (0.391)ns | 8.1x10 ⁻⁴ (2.2 x10 ⁻¹¹²)* |
| I vs. XI | 0.002 (8.5x10 ⁻¹⁹)* | 1.2x10 ⁻³ (5.1x10 ⁻³⁸)* | III vs. XII | 0.010 (0.335)ns | 9.2x10 ⁻⁴ (5.2x10 ⁻⁸²)* | VI vs. X | 0.001 (3.5x10 ⁻³⁴)* | 1.1x10 ⁻³ (2.7 x10 ⁻⁴⁸)* |
| I vs. XII | 0.002 (4.4x10 ⁻⁸)* | 1.8x10 ⁻³ (1.0x10 ⁻²²)* | III vs. XIII | 0.001 (1.3x10 ⁻³⁹)* | 1.0x10 ⁻³ (3.0x10 ⁻⁵⁸)* | VI vs. XI | 0.004 (1.2x10 ⁻³)* | 0.010 (0.066)ns |
| I vs. XIII | 0.001 (1.3x10 ⁻²⁰)* | 2.8x10 ⁻³ (7.5x10 ⁻⁹)* | IV vs. V | 6.9x10 ⁻⁴ (0)* | 6.9x10 ⁻⁴ (0)* | VI vs. XII | 0.002 (2.5x10 ⁻¹¹)* | 8.3x10 ⁻⁴ (2.2 x10 ⁻¹¹²)* |
| II vs. III | 0.009 (0.171)ns | 5.7x10 ⁻³ (9.6x10 ⁻⁴)* | IV vs. VI | 7.0x10 ⁻⁴ (0)* | 7.0x10 ⁻⁴ (0)* | VI vs. XIII | 9.5x10 ⁻⁴ (1.5x10 ⁻⁸⁶)* | 6.4x10 ⁻³ (2.6x10 ⁻³)* |
| II vs. IV | 6.7x10 ⁻⁴ (0)* | 6.7x10 ⁻⁴ (0)* | IV vs. VII | 7.1x10 ⁻⁴ (0)* | 7.1x10 ⁻⁴ (0)* | VII vs. VIII | 7.8x10 ⁻⁴ (5.7x10 ⁻²⁹⁸)* | 1.0x10 ⁻³ (3.0 x10 ⁻⁵⁹)* |
| II vs. V | 0.005 (3.4x10 ⁻³)* | 5.1x10 ⁻³ (6.3x10 ⁻⁴)* | IV vs. VIII | 7.9x10 ⁻⁴ (1.4x10 ⁻²⁹¹)* | 7.2x10 ⁻⁴ (0)* | VII vs. IX | 9.9x10 ⁻⁴ (3.5x10 ⁻⁸⁰)* | 1.3x10 ⁻³ (1.9x10 ⁻²⁸)* |
| II vs. VI | 0.002 (3.5x10 ⁻¹⁰)* | 2.1x10 ⁻³ (3.6x10 ⁻¹³)* | IV vs. IX | 6.8x10 ⁻⁴ (0)* | 6.8x10 ⁻⁴ (0)* | VII vs. X | 0.002 (5.2x10 ⁻²⁰)* | 0.017 (0.189)ns |
| II vs. VII | 0.001 (7.0x10 ⁻⁴⁷)* | 2.6x10 ⁻³ (6.4x10 ⁻¹⁰)* | IV vs. X | 7.2x10 ⁻⁴ (0)* | 7.3x10 ⁻⁴ (0)* | VII vs. XI | 0.001 (2.0x10 ⁻⁶⁴)* | 1.3x10 ⁻³ (1.1x10 ⁻³⁰)* |
| II vs. VIII | 8.7x10 ⁻⁴ (3.2x10 ⁻¹⁴⁹)* | 1.5x10 ⁻³ (8.6x10 ⁻²⁵)* | IV vs. XI | 7.3x10 ⁻⁴ (0)* | 7.4x10 ⁻⁴ (0)* | VII vs. XII | 0.001 (9.1x10 ⁻⁴⁵)* | 1.3x10 ⁻³ (1.9x10 ⁻²⁸)* |
| II vs. IX | 0.003 (7.3x10 ⁻⁸)* | 9.7x10 ⁻⁴ (3.4 x10 ⁻⁶⁰)* | IV vs. XII | 7.4x10 ⁻⁴ (0)* | 7.5x10 ⁻⁴ (0)* | VII vs. XIII | 0.001 (9.1x10 ⁻⁴⁵)* | 2.2x10 ⁻³ (6.4x10 ⁻¹³)* |
| II vs. X | 0.002 (1.5x10 ⁻⁹)* | 2.0x10 ⁻³ (5.0x10 ⁻¹⁴)* | IV vs. XIII | 7.5x10 ⁻⁴ (0)* | 7.7x10 ⁻⁴ (0)* | VIII vs. IX | 9.0x10 ⁻⁴ (3.0x10 ⁻⁹⁸)* | 7.9x10 ⁻⁴ (7.1 x10 ⁻¹³⁹)* |
| II vs. XI | 0.004 (2.7x10 ⁻³)* | 3.0x10 ⁻³ (6.4x10 ⁻⁸)* | V vs. VI | 0.001 (3.5x10 ⁻²⁰)* | 1.5x10 ⁻³ (1.5x10 ⁻²⁶)* | VIII vs. X | 8.0x10 ⁻⁴ (1.1x10 ⁻²¹²)* | 9.5x10 ⁻⁴ (1.9 x10 ⁻⁶⁸)* |
| II vs. XII | 0.017 (0.729)ns | 9.9x10 ⁻⁴ (3.4 x10 ⁻⁶⁰)* | V vs. VII | 0.001 (2.2x10 ⁻³²)* | 7.3x10 ⁻³ (6.4x10 ⁻³)* | VIII vs. XI | 8.8x10 ⁻⁴ (9.8x10 ⁻¹²⁰)* | 3.2x10 ⁻³ (1.0x10 ⁻⁶)* |

| 2021 | Bockle: α' (p) | Dang: α' (p) | 2021 | Bockle: α' (p) | Dang: α' (p) | 2021 | Bockle: α' (p) | Dang: α' (p) |
|---|---|--|-------------|--|---|--------------|------------------------------------|---|
| Pairwise comparisons using the Bonferroni procedure in 2022 (continued) | | | | | | | | |
| VIII vs. XII | 8.5×10^{-4} (2.9×10^{-153})* | 8.0×10^{-4} (7.1 $\times 10^{-139}$)* | IX vs. XII | 0.002 (7.4×10^{-9})* | 0.050 (1.00)ns | X vs. XIII | 0.002 (5.2×10^{-20})* | 2.7×10^{-3} (4.7×10^{-9})* |
| VIII vs. XIII | 7.7×10^{-4} (5.7×10^{-298})* | 8.4×10^{-4} (7.1 $\times 10^{-111}$)* | IX vs. XIII | 9.7×10^{-4} (3.5×10^{-80})* | 3.4×10^{-3} (3.8×10^{-6})* | XI vs. XII | 0.003 (6.8×10^{-4})* | 8.7×10^{-4} (1.7 $\times 10^{-97}$)* |
| IX vs. X | 0.001 (5.9×10^{-29})* | 1.6×10^{-3} (5.0×10^{-23})* | X vs. XI | 0.002 (1.9×10^{-19})* | 1.3×10^{-3} (1.4×10^{-37})* | XI vs. XIII | 0.001 (2.0×10^{-64})* | 7.8×10^{-4} (0)* |
| IX vs. XI | 0.006 (0.019)ns | 8.5×10^{-4} (1.7 $\times 10^{-97}$)* | X vs. XII | 0.003 (4.4×10^{-8})* | 1.6×10^{-3} (5.0×10^{-23})* | XII vs. XIII | 0.050 (1.00)ns | 3.7×10^{-3} (3.8×10^{-6})* |

FFHT: Fisher-Freeman-Halton test; α : significance level; α' : Bonferroni corrected significance level; ns: not significant ($p \geq \alpha$ or $p \geq \alpha'$); *: significant ($p < \alpha$ or $p < \alpha'$)

Table 2. Insect species composition in the study sites, number of foraging adults, and dominance status of recorded insect species.

| | | | Year 2021 | | | Year 2022 | | | Pooled two years | | |
|----------------|--|----------|--------------|--------------|---------------|--------------|--------------|---------------|------------------|---------------|----------------|
| Order/Family | Species | | Bockle (%) | Dang (%) | Total (%) | Bockle (%) | Dang (%) | Total (%) | Bockle (%) | Dang (%) | Total (%) |
| Coleoptera | | | | | | | | | | | |
| Chrysomelidae | <i>Aulacophora indica</i> Gmelin. 1790 §, IM, P | [62] | 223 (0.9) | 966 (3.7) | 1,189 (4.6) | 497 (1.9) | 1,287 (4.9) | 1,784 (6.9) | 720 (2.8) | 2,253 (8.7) | 2,973 (11.4) |
| | <i>Monolepta marginella</i> Weise. 1903 *, P | [63] | 591 (2.3) | 2,412 (9.3) | 3,003 (11.5) | 1,849 (7.1) | 5,532 (21.3) | 7,381 (28.4) | 2,440 (9.4) | 7,944 (30.5) | 10,384 (39.9) |
| | <i>Phyllotreta cruciferae</i> (Goeze. 1777) §, PA, P | [64] | 661 (2.5) | 473 (1.8) | 1,134 (4.4) | 833 (3.2) | 732 (2.8) | 1,565 (6.0) | 1,494 (5.7) | 1,205 (4.6) | 2,699 (10.4) |
| Coccinellidae | <i>Cheilomenes sulphurea</i> (Olivier. 1791) *, U | [65] | 218 (0,8) | 324 (1.2) | 542 (2.1) | 285 (1.1) | 370 (1.4) | 655 (2.5) | 503 (1.9) | 694 (2.7) | 1,197 (4.6) |
| Tenebrionidae | <i>Lagria hirta</i> (Linnaeus. 1758) §, P | [66] | 117 (0.4) | 236 (0.9) | 353 (1.4) | 212 (0.8) | 321 (1.2) | 533 (2.0) | 329 (1.3) | 557 (2.1) | 886 (3.4) |
| Hemiptera | | | | | | | | | | | |
| Aphididae | <i>Aphis crassivora</i> Koch. 1854 §, PA(COS), P | [67] | 106 (0.4) | 177 (0.7) | 283 (1.1) | 154 (0.6) | 198 (0.8) | 352 (1.4) | 260 (1.0) | 375 (1.4) | 635 (2.4) |
| Cicadellidae | <i>Bothrogonia</i> sp. Melichar, 1926 §, OW, P | [68] | 94 (0.4) | 117 (0.4) | 211 (0.8) | 106 (0.4) | 135 (0.5) | 241 (0.5) | 200 (0.8) | 252 (1.0) | 452 (1.7) |
| Coreidae | <i>Anoplocnemis curvipes</i> (Fabricius. 1781) *, P | [69] | 68 (0.3) | 72 (0.3) | 140 (0.5) | - | 93 (0.4) | 93 (0.4) | 68 (0.3) | 165 (0.6) | 233 (0.9) |
| Miridae | <i>Poecilocapsus</i> sp. Reuter, 1876 §, NE(NA), P | [70] | 1,338 (5.1) | 967 (3.7) | 2,305 (8.9) | 975 (3.7) | 457 (1.8) | 1,432 (5.5) | 2313 (8.9) | 1424 (5.5) | 3,737 (14.4) |
| Pyrrhocoridae | <i>Dysdercus cingulata</i> (Fabricius. 1775) §, SUT, P | [71] | - | - | - | 65 (0.2) | 75 (0.3) | 140 (0.5) | 65 (0.2) | 75 (0.3) | 140 (0.5) |
| Heteroptera | <i>Riptortus dentipes</i> (Fabricius. 1787) §, PA, P | [72] | - | 66 (0.3) | 66 (0.3) | 67 (0.3) | 74 (0.3) | 141 (0.5) | 67 (0.3) | 140 (0.5) | 207 (0.8) |
| Hymenoptera | | | | | | | | | | | |
| Apidae | <i>Amegilla calens</i> (Le Peletier. 1841) *, U | [73-76] | - | - | - | - | 78 (0.3) | 78 (0.3) | - | 78 (0.3) | 78 (0.3) |
| | <i>Amegilla</i> sp. Friese, 1897 *, U | [73-76] | - | 70 (0.3) | 70 (0.3) | 65 (0.2) | 72 (0.3) | 137 (0.5) | 65 (0.2) | 72 (0.3) | 137 (0.5) |
| | <i>Apis mellifera adansoni</i> Latreille. 1804 *, U | [77] | - | - | - | 65 (0.2) | 76 (0.3) | 141 (0.5) | 65 (0.2) | 146 (0.6) | 211 (0.8) |
| | <i>Xylocopa olivacea</i> (Fabricius. 1778) *, U | [78] | 199 (0.8) | 59 (0.2) | 258 (1.0) | - | 44 (0.2) | 44 (0.2) | 199 (0.8) | 103 (0.4) | 302 (1.2) |
| Tenthredinidae | <i>Dolerus</i> sp. Panzer. 1801 §, PA, P | [79, 80] | 338 (1.3) | 67 (0.3) | 405 (1.6) | 147 (0.6) | - | 147 (0.6) | 485 (1.9) | 67 (0.3) | 552 (2.1) |
| Lepidoptera | | | | | | | | | | | |
| Nymphalidae | <i>Danaus plexippus</i> (Linnaeus. 1758) §, NE, P | [81] | 94 (0.4) | - | 94 (0.4) | 34 (0.1) | - | 34 (0.1) | 128 (0.5) | - | 128 (0.5) |
| | <i>Hypolimnas misippus</i> (Linnaeus. 1764) *, P | [82] | 501 (1.9) | 234 (0.9) | 735 (2.8) | 230 (0.9) | - | 230 (0.9) | 731 (2.8) | 234 (0.9) | 965 (3.7) |
| Orthoptera | | | | | | | | | | | |
| Tettigoniidae | <i>Tettigonia viridissima</i> (Linnaeus. 1758) §, EUA, P | [83] | 69 (0.3) | 11 (0.0) | 80 (0.3) | - | 19 (0.0) | 19 (0.0) | 69 (0.3) | 30 (0.1) | 99 (0.4) |
| Total | | | 4,617 (17.7) | 6,251 (24.0) | 10,868 (41.8) | 5,584 (21.5) | 9,563 (36.8) | 15,147 (58.2) | 10,201 (39.2) | 15,814 (60.8) | 26,015 (100.0) |

*, afrotropical native species; §, non-native species, COS, Cosmopolitan species, EUA, Eurasia native species, OW, Old world origin, P, Pest species, PA, Palaearctic native species, NA, North American origin, NE, Nearctic native species, U, Useful species, SUT, Subtropical distributed species

Percentages of five other species (26.3%) were significantly high in Bockle [*Da. plexippus* ($p = 1.2 \times 10^{-10}$), *Dolerus* sp. (p

= 9.1×10^{-45}), *H. misippus* ($p = 7.0 \times 10^{-70}$), *Ph. cruciferae* ($p = 0.010$) and *Poecilocapsus* sp. ($p = 1.4 \times 10^{-44}$). Finally nine species (47.4%) were highly represented in Dang [*Ah. crassivora* (Fisher's exact test: $p = 0.021$), *An. curvipes* ($p = 1.9 \times 10^{-28}$), *Ap. mellifera adansoni* ($p = 6.2 \times 10^{-24}$), *Au. indica* ($p = 3.0 \times 10^{-83}$), *C. sulphurea* ($p = 9.4 \times 10^{-4}$), *L. hirta* ($p = 2.4 \times 10^{-6}$), *M. marginella* ($p = 0$), *X. (Kopthortosoma) olivacea* ($p = 1.1 \times 10^{-13}$) and *T. viridissima* ($p = 3.8 \times 10^{-6}$)]. According to the overall pooled data from the two years, between Bockle and Dang, no significant difference was recorded in two species (10.5%) [*Am. calens* (Fisher's exact test: $p = 0.608$) and *L. hirta* ($p = 0.446$)] while seven species were highly recorded in Bockle [*Ph. cruciferae* ($p = 1.2 \times 10^{-8}$), *Poecilocapsus* sp. ($p = 8.2 \times 10^{-52}$), *X. (Kopthortosoma) olivacea* ($p = 3.2 \times 10^{-8}$), *Da. plexippus* ($p = 5.0 \times 10^{-39}$), *Dolerus* sp. ($p = 6.2 \times 10^{-80}$), *H. misippus* ($p = 3.5 \times 10^{-61}$) and *T. viridissima* ($p = 1.1 \times 10^{-4}$)]. Finally ten species (52.6%) were highly represented in Dang [*Amegilla* sp. (Fisher's exact test: $p = 2.3 \times 10^{-8}$), *An. curvipes* ($p = 1.6 \times 10^{-10}$), *Ap. mellifera adansonii* ($p = 6.2 \times 10^{-24}$), *Au. indica* ($p = 1.2 \times 10^{-192}$), *Ah. crassivora* ($p = 5.0 \times 10^{-6}$), *Bothrogonia* sp. ($p = 0.016$), *C. sulphurea* ($p = 2.6 \times 10^{-8}$), *L. hirta* ($p = 1.0 \times 10^{-14}$), *M. marginella* ($p = 0$) and *R. dentipes* ($p = 4.1 \times 10^{-7}$)]. Pairwise analysis of the pooled occurrences of the 19 species collected during the two years in the two sites permitted us to divide them into four groups in which differences between the components were not significant while between groups combinations were statistically significant: the first group was made up of five species [*Am. calens*, *Ap. mellifera adansonii*, *Da. plexippus*, *Dy. cingulata* and *T. viridissima*]. The second group consisted of three species [*Amegilla* sp., *An. curvipes* and *R. dentipes*]. The third group was made up of two species [*Ah. crassivora* and *Dolerus* sp.] and the fourth group consisted of two other species [*L. hirta* and *H. misippus*]. Note that in the first group, significant differences were recorded when comparing *Ap. mellifera adansonii* to three species (*Am. calens*, *Da. plexippus* and *Dy. cingulata*) (Table A1).

According to the insect species composition of each sampling site (Table 2) *Ap. mellifera adansonii* and *Dy. cingulata* were recorded exclusively during 2022 in Bockle and Dang. *Amegilla* sp. and *R. dentipes* were not recorded in Bockle during the 2021 campaign. *Da. plexippus* was recorded exclusively in Bockle during 2021 and 2022 campaigns. *Dolerus* sp. and *H. misippus* were not recorded in Dang during the 2022 campaign. Three species (15.8%) [*An. curvipes*, *T. viridissima* and *X. (Kopthortosoma) olivacea*] were not recorded in Bockle during the 2022 campaign. *Am. calens* was recorded exclusively in Dang during the 2022 campaign. Finally eight species (42.1%) were recorded simultaneously in Bockle and Dang during each year of the study (*Ap. crassivora*, *Au. indica*, *Bothrogonia* sp., *C. sulphurea*, *L. hirta*, *M. marginella*, *Ph. cruciferae* and *Poecilocapsus* sp.). Which gives in Bockle, a total of 13 species i.e. 68.4% during the 2021 campaign and 15 species i.e. 78.9% during the 2022 campaign. In Dang we recorded a total of 15 species i.e. 78.9% during the 2021 campaign and 16 species i.e. 84.9% during the 2022 campaign. The difference

between the two sampling sites was not significant (Fisher exact test: $p = 1.00$). On the base of the species richness the family Apidae was the most represented (four species; 21.1%), followed by Chrysomelidae (three species; 15.8%), by Lepidoptera (two species; 10.5%) and the 10 remaining families (Alydidae, Aphididae, Cicadellidae, Coccinellidae, Coreidae, Miridae, Pyrrhocoridae, Tenebrionidae, Tenthredinidae and Tettigoniidae) were rarely represented, each by only one species (5.3%) (Table 2). Between sampling sites and sampling years variation was not statistically significant (Fisher-Freeman-Halton exact-test: $\chi^2 = 3.46$, $df = 12$, $p = 1.00$ for sampling sites; $\chi^2 = 15.63$, $df = 36$, $p = 1.00$ for sampling years).

On the base of the feeding behavior, the native range and the pest status of the captured insects, we recorded one (5.3%) predator species *C. sulphurea* (Coleoptera: Coccinellidae) native to the West African region, able to be used as biological control auxiliary against aphids, four (21.1%) useful Afrotropical native Hymenoptera Apidae known as pollinators [*Am. calens*, *Amegilla* sp., *Ap. mellifera adansonii* and *X. (Kopthortosoma) olivacea*], six (31.6%) phytophagous pest species [the indomalayan native species *Au. indica* (Coleoptera: Chrysomelidae), the Nearctic native species *Da. plexippus* (Lepidoptera: Nymphalidae), the pantropical native species *H. misippus* (Lepidoptera: Nymphalidae), the Afrotropical native species *M. marginella* (Coleoptera: Chrysomelidae), the Palaearctic native species *Ph. cruciferae* (Coleoptera: Chrysomelidae) and the eastern part of Eurasia native *T. viridissima* (Orthoptera: Tettigoniidae)], seven (36.8%) sap- or pod-sucking species [the afrotropical native species *An. curvipes* (Hemiptera: Coreidae), the cosmopolitan Palaearctic native species *Ah. crassivora*, the old-world native species *Bothrogonia* sp., the subtropical distributed species *Dy. cingulata*, the western Palaearctic native species *L. hirta* (Coleoptera: Tenebrionidae), the Nearctic native species *Poecilocapsus* sp. (Hemiptera: Miridae) and the Palaearctic native species *R. dentipes* (Heteroptera: Alydidae)]. The Palaearctic native stem and fruit borer species *Dolerus* sp. (Hymenoptera: Tenthredinidae) was recorded. The *Dolerus* larval stages feed on plants, mostly externally, but some species induce galls or live inside fruits, or live in tunnels in wood or shoots. Pest species were highly represented (five useful species i.e. 26.3% versus 14 pest species i.e. 73.7%; Fisher's exact test: $p = 0.009$). Which gives a total of eight Afrotropical native species (42.1%) and therefore native to the study area and 11 exotic origin species (57.9%), the difference being not significant (Fisher's exact test: $p = 0.517$).

3.2. Insect Species Abundance

A total of 26,015 adult insects were collected in the two study sites ($S = 19$ species; 78 to 10,384 adults; mean \pm standard error (se): $1,369 \pm 558$ individuals; median value: $Me = 452$ adults). Collected specimens were divided into 10,201 adults from Bockle (18 species i.e. 94.7%; 65 to 2,440 specimens; 567 ± 177 specimens; $Me = 230$ adults) and 15,814 adults from Dang (18 species i.e. 94.7%; 30 to 7,944 adults; 879 ± 439 specimens;

Me = 200 adults). During the 2021 campaign, we collected 4,617 individuals in Bockle (14 species i.e. 73.7%; 68 to 1,338 specimens; 330 ± 94 specimens; Me = 209 adults) and 6,251 adults from Dang (15 species i.e. 78.9%; 11 to 2,412 adults; 417 ± 163 individuals; Me = 177). During the 2022 campaign, we collected 5,584 individuals in Bockle (15 species i.e. 78.9%; 34 to 1,849 specimens; 372 ± 129 specimens; Me = 154 adults) and 9,563 adults from Dang (16 species i.e. 84.2%; 19 to 5,532 adults; 598 ± 339 individuals; Me = 114) (Tables 1 and 2). The differences noted between the four sample medians was not significant (Kruskal-Wallis test for equal median: $H = 13.32$; tie corrected $H_c = 13.43$; $p = 1.00$). Percentages of collected insects varied significantly between the two sampling sites (Fisher-Freeman-Halton asymptotic test: $\chi^2 = 2,340.3$, $df = 15$, $p = 0.0$ during the 2021 campaign; $\chi^2 = 2,338.3$, $df = 18$, $p = 0.0$ during the 2022 campaign; $\chi^2 = 2,340.3$, $df = 15$, $p = 0.0$ during the 2021 campaign; $\chi^2 = 4,090.0$, $df = 18$, $p = 0.0$ for the pooled two years data). Between the sampling sites, percentages of captured individuals significantly differed each other [Bockle in 2021 (17.7%) *versus* Bockle in 2022 (21.5%): Bonferroni's adjusted significance level $\alpha' = 0.025$, $p = 1.4 \times 10^{-26}$; Bockle in 2021 *versus* Dang in 2021 (24.0%): $\alpha' = 0.017$, $p = 1.3 \times 10^{-69}$; Bockle in 2021 *versus* Dang in 2022 (36.8%): $\alpha' = 8.5 \times 10^{-3}$, $p = 0.00$; Bockle in 2022 *versus* Dang in 2021: $\alpha' = 0.050$, $p =$

3.2×10^{-12} ; Bockle in 2022 *versus* Dang in 2022: $\alpha' = 0.010$, $p = 0.00$]. Pooled data of the two years showed that overall insects were lowly collected in Bockle (39.2%) than in Dang (60.8%) (Fisher's exact test: $\chi^2 = 2,441.2$, $p = 0.00$). Globally percentages of species occurrences did not vary significantly between the four sample series ($\chi^2 = 0.633$, $df = 3$, $p = 0.979$). No species were recorded exclusively in one sampling site. The percentage of the eight afro-tropical native species (51.9% of the total collection) [*Amegilla* sp., *Am. calens*, *An. curvipes*, *Ap. mellifera adansonii*, *C. sulphurea*, *H. misippus*, *M. marginella* and *X. (Kopthortosoma) olivacea*] was not statistically different from the percentage occurrence of the 11 entotic origin species (48.1% of the total collection) [*Ah. crassivora*, *Au. indica*, *Bothrogonia* sp., *Da. plexippus*, *Dolerus* sp., *Dy. cingulata*, *L. hirta*, *Ph. cruciferae*, *Poecilocapsus* sp., *R. dentipes* and *T. viridissima*] (Student t-test: $t = 0.477$, $df = 17$, $p = 0.640$).

3.3. Insect Community Structure

The numbers of species recorded from 2021 to 2022 at Bockle and Dang were close to each other and revealed in all cases, low species richness, the richness ratio being close to the null value (Table 3).

Table 3. Matrix of the species richness, diversity, evenness and dominance indexes for each study site.

| Indices | 2021 | | | 2022 | | | Both years | | |
|--|--|-------|--------|--------|-------|--|------------|--------|--------|
| | Bockle | Dang | Global | Bockle | Dang | Global | Bockle | Dang | Global |
| A. Richness indexes | | | | | | | | | |
| n (%) | 4,617 | 6,251 | 10,868 | 5,584 | 9,563 | 15,147 | 10,201 | 15,814 | 26,015 |
| S | 14 | 15 | 16 | 15 | 16 | 19 | 18 | 18 | 19 |
| n_{max} | 1338 | 2412 | 3003 | 1849 | 5532 | 7381 | 2440 | 7943 | 10385 |
| Mg | 1.541 | 1.602 | 1.614 | 1.623 | 1.637 | 1.870 | 1.842 | 1.758 | 1.771 |
| $d = S/n$ | 0.003 | 0.002 | 0.001 | 0.003 | 0.002 | 0.001 | 0.002 | 0.001 | 0.001 |
| Chao1 | 14 | 15 | 16 | 15 | 16 | 19 | 18 | 18 | 19 |
| Sampling Effort | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 | 100.0 |
| B. Diversity indexes | | | | | | | | | |
| H' | 2.222 | 1.969 | 2.185 | 2.087 | 1.581 | 1.846 | 2.239 | 1.785 | 2.042 |
| $H'_{max} = \ln(S)$ | 2.639 | 2.708 | 2.773 | 2.708 | 2.773 | 2.944 | 2.890 | 2.890 | 2.944 |
| D | 0.147 | 0.210 | 0.156 | 0.179 | 0.365 | 0.276 | 0.148 | 0.291 | 0.210 |
| $N_1 = e^{H'}$ | 9 | 7 | 9 | 8 | 5 | 6 | 9 | 6 | 8 |
| $N_2 = 1/D$ | 7 | 5 | 6 | 6 | 3 | 4 | 7 | 3 | 5 |
| Rare species: Chao1-S | 6 | 8 | 7 | 7 | 11 | 13 | 9 | 12 | 11 |
| Hill ratio = N_2/N_1 | 0.738 | 0.666 | 0.722 | 0.695 | 0.564 | 0.573 | 0.721 | 0.576 | 0.617 |
| C. Evenness index | | | | | | | | | |
| $J = H'/H'_{max}$ | 0.842 | 0.727 | 0.788 | 0.771 | 0.570 | 0.627 | 0.775 | 0.618 | 0.694 |
| E. Dominance index | | | | | | | | | |
| $I_{BP} = n_{max}/n$ | 0.290 | 0.386 | 0.276 | 0.331 | 0.579 | 0.487 | 0.239 | 0.502 | 0.399 |
| Pairwise comparisons of diversity indexes (Student t-test) | | | | | | | | | |
| Comparison | Shannon-Weaver index H' | | | | | Simpson's diversity index | | | |
| 2021: Bockle vs. Dang | $t = 13.61$; $df = 10,781$; $p = 7.4 \times 10^{-42}$ * | | | | | $t = 13.29$; $df = 10,784$; $p = 5.7 \times 10^{-40}$ * | | | |
| 2022: Bockle vs. Dang | $t = 26.10$; $df = 14,375$; $p = 1.0 \times 10^{-146}$ * | | | | | $t = 30.68$; $df = 14,598$; $p = 2.2 \times 10^{-200}$ * | | | |
| Both sites: 2021 vs. 2022 | $t = 24.30$; $df = 26,005$; $p = 5.6 \times 10^{-129}$ * | | | | | $t = 31.01$; $df = 22,773$; $p = 8.1 \times 10^{-207}$ * | | | |
| Both years: Bockle vs. Dang | $t = 31.98$; $df = 25,432$; $p = 4.7 \times 10^{-220}$ * | | | | | $t = 37.41$; $df = 22,675$; $p = 3.0 \times 10^{-297}$ * | | | |

ns: not significant difference; *: significant difference; n: sample size; n_{max} : maximum abundance; S: observed species richness; Mg: Margalef richness index; d: richness ratio; H' : Shannon-Weaver diversity index; H_{max} : maximum Shannon-Weaver diversity index; D: Simpson's diversity index; N_1 : Hill's first order diversity number; N_2 : Hill's second order diversity number; Hill: Hill's diversity ratio; J: Pielou's evenness index; IBP = Berger-Parker dominance index.

The lowest species richness was noted in Bockle in 2021 ($S = 14$ species; Margalef index: $Mg = 1.541$; richness ratio: $d = 0.003$) and the highest species richness was recorded in Dang

in 2022 ($S = 16$ species; $Mg = 1.637$; $d = 0.002$). The other index values were found between the two extremes. Although pairwise comparisons of the diversity indexes showed in all

cases significant differences, both sites presented a high diversity, a high even community (Pielou's values close to the unity) and a low dominance by a few species (Berger-Parker index were in all cases inferior to the median value; Table 3). The rank-abundance plotting of the pooled data presented a concave appearance suggesting the presence in the community of co-dominants (Figure 1A). The similar shape was noted in 2021 and 2022 species distribution of abundances (SADs) (Figures 1B and 1C). The individual rarefaction curves plotted for the two sampling sites and the two collecting years approached species saturation plateaus with similar slopes (Figure 1D). The same shape of the rank-abundance plotting was observed in each study site and during each year (Figure 2). The curve observed in Bockle during 2021 was situated faraway below that of the three other series,

suggesting the lowest species richness and the highest species richness was noted in Dang during 2022 (Figure 1B). For a standard sample of 4,501 individuals, the settlement in Dang 2022 appeared most diverse [$E(Sn=4,501) = 16 \pm 0$ species], followed by Dang 2021 [$E(Sn=4,501) = 15 \pm 0$ species], by Bockle 2022 [$E(Sn=4,501) = 15 \pm 0$ species] and lastly by Bockle 2021 [$E(Sn=4,501) = 14 \pm 0$ species]. Considering the Chao 1 non-parametric estimator, the sampling success showed in all cases, a maximal score (100.0%) (Table 3), suggesting that no rare species escaped during our collection sessions. Based on Hill's first and second order diversity numbers, the number of simply abundant species were in all cases close to the number of co-dominants and values of the Hill's ratio were very close to unity (see Table 3 above), corroborating a low dominance of the studied assemblages by a few insect species.

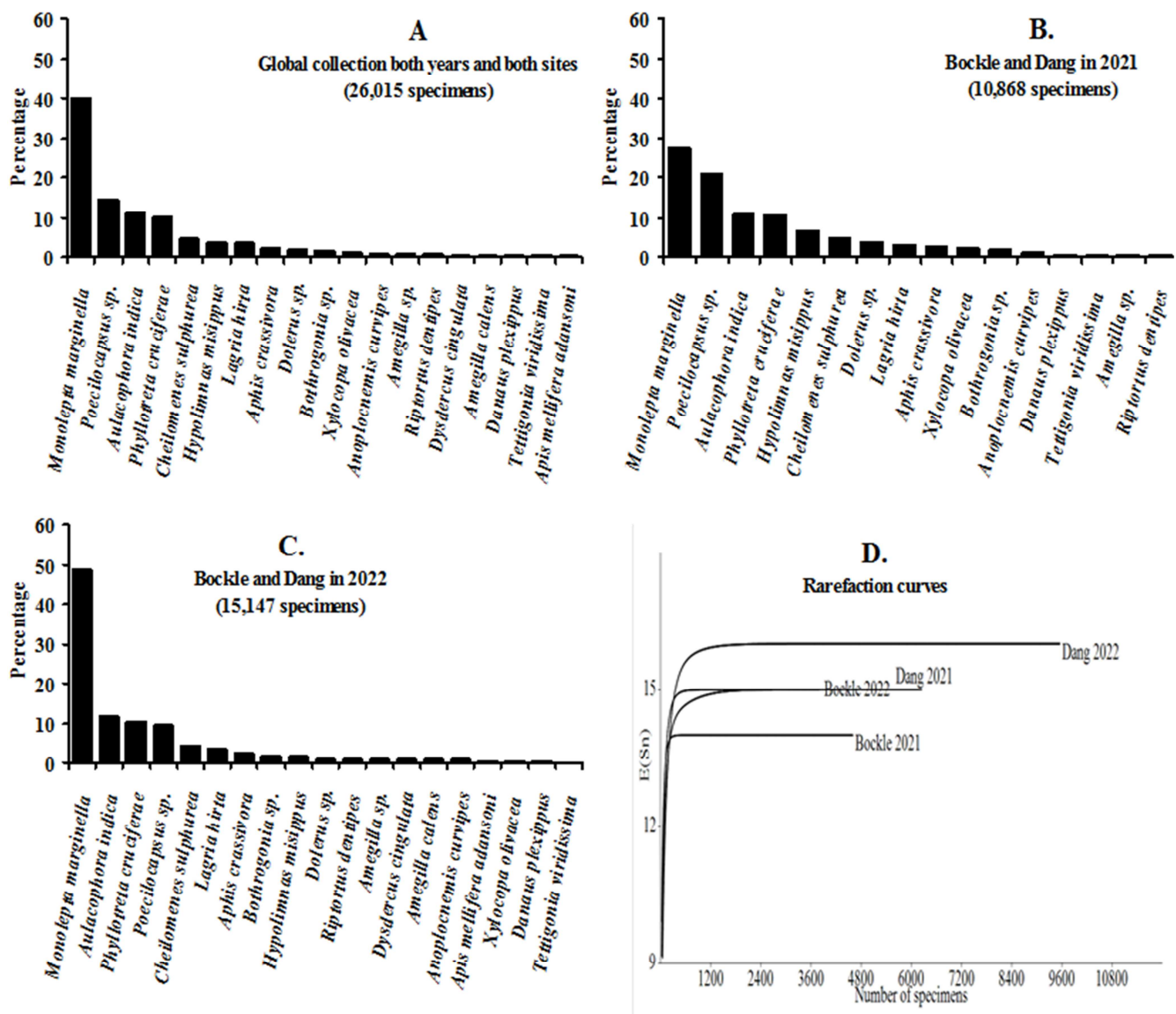


Figure 1. Rank-frequency diagrams of the collected insects in Bockle and Dang during 2021 and 2022 showing species in order of numerical dominance and the species rarefaction curves among the two study sites and the two collection years.

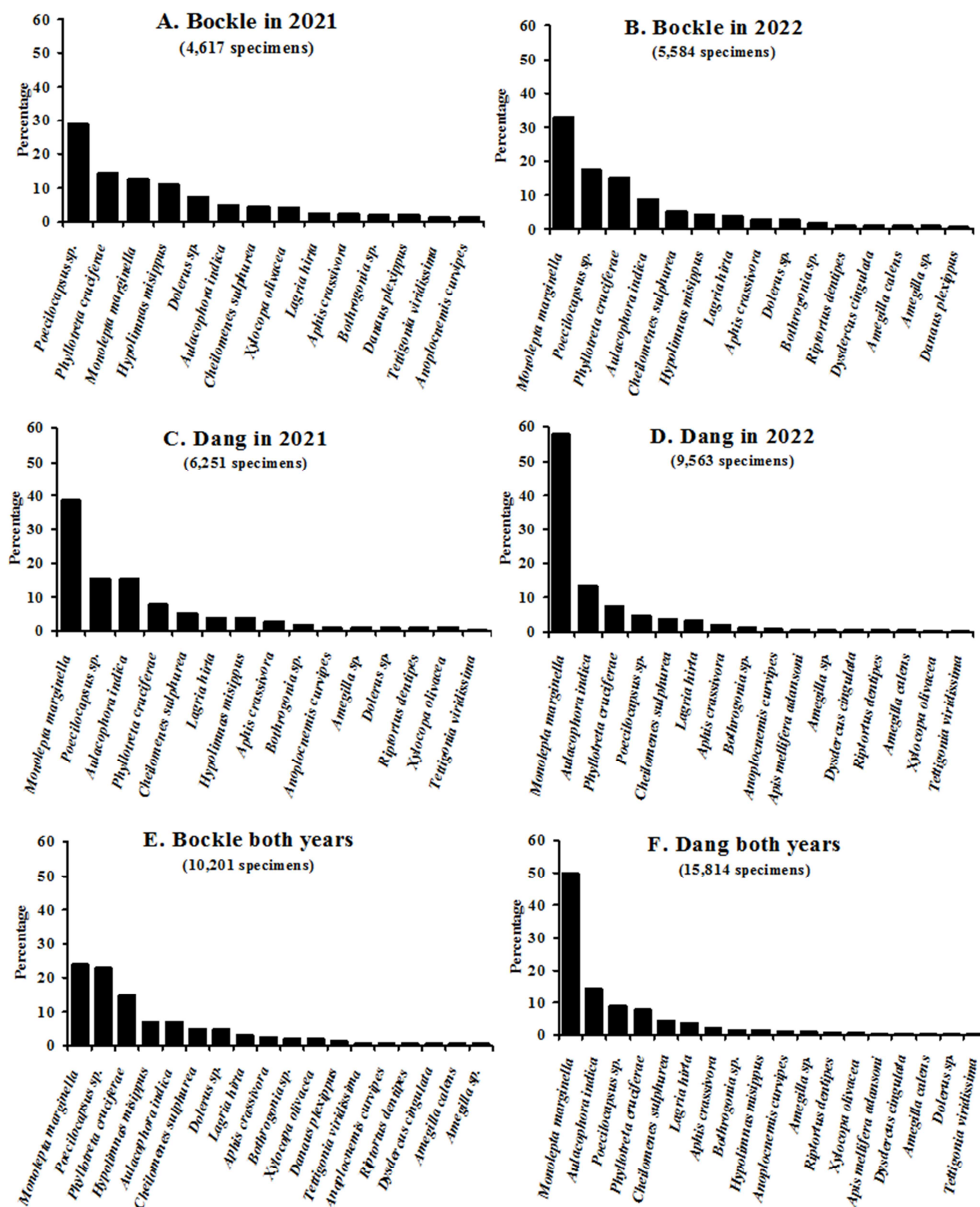


Figure 2. Rank-frequency diagrams of relative insect species abundances collected from two study sites. For each site percentages were calculated on the total number of individuals collected.

On the base of the Hill's first order diversity number (see Table 3 above) and the rank-abundance plotting (Figures 1 and 2), the number of simply abundant species varied from five species

(26.3% of the total species richness) during 2022 in Dang to nine species (47.4%) during 2021 in Bockle and 10 species were potentially simply abundant. They were divided into three

species (15.8%) recorded exclusively in Bockle [the Palaearctic phytophagous pest species *Dolerus* sp. (Hymenoptera: Tenthredinidae) recorded in 2021, the afrotropical native pollinator species *X. (Kopthortosoma) olivacea* (Hymenoptera: Apidae) recorded in 2021 and the cosmopolitan sap-sucking species *Ah. crassivora* (Hemiptera: Aphididae) recorded in 2022], two species (10.5%) recorded in 2021 at Bockle and Dang and in 2022 exclusively at Bockle [the pantropical and afrotropical native phytophagous species *H. misippus* (Lepidoptera: Nymphalidae) and the western Palaearctic origin sap-sucking species *L. hirta* (Coleoptera: Tenebrionidae)] and finally five species (26.3%) were recorded simultaneously in both sites and both years. These species were the indomalayan native phytophagous species *Au. indica* (Coleoptera: Chrysomelidae), the afrotropical native predator species *C. sulphurea* (Coleoptera: Coccinellidae), the afrotropical native phytophagous species *M. marginella* (Coleoptera: Chrysomelidae), the Palaearctic native phytophagous species *Ph. cruciferae* (Coleoptera: Chrysomelidae) and the Nearctic native sap-sucking species *Poecilocapsus* sp. (Hemiptera: Miridae). Rare species were very numerous (Table 3; Figures 1 and 2).

A total of 14 potentially rare species (73.7%) were divided into two rare species (10.5%) collected exclusively in Bockle in 2021 [the eastern part of the Eurasia native phytophagous species *T. viridissima* (Orthoptera: Tettigoniidae)] and during both years [the Nearctic native phytophagous species *Da. plexippus* (Lepidoptera: Nymphalidae)]. Three rare species (15.8%) were collected exclusively at Dang, namely two species (10.5%) in 2022 [the afrotropical native pollinator species *Ap. mellifera adansonii* (Hymenoptera: Apidae) and the sap-sucking species *L. hirta* (Coleoptera: Tenebrionidae)] and one species (5.3%) [*H. misippus* (Lepidoptera: Nymphalidae)] found in the cumulative data for the two years. We recorded two rare species [*Ah. crassivora* (Hemiptera: Aphididae) and *An. curvipes* (Hemiptera: Coreidae)] in 2021 at Bockle and during the two years at Dang. A single rare species [the old-world origin pod-sucking species *Bothrogonia* sp. (Hemiptera: Cicadellidae)] was simultaneously recorded during both years at both sampling sites. The rare species [the Palaearctic origin stem and pod borer *Dolerus* sp. (Hymenoptera: Tenthredinidae)] was recorded in 2021 at Dang and in 2022 at Bockle.

The Palaearctic sap-sucking rare species *R. dentipes* (Heteroptera: Alydidae) was recorded in 2022 at Bockle and during the two years in Dang. Two useful rare Hymenoptera Apidae [*Amegilla* sp. and *X. (Kopthortosoma) olivacea*] were recorded in the global data from Bockle and those collected in 2021 and 2022 in Dang. Finally two rare species [*Au. indica* (Coleoptera: Chrysomelidae) and *Dy. cingulata* (Hemiptera: Pyrrhocoridae)] were recorded in 2022 in Bockle and Dang respectively. Based on the Hill's N_2 index (Table 2) and the SAD plotting (Figures 1 and 2), the co-dominant species were numerous and the number varied from three species (15.8%) in Dang in 2022 to seven species (36.8%) in 2021 in Bockle. Seven (36.8%) potential co-dominant species have been identified. In 2021, *Dolerus* sp. dominated the assemblage

recorded in Bockle. Three species (15.8%) [the afrotropical native predator *C. sulphurea* (Coleoptera: Coccinellidae), the pantropical phytophagous species *H. misippus* (Lepidoptera: Nymphalidae) and *Poecilocapsus* sp.] co-dominated the two year's assemblages in Bockle and that recorded in Dang in 2022. One species (5.3%) [*Ph. cruciferae* (Coleoptera: Chrysomelidae)] dominated during the two years assemblages in Bockle and that recorded in Dang in 2022. Finally two species (10.5%) [*M. marginella* (Coleoptera: Chrysomelidae) and *Au. indica* (Coleoptera: Chrysomelidae)] co-dominated assemblages from both sites and both years.

Based on the species composition, although a few cosmopolitan species were sampled, a median level of dissimilarity was noted in 2021 and 2022 between Bockle and Dang assemblages [Bray-Curtis index: Bockle 2021 vs. Dang 2021: BC = 0.594; Bockle 2021 vs. Bockle 2022: BC = 0.666; Dang 2021 vs. Dang 2022: BC = 0.686; Bockle 2021 vs. Dang 2022: BC = 0.366; Bockle 2022 vs. Dang 2021: BC = 0.601]. Then a very low level of dissimilarity (BC = 0.366) was noted between Bockle 2021 and Dang 2022 while a very high level of dissimilarity (BC = 0.840) was noted between Dang 2021 and Bockle 2022. The other forms of combinations therefore showed dissimilarities between the two extremes [Bockle in both years vs. Dang in both years: BC = 0.603; Bockle and Dang in 2021 vs. Bockle and Dang in 2022: BC = 0.680]. The cluster analysis makes possible to recognize three groups at a Jaccard's similarity index between 0.68 and 0.80: Dang 2022 formed the first group, Bockle 2022 formed the second group. The third group consisted of Dang 2021 and Bockle 2021 (Figure 3).

Adjustment of the SADs to the five commonly known theoretical models showed that the fit was of excellent quality in the 2021 pooled data from Bockle and Dang ($r = -0.991$, $p = 1.2 \times 10^{-13}$, 16 species), of satisfactory quality in Bockle 2021 ($r = -0.978$, $p = 1.5 \times 10^{-9}$, 14 species), in Bockle 2022 ($r = -0.975$, $p = 6.6 \times 10^{-10}$, 15 species), in the pooled 2021 and 2022 data from Bockle ($r = -0.976$, $p = 5.4 \times 10^{-12}$, 18 species) and the in the overall assemblage ($r = -0.976$, $p = 1.0 \times 10^{-12}$, 19 species). The fit was of approximate quality in Dang 2021 settlement ($r = -0.964$, $p = 8.0 \times 10^{-9}$, 15 species), in the pooled data 2021 and 2022 in Dang ($r = -0.964$, $p = 1.2 \times 10^{-10}$, 18 species) and in the pooled data from Bockle and Dang in 2022 ($r = -0.964$, $p = 3.1 \times 10^{-11}$, 19 species). The poor quality fit was noted in Dang 2022 ($r = -0.942$, $p = 5.2 \times 10^{-8}$, 16 species).

On the base of the AIC values (Table 4) and the SAD plotting (Figures 1 and 2), the log-linear (LL) nomocenos model best fitted the pooled insect assemblage collected during the two years in Bockle (Table 4) [maximum abundance: $n_1 = 2.440$ individuals; sample size: $n = 10,201$ individuals; species richness: $S = 18$ species; log-linear regression slope: $a = (-0.101 \pm 0.006)$ individuals; Motomura's environmental constant: $m = 10^a = 0.792$; elevation of the log-linear regression: $b = (3.384 \pm 0.061)$; comparison of the slope to zero (Student's t test): $t = -17.867$; $p < 0.001$; comparison of the elevation to zero (Student's t test): $t = 55.193$; $p < 0.001$; coefficient of determination: $r^2 = 0.952$; regression ANOVA test: $F_1; 16 = 319.231$; $p < 0.001$; deviance: 383.79].

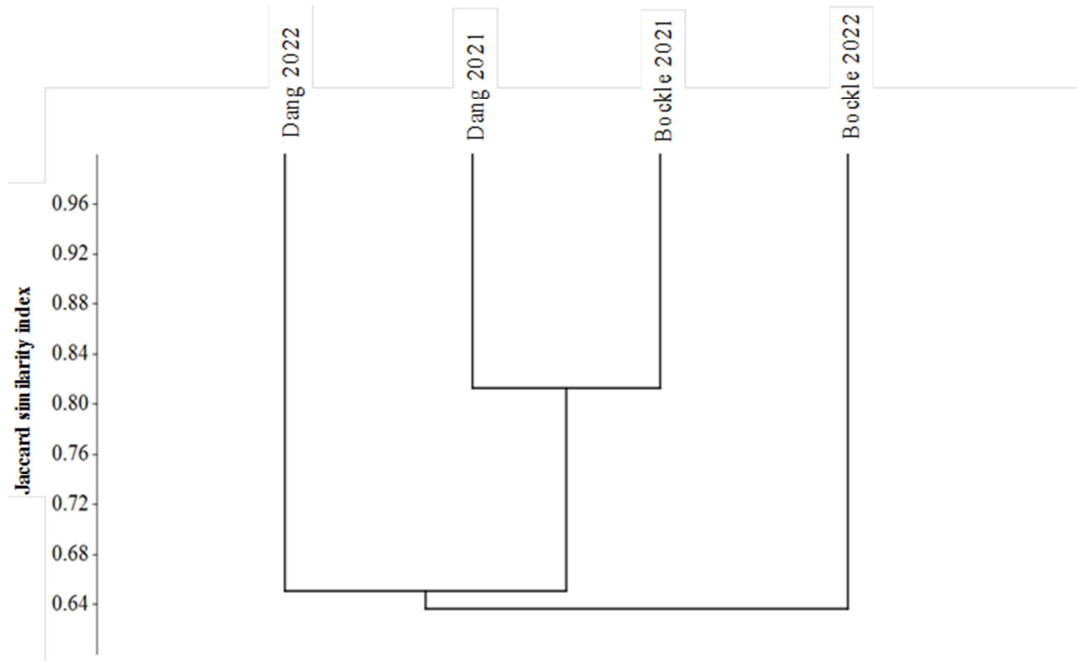


Figure 3. Hierarchical Cluster Analysis based on Jaccard's index using the "Unweighted Pair Group Method with Arithmetic mean" (UPGMA) algorithm and showing similarity in insect assemblages among two sampling sites and two collection years (Cophenetic correlation: 0.821).

Table 4. Akaike Information Criteria (AIC) values for the adjusted theoretical models.

| SAD model | AIC (BIC) values and the best fitted theoretical model | | | | | | | | |
|----------------------|--|------------------------------|---------------------------------|--------------------------------|------------------------------|---------------------------------|---------------------------------|-------------------------------|---------------------------------|
| | Year 2021 | | | Year 2022 | | | Both years | | |
| | Bockle S = 14; n = 4,617 | Dang S = 15; n = 6,251 | Global S = 16; n = 10,838 | Bockle S = 15; n = 5,584 | Dang S = 16; n = 9,563 | Global S = 19; n = 15,147 | Bockle S = 18; n = 10,201 | Dang S = 18; n = 15,814 | Global S = 19; n = 26,015 |
| Broken-Stick (BS) | 321.626 | 1442.03 | 1143.32 | 828.258 | 6858.59 | 8693.34 | 1680.71 | 9148.06 | 9123.81 |
| Log-linear (LL) | 280.668 | 591.34 | 389.82 | 380.74 | 2800.58 | 3392.14 | 519.31 * | 3215.65 | 3135.4 |
| Log-normal (LN) | 197.154 | 287.65 * | 452.11 | 251.127 | 653.25 | 856.54 | 908.95 | 556.34 | 825.10 * |
| Zipf (Z) | 273.145 | 470.67 | 1009.86 | 388.851 | 261.05 * | 927.58 * | 1517.9 | 443.38 * | 1446.41 |
| Zipf-Mandelbrot (ZM) | 177.672 * | 296.95 | 244.71 * | 178.269 * | 263.05 | 929.58 | 522.75 | 445.38 | 898.00 |

SAD: Species Abundance Distribution, S: species richness; n = sample size, * the best fitted theoretical model are in bold.

The Log-normal (LN) nomocenosis model best fitted the insect assemblage observed during 2021 in Dang (Table 4) [$n_1 = 2.412$ individuals; $n = 6,251$ individuals; $S = 15$ species; number of species in the modal octave $S_0 = 5$ species; maximum octave $R_{\max} = 5$; LN model parameter $a = 0.254$; mean logarithm of $S(R)$: 0.241; then the LN model was formulated as $S(R) = 5e^{(-0.254)R^2}$ where $S(R)$ is the number of species in the R^{th} octave from the mode; standard deviation of the lognormal distribution: deviance: 178.33; $\sigma = 0.507$; Preston's constant: $m' = 1/\sigma = 1.971$; number of species theoretically available for observation: $S^* = 35$ species; 20 rare species have therefore escaped our captures]. The same result was obtained using the overall pooled data from both sites and both years (Table 4) [$n_1 = 10.384$ individuals; $n = 26,015$ individuals; $S = 19$ species; $S_0 = 6$ species; $R_{\max} = 6$; LN parameter $a = 0.223$; mean logarithm of $S(R)$: 0.809; then the LN model was $S(R) = 6e^{(-0.223)R^2}$; deviance: 667.66; $\sigma = 0.507$; $m' = 1/\sigma = 1.971$; $S^* = 48$ species; 29 rare species have therefore escaped our captures]. In contrast Z model best fitted the SAD recorded in 2022 in Dang (Table 4) [$n_1 = 5,532$

individuals; normalization constant: $Q = 9,563$ individuals; deviance: 144.39; 16 species; decay coefficient or the average probability of occurrence of a species: $\gamma = 1.782$; the model was formulated as $n_i = 9,563(i)^{-1.782}$]. The same result was obtained in 2022 using the pooled data from both sites (Table 4) [$n_1 = 7,381$ individuals; $Q = 15,147$ individuals; deviance: 784.17; 19 species; $\gamma = 1.810$; model: $n_i = 15,147(i)^{-1.810}$]. Pooled data from both years showed the same result Dang (Table 4) [$n_1 = 7,944$ individuals; normalization constant: $Q = 15,814$ individuals; deviance: 305.22; 18 species; $\gamma = 1.796$; model: $n_i = 15,814(i)^{-1.796}$]. The ZM model best fitted the settlement recorded in 2021 in Bockle (Table 4) [deviance: 70.761, $Q = 4,617$, $n_1 = 1,338$ individuals, $S = 14$ species; starting point: $x_0 = (0.2; 0.2)^T$; tolerance of the functional value: $\varepsilon = 0.001$; damping factor: $\lambda_0 = 100$; $\beta = 0.460$; $\gamma = 0.910$; model: $n_i = 4,617(i+0.460)^{-0.910}$ with a high fractal dimension of the distribution of individuals among species ($1/\gamma = 1.099$)]. The same result was noted in 2021 in the pooled data from both sites (Table 4) [deviance: 247.03; $Q = 10,868$ individuals; $n_1 = 3,003$ individuals; $S = 16$ species; $x_0 = (1; 3)^T$; $\varepsilon = 0.001$;

$\lambda_0=100$; $\beta = 0.256$; $\gamma = 0.957$; model: $n_i = 10,868(i+0.256)^{-0.957}$ with a high fractal dimension of the distribution of individuals among species ($1/\gamma = 1.045$). Finally the ZM model best fitted the insect assemblage recorded in 2022 in Bockle (Table 4) [deviance: 65.949, $Q = 5,584$ individuals; $n_1 = 1,849$ individuals, $S = 15$ species; $x_0 = (1; 2)^T$; $\varepsilon = 0.001$; $\lambda_0=100$; $\beta = 0.240$; $\gamma = 0.878$; model: $n_i = 5,584(i+0.240)^{-0.878}$ with a high fractal dimension of the distribution of individuals among species ($1/\gamma = 1.138$)].

3.4. Association and Correlation Between Species

On the base of 2,640 sample units from two sampling sites and two collection years, overall, the species exhibit a positive association in presence/absence data between the 19 insect species (Schluter's Variance ratio $VR = 2.650 > 1$; W statistic: 6,995.45; $p < 0.001$). A negative correlation suggests that the concerned species repel each other in terms of presence/absence while a positive correlation suggests that the species in question are mutually tolerant (Table 5).

Table 5. Kendall's correlation tau τ between insect species recorded in 2,640 sample units.

| Species 1 / Species 2 | tau τ (p-value) | Species 1 / Species 2 | tau τ (p-value) | Species 1 / Species 2 | tau τ (p-value) |
|---------------------------------|----------------------------------|---------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|
| A. <i>Amegilla calens</i> | | D. <i>Aphis crassivora</i> (continue) | | I. <i>Da. plexipus</i> | |
| <i>Amegilla</i> sp. | 0.295 (4.2x10 ⁻¹¹⁴)* | <i>H. misipus</i> | -0.087 (1.8x10 ⁻¹¹)* | <i>Dolerus</i> sp. | -0.045 (6.0x10 ⁻⁴)* |
| <i>Ah crassivora</i> | -0.134 (5.9x10 ⁻²⁵)* | <i>L. hirta</i> | 0.111 (1.0x10 ⁻¹⁷)* | <i>H. misipus</i> | 0.417 (5.5x10 ⁻²²⁶)* |
| <i>C. sulphurea</i> | -0.076 (5.4x10 ⁻⁹)* | <i>Ph. cruciferae</i> | 0.274 (8.7x10 ⁻⁹⁹)* | <i>M. marginella</i> | -0.150 (7.8x10 ⁻³¹)* |
| <i>Da. plexipus</i> | 0.294 (9.9x10 ⁻¹¹⁴)* | <i>Poecilocapsus</i> sp. | 0.021 (0.11242)ns | <i>Ph. cruciferae</i> | -0.117 (2.5x10 ⁻¹⁹)* |
| <i>Dolerus</i> sp. | -0.061 (3.0x10 ⁻⁶)* | <i>T. viridissima</i> | 0.073 (1.9x10 ⁻⁸)* | <i>X. olivacea</i> | 0.301 (1.4x10 ⁻¹¹⁸)* |
| <i>Dy. cingulatus</i> | -0.123 (2.5x10 ⁻²¹)* | E. <i>Apis mellifera</i> | | J. <i>Dolerus</i> sp. | |
| <i>H. misipus</i> | 0.269 (2.0x10 ⁻⁹⁵)* | <i>C. sulphurea</i> | -0.149 (2.6x10 ⁻³⁰)* | <i>Dy. cingulatus</i> | 0.077 (3.2x10 ⁻⁹)* |
| <i>L. hirta</i> | -0.042 (1.2x10 ⁻³)* | <i>Da. plexipus</i> | 0.281 (7.3x10 ⁻¹⁰⁴)* | <i>H. misipus</i> | -0.040 (2.3x10 ⁻³)* |
| <i>M. marginella</i> | -0.204 (9.8x10 ⁻⁵⁶)* | <i>Dy. cingulatus</i> | -0.242 (3.0x10 ⁻⁷⁷)* | <i>L. hirta</i> | 0.606 (0.0)* |
| <i>Poecilocapsus</i> sp. | -0.062 (1.9x10 ⁻⁶)* | <i>L. hirta</i> | -0.083 (1.9x10 ⁻¹⁰)* | <i>Ph. cruciferae</i> | 0.125 (5.1x10 ⁻²²)* |
| B. <i>Amegilla</i> sp. | | <i>Poecilocapsus</i> sp. | -0.121 (8.6x10 ⁻²¹)* | <i>R. dentipes</i> | 0.626 (0.0)* |
| <i>Ap. mellifera</i> | 0.340 (1.6x10 ⁻¹⁵¹)* | <i>X. olivacea</i> | 0.589 (0.0)* | K. <i>Dysdercus cingulatus</i> | |
| <i>Ph. cruciferae</i> | -0.122 (4.0x10 ⁻²¹)* | F. <i>Aulacophora indica</i> | | <i>M. marginella</i> | 0.199 (4.4x10 ⁻⁵³)* |
| <i>Poecilocapsus</i> sp. | -0.075 (7.3x10 ⁻⁹)* | <i>Bothrogonia</i> sp. | 0.266 (4.9x10 ⁻⁹³)* | <i>R. dentipes</i> | 0.088 (1.0x10 ⁻¹¹)* |
| <i>T. viridissima</i> | -0.034 (9.0x10 ⁻³)* | <i>C. sulphurea</i> | 0.114 (1.2x10 ⁻¹⁸)* | L. <i>Hypolimnas misipus</i> | |
| <i>X. olivacea</i> | 0.469 (5.1x10 ⁻²⁸⁶)* | <i>Da. plexipus</i> | -0.145 (7.4x10 ⁻²⁹)* | <i>M. marginella</i> | -0.133 (1.3x10 ⁻²⁴)* |
| C. <i>Anoplocnemis curvipes</i> | | <i>H. misipus</i> | -0.128 (4.7x10 ⁻²³)* | <i>R. dentipes</i> | -0.048 (2.5x10 ⁻⁴)* |
| <i>Bothrogonia</i> sp. | -0.084 (1.0x10 ⁻¹⁰)* | <i>X. olivacea</i> | -0.283 (3.0x10 ⁻¹⁰⁵)* | <i>T. viridissima</i> | -0.046 (3.7x10 ⁻⁴)* |
| <i>C. sulphurea</i> | 0.100 (1.3x10 ⁻¹⁴)* | G. <i>Bothrogonia</i> sp. | | M. <i>Lagria hirta</i> | |
| <i>H. misipus</i> | -0.076 (4.0x10 ⁻⁹)* | <i>C. sulphurea</i> | 0.095 (2.5x10 ⁻¹³)* | <i>M. marginella</i> | 0.123 (2.4x10 ⁻²¹)* |
| <i>L. hirta</i> | 0.083 (1.8x10 ⁻¹⁰)* | <i>Dolerus</i> sp. | 0.095 (2.9x10 ⁻¹³)* | <i>Ph. cruciferae</i> | 0.080 (7.2x10 ⁻¹⁰)* |
| <i>M. marginella</i> | 0.199 (6.1x10 ⁻⁵³)* | <i>H. misipus</i> | -0.071 (4.0x10 ⁻⁸)* | N. <i>Monolepta marginella</i> | |
| <i>R. dentipes</i> | 0.091 (3.1x10 ⁻¹²)* | <i>Ph. cruciferae</i> | 0.165 (4.1x10 ⁻³⁷)* | <i>T. viridissima</i> | 0.185 (3.0x10 ⁻⁴⁶)* |
| <i>T. viridissima</i> | 0.072 (2.7x10 ⁻⁸)* | <i>R. dentipes</i> | 0.122 (4.2x10 ⁻²¹)* | <i>X. olivacea</i> | -0.293 (9.1x10 ⁻¹¹³)* |
| D. <i>Aphis crassivora</i> | | <i>T. viridissima</i> | 0.160 (7.9x10 ⁻³⁵)* | O. <i>Phyllotreta cruciferae</i> | |
| <i>Ap. mellifera</i> | -0.263 (4.6x10 ⁻⁹¹)* | <i>X. olivacea</i> | -0.157 (1.1x10 ⁻³³)* | <i>Poecilocapsus</i> sp. | -0.121 (1.1x10 ⁻²⁰)* |
| <i>Au. indica</i> | 0.341 (4.2x10 ⁻¹⁵²)* | H. <i>C. sulphurea</i> | | <i>R. dentipes</i> | 0.131 (8.0x10 ⁻²⁴)* |
| <i>Bothrogonia</i> sp. | 0.163c (3.8x10 ⁻³⁶)* | <i>Poecilocapsus</i> sp. | 0.008 (0.538)ns | <i>T. viridissima</i> | 0.130 (1.8x10 ⁻²³)* |
| <i>C. sulphurea</i> | 0.116 (3.5x10 ⁻¹⁹)* | <i>R. dentipes</i> | 0.554 (0.0)* | P. <i>Poecilocapsus</i> sp. | |
| <i>Da. plexipus</i> | -0.098 (3.6x10 ⁻¹⁴)* | <i>X. olivacea</i> | -0.109 (5.8x10 ⁻¹⁷)* | <i>X. olivacea</i> | -0.089 (7.9x10 ⁻¹²)* |
| <i>Dy. cingulatus</i> | 0.169 (9.8x10 ⁻³⁹)* | | | | |

ns: not significant correlation; * significant correlation. NB. As for the species not mentioned in this table, the data were insufficient to make it possible to detect the correlation

The useful afrotropical native pollinator *Amegilla calens* (Hymenoptera: Apidae) was negatively correlated with seven species (Table 5A) [the cosmopolitan Palaearctic native sap-sucking *Aphis crassivora* (Hemiptera: Aphididae), the useful afrotropical native predator *Cheilomenes sulphurea* (Coleoptera: Coccinellidae), the Palaearctic native phytophagous *Dolerus* sp. (Hymenoptera: Tenthredinidae), the subtropical distributed sap-sucking bug *Dysdercus cingulatus* (Hemiptera: Pyrrhocoridae), the western Palaearctic native sap-sucking *Lagria hirta* (Coleoptera: Tenebrionidae), the afrotropical native phytophagous pest

Monolepta. marginella (Coleoptera: Chrysomelidae) and the eastern par of Eurasia native phytophagous *Tettigonia viridissima* (Orthoptera: Tettigoniidae)] and it was positively correlated with three species (Table 5A) [the useful afrotropical native predator *Amegilla* sp. (Hymenoptera: Apidae), the Nearctic native phytophagous *Danaus plexipus* (Lepidoptera: Nymphalidae) and the pantropical distributed phytophagous *Hypolimnas misipus* (Lepidoptera: Nymphalidae)]. *Amegilla* sp. was negatively correlated with three species (Table 5B) [the Palaearctic phytophagous pest *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae), the

North American native sap-sucking *Poecilocapsus* sp. (Hemiptera: Miridae) and *T. viridissima*] and it was positively correlated with two other species (Table 5B) [the useful Hymenoptera Apidae afrotropical pollinators *Apis mellifera adansonni* and *Xylocopa olivacea*]. *Anoplocnemis curvipes* was negatively correlated with two species (Table 5C) [the old world origin sap-sucker *Bothrogonia* sp. (Hemiptera: Cicadellidae) and *H. misipus*] and positively correlated with five species (Table 5C) [*Bothrogonia* sp., *L. hirta*, *M. marginella*, *R. dentipes* and *T. viridissima*]. *Aphis crassivora* was negatively correlated with three species (Table 5D) [*Ap. mellifera adansonni*, *Da. plexipus* and *H. misipus*] and it was positively correlated with seven species (Table 5D) [the indomalayan native phytophagous *Auacophora indica* (coleoptera: Chrysomelidae), *Bothrogonia* sp., *C. sulphurea*, *Dy. cingulatus*, *L. hirta*, *Ph. cruciferae* and *T. viridissima*]. *Ap. mellifera adansonni* was negatively correlated with four species (Table 5E) [*C. sulphurea*, *Dy. cingulatus*, *L. hirta* and *Poecilocapsus* sp.] and it was positively correlated with two species (Table 5E) [*Da. plexipus* and *X. olivacea*]. *Au. indica* was negatively correlated with three species (Table 5F) [*Da. plexipus*, *H. misipus* and *X. olivacea*] and it was positively associated with two species (Table 5F) [*Bothrogonia* sp. and *C. sulphurea*]. *Bothrogonia* sp. was negatively correlated with two species (Table 5G) [*H. misipus* and *X. olivacea*] and it was positively correlated with five species (Table 5G) [*C. sulphurea*, the Palaearctic native phytophagous *Dolerus* sp. (Hymenoptera: Tenthredinidae), *Ph. cruciferae*, *R. dentipes* and *T. viridissima*]. *C. sulphurea* was negatively correlated with *X. olivacea* and positively correlated with *R. dentipes* (Table 5H). *Da. Plexipus* was negatively correlated with three species (Table 5I) [*Dolerus* sp., *M. marginella* and *Ph. cruciferae*] and it was positively correlated with two species (Table 5I) [*H. misipus* and *X. olivacea*]. *Dolerus* sp. was negatively correlated with *H. misipus* and positively correlated with four species (Table 5J) [*Dy. cingulatus*, *L. hirta*, *Ph. cruciferae* and *R. dentipes*]. *Dy. cingulatus* was only positively correlated with *M. marginella* and *R. dentipes* (Table 5K) while *H. misipus* was only negatively correlated with three species (Table 5L) [*M. marginella*, *R. dentipes* and *T. viridissima*]. *L. hirta* was only positively correlated with *M. marginella* and *Ph. cruciferae* (Table 5M) while *M. marginella* was negatively correlated with *X. olivacea* and positively correlated with *T. viridissima* (Table 5N). *Ph. cruciferae* was negatively correlated with *Poecilocapsus* sp. and positively correlated with *R. dentipes* and *T. viridissima* (Table 5O). Finally *Poecilocapsus* sp. was negatively correlated with *X. olivacea* (Table 5P). The other species combinations showed non-significant correlations or the data were insufficient to detect a possible correlation.

4. Discussion

4.1. Species Richness, Diversity, Abundance and Dominance

Our studies revealed the presence of 19 species, 19 genera, 13 families and six orders associated with cowpea plants.

Based on the field collection, Hemiptera represented more than 48.0% of the insects sampled, followed by Coleoptera (27.6%), Hymenoptera (21.9%), Lepidoptera (0.9%), Heteroptera (0.8%) and lastly Orthoptera represented 0.8% of the collected insects. These insect are frequently reported as pests in market gardens in several countries including Cameroon [20, 84-89]. The peculiarity of our results is that they are active on plants after the insecticide treatment applications, suggesting either the re-colonization of the fields from the neighbouring untreated fallows, or the cleaning of aerial plant organs by rainwater, or an appearance of individuals resistant to the chemicals used. Resistance would have been developed as a consequence of anarchic and uncontrolled use of pesticides by undereducated farmers in Cameroon [8, 24, 90, 91]. *Dolerus* sp. (Hymenoptera: Tenthredinidae) was the main borer of stems and pods. Phytophagous pests [Coleoptera Chrysomelidae (26.4%), Hymenoptera Tenthredinidae (0.5%), Lepidoptera Nymphalidae (0.9%) and Orthoptera Tettigoniidae (0.8%)] and sap-feeding pests [Coleoptera Tenebrionidae (0.3%), Heteroptera Alydidae (0.8%), Hemiptera Aphididae (39.9%), Cicadellidae (1.7%), Coreidae (2.4%), Miridae (0.5%), and Pyrrhocoridae (3.4%)], cumulatively represented 77.7% of the collection. The results were contrary to those reported in cowpea fields in Indonesia [27], in Egypt [29], in Nigeria [92], in the Guinean Savannah of Cameroon and the Sudano Sahelian Agro-ecological Zones [93] and other market garden plants in Cameroon [88, 89], where the order Homoptera Aphididae was most abundant. In the localities of Bockle and Dang (North-Cameroon), the species richness of insects associated with cowpea, was quite close to the observations made by several authors in untreated plots. A list of 19 insect pest insects associated with cowpea has been proposed by Zahra *et al.* [94]. We recorded three pests [*Aphis crassivora* Koch (Hemiptera: Aphididae), *Anoplocnemis curvipes* (Fabricius. 1781) (Hemiptera: Coreidae) and *Riptortus dentipes* (Fabricius. 1787) (Heteroptera: Alydidae)] in Bockle and Dang localities (Northern Cameroon). In Indonesia, observation of macrofauna populations in cowpea cultivation using light traps showed middle diversity and very even categories, respectively and the dominant insects were Lepidoptera and Coleoptera's order [31, 95]. However according to the same authors, the observation using a pitfall trap showed that the dominant macrofauna was Hymenoptera and Orthoptera's order. Meanwhile, in the observation using swing nets, the dominant insect was from the order Hemiptera or group of ladybugs. In the Southern Rajasthan (India), it was reported that the insect pest complex of cowpea was categorized into 5 orders (Hemiptera, Thysanoptera, Coleoptera, Diptera and Lepidoptera) comprising 14 families, the pestiferous fauna including population of flea beetle, jassids, whiteflies, sap sucking bugs, leaf miner, thrips, aphids, spotted pod borer and lycaenid caterpillar [96]. Compared to other vegetable crops, for example in Sudan, 28 pest species were reported damaging untreated eggplant fields, divided into 18 phytophagous species, seven species that destroy flowers and fruits, three stem-borers and root-borer species

[84]. Similarly in Bangladesh, 20 species that damage eggplant plants are divided into 15 phytophagous species, three pest species of flowers and fruits and two borer species [97]. The availability of wild species in the neighbouring fallows of cowpea plots would represent a microhabitat favourable to the propagation of pest insects. The damage caused by phytophagous insects (Coleoptera Chrysomelidae, Hymenoptera, Lepidoptera and Orthoptera) and sap-feeders (Coleoptera Tenebrionidae and Hemiptera) is greater on leaves and pods with a occurrence rate of 77.7%. This is explained by the fact that at the fruiting stage, the cowpea plant emits volatile compounds which attract insects among which useful species are recruited (pollinators and predators of other phytophagous insects) and several nectarivorous species including sap-sucking biters and stem and/or pod borers. The situation found in the localities of Bockle (Garoua) and Dang (Ngaoundere) in cultivated cowpea plots is therefore not surprising. In market gardens as it is the case in Ivory Coast, aerial plant organs such as leaves, flowers and pods can be more attacked than others, depending on the high production periods [20]. The differences observed could be explained by the high frequency of heavy rains which wash the insecticides, the misuse of pesticides by poorly educated farmers, the attacks in the field by insects varying considerably according to the phenological stage of the plant. Our study is the first step in evaluating impact of native and non-native insect species on the insect assemblage of cowpea plants cultivated in Bockle and Dang localities (North-Cameroon) especially when using a synthetic insecticide or aqueous leave extracts of local wild plants. The cultivated cowpea plots showed a relatively low species richness and diversity abundance, high level of species evenness with the high representation of non-native pest species. Similar results are reported in ground-dwelling ant communities in anthropized environments [51, 98, 99]. Recent reports shows that the same orders and families damage chili pepper plants (*Piper nigrum* L.) in the locality of Penja-Cameroon, egg-plants and potato plants in Balessing-Cameroon [88, 89, 100]. The low diversity of the insect pests is associated with low abundance in native species (eight species i.e. 42.1% of the total species richness and 36.5% of the total collected insects), resulting in the weak exploitation of resources. The exploitation of both food and nest sites was mostly achieved by non-native species (11 non-native species i.e. 57.9% of the species richness and 63.5% of the total abundance). Similar results were reported in egg-plant and potato plant fields in Balessing (Cameroon) [88, 89]. The high abundance level of the invasive non-native species in their introduced range is well known [101]. The low insect species diversity recorded reflects the negative effect of the chemical treatments or the presence of both three native pests [*Anoplocnemis curvipes* (Fabricius. 1781) (Hemiptera: Coreidae), *Monolepta marginella* Weise. 1903 (Coleoptera: Chrysomelidae), *Hypolimnas misippus* (Linnaeus. 1764) (Lepidoptera: Nymphalidae)] and the 11 non-native pests [*Aphis crassivora* Koch. 1854 (Hemiptera: Aphididae), *Aulacophora indica* Gmelin. 1790 (Coleoptera:

Chrysomelidae), *Bothrogonia* sp. Melichar. 1926 (Hemiptera: Cicadellidae), *Danaus plexippus* (Linnaeus. 1758) (Lepidoptera: Nymphalidae), *Dolerus* sp. Panzer. 1801 (Hymenoptera: Tenthredinidae), *Dysdercus cingulata* (Fabricius. 1775) (Hemiptera: Pyrrhocoridae), *Lagria hirta* (Linnaeus. 1758) (Coleoptera: Tenebrionidae), *Phyllotreta cruciferae* (Goeze. 1777) (Coleoptera: Chrysomelidae), *Poecilocapsus* sp. Reuter. 1876 (Hemiptera: Miridae), *Riptortus dentipes* (Fabricius. 1787) (Heteroptera: Alydidae), *Tettigonia viridissima* (Linnaeus. 1758) (Orthoptera: Tettigoniidae)]. The recorded native species are frequently reported as field pests on several plant species: *An. curvipes* (Hemiptera: Coreidae) is one of the most serious pests of cowpea pods and all the reported Coreinae species are known to be polyphagous feeding on both food crops and wild plants. For example in Côte d'Ivoire Yeboue et al. [102] have shown that *An. curvipes* has the higher number of host plants, infesting 90% of 72 plants surveyed including *Anacardium occidentale* (Sapindales: Anacardiaceae), *Mangifera indica* (Anacardiaceae), *Cocos nucifera* (Arecaceae), *Elaeis guineensis* (Arecaceae), *Ipomoea batatas* (Solanales: Convolvulaceae), *Cucumis sativus* (Violales: Cucurbitaceae), *Cucurbita maxima* (Cucurbitaceae), *Langenaria vulgaris* (Cucurbitaceae), *Hevea brasiliensis* (Malpighiales: Euphorbiaceae), *Manihot esculenta* (Malpighiales: Euphorbiaceae), *Arachis hypogea* (Fabales: Fabaceae), *Glycine max* (Fabaceae), *Phaseolus lunatus* (Fabaceae), *Vigna unguiculata* (Fabaceae), *Persea africana* (Laurales: Lauraceae), *Abelmoschus esculentus* (Malvales: Malvaceae), *Gossypium barbadense* (Malvaceae), *Musa paradisiaca* (Zingiberales: Musaceae), *Psidium guajava* (Myrtales: Myrtaceae), *Passiflora edulis* (Violales: Passifloraceae), *Oryza glaberrima* (Cyperales: Poaceae), *Zea mays* (Poaceae), *Coffea arabica* (Rubiales: Rubiaceae), *Citrus limosus* (Sapindales: Rutaceae), *C. maxima* (Rutaceae), *C. sinensis* (Rutaceae), *Lycopersicon esculentum* (Solanales: Solanaceae), *Solanum nodiflorum* (Solanaceae), *S. melongena* (Solanaceae) and *Theobroma cacao* (Malvales: Sterculiaceae). Moreover, it has been reported damaging *Citrus* orchard in Nigeria [103]. The leaf beetle *M. marginella* (Coleoptera: Chrysomelidae), is known to attacks leaves and flowers in pulse crops and high populations shred leaves and damage reproductive structures (often patchy and more common at field edges) in avocado orchard [63]. *Monolepta* Chevrolat, 1837 is the largest genus of the Galerucinae comprising about 600 species worldwide [104] and most of the species are distributed in tropical regions [105]. *H. misippus* (Lepidoptera: Nymphalidae) is a well-known African polymorphic and mimetic nymphalid butterfly, phytophagous, with a pantropical distribution. Caterpillars feed on a variety of plant families including Convolvulaceae, Malvaceae and Portulacaceae and the primary food type are Portulacaceae *Portulaca oleracea* and *Po. quadrifida* [106]. Non-native species damage cultivated plants not only in their native range but also in areas of introduction. This is the case of non-native pest species [62, 64, 66-68, 70-72, 80, 81, 83] that were recorded in Bockle and Dang.

Sap-feeding pests (vectors of plant viruses) are highly polyphagous and have developed resistance to several synthetic insecticides in several countries. Transfer of sap-feeding species from neighbouring fallows to cultivated eggplant plots may be the work of ground-dwelling and arboreal foraging ant species, as is the case after stopping applications of insecticides in citrus orchards in Cameroon [107, 108]. 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 Garoua and Ngaoundere (North-Cameroon). Our results showed a low occurrence level of the native pest species, in the presence of the non-native species generally considered as among the most ecologically destructive in cultivated areas where they have been introduced. The low representation of native species could be the result either of the regulation of their populations by local natural enemies, or of a negative force of introduced species. World-wide, synthetic pesticides are commonly used for pest control. But inappropriate use against pest insects in several countries has resulted in many unwanted effects, such as environmental pollution, non-target effect and human health hazards and the development of resistance to almost all classes of insecticides [24]. A similar situation would arise in Bockle and dang localities if the phytosanitary authorities do not take adequate measures to educate gardeners and thus protect the environment and populations.

4.2. Community Structure and Functioning Model

The insect species assemblage from the two-year's pooled data in Bockle was perfectly fitted by the log-linear nomocenos model LL (Motomura's geometric model GM), with the Motomura's environmental constant reaching a high value close to 1 ($m = 0.792$). Dang 2021 and the overall pooled settlement best fitted the log-normal nomocenos model LN (Preston's model) with the Preston's environmental constant reaching a high value ($m' = 1.971$ and $m' = 1.971$ respectively). The GM (preemption of the niche) describes a linear relationship between the abundances of the species (transformed into a logarithm) and the ranks. Contrary to the LN (Preston model) which describes the relationship between the logarithm of the abundance and the probit of the ranks of the species and which reflects a community where the majority of species shows moderate abundances, the GM (Motomura model) corresponds to a community in which a reduced number species is largely dominant. GM niche partitioning model is reported fitting SADs of several insect communities, for example ground-dwelling ants inhabiting a climax forest zone and a paraclimax grassland in the eastern Pyrenees (France) [109], the assemblages of dung beetles in the mountain meadows of the Southern Alps [110], sandfly communities in the Mayombe region of Congo [111], the Carabidae and Heteroptera inhabiting road verges and meadow-pasture pairs in managed grasslands in central Finland [112], the assemblage of grasshoppers in different types of vegetation in the littoral zone of Cameroon [113], the assemblage of insects associated with potato plants in Balessing (Cameroon) [89]. Given that nomocenos are

associations of species subject to the influence of the same factors and whose species profile is sufficiently close to be assimilated to the Log-linear or Log-normal model [114], these models therefore seem to characterize the stands of open forests and disturbed environments where there is strong competition between species for the exploitation of available resources. The settlement in Dang 2022, the two-year's pooled data in Dang and the overall pooled assemblage from both sites and both years were best fitted by the Zipf (Z) model while the settlement in Bockle in 2021 and 2022 and the pooled assemblage from both sites in 2021 best fitted the Zipf-Mandelbrot (ZM) model. Zipf's law, previously used exclusively in linguistics, is now frequently applied in animal ecology to characterize abundance distributions. This is how today this law is widely used to characterize SADs of insect communities [51, 89, 113]. For the Z model the frequency of each species is inversely proportional to its rank and the model describes an order of appearance of species according to their decreasing requirement to environmental conditions. Thus a ubiquitous species will appear very early and be abundant, while a specialized species will appear later, when the first species have modified the environment, and in small numbers. Z and ZM models are frequently fitted to communities from natural environments, suggesting evolved ecosystems where multi-species networked structure corresponds to an optimal structure for the circulation of information carried out on spatio-temporal scales [56, 115, 116]. Then insect assemblages associated with cowpea plants in Bockle and Dang localities, function on the basis of the maintenance of a complex information network developed in time and space (Zipf and Zipf-Mandelbrot models) closed to that from evolved environments (close to ecological balance) and then presented a fairly significant regeneration force compared to disturbed urban environments.

5. Conclusion

The purpose of this study in Garoua and Ngaoundere was to determine the biodiversity of insects associated with cowpea plants and characterize the community structure. Collected specimens of insects belonged to six orders, 13 families, 19 genera and 19 species. Pooled data showed low species richness, low diversity and a low dominance by a few species. Based on the species richness from the pooled data, Coleoptera, Hemiptera and Hymenoptera were species-rich orders [five species each (26.3%)] while Lepidoptera was represented by only two species (10.5%), Heteroptera and Orthoptera were rarely represented by only one species i.e. 5.3% each. Based on the species abundance, Hemiptera was mostly abundant (40.0%) followed by Coleoptera (27.6%), Hymenoptera (21.9%), Lepidoptera (0.9%). Heteroptera and Orthoptera were least abundant (0.8% respectively). The overall low diversity of the insect pests was associated with the overall low abundance in native species (eight species i.e. 42.1% of the total species richness and 36.5% of the total insect abundance), resulting in the weak exploitation of resources. The exploitation of both food and nest sites was

mostly achieved by non-native species (11 non-native species i.e. 57.9% of the species richness and 63.5% of the total abundance). In Bockle and Dang localities, amongst the recorded insect pests associated with cowpea plants, three Afrotropical native species were recorded [*Anoplocnemis curvipes* (Hemiptera: Coreidae), *Hypolimnas misippus* (Lepidoptera: Nymphalidae) and *Monolepta marginella* (Coleoptera: Chrysomelidae)]. Despite chemical treatments, cowpea plants were damaged in the field mostly by non-native pest insects. The community structure of insects associated with cowpea plants in Bockle and Dang, presented a fairly significant regeneration force compared to disturbed urban environments. In these localities of the country, all the conditions combine to soar. Due to the numerical and behavioural dominance of non-native insects, a significant number of resources are potentially exploitable. In due course,

once the invaders would completely monopolize available resources and saturate the localities, they would not allow native species the niche opportunities to re-establish themselves. The consequences of losing these native species, which may well interact with the endemic flora, will be of extreme concern. The high occurrence of pests necessitates the reaction of the national phytosanitary control service to reduce economic losses.

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Appendix

Table A1. Pairwise comparisons of the pooled species occurrences from the two study sites and two years collections using Bonferroni's procedure and the Fisher's exact p-values.

| | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) |
|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|
| a vs. b | 3.0×10^{-4} (0)* | b vs. f | 3.4×10^{-4} (0)* | c vs. k | 3.7×10^{-4} (0)* | d vs. q | 4.7×10^{-4} (7.9x10 ⁻²²³)* | f vs. k | 7.7×10^{-4} (4.8x10 ⁻⁵²)* | h vs. i | 4.1×10^{-4} (0)* |
| a vs. c | 3.0×10^{-4} (0)* | b vs. g | 3.4×10^{-4} (0)* | c vs. l | 3.8×10^{-4} (0)* | d vs. r | 1.8×10^{-3} (3.8x10 ⁻⁷)* | f vs. l | 5.9×10^{-4} (1.0x10 ⁻¹¹⁰)* | h vs. j | 1.9×10^{-3} (1.6x10 ⁻⁶)* |
| a vs. d | 3.0×10^{-4} (0)* | b vs. h | 3.4×10^{-4} (0)* | c vs. m | 3.8×10^{-4} (0)* | d vs. s | 4.6×10^{-4} (3.6x10 ⁻²⁴⁵)* | f vs. m | 6.7×10^{-4} (1.9x10 ⁻⁷⁸)* | h vs. k | 0.009 (0.231)ns |
| a vs. e | 3.1×10^{-4} (0)* | b vs. i | 1.0×10^{-3} (1.7x10 ⁻²³)* | c vs. n | 3.8×10^{-4} (0)* | e vs. f | 1.5×10^{-3} (7.0x10 ⁻¹¹)* | f vs. n | 7.8×10^{-4} (8.2x10 ⁻⁵¹)* | h vs. l | 1.1×10^{-3} (3.5x10 ⁻¹⁹)* |
| a vs. f | 3.1×10^{-4} (0)* | b vs. j | 3.4×10^{-4} (0)* | c vs. o | 3.9×10^{-4} (0)* | e vs. g | 9.3×10^{-4} (1.1x10 ⁻³³)* | f vs. o | 9.9×10^{-4} (1.1x10 ⁻²⁶)* | h vs. m | 1.8×10^{-3} (6.3x10 ⁻⁷)* |
| a vs. g | 3.1×10^{-4} (0)* | b vs. k | 3.4×10^{-4} (0)* | c vs. p | 3.9×10^{-4} (0)* | e vs. h | 6.3×10^{-4} (7.1x10 ⁻⁹²)* | f vs. p | 0.005 (0.016)ns | h vs. n | 0.010 (0.317)ns |
| a vs. h | 3.1×10^{-4} (0)* | b vs. l | 3.5×10^{-4} (0)* | c vs. q | 3.9×10^{-4} (0)* | e vs. i | 4.0×10^{-4} (0)* | f vs. q | 6.5×10^{-4} (1.2x10 ⁻⁸²)* | h vs. o | 3.9×10^{-3} (3.1x10 ⁻³)* |
| a vs. i | 3.1×10^{-4} (0)* | b vs. m | 3.5×10^{-4} (0)* | c vs. r | 4.8×10^{-4} (4.4x10 ⁻²⁰¹)* | e vs. j | 5.6×10^{-4} (1.8x10 ⁻¹³⁵)* | f vs. r | 1.2×10^{-3} (5.2x10 ⁻¹⁷)* | h vs. p | 9.5×10^{-4} (4.2x10 ⁻³¹)* |
| a vs. j | 3.1×10^{-4} (0)* | b vs. n | 3.5×10^{-4} (0)* | c vs. s | 3.9×10^{-4} (0)* | e vs. k | 6.0×10^{-4} (2.0x10 ⁻¹⁰²)* | f vs. s | 6.2×10^{-4} (8.5x10 ⁻⁹⁸)* | h vs. q | 1.7×10^{-3} (3.2x10 ⁻⁸)* |
| a vs. k | 3.2×10^{-4} (0)* | b vs. o | 3.5×10^{-4} (0)* | d vs. e | 1.4×10^{-3} (3.8x10 ⁻¹²)* | e vs. l | 5.0×10^{-4} (4.9x10 ⁻¹⁷⁷)* | g vs. h | 1.2×10^{-3} (2.8x10 ⁻¹⁷)* | h vs. r | 6.0×10^{-4} (2.0x10 ⁻¹⁰⁸)* |
| a vs. l | 3.2×10^{-4} (0)* | b vs. p | 3.6×10^{-4} (0)* | d vs. f | 8.4×10^{-4} (3.2x10 ⁻⁴¹)* | e vs. m | 5.5×10^{-4} (3.5x10 ⁻¹³⁷)* | g vs. i | 4.1×10^{-4} (0)* | h vs. s | 1.4×10^{-3} (1.1x10 ⁻¹³)* |
| a vs. m | 3.2×10^{-4} (0)* | b vs. q | 3.6×10^{-4} (0)* | d vs. g | 6.6×10^{-4} (4.5x10 ⁻⁸⁰)* | e vs. n | 6.1×10^{-4} (9.8x10 ⁻¹⁰¹)* | g vs. j | 8.7×10^{-4} (1.1x10 ⁻³⁹)* | i vs. j | 4.1×10^{-4} (0)* |
| a vs. n | 3.2×10^{-4} (0)* | b vs. r | 4.6×10^{-4} (2.0x10 ⁻²⁵³)* | d vs. h | 5.3×10^{-4} (2.8x10 ⁻¹⁶⁰)* | e vs. o | 6.9×10^{-4} (2.1x10 ⁻⁶⁸)* | g vs. k | 1.0×10^{-3} (3.7x10 ⁻²²)* | i vs. k | 4.2×10^{-4} (0)* |
| a vs. o | 3.2×10^{-4} (0)* | b vs. s | 3.6×10^{-4} (0)* | d vs. i | 4.0×10^{-4} (0)* | e vs. p | 1.1×10^{-3} (3.7x10 ⁻¹⁹)* | g vs. l | 7.0×10^{-4} (1.3x10 ⁻⁶⁵)* | i vs. l | 4.2×10^{-4} (0)* |
| a vs. p | 3.3×10^{-4} (0)* | c vs. d | 5.5×10^{-4} (2.9x10 ⁻¹⁴¹)* | d vs. j | 4.8×10^{-4} (2.2x10 ⁻²¹⁴)* | e vs. q | 5.8×10^{-4} (1.9x10 ⁻¹¹¹)* | g vs. m | 8.5×10^{-4} (1.2x10 ⁻⁴⁰)* | i vs. m | 4.2×10^{-4} (0)* |
| a vs. q | 3.3×10^{-4} (0)* | c vs. e | 4.7×10^{-4} (2.2x10 ⁻²²⁵)* | d vs. k | 5.1×10^{-4} (1.1x10 ⁻¹⁷³)* | e vs. r | 0.006 (0.065)ns | g vs. n | 1.1×10^{-3} (2.4x10 ⁻²¹)* | i vs. n | 4.3×10^{-4} (0)* |
| a vs. r | 3.3×10^{-4} (0)* | c vs. f | 3.6×10^{-4} (0)* | d vs. l | 4.5×10^{-4} (2.0x10 ⁻²⁶³)* | e vs. s | 5.2×10^{-4} (2.4x10 ⁻¹⁶¹)* | g vs. o | 1.7×10^{-3} (4.2x10 ⁻⁸)* | i vs. o | 4.3×10^{-4} (0)* |
| a vs. s | 3.3×10^{-4} (0)* | c vs. g | 3.7×10^{-4} (0)* | d vs. m | 4.7×10^{-4} (1.9x10 ⁻²¹⁶)* | f vs. g | 1.6×10^{-3} (2.3x10 ⁻⁸)* | g vs. p | 3.7×10^{-3} (1.6x10 ⁻³)* | i vs. p | 4.3×10^{-4} (0)* |
| b vs. c | 2.7×10^{-3} (1.2x10 ⁻⁴)* | c vs. h | 3.7×10^{-4} (0)* | d vs. n | 5.1×10^{-4} (1.5x10 ⁻¹⁷¹)* | f vs. h | 7.9×10^{-4} (1.9x10 ⁻⁴⁴)* | g vs. q | 8.1×10^{-4} (8.9x10 ⁻⁴⁴)* | i vs. q | 4.4×10^{-4} (0)* |
| b vs. d | 4.9×10^{-4} (5.4x10 ⁻¹⁸⁶)* | c vs. i | 8.3×10^{-4} (1.6x10 ⁻⁴³)* | d vs. o | 5.6×10^{-4} (1.7x10 ⁻¹²⁹)* | f vs. i | 4.0×10^{-4} (0)* | g vs. r | 8.0×10^{-4} (3.5x10 ⁻⁴⁴)* | i vs. r | 4.4×10^{-4} (0)* |
| b vs. e | 4.5×10^{-4} (2.0x10 ⁻²⁸⁰)* | c vs. j | 3.7×10^{-4} (0)* | d vs. p | 7.4×10^{-4} (1.6x10 ⁻⁵⁶)* | f vs. j | 6.8×10^{-4} (4.3x10 ⁻⁷⁷)* | g vs. s | 7.5×10^{-4} (2.2x10 ⁻⁵⁵)* | i vs. s | 4.5×10^{-4} (0)* |

Table A1. Continued.

| | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) | | α' (p-value) |
|---------|---|---------|---|---------|---|---------|---|---------|---|---------|---|
| j vs. k | 3.2×10^{-3} (3.6×10^{-4})* | j vs. s | 0.004 (0.009)ns | k vs. s | 1.6×10^{-3} (5.7×10^{-10})* | m vs. n | 2.6×10^{-3} (8.1×10^{-5})* | n vs. q | 2.0×10^{-3} (7.1×10^{-6})* | p vs. r | 9.7×10^{-4} (3.4×10^{-27})* |
| j vs. l | 2.2×10^{-3} (3.1×10^{-5})* | k vs. l | 1.3×10^{-3} (1.0×10^{-14})* | l vs. m | 2.4×10^{-3} (6.7×10^{-5})* | m vs. o | 1.3×10^{-3} (1.8×10^{-15})* | n vs. r | 5.8×10^{-4} (5.7×10^{-118})* | p vs. s | 6.7×10^{-4} (5.1×10^{-78})* |
| j vs. m | 0.050 (0.904)ns | k vs. m | 3.0×10^{-3} (1.8×10^{-4})* | l vs. n | 1.3×10^{-3} (2.2×10^{-15})* | m vs. p | 7.2×10^{-4} (1.3×10^{-60})* | n vs. s | 1.5×10^{-3} (1.6×10^{-10})* | q vs. r | 5.2×10^{-4} (2.2×10^{-162})* |
| j vs. n | 2.8×10^{-3} (1.7×10^{-4})* | k vs. n | 0.025 (0.883)ns | l vs. o | 9.2×10^{-4} (1.8×10^{-34})* | m vs. q | 0.017 (0.622)ns | o vs. p | 1.1×10^{-3} (5.0×10^{-18})* | q vs. s | 0.006 (0.062)ns |
| j vs. o | 1.3×10^{-3} (2.9×10^{-16})* | k vs. o | 2.1×10^{-3} (2.7×10^{-5})* | l vs. p | 6.3×10^{-4} (8.0×10^{-90})* | m vs. r | 5.3×10^{-4} (9.1×10^{-157})* | o vs. q | 1.2×10^{-3} (2.0×10^{-17})* | r vs. s | 5.0×10^{-4} (3.3×10^{-182})* |
| j vs. p | 7.3×10^{-4} (2.1×10^{-59})* | k vs. p | 8.8×10^{-4} (1.5×10^{-37})* | l vs. q | 3.4×10^{-3} (5.9×10^{-4})* | m vs. s | 0.005 (0.016)ns | o vs. r | 6.4×10^{-4} (6.1×10^{-83})* | | |
| j vs. q | 0.013 (0.501)ns | k vs. q | 2.0×10^{-3} (1.8×10^{-5})* | l vs. r | 4.9×10^{-4} (1.3×10^{-198})* | n vs. o | 2.3×10^{-3} (6.3×10^{-5})* | o vs. s | 1.0×10^{-3} (3.8×10^{-25})* | | |
| j vs. r | 5.4×10^{-4} (6.0×10^{-155})* | k vs. r | 5.7×10^{-4} (8.7×10^{-120})* | l vs. s | 0.007 (0.132)ns | n vs. p | 9.0×10^{-4} (1.7×10^{-36})* | p vs. q | 7.1×10^{-4} (2.4×10^{-64})* | | |

a: *Monolepta marginella* (Coleoptera: Chrysomelidae); b: *Aulacophora indica* (Coleoptera: Chrysomelidae); c: *Phyllotreta cruciferae* (Coleoptera: Chrysomelidae); d: *Cheilomenes sulphurea* (Coleoptera: Coccinellidae); e: *Lagria hirta* (Coleoptera: Tenebrionidae); f: *Aphis crassivora* (Hemiptera: Aphididae); g: *Bothrogonia* sp. (Hemiptera: Cicadellidae); h: *Anoplocnemis curvipes* (Hemiptera: Coreidae); i: *Poecilocapsus* sp. (Hemiptera: Miridae); j: *Dysdercus cingulata* (Hemiptera: Pyrrhocoridae); k: *Riptortus dentipes* (Heteroptera: Alydidae); l: *Apis mellifera adansonii* (Hymenoptera: Apidae); m: *Amegilla calens* (Hymenoptera: Apidae); n: *Amegilla* sp. (Hymenoptera: Apidae); o: *Xylocopa olivacea* (Hymenoptera: Apidae); p: *Dolerus* sp. (Hymenoptera: Tenthredinidae); q: *Danaus plexippus* (Lepidoptera: Nymphalidae); r: *Hypolimnas misippus* (Lepidoptera: Nymphalidae); s: *Tettigonia viridissima* (Orthoptera: Tettigonidae).

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