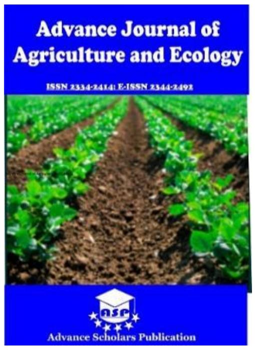
Advance Journal of Agriculture and Ecology
Adv. J. Agric. & Eco.
Volume: 9; Issue: 10
October-2024
ISSN 2334-2414
E-ISSN 2344-2492
Impact Factor: 5.39
Advance Scholars Publication
Published by International Institute of Advance Scholars Development
https://aspjournals.org/Journals/index.php/ajae/index



THE CONTROL AND CHECK OF HONEY FOR ADULTERATION IN YOBE STATE, NIGERIA: INFERENCE FROM POLLEN ANALYSIS AND VEGETATION STUDY OF *APIS MELLIFERA* FORAGED TAXA

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Keywords: *Apis mellifera, Floral preference, Honey adulteration, Pollen analysis, Vegetational history.*

The honeybee is the most valuable insect on planet earth. This is not because of the value of its direct products as they represent only 0.5% of the total agricultural production, but because of the enormous benefits accruing from the cross pollination of plants. This cross pollination ensures the improved quality and quantity of produce, fruits and seeds, improved species of self-germinating plants and also maintain the eco-balance on earth. As a matter of urgency, plants foraged by honeybees must be conserved for continuity if honey production is to be sustained and one of the ways to determine these plants is through pollen analytical studies. The study investigated the species of plants that were utilized in the course of honey production, vegetational history, biogeographical origin of honey and taxa most preferred by Apis mellifera (honey bees) in Yobe State, Nigeria. Four samples of honey were sourced. Samples were treated using standard palynological procedures. Pollen grains counts and fine morphological studies were made at x40 and x100 magnification respectively. Out of fifty-six pollen types belonging to twenty-eight plant families of apicultural importance most foraged by Apis mellifera encountered, one was identified to family level, forty-four to generic level, ten to species level, and one were unidentified. The identified species originated from numerous genera of trees, shrubs, grasses and herbs. Bade, Nangere, Damaturu, and Nguru localities had pollen grain counts of 9835, 10,329, 7868 and 8606 respectively. The predominant pollen types include those of Borassus aethiopium, Sarcocephalus latifolius, Vitellaria paradoxa, Senegalia mellifera, Mangifera indica, Calotropis procera, Daniella oliveri, Balanite orbicularis, Combretum spp., Khaya senegalensis, Parkia biglobosa, Psidium guajava, and Syzygium guineense. Indicators of Sudan savanna taxa: Acacia mellifera, Adansonia digitata, Balanite orbicularis, Borassus aethiopium, Calotropis procera, Piliostigma thonningii, Vitellaria paradoxa, Senegalia mellifera, and those from the plant family Poaceae were the highest pollen contributors (28.5 %) followed by human impact taxa (28.4 %). Pollen weight ranged from 0.40 - 0.45 g indicating that the honey samples were undiluted. The honey samples were all multi-floral, which affirmed that they were of good quality. The season of honey production was between the period of the dry season and to early rainy season (October-April). Pollen assemblages

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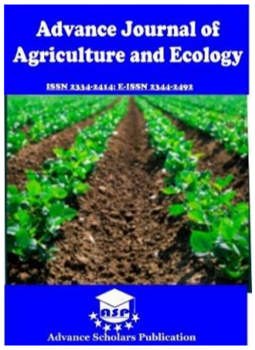

reflected the vegetation of the study area to be Sudanean savanna vegetation type that is highly impacted by human activities. Adequate conservation of these indicator species is strongly recommended for health, safety, renewable natural resource availability and environmental sustainability.

INTRODUCTION

The honey bees (*Apis mellifera var. adansonii*), the pollinators of plants the world over; play a crucial role for wild and cultivated plants, especially in the tropics where insect pollination is vital (Winfree, 2010; Ollerton *et al.*, 2011). Some honey components, such as carbohydrates, water, traces of organic acids, enzymes, amino acids, and pigments, come from bees and plants, while others, such as pollen and wax, appear during honey maturation (Agwu and Okeke, 1997).

The *Apis mellifera var. adansonii* (African honey bee) is very defensive and unpredictable; darker and smaller; more energetic and aggressive; and also irritable during the hot hours and hates noise. It builds its nest in closed spaces but migrates (swarms) often and abandoned its nest (absconds) when disturbed. It produces more drones (male bees). It gathers food all the year round, produces large quantity of honey yields every year (Breadbear, 2009).

The bee is the most valuable insect on planet earth. This is not because of the value of its direct products as they represent only 0.5% of the total agricultural production, but because of the enormous benefits accruing from the cross pollination of plants. This cross pollination ensures the improved quality and quantity of produce, fruits and seeds, improved species of self-germinating plants and also maintain the eco-balance on earth (Sivaram, 1995).

Co-evolution and mutualism have been cited as examples of relationships between honeybees and flowering plants. Honeybees and flowering plants are mutually dependent; honeybees need flowering plants for food in the form of pollen and nectar, whereas plants need honeybees for pollination (Essien *et al.*, 2023). Honey contains pollen grains which are collected by honeybees while foraging the flowers for nectar (Essien, 2020).

The flora of an area provides a good reflection of the major climatic regime of the area. The influence of climate on other components of the environment is so great that every other climatic zone has its own characteristic vegetation type (Ige, 2017). Essien (2019) reported that the vegetation of an area is an integral and basic component of the ecosystem that is sensitive to changes in the ecosystem. He therefore opined that vegetation changes are themselves a response to and a reflection of variation in one or more of the factors of the environment, particularly climate. Thus, a close correspondence exists between vegetation and the rest of the environment, particularly climate and soil.

As a matter of urgency, plants foraged by honeybees must be conserved for continuity if honey production is to be sustained and one of the ways to determine these plants is through

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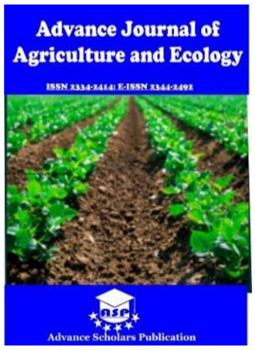

pollen analytical studies (Kayode & Oyeyemi, 2014; Byrant, 2018; Adekanmbi & Ogundipe, 2019). A combination of the insect and wind pollinated taxa found in a honey gives a unique understanding of the particular geographical location where the honey was produced and the plant communities in that region. This could shed more light on the important plants foraged by honeybees (Essien *et al.*, 2022a).

Findings from Neumann and Carreck, (2010) in Nnamani and Uguru (2013) revealed that the population of honeybee (*Apis mellifera* L.) has experienced serious decrease in Europe, North America and the world in general. These losses highlight the potential risks for our natural and agricultural biodiversity through lack of pollination, and the repercussions on food security and human nutrition (Ratnieks and Carreck, 2010).

It has been reported that lack of food and particularly scarcity of pollen, within intensively farmed agricultural landscapes and degraded environment as a result of human impacted activities have actually contributed to the loss of plant species which honey bees foraged for pollen and nectar sources. Other biotic factors such as availability of plant genetic resources and their ability of these plant species to blossom, compete for resources, fight against pathogens, parasites, predators, and abiotic factors such as climate and pollutants are all contributory factors to this decline (Gounari, 2006). Potts *et al.* (2010) opined that nutritional stress due to habitat loss also played an important role in the collapsed of honeybee colonies.

Due to the fact that honeybees are known to travel more than 3 km in search of their preferred forage sources, studying the pollen content in honey significantly aids in understanding the geographical, ecological, and botanical origins of honey. Knowledge of botanical source of honey is a prerequisite for beekeepers to undertake migratory beekeeping for increasing honey production and pollination. When determining the honey's commercial quality, characterization is crucial because the season of flowering and nectar production for the same species can vary depending on location (Zamarlicki, 1984).

Additionally, palynological investigations have been performed to determine single- and multiple-floral honeys (Seijo and Jato, 1998; Valencia-Barrera *et al.*, 1994; 2000). Identification of honey sources in an ecological zone is important for commercial beekeeping with the goal of increasing honey production. Knowledge of honeybee plants and time of pollen and nectar flow greatly influence the brood rearing activity and the functioning of honeybee colonies and production of honey as well as other hive products (Sivaram, 1995; Ostrowsha, 1998).

Recently, there are evident cultural, agricultural, unscientific and uncontrolled practices threatening the flora of several part of Yobe State. The report of a comprehensive and elaborate palaeoecological studies in Yobe State, Nigeria is almost non-existing and has not been given in any published literatures. The objectives of this study, therefore, are to ascertain the species of plants that were utilized in the course of honey production, vegetational

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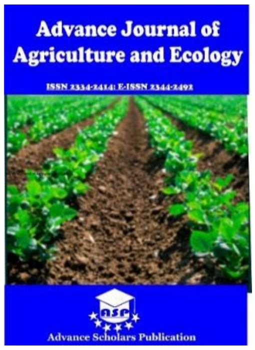

history and biogeographical origin of honey as well as the taxa most preferred by *Apis mellifera* (honey bees). Knowing that the bee plants could be used as the basis for legalized protection and propagation of bee plants and farms. Pollen analytical studies have been found useful in deciphering such plants.

MATERIALS AND METHODS

Study Area: Bade, Nangere, Damaturu and Nguru are localities within Yobe State, North Eastern Nigeria. Increased seasonality and irregularity of rainfall impose semi-arid condition on the study area. The harmattan season between December and January is basically influenced by the North-East Trade winds. It has mean annual temperature of between 25 and 38°C. There is extensive area of seasonal swamps. The vegetation is typically mixed Combretaceous woodland with *Vitellaria paradoxa*, *Acacia senegal*, *Acacia albida*, *Zizyphus* spp., *Adansonia digitata*, and *Piliostigma reticulatum* being the dominant trees. The common grasses in the zone, Aristida, *Brachiaria*, *Panicum*, *Chloris*, *Digitaria*, and *Eragrostis* are mostly short. Cultivation is intense and together with heavy grazing, bush burning and cutting for firewood/ charcoal, and browse, has contributed to extensive desertification in the study area.

Sample collection: Four honey samples were collected from vendors who sources from the wild at the study area between the months of September and December, 2022. The honey were extracted by pressing and squeezing the combs, filtered into a bottle through fine mesh-copper gauze to avoid introduction of debris. Once collected the samples were labelled and transported to the Laboratory, Department of Biology, Nigerian Army University Biu, for pollen analysis.

Determination of pH: Honey (10 g) was dissolved in 75 ml of distilled water in a beaker and vigorously mixed using a glass rod, pH electric meter was immersed in the honey and values were taken.

Honey colour: The Munsell Soil Color Chart was used.

Pollen analysis: Three basic procedures were followed; honey quantification/dilution, pollen extraction using acetolysis and microscopy. All procedures followed the recommendation and techniques reported in Erdtman (1969); Louveaux *et al.* (1978), and Agwu *et al.* (2013).

M**ounting and microscopic examination**: On a 25.4 mm x 76.2 mm (1"×3") slide 1 mm-1.2 mm thick, one drop of thoroughly shaken precipitates suspension was mounted and covered with 18mm x 18mm cover slip. To keep the precipitation from drying out, the mount was sealed off at the edges with colorless nail polish Counting was done using Olympus microscope at x400 magnification while detailed pollen morphological studies to aid identification was done using Leica microscope at x 1000 magnification. Reference slides, pollen atlas and photomicrographs (Sowunmi, 1978; 1995; Agwu & Akanbi, 1985; Agwu *et al.*, 2013; Shubharani *et al.*, 2013; Essien *et al.*, 2022b; Essien *et al.* 2023) was used for identification.

Weight of pollen grains: Honey (50 ml) and beaker (71.65 g) was weighed using the weighing balance. The honey was diluted with

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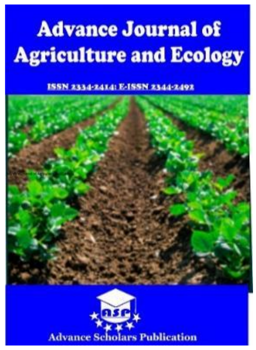

1000 ml of distilled water and the formular below was applied:

Weight of pollen x factor of 20 = weight of beaker/liter of honey samples.

Data analysis: Data generated from the study was presented in form of tables and/ or graphical representation (histogram). The classification for representation of pollen types followed was the one recommended by Louveaux *et al*. (1978) for expressing pollen grain frequencies: Very frequent (over 45%), frequent (16-45%), rare (3-15%) and sporadic (> 3%).

RESULTS AND DISCUSSIONS

Pollen Analysis

Pollen analytical examination of honey samples from four localities in Yobe State, Nigeria was carried out to ascertain the different pollen types present in the honey samples, the botanical, ecological and geographical origin of the honey, the season of honey production in the study localities as well as the weight of the pollen grains which could be used to deduce between adulterated and pure honey and the results revealed great diversity in size, shape, aperture and sculpturing of pollen grains.

A total of thirty-six thousand six hundred and thirty- eighty (36,638) pollen grains count were encountered. Result showed that out of fifty-six (56) pollen types belonging to twenty-eight (28) plant families documented, one (1) were identified to family level, forty-four (44) to generic level, ten (10) to species level, and one (1) were unidentified. After dilution, the colours of the honey samples were observed and ranged from light-brown, dark-brown, brown and light-brown and the result are presented in table 1. The weight of pollen grains for the samples ranged from 0.40 g to 0.45 g per 10 g of honey. The weight of the sediment recovered per sample and the colour of the honey after dilution are given in Table 1.

The identified species originated from numerous genera of trees, shrubs, grass, and herbs. Bade, Nangere, Damaturu, and Nguru localities had pollen grain counts of 9835, 10,329, 7868 and 8606 respectively. The predominant pollen types include those of *Borassus aethiopium*, *Sarcocephalus latifolius*, *Vitellaria paradoxa*, *Senegalia mellifera*, *Acacia mellifera*, *Calotropis procera*, *Daniella oliveri*, *Balanite orbicularis*, *Combretum* spp., *Khaya senegalensis*, *Parkia biglobosa*, *Psidium guajava*, and *Syzygium guineense*. Indicators of Sudan Savanna taxa: *Acacia melliferai*, *Adansonia digitata*, *Balanite orbicularis*, *Borassus aethiopium*, *Calotropis procera*, *Piliostigma thonningii*, Poaceae, *Senegalia mellifera*, *Vitellaria paradoxa* were the highest pollen contributors (%) followed by human impact taxa (%). The pollen weight was between 0.40-0.45 indicating that the honey samples were unadulterated. The honey samples were all multi-floral, which affirmed that they were of good quality

Figure 2 showed that the most abundant plant families in order of reducing percentage were Caesalpinaceae (19.92%), Mimosaceae and Papilionaceae (17.82%), Rubiaceae and Malvaceae (15.92%), Myrtaceae (14.67%), Meliaceae (10.63%), Anacardiaceae (5.98%)), Arecaceae (4.93%), Boraginaceae (3.75%),

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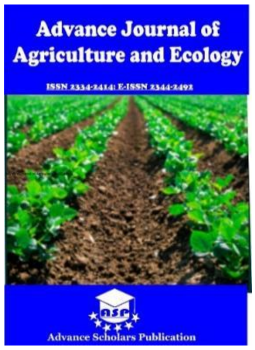

Euphorbiaceae (2.64%), and Sapotaceae (2.44%); while the least abundant were Caprifoliaceae and Loranthaceae (0.01%).
The classification recommended by Louveaux *et al.* (1970) for expressing pollen grains frequencies have been adopted: very frequent (over 45%), frequent (16-45%), rare (3-15%) and Sporadic (less than 3%). The pollen spectrum of the honey sample in percentage composition is presented in each of the Tables. The highest number of pollen types (43) was recorded for Nguru, (37) for Nangere and (27) for Bade respectively, whereas Damaturu (26) had fewer pollen types. The detailed pollen count of each sample is presented in Table 2. All the plants identified were grouped into different phytoecological groups (Table 4). Indicators species of the Derived savanna taxa contributed **9,835** (24.4%), Guinea savanna taxa **10,329** (18.6 %), Sudan Savanna taxa **7,868** (28.5%) and **8,606** (28.4%) recorded for human impact taxa. The predominant indicators species are presented Table 4.

Table 1: Physical properties of the four honey samples studied

Localities	Colour of honey after dilution	Weight of honey collected (g)	Weight of pollen (g)	pH value	Weight of honey (gram/litre)
Bade	Dark-brown	10	0.44		1135
Nangere	Light-brown	10	0.40		1271
Damaturu	Brown	10	0.45		1126
Nguru	Light-brown	10	0.43		1253

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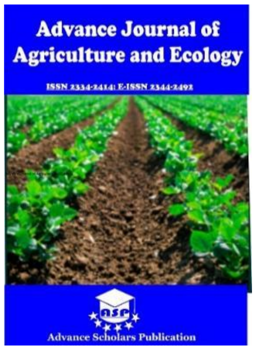
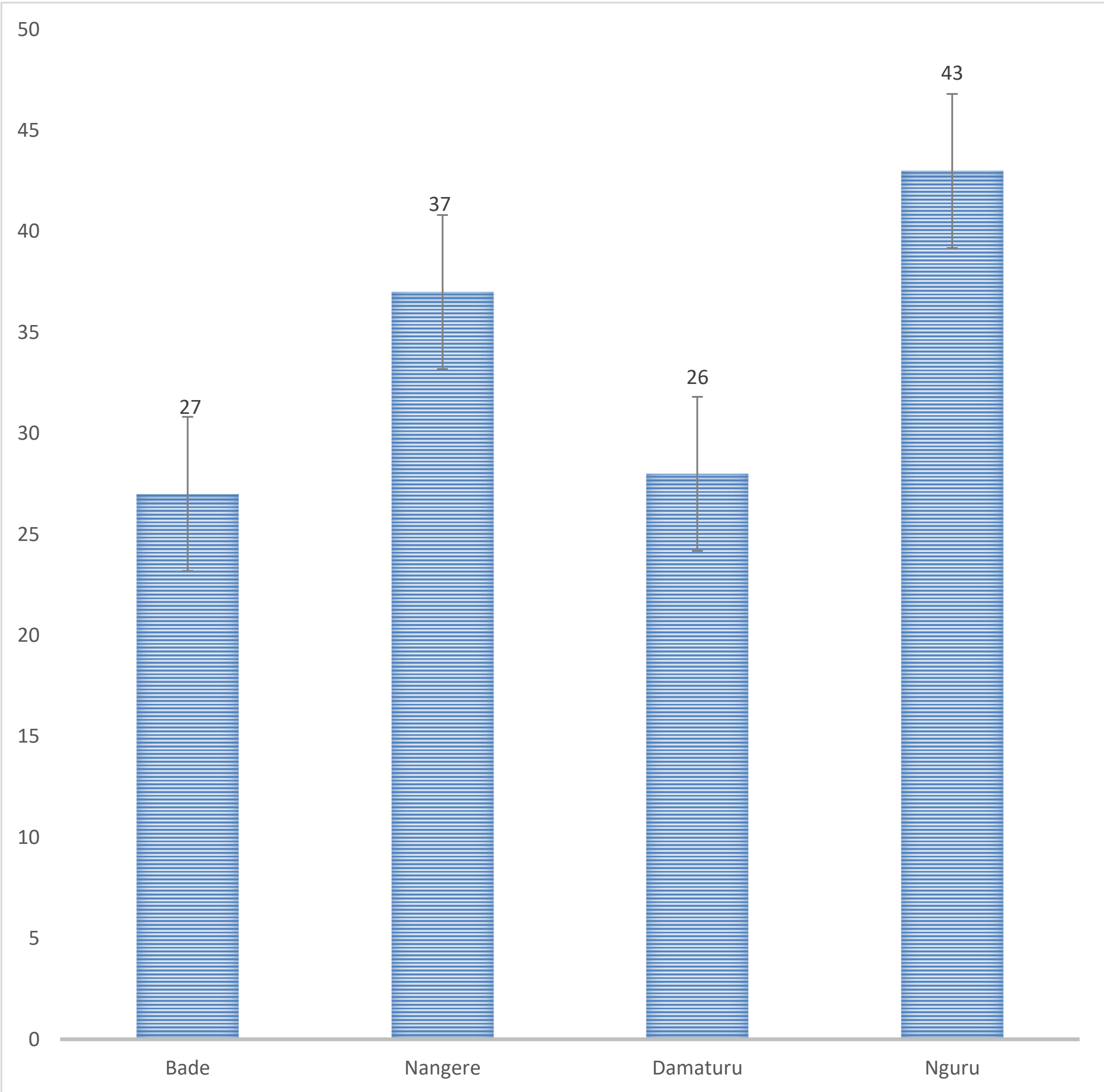


Figure 1: Histogram showing number of identified pollen types in the four honey samples from the study area clearly an indication of the high diversity of pollen types in Yobe State

Figure 2: Relative abundance of the pollen types based on Plant family



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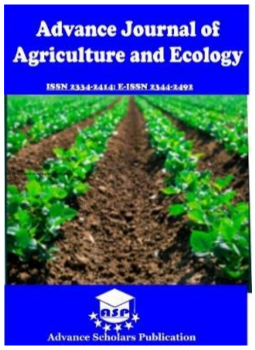

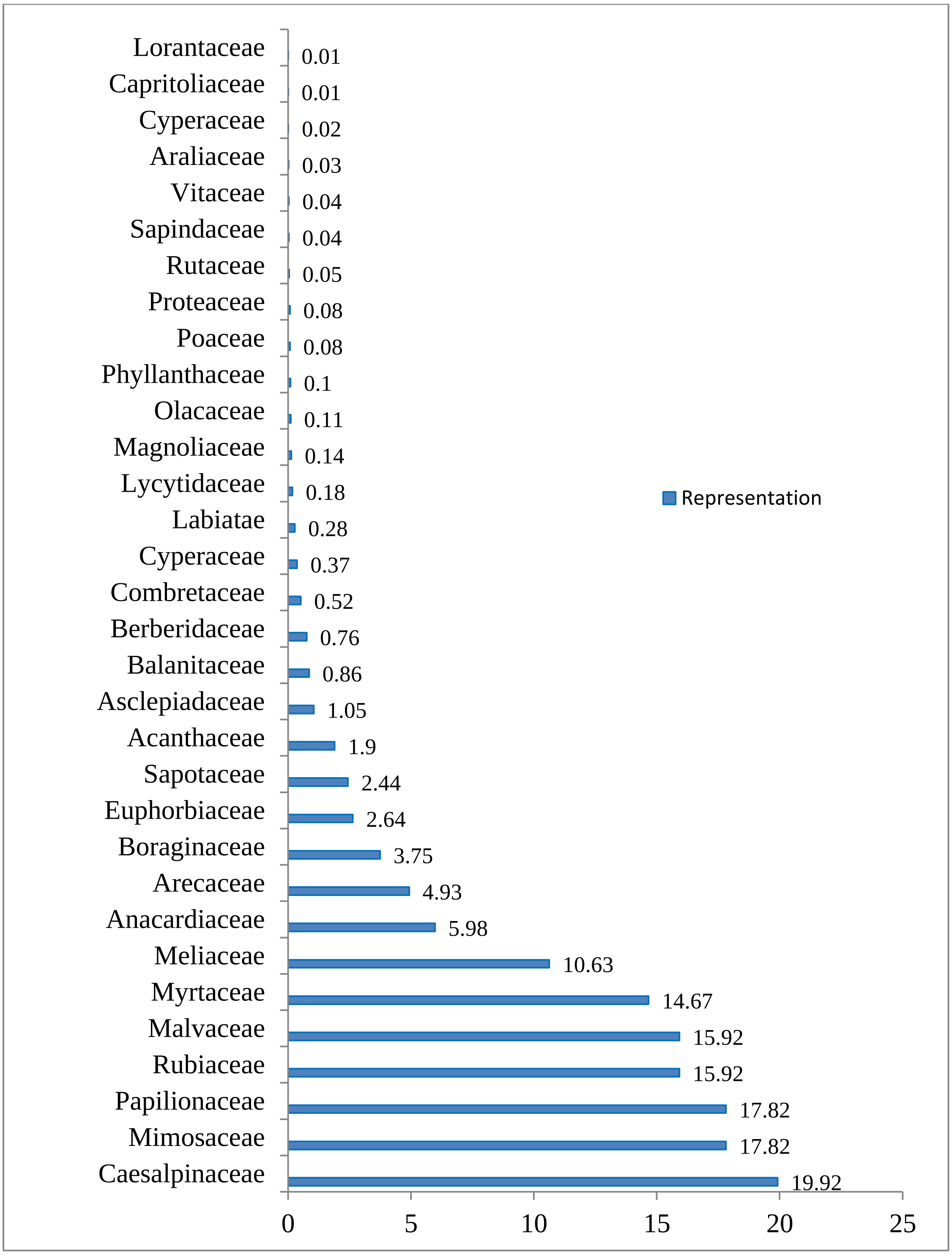

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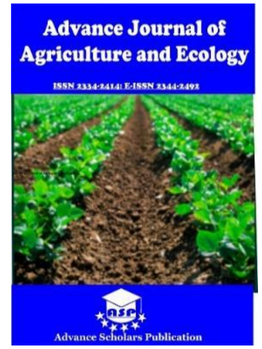

Table 2: Absolute pollen counts/ types recovered from recent honey samples in Yobe State

Pollen types/families	Localities in Shani									
	Bade	%	Nangere	%	Damaturu	%	Nguru	%	Total	%
1. ACANTHACEAE										
Strobilanthes spp.	289	2.9	483	4.7			43	0.5	815	2.2
2. ANACARDIACEAE										
Lannea acida	273	2.8	154	1.5					427	1.1
Mangifera indica	276	2.8	186	1.8	265	3.4			727	2.0
3. ARECACEAE										
Borassus aethiopium	432	4.4	145	1.4	237	3.0	532	6.1	1346	3.7
Hyphaene spp.	318	3.2							318	0.8
4. ASCLEPIADACEAE										
Calotropis procera	571	5.8	81	0.8	289	3.7	311	3.6	1252	3.4
5. BALANITACEAE										
Balanite orbicularis	692	7.0	235	2.3	183	2.3	199	2.3	1309	3.6
6. BERBERIDACEAE										
Mahonia oiwakensis					321	4.0			321	0.8
7. BORAGINACEAE										
Cordia africana			145	1.4	176	2.2	254	2.9	575	1.7
Cordia suckertii	412	4.2							412	1.1
8. CAESALPINACEAE										
Caesalpinia pulcherrima			23	0.2					23	0.06
Daniellia oliveri	251	2.6	556	5.3	265	3.3			1072	2.9
Piliostigma thonningii					163	2.0	240	2.8	403	1.0

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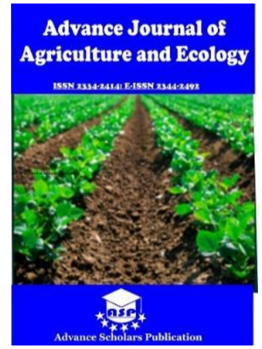

Senegalia mellifera	324	3.3	467	4.5	87	1.1	541	6.3	1419	3.9
Senna alata	123	1.3			121	1.5			244	0.6
Senna occidentalis	445	4.5							445	1.2
9. COMBRETACEAE										
Combretum spp.			378	3.6	256	3.2	356	4.1	990	2.7
10. CYPERACEAE					312	3.9			312	0.8
Cyperus spp.			125	1.2			111	1.3	236	0.6
11. EUPHORBIACEAE										
Alchornea cordifolia	62	0.6			146	1.8	397	4.6	605	1.6
Euphorbia hirta			145	1.4	176	2.2	254	2.9	575	1.6
12. LABIATAE										
Leonotis nepetifolia							476	5.5	476	1.3
13. LYCYTIDACEAE										
Crateranthus letesturi	201	2.0	222	2.1	123	1.6	254	3.0	800	2.1
14. MALVACEAE										
Abutilon mauritanum	148	1.5	167	1.6					315	0.8
Adansonia digitate	179	1.8			124	1.6	387	4.5	690	1.9
Sida acuta			328	3.2					328	0.9
15. MAGNOLIACEAE										
Magnolia coco	124	1.3	274	2.6			164	1.9	562	1.5
16. MELIACEAE										
Azadirachta indica	240	2.4			197	2.5	232	2.7	669	1.8
Khaya senegalensis	236	2.4	544	5.2	120	1.5			900	2.4
Trichilia prieureana	231	2.3			159	2.0	121	1.4	511	1.4
17. MIMOSACEAE										
Acacia mellifera	190	1.9	578	5.6	480	6.1	376	4.4	1624	4.4
Acacia spp.			276	2.7	189	2.4	153	1.8	618	1.7

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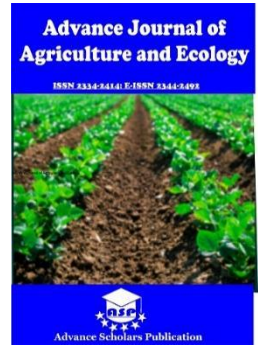

Albizia zygia			198	1.9	178	2.3	132	1.5	508	1.4
Parkia biglobosa	345	3.5	123	1.2	470	6.0	111	1.3	1049	2.9
Pentaclethra macrophylla	237	2.4	175	1.7			349	4.0	761	2.0
Prosopis africana	132	1.3	275	2.7					407	1.1
18. MYRTACEAE										
Eucalyptus spp.					146	1.9	592	6.9	738	2.0
Psidium guajava	428	4.6	271	2.6	364	4.6			1063	2.9
Syzygium guineense	412	4.2	387	3.7	587	7.5			1386	3.8
19. OLACACEAE										
Olax laxiflora	126	1.3	154	1.5			121	1.4	401	1.0
20. PAPILIONACEAE										
Bauhinia tomentosa					311	4.0			311	0.8
Canavalia virosa							239	2.8	239	0.6
Crotalaria spp.			245	2.4					245	0.6
Indigofera spp.			312	3.0					312	0.8
Milettia pinnata	468	4.7	199	1.9					667	1.8
21. PHYLLANTHACEAE										
Phyllantus spp.	165	1.7	420	4.0	133	1.7			718	2.0
22. POACEAE	164	1.7	109	1.0	195	2.5			468	1.3
23 PROTEACEAE										
Protea madiensis	131	1.3	298	2.9			232	2.7	661	1.8
24. RUBIACEAE										
Crossopteryx febrifuga	124	1.3	274	2.6			164	1.9	562	1.5
Morellia senegalensis					178	2.3	193	2.2	371	1.0
Mitragyna inermis	189	1.9					231	2.7	420	1.1
Sarcocephalus latifolius	387	3.9	274	2.6	587	7.5	412	4.8	1660	4.5
25. RUTACEAE										

Advance Journal of Agriculture and Ecology
Adv. J. Agric. & Eco.
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October-2024
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Impact Factor: 5.39
Advance Scholars Publication
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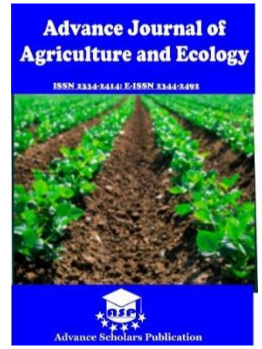

Citrus spp.			468	4.5					468	1.3
26. SAPINDACEAE										
Allophyllus africanus			287	2.8	162	2.0	196	2.3	645	1.7
27. SAPOTACEAE										
Mimusops warneckei	234	2.4	159	1.5			121	1.4	514	1.4
Vitellaria paradoxa	276	2.8	189	1.8	153	1.9	112	1.3	730	2.0
28. INDETERMINATA					15	0.2			15	0.04
Total Pollen Counts	**9,835**	**100**	**10,329**	**100**	**7,868**	**100**	**8,606**	**100**	**36,638**	**100**

Advance Journal of Agriculture and Ecology
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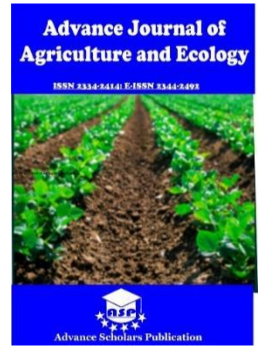

Table 3: Floral sources of the honey samples from the study area

Samples	Pollen type				Remark on floral origin	Pollen count / Category
	Very frequent (> 45%)	**Frequent (16 – 45%)**	**Rare (3 – 15.9%)**	**Sporadic (< 3%)**		
Bade	--	--	*Borassus aethiopium* (4.4), *Hyphaene* spp (3.0), *Calotropis procera* (5.8), *Balanite orbicularis* (7.0), *Cordia suckertii* (4.2), *Senegalia mellifera* (3.3), *Senna occidentalis* (4.5), *Parkia biglobosa* (3.5), *Psidium guajava* (4.6), *Syzygium guineense* (4.2), *Milettia pinnata* (4.7), *Sarcocephalus latifolius* (3.9).	*Strobilanthes* spp. (2.9), *Lannea acida* (2.8), *Mangifera indica* (2.8), *Daniellia oliveri* (2.6), *Senna alata* (1.3), *Alchornea cordifolia* (0.6), *Crateranthus letesturi* (2.0), *Abutilon mauritanum* (1.5), *Adansonia digitate* (1.8), *Magnolia coco* (1.3), *Azadirachta indica* (2.4), *Khaya senegalensis* (2.4), *Trichilia prieureana* (2.3), *Acacia mellifera* (1.9), *Pentaclethra macrophylla* (2.4), *Prosopis Africana* (1.3), *Olax laxiflora* (1.3), *Phyllantus* spp. (1.7), *Poaceae* (1.7), *Protea madiensis* (1.3), *Crossopteryx febrifuga* (1.3), *Mitragyna inermis* (1.9),	Multifloral	**9,835/ I**

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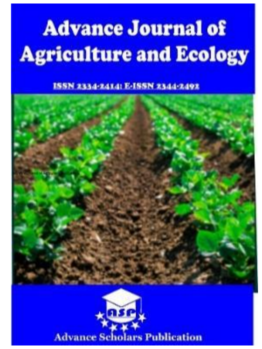

				Mimusops warnecke (2.4), *Vitellaria paradoxa* (2.8).		
Nangere	--	--	*Strobilanthes* spp. (4.7), *Daniellia oliveri* (5.3), *Senegalia mellifera* (4.5), *Combretum* spp. (3.6), *Sida acuta* (3.2), *Khaya senegalensis* (5.2), *Acacia mellifera* (5.6), *Syzygium guineense* (3.7), *Indigofera* spp. (3.0), *Phyllantus* spp. (4.0), *Citrus* spp. (4.5).	*Lannea acida* (1.5), *Mangifera indica* (1.8), *Borassus aethiopium* (1.4), *Calotropis procera* (0.8), *Balanite orbicularis* (2.3) *Cordia africana* (1.4), *Caesalpinia pulcherrima* (0.2), *Cyperus* spp. (1.2), *Euphorbia hirta* (1.4), *Crateranthus letesturi* (2.1), *Magnolia coco* (2.6), *Acacia* spp. (2.7), *Albizia zygia* (1.9), *Parkia biglobosa* (1.2), *Pentaclethra macrophylla* (1.7), *Prosopis africana* (2.7),	Multifloral	**10,329**/ **I**

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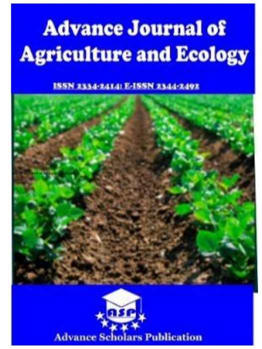

				Psidium guajava (2.6), *Olax laxiflora* (1.5), *Crotalaria* spp. (2.4), *Milettia pinnata* (1.9), Poaceae (1.0), *Protea madiensis* (2.9), *Crossopteryx febrifuga* (2.6), *Sarcocephalus latifolius* (2.6), *Allophyllus africanus* (2.8), *Mimusops warneckei* (1.5), *Vitellaria paradoxa* (1.8).		
Damaturu	--	--	*Mangifera indica* (3.4), *Borassus aethiopium*(3.0), *Calotropis procera*(3.7), *Mahonia oiwakensis*(4.0), *Daniellia oliveri*(3.3), *Combretum* spp.(3.2), *Cyperus* spp.(3.9), *Acacia mellifera*(6.1), *Parkia biglobosa*(6.0), *Psidium guajava*(4.6), *Syzygium guineense*(7.5), *Bauhinia tomentosa*(4.0), *Sarcocephalus latifolius*(7.5).	*Balanite orbicularis* (2.3), *Cordia africana* (2.2), *Piliostigma thonningii* (2.0), *Senegalia mellifera* (1.1), *Senna alata* (1.5), *Alchornea cordifolia* (1.8), *Euphorbia hirta*(2.2), *Crateranthus letesturi*(1.6), *Adansonia digitate*(1.6), *Azadirachta indica*(2.5),*Khaya senegalensis*(1.5), *Trichilia prieureana*(2.0), *Acacia* spp.(2.4), *Albizia zygia*(2.3), *Eucalyptus* spp.(1.9), *Phyllantus* spp.(1.7), *Poaceae*(2.5), *Morellia senegalensis*(2.3), *Allophyllus africanus*(2.0) *Vitellaria paradoxa*(1.9).	Multifloral	**7,868**/ I

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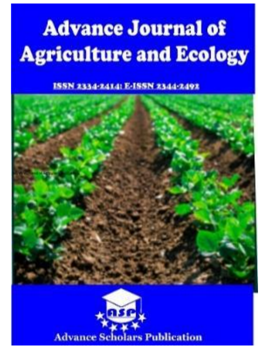

Nguru	--	--	*Borassus aethiopium*(6.1), *Calotropis procera(3.6),Senegalia mellifera*(6.3),*Combretum* spp.(4.1), *Alchornea cordifolia*(4.6), *Leonotis nepetifolia*(5.5), *Crateranthus letesturi*(3.0), *Adansonia digitate*(4.5), *Acacia mellifera*(4.4), *Pentaclethra macrophylla*(4.0), *Eucalyptus* spp.(6.9), *Sarcocephalus latifolius*(4.8).	*Strobilanthes* spp.(0.5), *Balanite orbicularis*(2.3), *Cordia africana*(2.9), *Piliostigma thonningii*(2.8), *Cyperus* spp.(1.3), *Euphorbia hirta*(2.9), *Magnolia coco*(1.9), *Azadirachta indica*(2.7), *Trichilia prieureana*(1.4), *Acacia mellifera*(1.8), *Albizia zygia*(1.5), *Parkia biglobosa, , Olax laxiflora*(1.4), *Canavalia virosa*(2.8), *Protea madiensis*(2.7), *Crossopteryx febrifuga*(1.9), *Morellia senegalensis*(2.2), *Mitragyna inermis*(2.7), *Allophyllus africanus*(2.3), *Mimusops warneckei*(1.4), *Vitellaria paradoxa*(1.3).	Multifloral	**8,606/ I**

***Floral origin:** selected based on most represented (very frequently and frequently occurring) plant species
Categories: I (<20,000), II (20,000 – 100,000), III (100,000 – 500,000), IV (500,000 – 1,000,000) and V (>1,000

Table 4: Vegetation inference from pollen types recovered from honeys from the study area

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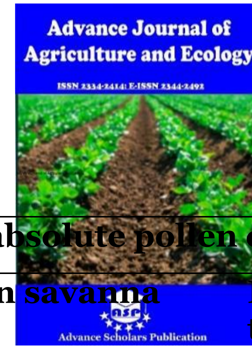

Palaeoecological data	**Vegetation type represented from absolute pollen counts**				
	Derived savanna	**Guinea savanna**	**Sudan savanna**	**Human impact taxa**	**Suggestive inference on biogeographical origin of honey**
Selected pollen types	*Alchornea cordifolia*, *Allophyllus africanus*, *Crossopteryx febrifuga*,, *Daniella oliveri*, *Milettia pinnata*, *Mimusops warneckei*, *Morelia senegalensis*, *Parkia biglobosa*, *Mahonia oiwakensis*, *Crateranthus letesturi*, *Pentaclethra macrophylla*, *Phyllanthus* spp.,	*Lannea acida*, *Albizia zygia*, *Combretum* spp., *Prosopis africana*, *Sarcocephalus latifolius* *Senna alata*,, *Syzygium guineense*, *Trichilia prieureana*, *Khaya senegalensis*, *Cyperus* spp.	*Piliostigma thonningii*, *Vitellaria paradoxa*, *Acacia mellifera*, *Acacia* spp., *Adansonia digitata*, *Senegalia mellifera*, *Calotropis prosera*, *Cordia africana*, *Cordia suckertii*, *Hyphaene* spp., *Magnolia coco*, Poaceae, *Protea madiensis*, *Balanite orbicularis*, *Borassus aethiopium*, *Strobilanthes* spp.,	*Euphorbia hirta*, *Psidium guajava*, *Mangifera indica*, *Mitragyna inermis*, *Canavalia virosa*, *Crotalaria* spp. *Indigofera* spp., *Sida acuta*, *Azadirachta indica*, *Citrus* spp., *Caesalpinia pulcherrima*, *Bauhinia tomentosa*, *Eucalyptus* spp., *Abutilon*	

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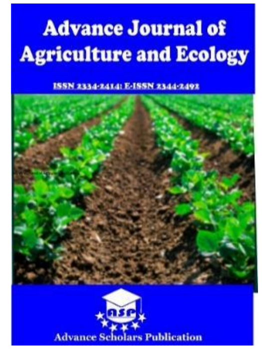

		Senna occidentalis			*mauritianum, Leonotis nepetifolia,*	
Total pollen count		**9,835**	**10,329**	**7,868**	**8,606**	
Localities	Bade (%)	40.65	30.60	17.52	26.20	-Sudan savanna/ Human impact
	Nangere (%)	24.95	41.48	19.17	27.56	-Sudan savanna/ Human impact
	Damaturu (%)	14.17	16.40	18.09	21.70	-Sudan savanna/ Human impact
	Nguru (%)	20.23	11.52	45.25	24.54	-Sudan savanna/ Human impact
Total pollen indicator of the vegetation (%) of Yobe State		**24.4**	**18.6**	**28.5**	**28.4**	**Yobe State is largely Sudan savanna that is highly impacted by human activities.**

Total pollen count = 36,638

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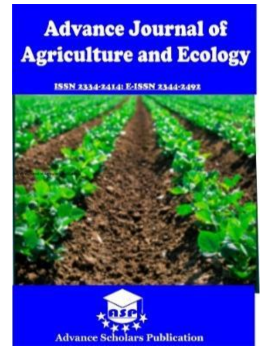

Vegetation history and biogeographical origin of honey: The determination of a biogeographical origin of honey is based on the entire spectrum being consistent within the flora of that particular region (Louveaux *et al.,* 1978). The abundance of *Acacia mellifera*, *Acacia* spp., *Adansonia digitata*, *Balanite orbicularis*, *Borassus aethiopium*, *Calotropis procera*, *Combretum* spp., *Cordia africana*, *Daniella oliveri*, *Parkia biglobosa*, *Sarcocephalus latifolius*, *Piliostigma thonningii*, Poaceae, *Senegalia mellifera*, and *Vitellaria paradoxa* reflects the vegetation of Sudan Savanna. The occurrence of the pollen of the above listed plants in the pollen spectrum of the studied samples confirms their biogeographical origin reflecting Sudan savanna ecovegetation type that is anthropogenically disturbed. Similar findings on other vegetation zones were reported by Agwu & Okeke (1997); Essien *et al*. (2022c), Essien *et al*. (2023) as well as Essien & Olaniyi (2023).

According to pollen analysis of these honey samples, Sudan Savanna taxa were the highest pollen contributor (28.5 %) followed by Human Impact taxa (28.4 %). The suggestive vegetational inference inferred from this honey pollen analysis revealed that the vegetation of Yobe State is largely Sudan Savanna highly impacted by human activities. Similar findings were reported by Essien *et al*. (2023) who opined that the plant *Senegalia mellifera* whose pollen grains are present in the pollen assemblage of the honey samples studied is used as fencing, livestock feed and building material for huts. The wood is prized also for fuel and making charcoal. All these are predominant indigenous occupations/ cultural lifestyle and heritage of the inhabitant of the study area.

The pollen analysis shows a fairly similar floral composition for the entire honey samples studied which is in line with the work of Sowunmi (1976) in Southeastern Nigeria and the high floral diversity of the forested-savanna ecozone by Agwu *et al*. (2013) in Northcentral Nigeria. The percentage of human impact indicator species could be attributed to anthropogenic activities in this region such as the activities of herdsmen (livestock grazing, annual bush burning, etc.), deforestation, urbanization, and agricultural activities in line with Essien *et al*. (2022a) reports. From Table 4, there were clear indications that the study regions of Yobe State are largely Sudan Savanna highly impacted by human activities with little variation with respect to the different study localities.

Season of honey production: Most plants flower during the dry seasons, allowing honeybees graze during those times. For instance, the flowers of *Senegalia mellifera* are sources of nectar for honey-producing bees. To produce honey in the study area efficiently, this study examined the numerous pollen types and their distinct flowering seasons. According to Dalziel (1937) and Keay (1959) studies, flowering seasons differ for different plants. For example, *Mangifera indica* (February-May), *Morellia*

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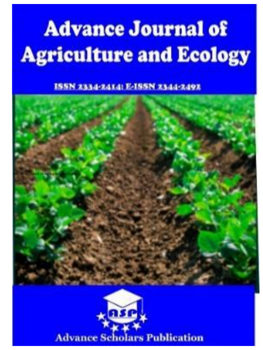

senegalensis (November to January; March to April), *Mimusops warneckei* (April to June), *Alchornea cordifolia* (October to November; June - August), *Bombax buonopozense* (January to March), *Brachystegia eurycoma* (April to May), *Daniella oliveri* (November to January; March to April), *Delonix regia* (April to August), *Elaeis guineensis* (October-April), *Parkia biglobosa* (December to April), *Paullinia pinnata* December to January), *Trichilia prieureana* (January to March), *Tridax procumbens* (June to September), *Vitellaria paradoxa* (April to June). According to Sowunmi (1976) and Agwu & Akanbi (1985), *Parkia biglobosa*, and *Phyllanthus* spp. all have flowering periods between January and October. These flowering seasons can be used by beekeepers to maximize the production of honey in the study area.

Floral preference of honeybees (*Apis mellifera* var. *adansonii*): Pollen analysis of honey samples examined indicates the presence of pollen types of different plants species, most likely a reflection of more species diversity characteristics of Human impacted Sudanean Savanna vegetation type. The determination of the floral origin of honey is based on the relative frequencies of pollen types of various nectar producing plants species in the honey samples. Generally entomophilous plants were observed to be more abundant in the pollen spectrum of each honey sample studied and the honey from the source localities were rich in pollen types.

In terms of floral sources, this study revealed that all the honey samples were multifloral (Table 3); suggesting that honeybees (*Apis mellifera* var. *adansonii*) produced honey by gathering a variety of pollen and nectar that they found to be most appealing. According to Agwu *et al*. (2013), Kayode & Oyeyemi (2014), Adeonipekun *et al*. (2016), Adekanmbi & Ogundipe (2009), and Essien *et al*. (2022c), the majority of Nigerian honeys fall into the type I description of Parades and Bryant (2019). The pollen types from the least abundant families may not have been fully domesticated, or their pollen does not rank among the top choices for honeybees.

Based on the relative frequencies of the various pollen types from nectariferous and polleniferous species in the honey samples, the botanical origin of the honey is identified. The predominance of plant families like the Caesalpinaceae, Mimosaceae, Papilionaceae, Rubiaceae, Malvaceae, Myrtaceae, Meliaceae, Anacardiaceae and Arecaceae (Figure 2) has been reported in numerous other studies (Dukku, 2013; Kayode & Oyeyemi, 2014; Adekanmbi & Ogundipe, 2009), which is unmistakably a reflection of the importance of these families in honey The least numerous families might not have been fully domesticated or their pollen may not be favoured by honeybees over the most numerous families.

The study showed that all honey samples were multifloral (Table 3), implying that honeybees (*Apis mellifera* var. *adansonii*) foraged for several preferred pollen and nectar sources to

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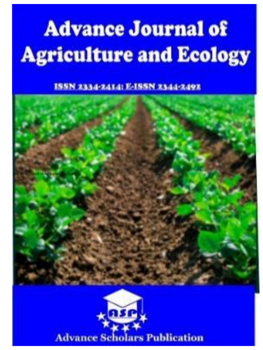

produce the honey. Agwu and Njokuocha (2004) reported that the differences which were observed in the number of contributing plant species in the honey samples may be attributed to the variation in edaphic factors, microclimate, lack of uniformity in the establishments of plants (including flowering period) and selective behaviors of bees during their foraging activities.

Originality of honey: Deciphering the botanical and/or ecological origin and the authenticity of honey samples from Yobe State, Nigeria was the focus of this study. Complimentarily, knowing the best times for apiculture by understanding the flowering seasons of the plant was another objective. Having seen evident impact of humans in the study location, pollen analytical study shed more light on the important bee plants that may require preservation for continuous supply of quality honey in Yobe State. The study found that all honey samples were acidic in nature (Table 1) and pollen weight revealed that the honey sample were not adulterated. Cases of honey adulteration have been reported in many cities in Nigeria. For example, Agwu *et al*. (2013) from Dekina; Aina *et al*. (2014) from Kogi East; Anidiobu (2016) from Kabba; Essien *et al*. (2022a) from Ijumu has been reported to be good. This study confirms those from Yobe State; that were randomly sampled are also of good quality. Honey quality can be measured by its pollen diversity and count (Ige & Modupe, 2010; Oyeyemi, 2017; Essien *et al*., 2022c). The high diversity of pollen types (Figure 1) further supports the originality of the honey samples (Bogdanov & Martin, 2002).

Conclusion

Pollen analysis is still an indispensable method for the determination of vegetational history and biogeographical origin of honey; major season of honey production; floral preference of honey bees, and purity status of honey based on its floral and geographical origin. It can to some extent, reflect the floristic characteristics of the area the honey was collected from. This study has revealed some important indicator species of vegetation types in Yobe State as well as honey bees (*Apis mellifera* var. *adansonii*) preferred pollen and nectar sources. These plants include those of *Borassus aethiopium*, *Sarcocephalus latifolius*, *Vitellaria paradoxa*, *Senegalia mellifera*, *Mangifera indica*, *Calotropis procera*, *Daniella oliveri*, *Balanite orbicularis*, *Combretum* spp., *Khaya senegalensis*, *Parkia biglobosa*, *Psidium guajava*, and *Syzygium guineense*. Among others. The present study revealed that indicator species of Sudan savanna taxa documented in these study are worthy of conservation and their sustainable exploitation managed in the apiculture to enhance large scale production of honey in Yobe State, Nigeria. The study further revealed that the vegetation of Yobe State is largely Sudan Savanna type and is currently being impacted by human activities of subsistence.

Advance Journal of Agriculture and Ecology
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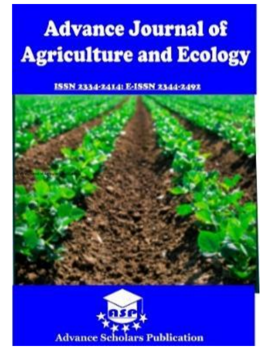

Source of Funding

This project was self-funded.

Disclosure of conflict of interest

The author declares that there is no conflict of interest.

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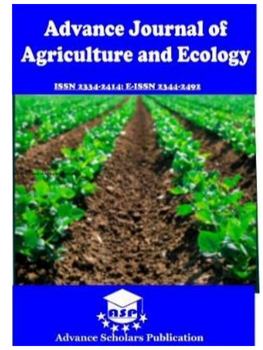

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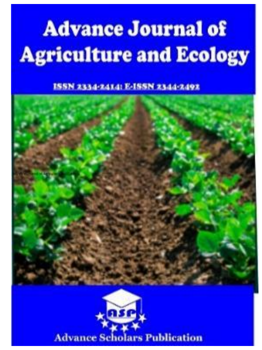

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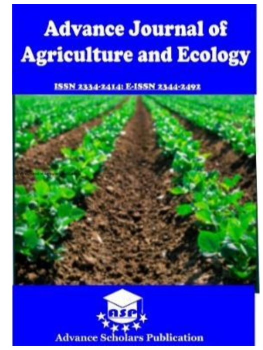

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