Chapter

Understanding Past and Present Vegetation Dynamics Using the Palynological Approach: An Introductory Discourse

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Abstract

Palynology is a multi-disciplinary field of science that deals with the study and application of extinct, [fossilised] and extant palynomorphs (pollen and spore) and other related microscopic biological entities in the environment. It is divided into palaeo- and actuo-palynology, and provides substantial proxies to understanding past and present vegetation dynamics respectively. With reference to the two geological principles of uniformitarianism and of the evolution of fauna/flora, the distribution of plant indicators across ecological zones, palynomorph morphology and pollen analysis, palynology can be used to identify the change in past and present local and regional vegetation and climate and humans impact on the environment. Other supportive areas of endeavour like radiocarbon dating, sedimentology, taphonomic processes and geomorphology can be used to triangulate inferences drawn from palynological data. Palynomorphs are made of outer cell walls embedded with an inert, complex and resistant biopolymeric signature (called sporopollenin) which helps to facilitate long term preservation in different environmental matrices under favourable conditions, hence its widespread applicability. Palynology have proven to very reliable in reconstructing past vegetation, decrypting essential honeybee plants and understanding the impact of climate on plant population using pollen analysis, for which is the basis for the application of palynology in environmental studies. The application of palynology in climate, vegetation and anthropogenic studies begins with the selection of matrix (sediments from lake, river, ocean, excavation, relatively intact soil profile, bee products), coring or collection of samples, subjection to a series of chemically aided digestion, separation, physical filtration, decanting, accumulating of palynomorphs, microscopic study and ends with the interpretation of recovered information. Literature review on the application of palynology for understanding vegetation and climate interactions is presented in this paper.

Keywords: Palynology, vegetation dynamics, pollen, spores, palynomorphs, palaeo-vegetation, pollen analysis, environmental reconstruction, climate, Quaternary

1. Introduction

In this review, vegetation dynamics is the succession pattern, spatial distribution, diversity and interaction of plants with humans traceable by pollen footprints in terrestrial ecosystems. Kim [1] opined that vegetation dynamics is greatly influenced by climatic factors and patterns of land use by humans. The changes in vegetation pattern occur rapidly or gradually, and palynology can be used to study these changes. Palynology provides fair playing ground for participatory and collaborative research bordering on understanding past and recent changes in the vegetation of an area. By virtue of the principles of palynology and of pollen analysis, pollen grains and spores are best applied to resolving environmental puzzles especially those related to vegetation change. It is important to emphasise that palynology is highly preferred and considered rich in providing indices on the change in vegetation in a place for several reasons; the chemically resistant compound embedded in the outer walls of pollen and spores facilitating preservation, the ubiquitous nature of pollen and spore, high pollen productivity, distinctiveness in the morphology of pollen types helping in identification of parent flora among others. The organic compound in the pollen is resistant to microbial attack, temperature regimes and pressure when buried in the soil and lastly because palynomorphs are produced in abundance, transported by wind, human, insects (and other animals) or water to different environments and ubiquitous in nature. The ubiquitous characteristic nature of pollen is a function of its productivity and there is currently very limited data on it. Unpublished data with Sowunmi [2] and Obigba [3] has revealed that the pollen productivity for *Tridax procumbens* L. is 116,270, *Ricinus communis* L. - 1.7 million, *Bombax buonopozense* P. Beauv. - 5.3 million, *Adansonia digitata* L. - 2.6 million, *Annona senegalensis* Pers. - 796,791, *Vitellaria paradoxa* C.F. Gaertn. - 793,529, *Elaeis guineensis* Jacq. - 111,640, *Vitex doniana* Sweet - 31,160, *Parkia biglobosa* (Jacq.) D. Don. - 6,306 and *Bridelia ferruginea* Benth. – 740 in a single flower irrespective of the size of the pollen grain and the flower. This is indicative of that fact that a single flower in a tree can produce millions of pollen grains and by this singular action; it is now possible to find pollen in different environmental matrices.

1.1 Palynology and its applications

The term palynology was first introduced in 1944 [4]. The word palynology was derived from two Greek words "*paluno*" meaning "to sprinkle" or 'dust' supposedly related to airborne or wind dispersed pollens and '*logos*' meaning 'study'. Palynology as simply pronounced as 'pal-uh-NOL-uh-jee' is the study of pollen, spores and microscopic sized entities of biological and uncertain origin (ranging from 5 to 500 μm). These entities have resistant cell wall capable of withstanding routine pollen analytical processes involving strong acids treatment. It is also referred to the study of fossilised and extant microscopic structures and their application in the environment [5]. These entities include pollen, spore, algae and their spores, dinoflagellates and their cysts, amoeba and acritarchs of unknown origin. Their ability to withstand the actions of strong acids (hydrochloric, hydrofluoric and sulphuric acids) is credited to the presence of a cellulosic chemical compound called sporopollenin [6], a compound word for the chemically similar CHO compound in spores – sporonin and pollen – pollenin [7].

Sowunmi [2] defined palynology as

> *'the study of extant or fossil microscopic-sized structures, palynomorphs, which cannot be dissolved by hydrofluoric and hydrochloric acids and which are generally resistant to degradation in acidic and non-oxidative sediments or deposits, their dispersal and the applications thereof' (p. 2).*

It is primarily divided into two (past – palaeopalynology and present - actuopalynology), and has become highly applicable in several other emerging fields but only those involving vegetation dynamics will be discussed here. Palaeovegetation (or palaeoecology), petrolipalynology, palynostratigraphy, archaeopalynology, forensic palynology, pharmaceutical palynology, melissopalynology, paleobotany, palynotaxonomy or systematic palynology, and aeropalynology are some of the areas of research in palynology. There are several other emerging fields of interdisciplinary research in palynology which has spanned into plant systematics, apiculture, public health, earth sciences, climatology, environmental reconstruction and archaeology, however, other supportive mechanisms like radiocarbon dating, sedimentology, taphonomic processes and geomorphology can be used to triangulate inferences drawn from recovered palynomorphs.

1.2 Palaeovegetation and environmental reconstruction

This area of research is centred on understanding past ecological dynamics in view to elucidating the past and present legacies of humans, the changes in the regional and local ecosystems, the impact of climate variability and how these information can be used in predicting future changes or current patterns. Palynology has been used for decades for understanding palaeovegetation dynamics and changes from analysing different substrates like guano deposits [8, 9], climate changes in forests [10], rock shelters [11], lakes sediments [12] or surface sediments [13]. The word 'palaeo' means 'past, ancient, old or prehistoric', so, it will be acceptable to say palaeovegetation is vegetation of the past or prehistoric vegetation. One of the way in understanding change in vegetation is by studying palynomorph abundance and variability in undisturbed stratified sediments. Two geological principles are used to support palaeovegetation studies. The first is the Principle of Uniformitarianism which proposes that the natural geologic laws or processes that exist in the present day are same or at one time were observed in the universe in the past, and these changes apply to every other area on earth. The inference is that, the earth has always had uniform changes and that the present changes can be used to uncover changes that occurred in the past and vice versa. Therefore, the changes that occurred in past in terms of vegetation are almost same as at today. The second law is the 'Evolution of fauna and flora' which says that in a vertically stratified sedimentary soil profile, the stratum on top is younger in age and formation than the one below. What this means is that, the farther the stratum down the earth, the older the soil and the closer the stratum to the surface, the younger it will be. This also implies that these strata are embedded with fossilised plant and animal remains preserved over time. In recent times, the law has been referred to as the 'principle of fauna/flora succession' [14, 15] where fossilised materials succeed themselves in the vertical strata. That is, the fossilised fauna and flora beneath evolved to the next stratum just next to it (on top) and so on till it gets to the earth surface or top soil. This order occurs in a reliable format except for disturbed and distorted soil profile. This principle is applied to paleo-vegetation up to what I called 'actuo-vegetation' using pollen analysis of each stratum referred to as sub sample. Since inception several studies have been conducted on this. Novello *et al.* [16] described how palynology was used to decipher last glacial (115,000 years before present) to Holocene (about 12,000 years before present) vegetation and environmental change in South America using cave deposits. Using certain pollen types, the palaeovegetation changes with respect to pollen abundance in sediments through routine pollen analysis are presented below. These reviews provide clues to the vegetation dynamics based on the presence or absence of pollen grains in the sediments and possible factors influencing their abundance in the sampled regions.

1.3 Melissopalynology and conservation of bee flora

Melissopalynology is the branch of palynology that deals with the study of palynomorphs in honey and other honeybee products like propolis, beewax and bee breed. The aim is to find out the botanical and geographical origin of the honey [17]. Honey is produced by the action of eusocial honeybees foraging for proteins and carbohydrates. They visit 'nectariferous' and 'polliniferous' flowers (**Figure 1**, No 6 & 8) for pollen and nectar and sweet fruits like pineapple, mango, water melon and others (**Figure 1**, No. 1–5 & 7) for natural sugars. Honeybees are regular visitors of very colourfully scented flowers for nectar or pollen because their larval and adult dietary requirements depend on it [18]. Pollen is the bee's major source of protein, fat, minerals and vitamins, while nectar is the major source of carbohydrates from which honeybees source for energy. In the course these foraging expedition, the honeybees collects pollen and other non-pollen materials (honeydew elements) co-incidentally for the production of honey in their hives. The pollen is the focus for this aspect of palynology and its usefulness for vegetation dynamics of the present day. Preliminarily, pollen grains are the male microgametophyte of either unicellular or multicellular form that is produced in the flowers with the primary responsibility of pollination and fertilisation. This invariably means they can be used to track flowering patterns for honeybee plants. Honey bees are major pollinators among flying insects and are so essential in conserving plant diversity.

Apiculture is the aspect of agriculture that covers this part of biological sciences. Melissopalynology thus deals the representation of pollen types (that is flowering plants visited by honeybees) in honeys collected and marketed for humans. Depending on the rate of foraging and seasonality of flowering in honeybees plants, honeybee farmers can collect or extract honey from honeycombs or artificially manufactured hives on a weekly or monthly basis. The taste, colour, texture and fragrance of the honey are dependent on the type of flora visited. If the honey is derived from a single flora, it is called unifloral and if it is from several floras, it is referred to as multifloral or polyfloral honey. In understanding flora dynamics, mulitfloral honeys

Figure 1.
Honey bee foraging for nectar and/or pollen: 1: Citrullus lanatus *(Thunb.) Matsum. & Nakal (water melon) fruit, 2–3:* Mangifera indica *(mango) fruit, 4–5:* Anacardium occidentale *L. (cashew) fruit. 7:* Antigonon leptopus *Hook. & Arn. (Mexican creeper) flower, 7:* Ananas comosus *(L.) Merr. (pineapple) fruit, 8:* Canthium danlapii *flower. (Source: Author original photos).*

are best for analysis. This can reflect the yearly pollen calendar for a locality where plants are cultivated or grown in the wild. Several studies have been carried out in this aspect by many researchers. Vegetation dynamics *vis-a-vis* floral diversity can be safely constructed using melissopalynology to show flowering pattern for important bee plants. Flora that needs to be conserved for enhancing health of honeybee colonies and the production of economically and medicinally important honey can be revealed through melissopalynology. A perfect example is presented in Lau *et al*. [19] paper where they studied the annual spatial and temporal dynamics in the vegetation of urban and suburban areas in Texas, Florida, Michigan and California by collecting pollen foraged by honeybees. Hence, pollen is an essential tool in the analysis of honey as it indicates the major and minor plant taxa utilised by honeybees.

1.4 Aeropalynology

The atmosphere is made of several airborne particulate matter of which pollen and spores are part of. Wind dispersed pollen and spores are released from lower green and flowering plants respectively at different times in the year and can be used to trace seasonality and presence of pollen in the atmosphere for public health reasons. Aeropalynology as the name implies is the study of airborne palynomorphs sampled through a pollen trap. This study is important if deleterious allergy triggers must be identified. One of the founding fathers of palynology, Erdtman, defined aeropalynology as the study of pollen and spores in the atmosphere [20]. In Ezike *et al*. [21], a monthly survey airborne palynomorphs in North Central Nigeria was carried for one year with the aim of finding the abundance, diversity and variation of wind pollinated flora in the region. The study attempted to the link pollen dispersal and meteorological environmental changes using a pollen trap. Fern spores, pollen types, algal cysts and diatoms were recovered with varying abundance across the year. Aeropalynology can be used to identify phytoecological groups in the atmosphere which is supposed to be a representation of the regional vegetation. In Anyigba, Kogi State, Essien and Nkang [22] recovered 47 airborne palynomorphs (pollen types) from 29 plant families through the pollen analysis after collecting samples for both dry and wet seasons. They found three major vegetation types (forest, savanna and human impacted). Thus, airborne palynomorphs can be used as indicators for regional flora or of the immediate environment. Monthly retrieval of airborne palynomorphs can be used to infer the flowering seasonality of wind dispersed or pollinated plants in that region.

1.5 Archaeopalynolgy

This area of research is in environmental archaeology where the interaction of humans with their environment (particularly the plants) in antiquity is deciphered by detail analysis of pit excavations. The archaeological materials alongside with the palynomorphs recovered are used to interpret past interactions of humans with their flora. There are anthropological studies available on this aspect involving the use of palynology e.g. farming history and prehistoric weapon production and furnace use [11, 23]. Johnston [24] mentioned that archaeologists in the course of their study find fossilised pollen and spores of different shapes in excavations; hence, archaeopalynology is the study of palynomorphs in archaeological sites in an attempt to reconstruct the ancient lifestyle (diets, farming practices, raw material sourcing), food sources, physical landscape, domestication attempts and the understanding the impact of humans on earth. The methods in the analysing archaeopalynological samples are outlined in the paper by Dontella and Federico [25]. It includes removal of organic and inorganic matter, microscopy, identification and counting. Based on the pollen types found, the vegetation types and interaction of humans with the flora can be elucidated. The law of geologic laws of uniformitarianism and flora/fauna succession is also applied here. It is important to succinctly note that pollen analysis remains the basis for the application of palynology in vegetation studies. Some important archaeo-palynological works has been carried out in Nigeria like those of Orijemie [11, 23].

2. Pollen analysis, identification and vegetation-climate interaction

2.1 Pollen (or palynomorph) analysis

The application of palynology in any field is basically dependent on the use of pollen analysis for deducing inference on vegetation-climate-human interactions. Pollen analysis is relatively laborious, time consuming and expertise demanding. The purpose for pollen analysis is to disintegrate the palynomorphs from their matrices and concentrate them for proper identification. It is only the series of analytical procedures commencing with the collection of palynomoprh embedded substrates (honeybee products – pollen pellet, honey, propolis, terrestrial and aquatic sediments, air borne particulate matter, excavations, anther from flowers, faecal matter, drug samples and rocks) from the field to laboratory processing of the substrates (**Figure 2**). Microscopy which helps to determine relative abundance of one palynomorph type in comparison to other follows immediately after the laboratory processing. Depending on the type of matrix and the aim of the analysis, different laboratory procedures are employed. For example, the qualitative study of palynomorphs requires acetolytic (chemical removal of protosplamic content using 9:1 of acetic anhydride and concentrated hydrochloric acid) processing for elucidation of exine ornamentations or patterns. This may not be necessary for quantitative study of pollen and spores in honey or sediments. They type of matrix determines the number of treatments to be used. For soil matrices, the numbers of chemical processes are more than other matrices like honey, drugs samples, or pollen pellet.

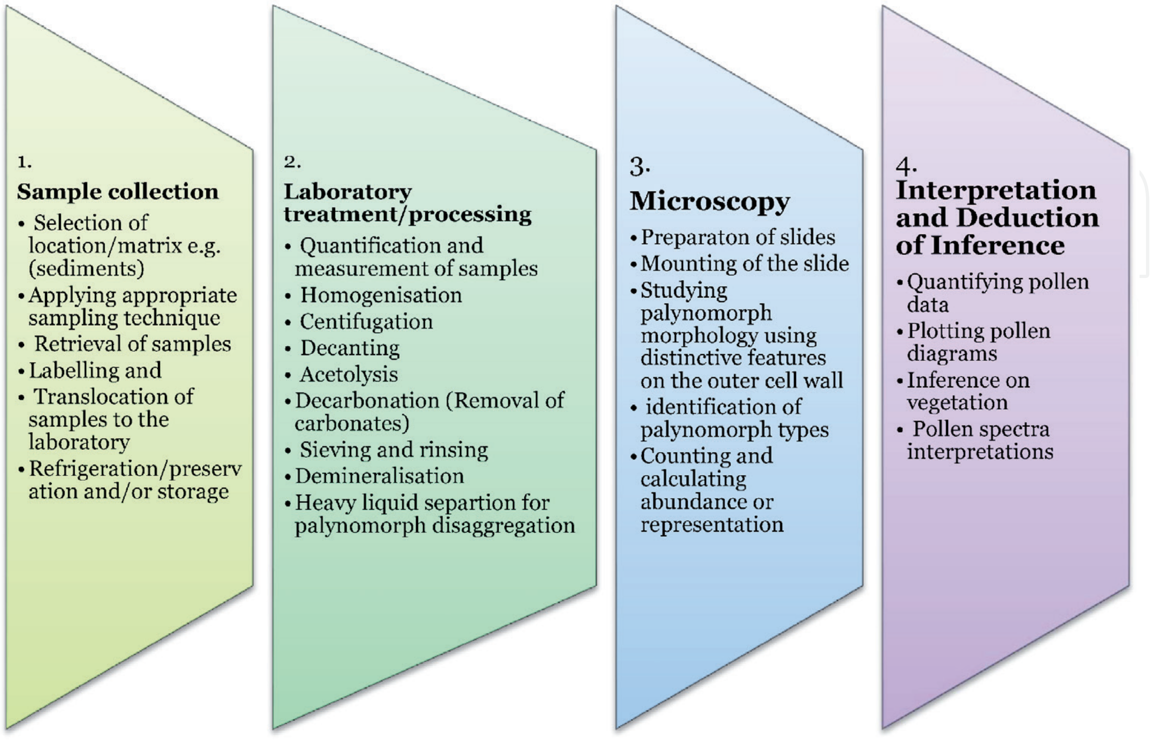

Figure 2.
Illustrating the stages involved in pollen analysis.

Categorisation	Quantification (in %)	Interpretation based on dominance of the plant species
Predominant	more than 45	Overwhelmingly abundant flora in the vegetation
Secondary	16–45	Major vegetation coverage in the area that is complimenting the 'predominant' plant species
Important minor	3–15	Very useful flora present in the vegetation
Minor	between 1–3	Scanty and insignificant in number
Present	less than 1	Rarely noticed in the vegetation

Table 1.
Palynomorph quantitative representation and interpretation in vegetation studies.

Erdtman [20] and Faegri and Iversen [26] gives full description of pollen analysis, however, the figure below shows a summarised procedure for pollen analysis of palynomorph embedded samples.

In the interpretation of results from pollen analysis, there are several limiting factors. These factors influence the representation of palynomorphs when recovered. Some of them are pollen dispersal mechanism, pollen productivity, and differential preservation capacity against environment induced deterioration. In interpreting of pollen analysis, microscopy, identification and counting are used as the quantification presented in **Table 1**. In counting and providing information about the abundance of a particular pollen type, Jones and Byrant [27] and Louveaux, *et al*. [28] formula is used as shown in **Table 1** above.

2.2 Pollen identification

The application of palynology on every other area of research is largely dependent on the accurate identification which is powered by the impeccable description of the morphological features of the pollen types recovered from the environmental matrix. Pollen grains are unicellular to multicellular units composed of a cell wall and protoplasm. The morphological features and their distinctiveness are found on the cell wall especially in the outer cell wall called the exine. The parameters used in describing pollen grains are polarity, symmetry, aperture types, pollen class, pollen size, and exine ornamentation (details in **Figure 3**). Expert experience is highly in identification since some pollen types may have close resemblance but represent different vegetation types e.g. *Lophira alata* Banks ex Gaertn. is found in tropical freshwater swamp forests and *Lophira lanceolata* is representative of wooded savanna. Pollen from the Melastomaceae and Combretaceae are almost indistinguishable, hence are classified into one group even though other gross morphological feature are different. Palynomorph identification is carried out using pollen albums, reference pollen collections and published atlases [29–31].

2.3 Late quaternary climate vegetation interaction in tropical West Africa

According to the geological time scale, the Late Quaternary is from 65,000 years BP (before present) to date. During the period, the plant communities were greatly influenced based on their response to climate change. Information on the fluctuation in mangrove and freshwater swamp forests, the relative dominance of other forms of forests and savanna is provided. As provided in details in Sowunmi [32] paper, the following were some of the vegetation-climate changes that had occurred basically in the expansion and contraction of forests and savanna and a wet-dry climate cycle. These changes were categorised into six time frames as presented in **Table 2**.

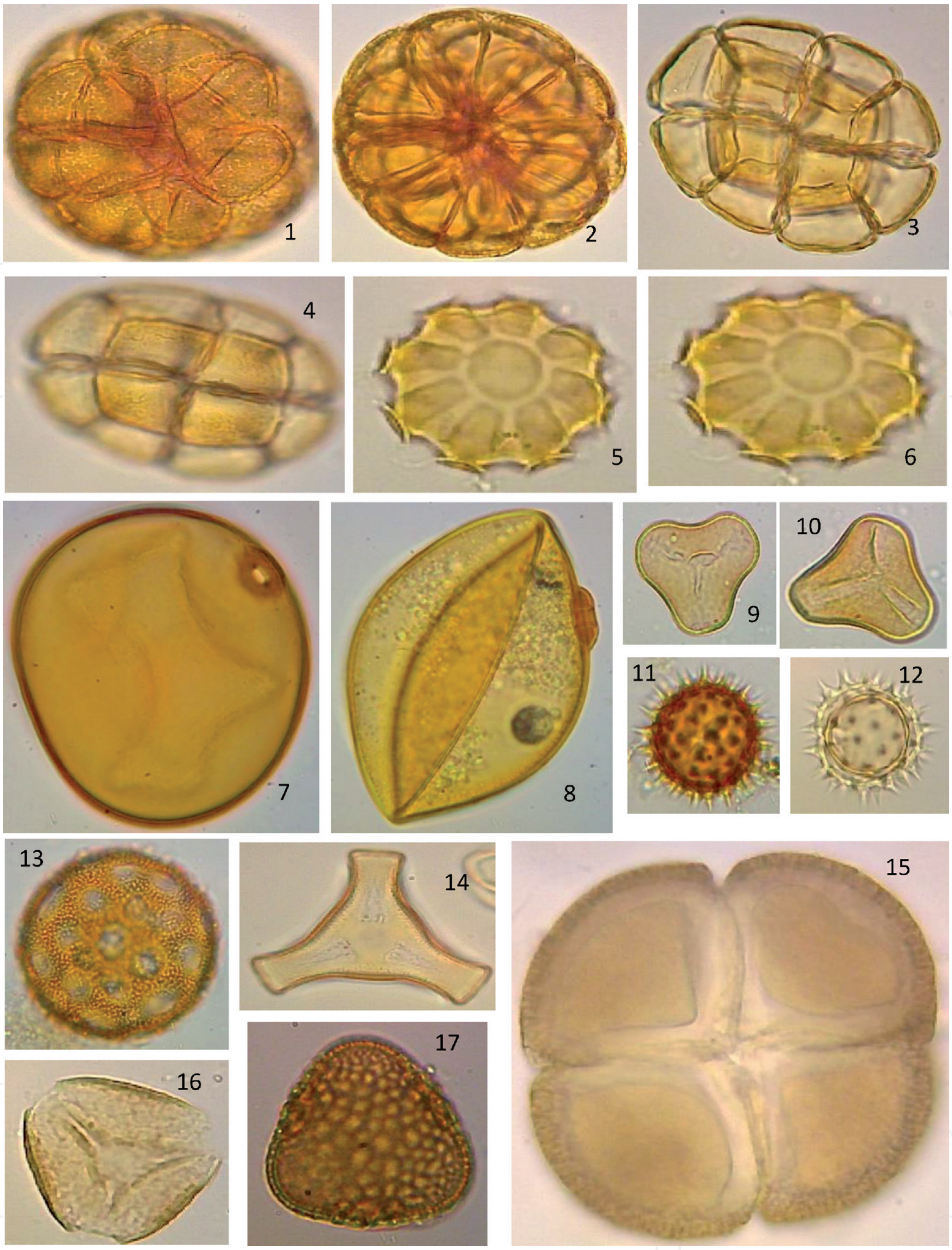

Figure 3.
Pollen grains (or types) of different flora and their morphological distinctiveness: 1–2: Parkia biglobosa, *3–4:* Acacia *sp. Martius, 5–6:* Securidaea *sp. 7–8:* Zea mays, *9–10:* Elaeis guineensis, *11–12: Asteraceae grain, 13:* Talinum triangulare*, 14: Loranthaceae– cf.* Tapinanthus *sp. (Blume) Rchb. 15:* Annona sengalensis, *16:* Parinari *sp. 17:* Bombax costatum *Pellegr. & Vuill. (**Source:** Author original photomicrographs).*

3. Empirical studies

3.1 Palynomorphs, human-plant interactions and vegetation change

Anthropocentric (human cultural) and the anthropocene (climate/human induced) forces have altered ecosystems, plant growth response, habitat characteristics, and behaviour of plants in recent times. In West Africa, there are evident

Phases	Time frame	Climate	Savanna	Forest	Sea level
1	between 40,000 and 30,000 yrs. BP	Wet	Reduction of savanna	Extensive presence of freshwater swamp, distension of mangrove swamp farther south of the present day limits. Dry forests in the northern region became wetter (that is a gradual movement from drier to wetter type forest conditions)	Sea transgression which led to the re-establishment of the mangrove swamp (Inchirian transgression).
2	between 30,000 and 25,000 yrs. BP	Drier	Expansion of savanna southwards to cover forests. Deserted or Saharan landscape replaced by Sudanian vegetation farther north. Ergs formation in sahel and sudan	Destruction of forests or reduction of forests into pockets or refugia	Occurrence of the Ogolian regression, fall in sea levels
3	between 25,000–5,000 yrs. BP	Wetter		Forests re-established, became denser with increased species diversity, regrowth, expansion and extension of the Mangrove swamp	Nouakchottian transgression, rise in sea level
4	between 5,000 and 3,500 yrs. BP	Very wet and later dry	Expansion of savanna	Mangrove swamp forest disappeared (? 4000–3500 yrs. BP), forest reduction	Nouakchottian transgression continuation until 4000 yrs. BP from 5000 yrs. BP, later sea regression
5	between 3,500 and 3,000 yrs. BP	Wetter	Contraction of savannas	Expansion of forests	
6	From 3,000 yrs. to present day	Warm and dry	Sudan and Sahel savannas depreciated in vegetation.	Northern axis of the forests was replaced by woodland savanna	
	increase in human inference in the natural vegetation (the Anthropocene), burning of vegetation, animal grazing and extensive farming				

*Source: Sowunmi [32]. * BP = before present.*

Table 2.
Climate vegetation changes in West Africa in the late quaternary.

adaptive changes in certain plants including their survival and growth in diverse vegetation zones. Today, many savanna species are found growing favourably in residential areas in mangrove and fresh water swamp regions in West Africa. Although a few species are still considered useful in deciphering vegetation dynamics during pollen analysis as presented in **Table 3**. This is particularly noticed in

Vegetation types	**Pollen/flowering plants**						**Spores/lower plants**		
Savanna	*Berlinia grandiflora. Borassus aethiopum*	*Bombax costatum, Lophira lanceolata*	*Vitellaria paradoxa, Bridelia ferruginea*	*Syzygium guineensis, Hymenocardia acida, Pavetta crassipes*	*Adansonia digitata, Parkia biglobosa*	*Lannea* spp.			
Montane	*Justicia laxa*	*Justicia flava*	*Podocarpus milanjianus*	*Myrica arborea*	*Podocarpus latifolius*				
Open/disturbed forest/open vegetation	*Elaeis guineensis, Solanum torvum*	*Alchornea cordifolia*	Asteraceae, Poaceae (grasses)	*Ageratum conyzoides, Ludwigia erecta*	*Piper umbellatum*	Amaranthaceae/ Chenopodiaceae	*Sydowia polyspora*	*Alternaria* spp.	
Rainforest/ Freshwater swamp forest	*Milicia excelsa, Alstonia boonei,*	Cyperaceae, *Symphonia globulifera*	*Irvingia gabonensis*	*Piptadeniastrum africanum, Celtis brownii,*	*Uapaca* spp., *Typha dominigensis.*	*Mitragyna ciliata*	*Botryoccocus brauni, Pseudoschizaea* sp.,	*Ceratopteris* sp.	*Selaginella* sp. *Botryococcus* sp.
Mangrove swamp	*Rhizophora mangle*	*Rhizophora racemosa*	*Rhizophora harrisonii*	*Nypa fruticans, Avicennia germinans*	*Bruguiera* sp.	*Avicennia nitida*	*Acrostichum aureum*	*Pteris* sp.,	*Nephrolepis* sp., *Valsaria* sp.
Human interference/ Cultivation/ Farming/Fire	*Alchornea cordifolia,*	*Musa sapientum, Triumfetta rhomboidea*	*Alchornea laxiflora*	*Elaeis guineensis, Ipomoea* spp.	*Solanum* spp. *Momordica charantia*	*Vigna gracilis*	*Alternaria* spp.	*Pteris intricata*	*Ustilago* spp.
	Dioscorea spp., *Sorghum bicolor,*	*Arachis hypogea, Corchorus olitorius*	*Citrus* sp., *Manihot esculentus*	*Zea mays, Ocimum gratissimum, Sesamum indicum*	Poaceae, *Corchorus olitorius,*	*Aspilia africana, Chromolaena odorata*	*Cytobasidium* spp.	*Nephrolepis biserrata*	*Glomus* sp.,
Residential and Ornamentals	*Lagerstromia indica*	*Aspilia africana*	*Thunbergia grandiflora*	*Caesalpinia pulcherrima*	*Mangifera indica*	*Pinus* spp.	*Alternaria* spp.	*Cladosporium* spp.	*Fusarium* spp.

Source: Orijemie [11, 23], Adekanmbi et al. [33], Akinbola et al. [34], Redondo et al. [35], Numbere [36].

Table 3.
Palynomorph (plants) based on indication of vegetation types in tropical West Africa.

the way savanna species thrive and survive in forest regions in southern Nigeria, although the survival of forest species in savanna has not been convincingly proven. Anthropogenic factors has led to the opening of forests canopies and planting of savanna (including ornamental) plants species and the guinea savanna region and deciduous low land rain forest is fast becoming a forest-savanna mosaic sometimes referred to as forest savanna transition. The availability of water, human interference through cultivation, burning, soil spatial variations, or herbivory pressure characterise this transition zone. Depending on the microclimate and anthropogenic impact, savanna and forest plant species co-exist, hence the presence of other vegetation-specific plant indicators are used to make decisions. Spores are usually used as bio-indicator for microclimates hence; the percentage of pollen and spore are good indices for understanding vegetation change and climate variability. Correct pollen identification is crucial to this application. **Table 2** shows the plant or pollen indicators that can be used to different vegetation types if there abundance in sediments is measured on the basis of **Table 1** above.

3.2 Understanding vegetation dynamics using percentage representation of palynomorphs recovered from environmental matrices

As earlier established in this review, pollen and spore percentage representation can be used to understand vegetation changes. This section will focus on changes in the abundance of certain pollen types (inferably, the plant species) in different environments across the globe and the possible factors influencing these changes. Some of these plants in *Typha* spp., *Elaeis guineensis, Bridelia* spp. *Annona* spp., Cyperaceae, Chenopodiaceae, Asteraceae, and Amaranthaceae to mention but a few. Haung et al. [37] in their study on pollen distribution in a large freshwater lake (Boston Lake) in the arid regions of Xinjiang, China using 61 surface samples found *Typha* L. to have average percentage representation (8.6%) when Chenopodiaceae had *ca.* 50%. Remarkably, *Typha* and *Phragmites* plants were abundant on the west side of the lake, and they asserted that hydrodynamic conditions affect *Typha* pollen. This indicates that lithological factors could moderate the representation of palynomorphs in sediments for some plant species just like the factors influencing the dominance of some plants in a region over others.

In Cameroun, Assi-kaudjhis [38] studied vegetational evolution in the Crater Lake Bambili which lies in the volcanic zone through the pollen analysis of sediments cored from two sites around the lake, a region located in the Guinean-Congolian forest belt. An inventory of the plant biodiversity was taken, and *Annona senegalensis, Bridelia ferruginea,* and *Typha* were found from 1600 m – 800 m asl as savanna elements within the local vegetation. Two cores of 13.5 m and 14.01 m depths, respectively, were taken from a few meters from the lake in 2007 and 2010. The results from pollen analysis revealed that *Bridelia*-type pollen was recorded (7.82%), Amaranthaceae/Chenopodiaceae, Poaceae (75.68–34.44%) and undifferentiated Asteraceae pollen was recovered from the sediments (30.29%). There was generally low amount of tree pollen. The distinctive pollen of *Annona senegalensis* and *Typha* were not found in the core while *Bridelia* was under-represented. Njokuocha [12] studied a 116 cm core from Holocene deposits in Lake Obayi in Nguru, Nsukka, which yielded 78 pollen types from 47 families. Njokuocha [12] found that *Elaeis guineensis* was well represented n sediments at depth 88–116 cm (*ca.* 40%) with Poaceae which was continually abundant in the core with specific abundance ranging from 20 to 40% representation in depths between 25 and 45 cm.

Marlon *et al.* [39] carried out high resolution sedimentological, geochemical and pollen analysis on a 5.75 m sediment core from the coastal plains of the Doce River, southeastern Brazil, which was characterised by many valleys resulting from Quaternary deposition of silt. The region was composed of tropical rainforest like Annonaceae, pioneering freshwater species like *Cyperus* sp. L. (*ca.* 80%), Asteraceae (*ca.* 18%) and Amaranthaceae (*ca.* 2%). From depth 5.5–1.5 m, five ecological groups were observed where *Typha* was only *ca.* 2% with Cyperaceae (3–30%), Poaceae (30–80%). Within lake regions of 1.5–0.8 m depth, *Typha* was only *ca.* 2% represented while Poaceae was 14–40%. The herbaceous plain of depth 0.7–0 m on the surface also yielded under-representation of *Typha* and *Hydrocleis* pollen (< 2%). No detailed discussion was reported on why the *Typha* pollen was under-represented.

In India's Lonar Crater Lake, Riedel *et al.* [40] investigated modern pollen vegetation relationships using Holocene lacustrine sediments and surface samples. They found *Typha augustata* L. near the site of coring and *Annona squamosa* L. characterised the steep faces above the dry deciduous forest in around the site which made up *ca*. 30% of the local vegetation. Results revealed strong differences in pollen assemblages and studied trapping media samples although local arboreal vegetation was adequately represented in soil samples. The pollen of *Typha* and Cyperaceae pollen accounted for 33% of the total pollen present. Poaceae was over-presented while the pollen of *Annona* L. appeared scattered or with single grains even when it formed part of the local vegetation. Channel and surface run off water transport influence pollen assemblages.

Travedi *et al.* [41] reported the under-representation of *Annona cf. squamosa* whilst attempting to establish modern pollen rain vegetation relationship from ten surface samples from Chaudhari-Ka-Tal, Raebareli District, Utter Pradesh of India. They averred that low pollen productivity owing to its entomophilous mode of pollination may have been the factor responsible for the under-representation. There was sparse abundance of *Annona* plants in the local vegetation. Pollen spectra from three of the surface samples revealed that *Annona* pollen was merely 0.65% while *Typha* pollen ranged from 3.2 to 28% from the southern flank samples analysed from the lake. From the western flank, *Annona* pollen was merely 1.65% in the sediments and *Typha* ranging from 17.6 to 22%. The eastern flank of the lake recorded the highest occurrence of *Typha* pollen (ranging from 22.3 to 39%) probably due to the marshy nature of the lake. They however argued that the under-representation of tree taxa could be attributed to low pollen productivity when compared with grasses and herbaceous taxa. Chenopodiaceae/Amaranthaceae pollen was reported to be over-represented also. The increase in fungal spores may have indicated microbial attack, however, there was no certainty on the possible causes of under-representation mentioned and also no further studies were carried out on the exine chemistry to substantiate on the variations in percentage occurrence in the same lake.

3.3 Climate variability induced vegetation dynamism and interactions

The succession of one vegetation type by another is influenced by climatic, human or edaphic factors, or a combination of the triad. Across the globe, the phenomenal change and succession of vegetation in the past and present have been revealed through palynological studies. Few empirical studies are reported in this chapter for clearer understanding.

In Maya region of southern Mexico and Central America, Franco-Gaviria *et al.* [42] investigated the impact of climate variability and human activities on the vegetation communities from two sediment sequences collected from two lakes (Lakes San Lorenzo and Esmeralda) in the highlands of Chiapas, Mexico during the late Holocene. The records reveal a long-term trend towards drier conditions with superimposed centennial-scale droughts. A declining moisture trend from 3,400 to 1,500 cal yr. BP consistent with southward displacement of the Intertropical Convergence Zone was reported. According to them, the climatic conditions with dense human occupation converted the vegetation from forest to more open systems. From paleoecological records of the area, cultural abandonment of the area which occurred ca. 1500 cal yr. BP probably favoured the forest recovery process at that time. About 600 cal yr. BP, wetter conditions promoted the establishment of modern montane cloud forests, with a diverse mixture of temperate and tropical elements. Some of the palynomorphs found in abundance were *Pinus* sp. L. and Cyperaceae pollen (at 3400–3200 cal yr. BP), *Pinus* sp. (over 200%), *Myrica* sp. L. (5–12%), *Quercus* L. (22–68%) and *Alnus* sp. Mill (2–8%) pollen (3200–2400 cal yr. BP). *Alchornea* Sw., Poaceae and *Quercus* aboreal elements peaked at ca. 2500–1500 cal yr. BP. Herbaceous taxa like Amaranthaceae, Asteraceae, Poaceae decreased from 1200 to 600 yr. BP at Lake san Lorenzo. Charcoal concentrations were low generally, but had peaks at ca. 2,500, 1600 and 1100 yr. cal BP. They concluded that the importance of microhabitats is in the maintenance biodiversity through time, even under scenarios of high climate variability and anthropogenic pressure.

In south western region of Nigeria, Orijemie [43] investigated climate-vegetation dynamics using an 8 m-core drilled in Ikorigho with comparison with Ahanve to provided evidence of late Holocene mangrove dynamics and environmental changes. The vegetation was found to have changed from mangrove to low land rainforest. Mangrove swamp forest species were indicated by pollen and spore of *Rhizophora* spp. L., *Avicennia* spp. L. and *Acrostichum aureum* L.; freshwater swamp forest include *Uapaca* Baill., *Mitragyna ciliata* Aubrev. & Pellegr. and *Symphonia globulifera* L.f. and a few lowland rainforest taxa (*Celtis brownie* Rendle, *Pycnanthus angolensis* (Welw.) Warb). There were marked reduction in *Rhizophora* spp. at certain periods which almost always coincided with an upsurge in Poaceae and Cyperaceae pollen obviously indicative of prevailing drier climate, and lowered sea level. In constrast, Sowunmi [44] reported that the environment in Ahanve – Badagry, experienced a very reduced or complete disappearance of mangrove species ca. 3100 yrs. B.P. Non-pollen palynomorphs like few charcoal particles at the lowest sections, and significant increase in charcoal particles in the topmost sections were found of the core providing evidence of relatively recent history of human interactions like tree felling, bush burning and agriculture.

In central Gabon, Ngomanda *et al.* [45] investigated vegetation changes during the past 1300 years are reconstructed in western equatorial Africa using a high-resolution pollen record from Lake Kamalete. The Kamalete pollen data showed the persistence over the past 1300 years of a relatively stable forest-savanna mosaic, associated with significant changes of the forest component. Three successive stages of forest dynamics was found. First, at 1325 yrs. BP, moist semi-evergreen rainforest existed around the catchment of Lake Kamalete. There was consistent presence of above 70% Gramineae pollen that the site was always primarily in savanna. Secondly, from c. 1240 to 550 yr. BP, a noticeable increase in shade-intolerant plant species indicate openings in the rainforest canopy. Thirdly, at 550 cal BP, a mature forest was re-established, corresponding to progressive savanna colonisation by forest pioneer species such as *Aucoumea klaineana* Pierre, *Lophira alata* and *Fagara macrophylla* (Oliv.) Engl. This new phase of forest expansion coincided with a marked lithological change, indicating an increase in lake-level. It was concluded that the major vegetation changes observed were due to climatic variability, and anthropogenic action had limited influence.

In Benin Republic in West Africa, Tossou *et al.* [46] was able to present information on the coastal halophytic mangrove vegetation history based on palynological data collected. They found that the mangrove swamp went through several physiognomic changes from the middle to late Holocene. In the course of the middle Holocene that is from 7500 to 2500 yr. BP. They found that the mangrove was extensive, and with high density of monospecific mangrove species dominated by Rhizophora. During the late Holocene, the mangrove regressed around 3000 years BP which indicated a period of drop in sea level and disappeared about 2500 yr. BP. It has been replaced by swamp meadows dominated by *Paspalum vaginatum* Sw. and a fresh water environment colonised by taxa such as *Persicaria* Mill., *Typha*, *Ludwigia* L., and *Nymphaea lotus* indicating a return of wetter climate drop in sea level.

In Lake Chad region, Amaral *et al.* [47] reported palynological evidences on the climate and vegetation changes that occurred in the Sahara – Sahel boundary which shifted northwards during the termination period of the African Humid Period (AHP). Dates obtained for sediments where between ca. 6700 and ca. 5000 yr. BP which encompassed part of the termination of the AHP. Results showed that, between ca. 6700 and ca. 6050 yr. BP, the vegetation close to humid savanna woodland, including elements currently found further southward, thrived in the vicinity of the Mega-Lake Chad in place of the modern dry woodland, steppe and desert vegetation. At the same time, the montane forest populations extended further southward on the Adamawa Plateau. The high abundance of lowland humid pollen taxa, particularly of *Uapaca*, was interpreted as the result of a northward migration of the corresponding plants during the AHP. The data retrieved indicated that between ca. 6700 and ca. 5000 yr. BP vegetation and climate changes must have occurred progressively, but that century-scale climate variability was superimposed on this long-term mid-Holocene drying trend as observed around ca. 6300 yr. BP, where pollen data indicate more humid conditions.

In Ghana, West Africa, Miller and Gosling [48] presented a fossil pollen record from sediment cores extracted from Lake Bosumtwi. The record covered the last c. 520,000 yrs. BP making it a apart of the Late Quaternary. The fossil pollen assemblages revealed that there was a dynamic vegetation change which can be broadly characterised as indicative of shifts between savanna and forest which also reflected the glacial – interglacial period. Savanna elements which heavily dominated the vegetation included Poaceae pollen (>55%) and was associated typically associated with Cyperaceae, Chenopodiaceaee/Amaranthaceae and Caryophyllaceae. Forest formations are were more diverse than the savanna, with the key taxa occurring in multiple forest zones being Moraceae, *Celtis* sp., *Uapaca* sp., *Macaranga* and *Trema* spp. Lour. The fossil pollen data indicated that over the last c. 520,000 yr. BP, the vegetation of lowland tropical West Africa has mainly been savanna; however six periods of forest expansion were evident which most likely correspond to global interglacial periods. A comparison of the forest assemblage composition within each interglacial suggests that the Holocene (11,000 yrs) forest occurred under the wettest climate, while the forest which occurred at the time of Marine Isotope Stage 7 probably under the driest climate.

In Cameroun, Lebamba *et al.* [49] investigated the vegetation dynamics and human interference of the Adamawa Plateau which is in between the Guineo-Congolian rain forest and Sudanian savanna in Central Cameroun from African Humid Period to the present day through the analysis of pollen and spores. They presented a 4000-yr old pollen sequence derived from the Lake Tizong sediments that extended from the end of the. Pollen sequence were distinguished into two major short-duration forested phases that lasted between ca. 3900–3000 yr. BP, and ca. 1900–1450 yr. BP. Within 4000–3000 yr. BP, arboreal/montane forest plants (*Podocarpus* sp. L'Her ex Pers., *Olea* sp. L., and *Rubus pinnatus* Willd.) dominated the vegetation, with associated semi-deciduous forest elements like *Celtis* sp. indicative of dry climate. A decrease in tree taxa was noticed and increase in freshwater forest taxa (Cyperaceae) around 3000–1900 yr. BP indicating a wet climate at that time with a slight increase in arboreal plants. From 1450 yr. till present savanna elements (e.g. *Hymenocardia* sp.) become more dominant. It was also found that a critical ecological threshold occurred around 3000 yr. BP when Poaceae reached higher percentages than forest taxa. Savanna was established until the present day with a brief expansion of lowland semi-deciduous forest, dominated by *Myrianthus arboreus* P.Beauv.-type pollen, between ca. 1000–700 cal. yr. BP. Although, human impacts and climatic factors driving vegetation change were difficult to differentiate, the late Holocene on the Adamawa plateau was characterised by a variable climate that resulted in significant vegetation transitions.

3.4 Honey, pollen and vegetation representation

Pollen analysis of honey samples started a long time ago dating back to late 1970 with Sowunmi [50] as foremost. Several reports are available on the melissopalynological analysis of honeys from different parts of Nigeria as reviewed as follows. One of the earliest studies was that of Agwu and Akanbi [51] in view to understanding the botanical origin of the honeys from Bichi, Edem-Ani, Nanka, Nimo Nsukka and Ogbomosho including Ohafia and Port Harcourt. They found out that 56 pollen types were identified in all belonging to 14 families, genera and tribes. Ogbomosho had the highest (29) number of pollen types. The study revealed that most of the honeys were rich in pollen apart from the Port-Harcourt and Ohafia honeys that were adulterated. The species that were dominant or most preferred by honeybees include *Vitellaria paradoxa, Lannea* sp. A. Rich. in Guillem, *Elaeis guineensis, Parkia clappertoniana* Keay, *Prosopis africana* (Gull. & Perr.) Taub., *Crossopteryx febrifuga* (Afzel. ex G. Don) Benth. and *Nicotiana tabacum* L. The vendors claim were verified as the pollen representation showed the vegetation where the honeys were produced. After this time, several others have been published.

Agwu *et al.* [52] analysed honey samples from four honey samples from different localities in Kogi State (Olowa, Ajogoni, Itama and Ojowu), Nigeria to determine their floral sources, ecological origin and season of production. Grains counts of 532, 589, 1033 and 720 were recovered respectively. Thirty-two pollen types encountered, 23 were identified to family level and two were unidentified. The predominant pollen types include those of *Acanthus* spp. L., *Alchornea cordifolia* (Schum. & Thonn.) Mull.Arg., *Anacardium occidentale* L., *Cassia mimosoides* L., *Elaeis guineensis*, *Hymenocardia acida* Tul., *Phyllanthus niruri* L., *Mangifera indica* L., *Tridax procumbens*, and *Zea mays* L. Results suggested vegetation types reflecting the lowland rainforest and secondary grassland and of quality. Kayode and Oyeyemi [53] undertook a study to determine the pollen quality of eight honey samples collected from Odigbo and Okitipupa areas of Ondo State, Nigeria. The result showed diverse pollen types that were visited by worker bees for their nectar and pollen source. The most frequently represented families were Fabaceae and Euphorbiaceae with 14 taxa and eleven taxa of pollen grains respectively. Some important plant taxa identified that are frequently visited by the bees include, *Lannae* sp., *Nauclea* sp. L., *Pericopsis* sp. Thwaites, *Lophira lanceolata* Tiegh. ex Keay, *Phyllanthus discoides* (Baill.) Mull.Arg, *Elaeis guineensis*, *Nauclea diderrichii* (De Wild. & T.Durand) Merr., *Brachystegia eurycoma* Harms and members of Combretaceae or Melastomataceae. These plants were found to be of great importance to the bees for honey production.

Melissopalynological analysis of four honey samples from four localities of Kogi State (Idah, Ajaka, Igalamela–Odolu and Inachalo-Oforachi) was carried out by Aina *et al.* [54] in a bid to ascertain the species of plants which were incorporated into honey. Pollen grain counts of 2274 to 3,195 were recorded. A total of 21 pollen types were recorded, 19 of which were identified to family level. Some predominant pollen types included *Leuceanea glauca* (Lam.) de Wit, *Parkia biglobosa*, *Elaeis guineensis*, *Phyllanthus* sp. and *Bombax buonopozense*. The four honey samples were found to be unadulterated and certified to be of quality. From the pollen identifications, the botanical and geographical origin as well as the season of honey production of each sample were determined and also associated with definite vegetation types which reflected the vegetation of low land rainforest/Guinea savanna.

Oyeyemi [55] collected three honey samples from an apiary for three months to determine the change in pollen content for the months of October to December in Ado Ekiti. The study revealed that pollen count ranged from 106,962 to 171,487. The honey samples were found to be multifloral in source and had abundant *Nauclea* sp., *Entada* sp. Adans., *Vitellaria paradoxa, Lannea* sp. members of the Rutaceae and Combretaceae or Melastomaceae which indicated that these plants were available at the locality where the apiary is situated to serve as pollen and nectar sources. Other pollen types encountered include *Vitex doniana*, Poaceae, and *Irvingia* sp. Hook.f. There was variation in the total pollen count for the months of sampling; however, the honeys indicated a high richness in pollen diversity and quality.

Adekanmbi and Ogundipe [56] analysed three honey samples bought from open markets in Lagos, Nigeria. The proportion of pollen from each of the honey samples varied from 196 to 280. The most abundant taxa were *Tridax procumbens* and *Elaeis guineensis.* The pollen grains in the Palmae and Asteraceae plant families are of great importance to the bees for honey production; this can be seen in the abundance displayed. Other pollen taxa recovered belong to the families Mimosaceae, Euphorbiaceae, Sapotaceae and Anacardiaceae providing clue on the ecological origin of the pollen grains in the honey sample. Pollen analysis of honey proved to be useful in deciphering nectar sources of honeybee *Apis mellifera adansonii* Latreille.

4. Conclusion

The genetically conscripted chemical signature called sporopollenin in the outer cell walls enhances the ability of palynomorphs to retain their shapes even after subjection to heat and pressure in sediment treatment with concentrated acid during routine palynological procedures. This enables clear identification of pollen types and in extension the vegetation dynamics. The identification of pollen flora in honey is currently been considered as good means of understanding economically and traditionally important plants for conservation and reforestation. The daily dispersal of pollen (including the allergenic ones) in the atmosphere sheds light on the seasonally of vegetation, their flowering, productivity of pollen and contamination of atmospheric quality. Studying cores from lakes, rivers and soil profiles provides evidence for the change in vegetation in relation to climate, plant response to stress and human interference in the past. This is applied based to vegetation science by virtue of the percentage representation pattern of palynomorphs. Although caution must be exercised in interpreting palynological data due to the moderating factors like differential preservation of pollen grains based inertness of the chemical compound in its outer wall, limited knowledge on pollen productivity of flowering plants, dispersal mechanisms which affects the quantity of grains recovered from soil and honey or atmospheric samples, issues of pollen morphological similarities. Describing and attributing vegetation characteristics to a locality or region, the modern behaviour of plants is to be considered.

Acknowledgements

The author's special appreciation goes to Prof (Canon) M. Adebisi Sowunmi for laying the academic foundation for the understanding of palynology. Her academic, career-based and motherly advices were so helpful and she is so highly appreciated. Her contributions were highly transformative. The author is also grateful to Dr. E.A. Orijemie and Mr. P.C. Opara for their support, encouragement and support. To my parents Mr. and Mrs. Austin O. Kobi, I express my gratitude for the prayers and financial support.

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