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Entomofauna of cashew inflorescences (*Anacardium occidentale* L., 1753) in the Bagoué region of northern Côte d'Ivoire

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Abstract

In Ivory Coast, several agronomic research works are conducted to improve the production of cashew trees. However, very few studies have been devoted to pollinating insects. This study aims to identify the insects visiting the inflorescences of the cashew tree in order to improve the fruit setting of this plant. To do this, insects visiting the flowers were observed and then captured 4 times a month from December 2021 to April 2022 during the flowering period. Insects were captured using entomological netting in the three departments of the Bagoue region throughout the flowering period. To do this, before flowering, thirty (30) cashew trees of the same diameter were randomly selected in each orchard and marked with a ribbon. The results indicate the presence of 53 insect species belonging to 25 families and 7 orders on cashew inflorescences. The orders Hymenoptera, Diptera, Heteroptera and Lepidoptera are the most diverse in each department. In terms of family taxonomy, the Apidae, Megachillidae, Hallictidae and Noctuidae families are the richest in species in these localities. Regarding abundance, 25,035 specimens were collected. The order Hymenoptera (85.48%), the family Apidae (68.64%) and the species *Apis mellifera* (38.42%) were the most abundant taxonomic groups. Some species (*Ammophila sabulosa*, *Ectommius literates*, *Glypsus erubescens* and *Leptinotarsa decenlineata*) were present in the department of Boundiali but absent in the ones of Kouto and Tingréla.

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Introduction

The cashew tree was introduced to northern Côte d'Ivoire in 1960 to curb deforestation and combat soil erosion (Goujon *et al.*, 1973). But the plant has become an important crop due to the marketing of associated products such as apples and cashew nuts (Agboton *et al.*, 2014). In 2010, cashew nuts became Côte d'Ivoire's third largest agricultural export after cocoa (Koné, 2010). This performance places the country in first place among the world's cashew nut producers and exporters (Diop, 2016). Despite the achievements recorded, the current annual yield of Ivorian orchards, estimated between 350 kg and 500 kg per hectare, still remains low because it should reach 1.6 tonnes / hectare (Djaha *et al.*, 2010). Poor pollination of flowers is thought to be one of the main causes (Bhattacharya, 2004). Many studies justify cashew's low productivity in part by under-pollination (Reddi, 1987; Freitas *et al.*, 2014). Such was the case in a study conducted in India, which found that 25 to 72% of the pistil was not pollinated due to a lack of pollinating insects (Reddi, 1987). Insects are the essential pollinators of the cashew tree. (Freitas *et al.*, 2014) showed that the honey bee (*Apis mellifera*), whilst not native to the region, is the most efficient pollinator of cashew trees in north-east Brazil. Research in India has shown that the insects that visit cashew trees are mainly ants and bees (Bhattacharya, 2004). According to these authors, bees visit and gather pollen from flowers more actively during the day, when the pollen and stigmas are receptive, compared with Diptera, Lepidoptera and Coleoptera, whose visits are less frequent and irregular without touching the pistil. They only collect nectar and are therefore not involved in pollen transfer. Nevertheless, in Côte d'Ivoire (the world's leading cashew producer), there is very little data on the insects that visit the inflorescences of this crop.

This study was conducted to remedy this lack of data. The general objective of this research is to improve the fruiting rate of cashew trees by controlling the entomofauna living in the inflorescences of this Anacardiaceae. Specifically, the insects visiting cashew inflorescences were inventoried and their diversity assessed.

Materials and methods

Study area

This study was conducted in the Bagoue region of northern Côte d'Ivoire. It belongs to the dry tropical climatic regime of the Sudano-Sahelian type, whose seasonal rhythm is regulated by the movement of the intertropical front (Jourda *et al.*, 2005). The climate is characterized by a raining season from May to October, with maximum rainfall in September, and a dry season from November to April, marked by the harmattan from December to February. The average annual temperature varies between 25°C and 35°C (Kouakou *et al.*, 2012).

Data collection

Observations were made in a total of fifteen (15) orchards of the same age, including five (5) per department (Boundiali, Kouto and Tengrela). The observations were conducted using three (3) capture techniques. Finger catching was carried out after direct observation, using entomological nets and coloured trays. In each cashew orchard, insects were collected once a week from the flowers of 30 cashew trees of the same diameter during the flowering period (December-April). After capture, the insects were stored in pillboxes containing 70% alcohol, then transported to the laboratory.

The insects collected were identified to species level using the identification keys (Atlas Hymenoptera and Atlas Lepidoptera) (Pauly, 1979 and 1998; Pauly *et al.*, 2009; Pauly *et al.*, 2010) and the Phytosanitary Manual of Heteroptera and Predators of West Africa (Wiyao *et al.*, 2011).

Data analysis

Diversity and structure of insects has been described by taxonomic composition, rarified richness, abundance, the Shannon-Weaver diversity index (H') (Quinn and Hickey, 1990) and the regularity index (Piélou, 1969). The Shannon-Weaver diversity index was used to assess insect taxonomic diversity.

Equitability was used to examine the level of organization of the Entomofaunal population. All these analyses were done using the vegan package (Oksanen *et al*., 2013) of the R software version 3.0.2 (R Core Team, 2013). Insect abundance was obtained by counting all individuals per taxon per sample.

Results

Entomofauna of the cashew inflorescence in the Bagoué region in Côte d'Ivoire

Taxonomic composition

In Boundiali department, the insects collected were composed of 46 species divided into 24 families and 6 orders. In Tingréla, the entomofauna is composed of 44 species from 24 families and 6 orders. In the department of Kouto, 50 species were collected, divided into 25 families and 7 orders. Five (5) orders are common to all three departments in the study area. These are the orders of Hymenoptera, Lepidoptera, Diptera, Hemiptera and Coleoptera. The order of Neuroptera was specific to the departments of Kouto and Tingréla while the Blattoptera was collected in Boundiali and Kouto. The orders Hymenoptera, Lepidoptera, Diptera and Hemiptera had the highest number of species and families in the three localities (Table 1). The families Apidae, Megachilidae, Hallictidae, Formicidae, Sphecidae, Vespidae, Noctuidae, Péridae, Papillonidae, Lycaenidae, Muscidae, Sarcophagidae, Syrphidae, Calliphoridae, Stratiomyidae, Ciccadelidae, Coréidae, Miridae, Pentatomidae, Carabidae, Coccinellidae, and Chrysomellidae were common to the three departments (boundiali, kouto and tingréla). On the other hand, the family Pyrrhocoridae and Blattidae were specific to the localities of Boundiali and Kouto. The Chrysopidae were more specific to the localities of Kouto and Tingréla. The Apidae family (eight (8) species), followed by the Noctuidae family (five (5) species) and the Halictidae family (four (4) species) are the families with the highest number of species in all departments (Table 1).

Concerning species, some were observed only in Boundiali and Kouto. These were *Amonphila sabulosa* and *Ectommius literates* in Boundiali and *Glypsus erubescens* and *Leptinotarsa decenlineata* in Kouto. Species such as *Dactylurina staudingeri*, *Amegilla* sp, *Dysdercus volkéri*, *Coccinelila* sp and *Ectobus pallidus* were recorded in the localities of Boundiali and Kouto, whereas *Anthidiini* sp, *Ancistrocerus trifaciatus*, *Chrysoperla carnea*, *Chrysoperla affinis* were observed in Kouto and Tingréla (Table 1). With a population of 50 species, the Kouto department was the richest.

Table 1. Taxonomic list of the entomofauna of cashew tree inflorescences in the Bagoué region in Côte d'Ivoire

Orders	Families	Taxa
Hymenoptera	Apidae	*Apis mellifera****
		*Dactylurina staudingeri***
		Xylocopa sp.***
		Amegilla sp.**
		*Meliponula ferrufinea****
		*Meliponula bocandei****
		*Meliponula togoensis****
		*Xylocopa olivacea****
	Megachilidae	*Heriades* sp.***
		Anthidiini sp.**
		Megachile sp.***
	Hallictidae	*Stictonomia schubotzi****
		Pseudapis sp.***
		Halictus sp.***
		Lasioglossum sp.***
	Formicidae	*Camponotus* sp.***
		Formica sp.***
		*Crematogaster scutellaris****
	Sphecidae	*Isodontia mexicana****
		*Ammophila sabulosa**
	Vespidae	*Ectommius literates**
		*Ancistrocerus trifaciatus***
		Vespa sp***
Lepidoptera	Noctuidae	*Heliophis viriplaca****
		*Chrisodeix chalcites****
		Mythimna sp***
		*Mythimna albipuncta****
		Diarsia sp.***
	Péridae	*Pieris napi****
		Colias sp.***
	Papillonidae	*Papilloni machon****
	Lycaenidae	*Lycaeni virgaureae****
Diptera	Muscidae	*Musca automnalis****
	Sarcophagidae	*Sarcophaga canaria****
	Syrphidae	*Cheilosia* sp.***
		*Episyrphus balteatus****
	Calliphoridae	*Calliphorissa vicina****
	Stratiomyidae	*Exairata spingera****
Hemiptera	Ciccadelidae	*Ciccadelelila* sp.***
	Coréidae	*Anoplocnemis curvipes****
	Pyrrhocoridae	*Dysdercus volkeri***

	Miridae	*Taylaridygus* sp.***
	Pentatomidae	*Spavia* sp.***
		*Glypsus erubescens***
		Cléptus sp.***
Coleoptera	Carabidae	*Croscherichia sangunolenta****
	Coccinellidae	*Leptinotarsa decenlineata**
		Coccinelila sp.**
	Chrysomellidae	*Lamprocopa occidentallis****
Nevroptera	Chrysopidae	*Chrysoperla carnea***
		*Chrysoperla affinis***
Blattoptera	Blattidae	*Ectobus pallidus***
7	25	53

Entomofaunal diversity

The Shannon indices for the three departments were (H' = 3.26) in Kouto, (H' = 2.58) in Tengrela and (H' = 2.3) in Bagoue. Even though the index obtained in the department of Kouto stands out from the others, the Kruskal-Willis test shows that the difference between the Shannon indices is not significant (P = 0.36) (Fig. 1a). The equity index fluctuates between 0.62 (Boundiali) and 0.69 (Kouto and Tingréla). Altogether, the entomofaunal population is well organised and structured in the three departments. The Kruskal-Wallis test shows that there is no significant difference between the equitability index of the departments (P = 0.35) (Fig. 1b). The Kouto department recorded 49.9 species, followed by the Boundiali department with 46 species and the Tengrela department with 45 species. No significant difference was observed between the rarefied richness according to the Kruskal-Wallis test (P = 0.24) (Fig. 1c).

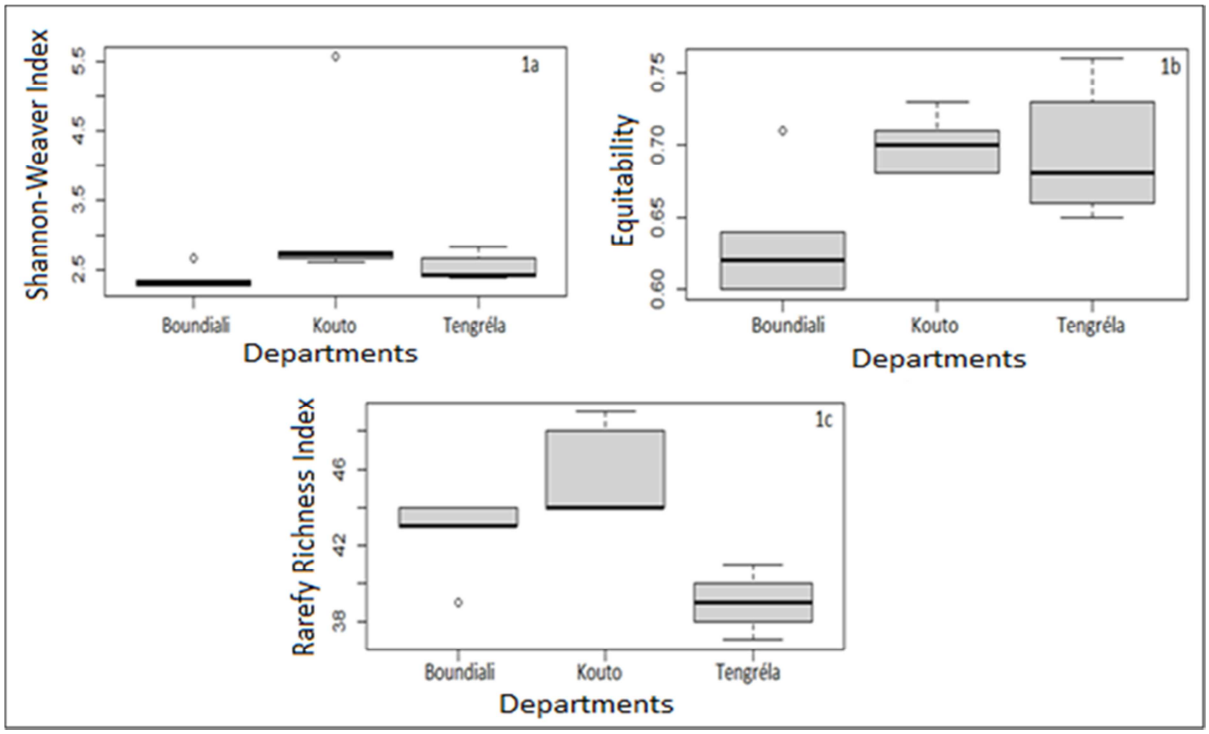

Fig. 1. Box plots indicating variations in the Shannon-Weaver, Equitability and Rarefied Wealth indices between the departments of the Bagoué region in Côte d'Ivoire (1a: Shannon-weaver; 1b: Equitability; 1c: Rarefied Wealth

Relative abundance

A total of 25,072 insects were collected. The most abundant insect orders on cashew inflorescences in Bagoué were Hymenoptera, Lepidoptera and Diptera, respectively in the proportions of 85.48%, 7.14% and 4.40% of total abundance. These three insect orders represent 96.64% of the total number of insects. The orders Heteroptera, Blattoptera, Coleoptera and Neuroptera were the least abundant orders on cashew inflorescences. The relative proportions of these three orders are 2.64%; 0.44%; 0.30%; 0.12%. The cumulated effect of these orders represents 3.36% of all orders (Fig. 2).

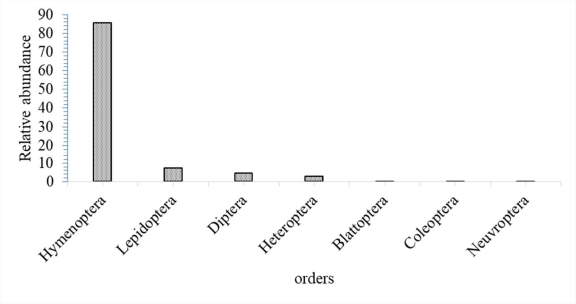

Fig. 2. Relative abundance of orders of insects dependent on cashew tree inflorescences in the Bagoué region in Côte d'Ivoire

Table 2. Relative abundance of families and species of insects in the inflorescences of cashew tree in the Bagoué region in Côte d'Ivoir

Families	Taxa	Percentages
Apidae	*Apis mellifera*	38,42
	Dactylurina staudingeri	0,82
	Xylocopa olivacea	0,48
	Xylocopa sp.	0,20
	Amegella sp.	0,32
	Meliponula ferrufinea	4,21
	Meliponula bocandei	18,73
	Meliponula togoensis	5,46
		68,65
Megachillidae	*Heriades* sp.	0,99
	Anthidiini sp.	0,06
	Megachile sp.	0,52
		1,56
Halictidae	*Stictonomia schubotzi*	2,99
	Pseudapis sp.	1,39
	Halictus sp.	0,41
	Lasioglossum sp.	0,46
		5,25
Formicidae	*Camponotus* sp.	10,14
	Formica sp.	1,74
	Crematogaster scutellaris	1,36
		13,25
Sphécidae	*Isodontia mexicana*	0,23
	Ammophila sabulosa	0,04
		0,27
Vespidae	*Ectommius literates*	0,03
	Ancistrocerus trifaciatus	0,08
	Vespa sp.	0,34
		0,45
Noctuidae	*Chrisodeix chalcites*	1,41
	Mythimna sp..	0,65
	Heliophis viriplaca	1,71
	Mythimna albipuncta	0,94
	Diarsia sp.	0,09
		4,80
Piéridae	*Pieris napi*	2,47
	Colias sp.	0,17
		2,64
Papillonidae	*Papilloni machon*	0,40
		0,40
Lycaenidae	*Lycaeni virgaureae*	0,12
		0,12
Muscidae	*Musca automnalis*	0,43
		0,43
Sarcophagidae	*Sarcophaga canaria*	1,50
		1,50
Syrphidae	*Cheilosia* sp.	0,29
	Episyrphus balteatus	0,95
		1,24
Calliphoridae	Calliphorissa vicina	0,29
		0,29
Stratiomyidae	*Exairata spingera*	1,01
		1,01
Ciccadellidae	*Ciccadelelila* sp.	0,47
		0,47
Coréidae	*Anoplocnemis curvipes*	0,90
		0,90
Pyrrhocoridae	*Dysdercus volkeri*	0,13
		0,13
Lygaéidae	*Aspilocoryplus* sp.	0,10
Miridae	*Taylaridygus* sp.	0,02
		0,02
Pentatomidae	*Spavia* sp.	0,19
	Spavia sp.	0,19
	Clétus sp.	0,71
	Glypsus erubescens	0,12
		1,03
Blattidae	*Ectobus pallidus*	0,44
		0,44
Carabidae	*Croscherichia sangunolenta*	0,12
		0,12
Coccinellidae	*Leptinotarsa decenlineata*	0,05
	Coccinelila sp.	0,09
		0,13
Chrysomellidae	*Lamprocopa occidentallis*	0,17
		0,17
Chrysopidae	*Chrysoperla carnea*	0,08
	Chrysoperla affinis	0,05
		0,12

At the family taxonomic rank, the highest proportions were observed among the Apidae (68.64% of individuals), Formicidae (8.49% of individuals), Hallictidae (5.25% of individuals) and Noctuidae (4.80% of individuals). The proportions of these families represent 87.19% of the insects collected from cashew inflorescences. The families of Péridae, Sarcophagidae, Megachilidae, Syrphidae, Stratiomyidae followed with 1.78%, 1.59%, 1.56%, 1.24%, 1.10% respectively. The least abundant families on cashew inflorescences were the Coreidae and Pentatomidae (0.95% each), Ciccadelidae (0.50%), Vespidae (0. 48%), Blattidae (0.47%), Muscidae (0.46%), Papillonidae (0.43%), Calliphoridae (0.30%), Sphecidae (0.27%), Chrysomellidae (0.18%), Pyrrhocoridae (0.14%). Other families such as Lycaenidae, Carabidae and Chrysopidae recorded 0.13% each. The lowest proportions were recorded for Lygaeidae (0.10%) and Miridae (0.01%) (Table 2). Concerning species, the

most abundant on cashew inflorescences was *Apis mellifera* with 38.42% of the total population. It was followed by *Meliponula bocandei* (18.73%), *Camponatus* sp. (10.14%), *Meliponula togoensis* (4.69%) and *Stictonomia schubotzi* (2.87%) (Table 2).

Discussion

Considering all the localities in the study area, the analyses showed that inflorescence insects are grouped into 53 species.

These species are divided into seven orders and 25 families. The orders Hymenoptera, Heteroptera, Diptera and Lepidoptera dominate this diversity. This great diversity could be explained by the fact that the plants cultivated are conducive to the proliferation of insects.

The cashew tree produces mainly in the dry season. Due to the scarcity of wild plants during this period, cashew flowers are a source of food and a refuge plant for many insects.

This high diversity of insects could also be explained by the favourable ecological conditions offered by the cashew tree. Its foliage creates a microclimate that favours the proliferation of many insects. That result is similar to one obtained in a study conducted by (Tuo *et al.*, 2021) on four cashew varieties in the Poro region of Côte d'Ivoire. These authors showed that the orders Hymenoptera, Heteroptera and Diptera were more diverse in families on the inflorescences of the four cashew genotypes. On the other hand, (Freitas and Paxton, 1996), in a study conducted in north-east Brazil, showed by direct observation of cashew inflorescences and counting pollen grains adhering to insects that Hymenoptera was the most diverse order. These insects are anthophilous and constantly search for food (nectar and pollen) on cashew inflorescences.

The less diverse orders of Neuroptera, Coleoptera and Blattoptera show that these insects visit cashew flowers least or have other food sources than cashew nectar and pollen. This result is similar to that reported by (Freitas and Paxton, 1996) which shows that insects belonging to these orders do not distinguish young flowers with fresh pollen or receptive pistils from those that are already too old. They visit the flowers only when they have some viable pollen or else they show no consistency in visiting cashew flowers. (Bhattacharya, 2004) has shown that these insects visit the flowers but less frequently, irregularly and without touching the pistil.

As regards families, the Apidae, Megachillidae, Hallictidae and Noctuidae families present the greatest diversity of species on inflorescences in all localities. These results may be explained as these families account for the majority of insect species that visit cashew flowers. Cashew inflorescences constitute a food reservoir for visiting insects. This result is similar to those obtained by (Silué *et al.*, 2022) concerning cashew tree flowers in Côte d'Ivoire. They showed that the families Apidae, Hallictidae and Megachillidae were the most diverse as regards species.

Some species are present in one or two departments and absent in the other. This repartition of species can be explained by differences in climatology between the two departments. Tengréla department, which has a frontier with Mali, differs from the other two departments (Kouto, Boundiali) in terms of its vegetation and soil characteristics. The vegetation changes and becomes increasingly dense travelling from Tengréla to Boundiali. This gradient of heterogeneity can have an impact on the taxonomic distribution of species in the region. Our results corroborate those of (Acapovi *et al.*, 2001) obtained in the Kabadougou region, which showed that insect species were present in one department and absent in the other.

Hymenoptera was the most abundant order on cashew trees throughout the study area. This result could be explained using the argument that

Hymenoptera is an order composed of a diversity of insects that visit cashew inflorescences. The main food source for these insects is cashew nectar and pollen. This result is similar to that of (Bhattacharya, 2004), who showed in a study in Brazil that the insects that visit cashew trees are mainly Hymenoptera. In a study conducted in the north of Côte d'Ivoire on four cashew varieties showed that insects belonging to the order Hymenoptera were more abundant on the inflorescences of these different varieties (Tuo *et al*., 2021).

The Apidae family recorded the highest relative abundance at all the study sites. These results could be explained through the fact that Apidae and specifically *Apis mellifera* species are abundant on inflorescences. Coulibaly (2019) demonstrated in the north of Côte d'Ivoire that *Apis mellifera* is more abundant on the inflorescences of mango trees, a plant closely related to cashew trees as it belongs to the same family (Anacardiaceae). These results are similar to those obtained by (Tuo *et al*., 2021; Silué *et al*., 2022) on cashew inflorescences in Côte d'Ivoire. These authors obtained that the Apidae family was composed of a large diversity of species visiting cashew tree flowers, which could be the cause of the high abundance of this family on the flowers.

Regarding the abundance of species, *A. mellifera* was the most abundant. This result may be due to the constant presence of this species in cashew plantations. Indeed, the honeybee *A. mellifera* is known to form colonies of up to 25,000 individuals (Walters and Taylor, 2006). This could directly affect the number of individuals visiting cashew inflorescences.

This finding is similar to that obtained by (Silué *et al*., 2022) who showed that the species *A. mellifera* is more abundant on cashew inflorescences in production areas in Côte d'Ivoire.

Conclusion

This study identified 53 species of insects that visit the inflorescences of cashew trees in the Bagoué region of northern Côte d'Ivoire. The main orders that these species are classified under are Hymenoptera, Diptera, Heteroptera and Lepidoptera. As regards families, the Apidae, Megachillidae, Hallictidae and Noctuidae were the most abundant in all the locations studied. Definitively, the greatest abundances were recorded by the order Hymenoptera, the family Apidae and the species *Apis mellifera*.

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