INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print); 2222-5234 (Online)
Website: https://www.innspub.net
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Vol. 28, Issue: 3, p. 80-89, 2026

RESEARCH PAPER OPEN ACCESS

Diversity of melliferous plants in a forest ecosystem in the Sudanian zone: The case of the Badenou classified forest in northern Côte d'Ivoire

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Key words: Honey plants, Beekeeping, Badenou classified forest, Côte d'Ivoire

Received: February 20, 2026 **Accepted:** March 04, 2026 **Published:** March 09, 2026

DOI: https://dx.doi.org/10.12692/ijb/28.3.80-89

ABSTRACT

The practice of modern beekeeping around classified forests can generate income for local population and constitute a sustainable solution to deforestation. However, successful beekeeping requires the presence of honey-producing plants in the apiaries environment. Indeed, the quantity and quality of the honey obtained depend on the nature and abundance of plants foraged by the bees. This study aims to assess the diversity of the melliferous flora in the Badenou classified forest. Data was collected in the Badenou classified forest using floristic inventories and monthly observations of bee foraging activity carried out over a 12-month period. The recorded honey plant flora consists of 112 species belonging to 85 genera and 36 families. This melliferous flora is composed of herbaceous melliferous species (49.11%), shrubs (36.61%), trees (7.14%), bushes (3.57%), and vines (3.57%). Considering the nature of the nutrients collected by bees from flowers, the melliferous flora consists of nectar-polliniferous species (40.18%), nectariferous species (37.50%), and polliniferous species (22.32%). This reflects high proportions of species that provide nectar (77.68%) and pollen (62.50%) for bees. This work shows that the Badenou classified forest has a diverse honey plant flora for the development of modern beekeeping. However, taking into account the temporal availability of floral food resources for bees can consolidate the results obtained.

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INTRODUCTION

In Côte d'Ivoire, forests are suffering significant degradation and loss of area (Vanga, 2011; Goné *et al.,* 2013). From 1990 to 2015, Côte d'Ivoire's forest cover declined considerably. In 1990, forests covered 7,850,864 ha, or 24% of the national territory. In 2000, they covered 5,094,452 ha, corresponding to 16% of the national territory. In 2015, their total area was 3,401,146 ha, representing 11% of the national territory (Koné, 2018). Thus, over this 25-year period, Côte d'Ivoire lost more than half of its forest area. Deforestation in Côte d'Ivoire is mainly due to human activities (Kassi *et al.*, 2010; Koné *et al.*, 2014). The expansion of agriculture, which accounts for 62% of this phenomenon, is the main cause (REDD+ Côte d'Ivoire, 2016).

In light of this situation, it is urgent to propose solutions to save the forests in Côte d'Ivoire. The main ways to achieve this goal are the adoption of sustainable agricultural practices, the strengthening of forestry legislation and rigorous enforcement, and the sustainable monetary valuation of forest ecosystem services for the benefit of local communities. This work follows the latter approach to preserving forest ecosystems, considering that the development of beekeeping around classified forests can generate income for local populations and provide a sustainable solution to deforestation. Indeed, the participatory approach to forest management is currently recognized as one of the essential conditions for the sustainability and resilience of these ecosystems (Ahouandjinou *et al.*, 2017). From this perspective, income-generating activities such as beekeeping, which enable the sustainable development of forests, should be promoted (Ahouandjinou *et al.*, 2017; Dusengimana and Maake, 2024).

There are several reasons why beekeeping is a good option in the search for solutions to deforestation. Firstly, beekeeping is an economic activity whose success is directly linked to the existence of sufficient quantities of plants and flowers for bees (Bouzebda *et al.,* 2018). It is also an activity that can easily be combined with other agricultural activities, as it requires relatively few financial, material and human resources (Owuor *et al.*, 2022; Dusengimana and Maake, 2024). Secondly, beekeeping contributes to increased agricultural production thanks to the pollinating action of foraging bees on crops (Adamou and Fohouo, 2014; Tchindebe and Fohouo, 2014; Vaziritabar *et al.*, 2015; Egono *et al.*, 2018; Pharaon *et al.*, 2019; Ambreen *et al.*, 2021). Finally, beekeeping is an activity that improves the living conditions of those who practice it through the use and sale of its products (Vaziritabar *et al.*, 2014; Hairin *et al.,* 2022; Okonta *et al.*, 2023; Dusengimana and Maake, 2024). According to a study conducted in northern and central Côte d'Ivoire by Ohoueu *et al.* (2017), honey and wax, the main products of beekeeping, sell well in in northern and central Côte d'Ivoire. However, knowledge of the honey plants growing in the environment surrounding apiaries is necessary for the development of sustainable beekeeping in a given region (Dongock *et al.*, 2004; Népidé and Tchuenguem, 2016; Fohouo *et al.*, 2018). Indeed, bee products reflect the nature of honey plants in terms of both quantity and quality (Dongock *et al.*, 2008; Balagueman *et al.*, 2017). This study was conducted in the Badenou classified forest with the aim of assessing the diversity of its melliferous flora with a view to gradually developing modern beekeeping there.

MATERIALS AND METHODS

Study area

The study was conducted in the Badénou classified forest located in the northern part of Côte d'Ivoire between longitudes 5° 32' 06" and 5° 49' 67" West and latitudes 9° 41' 63" and 9° 51' 63" North (Yaokokoré-Béibro *et al.*, 2010). This forest covers an area of 26,980 ha and is located in the southeast of the sub-prefecture of M'bengué and the south of the sub-prefecture of Diawala. Floristic surveys were carried out in the peripheral part of this classified forest, near the villages of Tiébila and Nafoun (Fig. 1). These sites were chosen for their geographical proximity to the two villages. This area is located in the Sudanese phytogeographical

sector of Côte d'Ivoire. The natural vegetation therefore consists mainly of tree and shrub savannahs, wooded savannahs, open forests, and gallery forests along watercourses (Guillaumet and Adjanohoun, 1971). The climate is Sudanese, characterized by a long dry season lasting seven months (November to May), with a period of harmattan (December to February) and a rainy season from June to October, with maximum rainfall in August (Soro *et al.*, 2018).

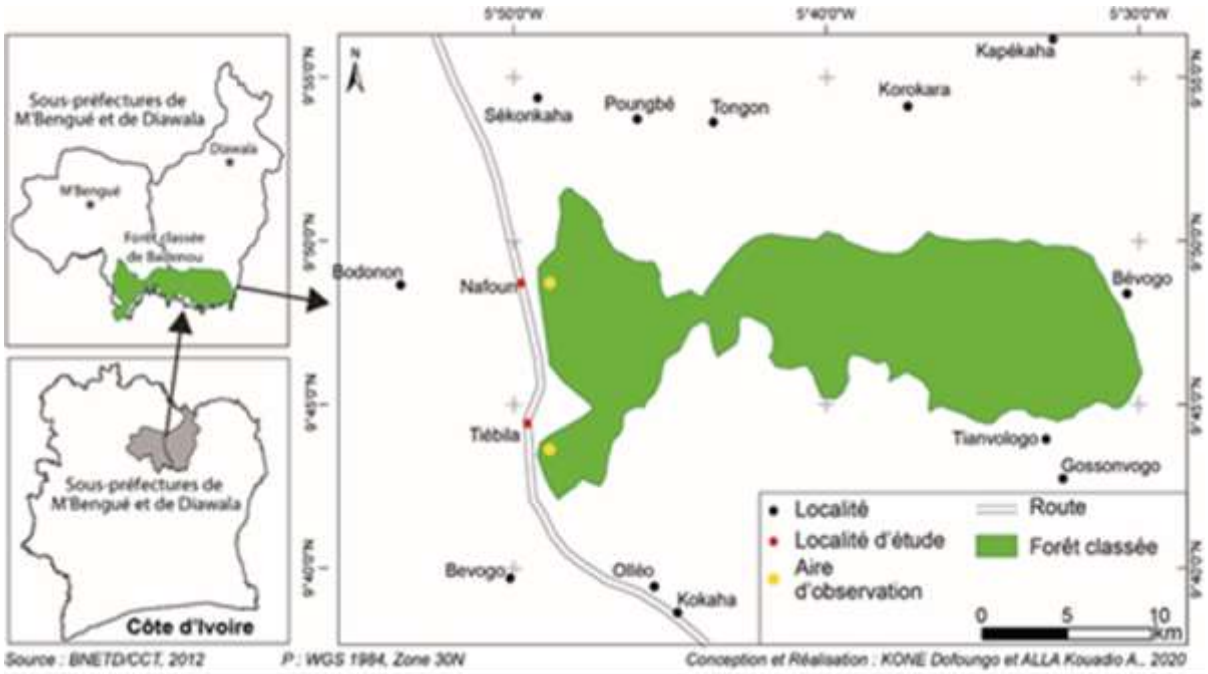

Fig. 1. Location of the study area

Materials

This study required the use of biological and technical material. The biological material used in this study consisted of plant species identified in the Badenou classified forest and honeybees (*Apis mellifera*) observed while foraging on flowers. The technical equipment included :

1. ten kenyan hives grouped into two apiaries to house the bee colonies in order to increase the likelihood of encountering foragers in the observation areas;
2. a Global Positioning System (GPS) for locating observation areas and plots for floristic surveys;
3. a 100-meter tape measure and stakes for marking out the plots;
4. a pruning shears, for collecting plant samples to be sent to the herbarium;
5. straps, cardboard boxes, and newspaper for pressing and drying harvested plant samples;
6. flora survey sheets for recording observations;
7. a binocular magnifying glass and old plant samples stored in the herbarium of the Swiss Center for Scientific Research in Côte d'Ivoire for plant identification in the laboratory.

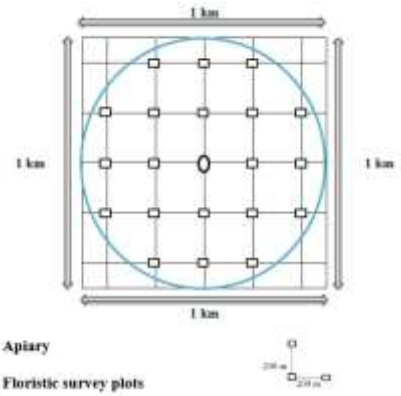

Fig. 2. Distribution of floristic survey plots at an inventory site

Data collection device

Two inventory sites were delineated in the peripheral part of the classified forest, near the

villages of Nafoun and Tiébila. Each inventory site is a circle with a diameter of 1 km, corresponding to an area of 78.5 ha (Fig. 2). Thus, the total area of the two inventory sites is 157 ha. Within each inventory site, 20 rectangular plots measuring 20 m × 25 m (500 m²) and spaced 200 m apart were created (Fig. 2).

Inventory of honey plant species

Honey plants were inventoried using direct field observation. All floristic survey plots were visited regularly every month for a year to record all plants whose flowers are visited by bees. Observations were made with the naked eye for herbaceous plants and shrubs, or with binoculars when necessary for trees and bushes. Honey plants are those whose flowers have been visited by foraging bees to collect pollen and/or nectar. hen foraging bees landed on flowers and moved their hind legs, forming visible pollen balls in their baskets, the plant was classified as polliniferous. When foraging bees inserted their proboscis into flowers to absorb nectar, the plant was considered nectariferous. When bees collected both pollen and nectar from the same plant, it was described as nectariferous and polliniferous. his method has been used in similar studies in Cameroun (Dongock *et al.*, 2004) in Benin (Yédomonhan *et al.*, 2009) and in Côte d'Ivoire (Iritié *et al.*, 2014). The botanical nomenclature of species used is that of the online database of African plants (http://www.ville-ge.ch/musinfo/bd/cjb/africa/).

Data treatment and analysis

The data collected using the floristic survey forms were entered into an EXCEL 2016 spreadsheet. Pivot table reports were used to provide information on the diversity of the honey plant flora. The parameters used to assess the diversity of honey plant flora are taxonomic diversity, morphological diversity of honey plants, and their nutritional value for bees. The taxonomic diversity of the melliferous flora was determined based on species richness, number of genera, and number of families. Species families were determined according to phylogenetic classification (APG, 2016). The morphological types of plant species were determined using the works of Aké-Assi (2001; 2002) and Chatelain *et al.* (2011). The nutritional value of honey plant species for bees was determined by noting the nutrients collected by bees when foraging on flowers.

RESULTS

Taxonomic diversity of honey plants

Observation of the foraging activity of bees has led to the identification of 112 honey plant species. These honey plant species belong to 85 genera and 36 families (Table 1). The diversity parameters of the honeybee flora are presented according to site and according to different types of vegetation (Table 2). The honey plant flora recorded around the Tiébila apiary is rich with 96 species belonging to 79 genera and 34 families. At the Nafoun site, 94 species divided into 72 genera and 33 families have been inventoried.

Table 1. Parameters of honeybee flora diversity according to location

Floristic parameters	Location		
	Nafoun	Tiébila	Nafoun and Tiébila
Number of species	94	96	112
Number of genera	72	79	85
Number of families	33	34	36

Table 2. Parameters of honeybee flora diversity according to different types of vegetation

Floristic parameters	Types of vegetation					
	Open forest	Tree savanna	Shrub savanna	Grassy savanna	Fallow land	Total
Number of species	70	80	93	31	31	112
Number of genera	58	64	71	25	25	85
Number of families	25	30	31	16	13	36

In terms of vegetation types, the richest in honey plant species are shrub savanna (93 species, 71 genera, and 31 families), tree savanna (80 species, 64 genera, and 30 families), and open forest (70 species, 58 genera, and 25 families).

The distribution of honey plant species by genera is shown in Fig. 3. The genera containing the most species are *Borreria* (6 species, or 5.36%) and *Sida* (4 species, or 3.57%). A total of 69 genera, or 81.18% of this taxonomic level, are monospecific and contain 61.61% of the honey plant species recorded.

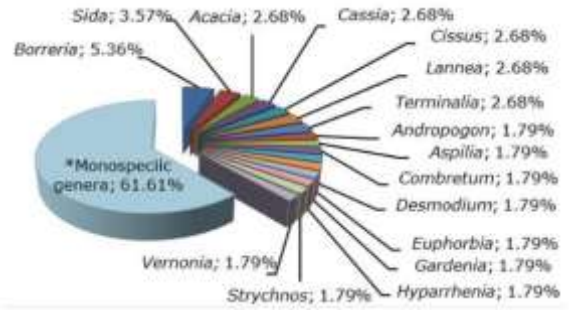

Fig. 3. Distribution of recorded honey plant species by genera

* Monospecific genera : *Aeschynomene, Afrormosia, Afzelia, Ageratum, Allophylus, Anacardium, Annona, Anogeissus, Antidesma, Brachiaria, Bridelia, Centrosema, Chromolaena, Commelina, Corchorus, Crossopteryx, Crotalaria, Croton, Ctenium, Daniellia, Detarium, Dichrostachys, Entada, Eulophia, Evolvulus, Fadogia, Fimbristylis, Flacourtia, Gmelina, Guiera, Holarrhena, Hymenocardia, Hyptis, Isoberlinia, Kyllinga, Lonchocarpus, Maytenus, Melothria, Mimosa, Mitracarpus, Mitragyna, Monechma, Ochna, Olax, Pachycarpus, Pandiaka, Panicum, Parinari, Parkia, Paspalum, Passiflora, Pennisetum, Piliostigma, Pterocarpus, Saba, Sarcocephalus, Securinega, Spigelia, Sporobolus, Sterculia, Synedrella, Syzygium, Tamarindus, Triumfetta, Vitellaria, Vitex, Waltheria, Ximenia, Zanthoxylum*

The distribution of honey plant species by family is shown in Fig. 4. The families richest in honey plant species are Fabaceae (24 species, or 21.43%), Rubiaceae (13 species, or 11.61%), Poaceae (10 species, or 8.93%), Malvaceae (8 species, or 7.14%), Asteraceae (7 species, or 6.25%), and Combretaceae (7 species, or 6.25%).

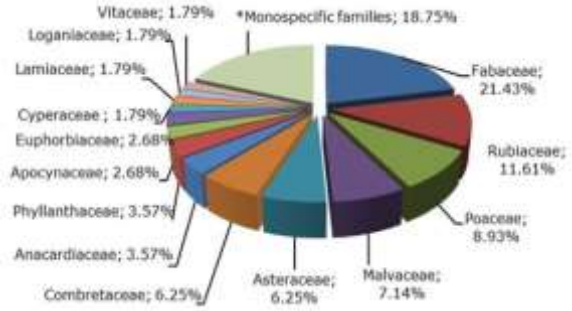

Fig. 4. Distribution of honey plant species by family

*Monospecific families: Acanthaceae, Amaranthaceae, Annonaceae, Celastraceae, Chrysobalanaceae, Commelinaceae, Convolvulaceae, Cucurbitaceae, Lamiaceae, Loganiaceae, Myrtaceae, Ochnaceae, Olacaceae, Orchidaceae, Passifloraceae, Rutaceae, Salicaceae, Sapindaceae, Sapotaceae, Vitaceae, Ximeniaceae

Morphological diversity of honey plants

The honey plant species identified belong to different morphological types (Fig. 5). Herbaceous plants, shrubs, and trees represent respectively 49.11% (55 species), 36.61% (41 species), and 7.14% (8 species) of the honey plant flora. small trees (4 species) and lianas (4 species) each represent 3.57% of honey plant species.

Fig. 5. Distribution of honey plant species according to morphological types

Diversity of honey plants according to the nutrients collected by bees

Based on the nutrients collected by bees from flowers, honey plant species are divided into three groups (Fig. 6). The first group is that of nectariferous plant species. These are plant species whose flowers have

been visited by bees to collect nectar. A total of 42 nectariferous plant species have been identified, representing 37.50% of the honey plant species inventoried. The second group consists of polliniferous plant species. These are plant species whose flowers have been visited by bees to collect pollen. This group contains 25 species, corresponding to 22.32% of the honey plants listed. The third group includes nectaro-polliniferous plant species. These are plant species whose flowers have been visited by bees to collect nectar and pollen. Forty-five species belong to this group, which corresponds to 40.18% of the identified honey plant species.

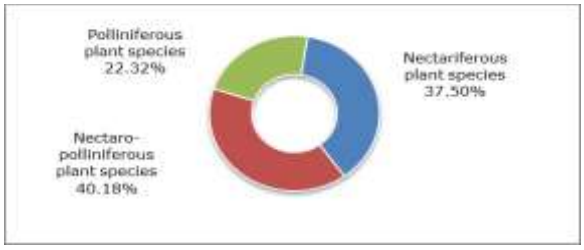

Fig. 6. Distribution of honey plant species according to the nutrients collected by bees

DISCUSSION

The presence of honey plant species in a given area is one of the primary criteria for assessing its honey production potential (Dongock *et al.*, 2004; Iritié *et al.*, 2014). The specific richness of honey plants recorded around the two experimental apiaries set up in the Badenou classified forest is 112 species. This specific richness of honey plants differs from that obtained in certain studies carried out by other authors in Côte d'Ivoire (Iritié *et al.*, 2014; Kouassi *et al.*, 2019; Assi-Kaudjhis *et al.,* 2020; Assi-Kaudjhis *et al.,* 2023) and Benin (Yédomonhan *et al.*, 2009; Ahouandjinou *et al.*, 2017). Indeed, Iritié *et al.* (2014) have catalogued 160 honey plant species in the agroforestry zone of the Yamoussoukro Higher School of Agronomy. In the department of Katiola, Kouassi *et al.* (2019) identified 126 honey plant species. Assi-Kaudjhis *et al.* (2020) identified 157 species of honey plants in the department of Toumodi. In the department of Dabakala, 72 species of honey plants were identified by Assi-Kaudjhis *et al.* (2023). In the Sudanese-Guinean zone of Benin, the work of Yédomonhan *et al.* (2009) revealed that the melliferous flora surrounding an apiary in the district of Manigri is composed of 87 species. In the Sudanese zone of this country, a study conducted by Ahouandjinou *et al.* (2017) in the classified forest of the Kouandé hills led to the identification of 86 honey plant species. This numerical difference between areas could be explained by the phytogeographic zone considered, the general floristic composition of the observation areas, the foraging behavior of honeybees, and the duration and frequency of observation.

The honey plant species identified in the environment surrounding the two apiaries belong to different families, the richest of which are Fabaceae, Rubiaceae, Poaceae, Malvaceae, Asteraceae, and Combretaceae. The numerical importance of honey plant species belonging to these families is not unique to the Badenou classified forest. Indeed, the predominance of these families has been noted by several authors in similar studies in West and Central Africa (Koudegnan *et al.*, 2012; Koudegnan *et al.,* 2015; Balagueman *et al.,* 2017). These families are believed to be the most important sources of floral nutrients for bees. Thus, the presence of these families in a forest or savanna would indicate high honey-producing potential. This result also reflects the overall floristic composition of the vegetation around apiaries.

Furthermore, in terms of species richness, these different families are the most representative of most forests in West and Central Africa (Kassi *et al.*, 2012 ; Missa *et al.*, 2015 ; Tiébré *et al.*, 2016).

Bees foraged on flowers to collect pollen, nectar, or both (pollen and nectar) from 22.32%, 37.50%, and 40.18% of the identified melliferous species, respectively. Thus, the species from which bees collected nectar represent 77.68% of the honey plant flora, while those from which pollen was collected represent 62.50%. These high proportions of plant species that provide nectar and pollen for bees are a botanical asset for intensifying honey production

around the Badenou classified forest. Indeed, the nature of the nutrients taken from plants by bees is a key factor in the honey-producing potential of a given area (Iritié *et al.,* 2014; Dongock *et al.*, 2017).

Furthermore, the high number of plant species visited by bees for nectar and/or pollen is an asset for the sustainable production of honey with good nutritional and therapeutic qualities.

Like all living beings, bees need a rich and varied diet to maintain their health. The nectar transformed into honey provides them with the energy they need (Di Pasquale, 2014). It is in pollen that they find all the other nutrients they need, such as proteins, lipids, vitamins, and trace elements, both for themselves and for the development of their larvae (Henry *et al.*, 2016). Since not all honey plants contain all of these nutrients, bees are more likely to obtain a balanced diet by foraging on as many different honey plants as possible (Bruneau, 2006; Bruneau et Colin, 2006). According to Pain and Maugenet (1966), the proportion of vitamins in pollen varies depending on its origin. From a nutritional and therapeutic point of view, it is recognized that the quality of honey reflects the nature of the plants visited by bees to produce it (Biri, 2002; Peter, 2008). Each species of honey plant can make honey more nutritious and therapeutic thanks to its vitamin, polyphenol, and other nutrient content. Honey made from a wide variety of plant species should therefore have better nutritional and therapeutic properties due to the complementary nature of the nutrients provided by the different species.

CONCLUSION

The aim of this study was to determine the diversity of the melliferous flora in the Badenou classified forest. Floristic inventories and monitoring of bee foraging activity carried out in this classified forest have identified 112 melliferous plant species belonging to 85 genera and 36 families. This melliferous flora is characterized by a diversity of morphological types. It consists of herbs (49.11%), shrubs (36.61%), trees (7.14%), small trees (3.57%), lianas (3.57%). The honey plant flora recorded consists of nectaro-polliniferous species (40.18%), nectariferous species (37.50%) and polliniferous species (22.32%). The diversity of the honey plant flora in the Badenou classified forest has thus been assessed. However, the results obtained can be consolidated by taking into account the temporal availability of floral food resources for bees.

ACKNOWLEDGEMENTS

The authors would like to thank SODEFOR's senior management and its Korhogo Management Center for agreeing to this study being carried out in the Badénou classified forest.

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