MELLIFEROUS TAXA, FLORAL CALENDAR, MELISSOPALYNOLOGY, AND ORGANOLEPTIC CHARACTERIZATION OF ABORIGINAL OGIEK HONEY IN THE EASTERN MAU FOREST BLOCK, KENYA

BY

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DECLARATION

I certify that this thesis is my original work and has not been previously submitted for a degree in any other University

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DEDICATION

This work is dedicated to my family for having been supportive towards my academic pursuits.

ABSTRACT

Mau forest is one of the five water towers in Kenya serving as a critical catchment area for rivers and lakes in both Kenya and Tanzania. It plays a critical role in livelihood support. Eastern Mau forest has experienced most of the deforestation, loss of ecosystem vitality and biodiversity due to non-inclusion of local community in the conservation efforts. The Kenyan government legislative and policy frameworks have acknowledged the need for involvement of the Ogiek community. The community have long lived in the forest and area knowledgeable in forest conservation and bee keeping. Beekeeping by the Ogieks has been recommended under livelihood support programs to reduce destructive forest exploitation, this is by lack of information on: the authenticity of botanical and geographical origin of the Ogiek honeys, floral calendars to enhance apiary management and, organoleptic profile to enable sale in regulated honey markets. The objective of this study was to characterize melliferous flora, the botanical and geographical origin of Ogiek honeys and their organoleptic profile. A simple stratified random sampling research design was adopted with Kapkembu, Nessuit, and Mariashoni areas, Eastern Mau as the strata. The Ogiek bee keepers' hives were the source of honey samples. Ten grams of each of the twenty seven honey samples collected from Eastern Mau forest formed the unit of analysis. Approved methods of honey analysis were used. Collection of field data for development of floral calendar adopted belt transects around selected bee colonies for twelve months. Data was subjected to Analysis of Variance, Tukeys honestly significant difference post-hoc test, multivariate analysis, Jaccards similarity coefficient, quantitative descriptive analysis, and two-step cluster algorithms on SPSS base 20. Means of organoleptic data was subjected to Friedman's test. Total of eighty six plant species are foraged by *Apis mellifera*. *Cissus rotundiflora* Vahl. (Vitaceae), *Trema orientalis*L. (Ulmaceae), *Maerua triphylla*A. Rich (Capparaceae), *Aloe secundiflora* Engl. (Asphodelaceae), *Tribulis terrestis*L. (Zygophyllaceae) and *Polyscias fulva*J.R. Forst. and G. Forst. (Araliaceae) are reported for the first time in Eastern Mau. Trees formed 41.86%, Herbs (25.58%), Shrubs (23.25%), and climbers (9.3%) of the bee forage. The peak availability of forage from the floral calendar was in April and May (2016) during the study. The *Acacia* species provide successive bloom mosaic year round. The highest similarity was observed in a comparison between (NE-S3-8) and NE-S1-8) within same site. The mean number of pollen types were highest in April (12.8), and lowest in December (9.7). There is a significant positive correlation (r=0.607*, 0.05) between number of pollen types and pollen density. Mean Shannon weaver diversity index was 2.32 across all seasons and sites of sample collection. *Vernonia auriculifera, Cordia abyssinica, Acacia* spp were very frequent pollen types, with *Acacia* type pollen having 85.2% frequency of occurrence in the honey samples. The rare, infrequent, frequent, very frequent pollen types observed in this study constitute the pollen spectrum that determine the geographical origin of Ogiek honeys in Eastern Mau forest. Botanical origin from predominant pollen types were *Acacia spp type, Eucalyptus type, Croton spp. type, Albizia coriaria type, Cordia abyssinica type, and Vernonia auriculifera type.* Floral fresh aroma family was the most dominant in 50% of the unifloral honey samples represented by *Acacia*, *Croton* and *Albizia* honey. Friedman's test (N=12, df=7, X^2 =14.07, Least Significant Difference= 23.52) revealed a significant difference in the sum of rankings in all organoleptic attributes. This study provides significant information on the floral calendar, unifloral and multifloral botanical origin as well as pollen spectrum denoting the geographical origin, and an organoleptic profile of unifloral Ogiek produced honeys Eastern Mau. The information from this study is important for extension services and policy development.

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LIST OF ABBREVIATIONS

ANOVA	Analysis of variance
AOAC	Association of official analytical chemists
CNS	Central nervous system
COMESA	Common market for East and Central Africa
DN	Diastase number
EC	European commission
FAO	Food and agricultural organization
GC	Gas chromatography
GEF	Global environmental fund
GPS	Global positioning system
HDE	Honey dew elements
HDE/P	Ratio of honey dew element to pollen
HPLC	High pressure liquid chromatography
IBM	International Bureau of machines
ICBB	International Commission of bee botany
ICS	Interim coordinating secretariat
IHC	International honey commission
IIN	Indigenous information network
ISO	International standards organization
KFS	Kenya forest service
KOH	Potassium hydroxide
NAOH	Sodium Hydroxide

NECOFA	Network for Ecological farming in Africa
NEMA	National Environment Management Authority
NHB	National Honey board
pH	Potential hydrogen
QDA	Quantitative Descriptive Analysis
REDD	Reduced emission from deforestation and forest degradation
SPSS	Statistical package for social scientists
SRSS	Simple random stratified sampling
UN	United Nations
UNDP	United Nations Development Program
UNEP	United Nations Environmental Program
WHO	World health organization

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Mau forest complex's biodiversity is under threat as evidenced in Sierra Leone area of Western Mau and Eastern Mau degradations (ICS, 2009). These threatened areas provide an upper catchment for source of environmental services including: rain flow regulation, flood mitigation, water storage and purification, ground water recharge, soil erosion control, reduced siltation , protection of biodiversity, carbon sequestration, and regulation of microclimate which provides favorable conditions for crop production (ICS, 2009; UNEP *et al.*, 2006).

The Mau forest complex is the largest indigenous afromontane close canopy forest in East Africa, made of seven forest blocks and transcending large parts of central rift valley. The value of goods and services from Mau forest complex is about 20 billion dollars, not including its vital social-economic contribution, support for rural livelihoods as well as potential economic activities in the energy sectors. The Mau forest complex is a critical catchment area for lakes and rivers in Kenya and Tanzania and is key in the attainment of food self-sufficiency and poverty alleviation in the lake basin region. It is biodiversity rich and has many other optional values yet to be identified (Sang, 2002).

The high deforestation rate of 25%-40% in the last decade has led to the loss of health and vitality of the forest ecosystem, change in the composition of tree species, loss of biodiversity and reduction in crown cover (NEMA, 2013). This threatens up to 5 million livelihoods as well as other ecological services. Easter Mau forest block has experienced the highest forest excisions of up to 54.3%. Much of the forest degradations have been attributed to the forest dwellers and forest adjacent communities living in 5 km radius of the forest edges as well as lack of involvement of the local community in the management of the Eastern Mau forest

block. This has put pressure on the indigenous forest species (Okemwa, 2014). Insufficient incentives for forest conservation as well as market failures coupled with underpriced forest goods and services has made Mau forest conservation less competitive than other land uses by the local communities (Langat and Cheboiwo, 2010).

There is need to deal with environmental degradation issues, not through the traditional approach but rather with contemporary strategies (Ochola *et al.,* 2010). Currently the action plans, legislative and strategic interventions, and other policy frameworks developed by the Kenyan government (ICS, 2009; Kenya Forest Act, 2005) have adopted a stakeholder centered forest management approach that embraces community participation, livelihood support and incentivisation as practices that are compatible with forest resource conservation. Establishment of markets for forest products is an economic incentive aimed at increasing forest production and reducing pressure on the forest. This approach fosters a better acceptance and participation. Ethnobotanical conservation of plant species is increasingly being recognized as crucial for sustainable diversity development (Barbara and Jurgen, 2009). This is exemplified by rehabilitation programs in the Sururu forest stations and in East Mau undertaken by NECOFA (NECOFA, 2013), UNDP-GEF, as well as 'Zuia Ndovu Na Casurina' project in Kwale, Kenya as well as in Nyika National Park, Malawi. Honey production is one of the forest activities that are aimed at in the livelihood support programs (AGROMISA, 2009; Suresh *et al*., 2009).

The Kenyan government has incorporated the Ogiek in the rehabilitation programs of the forest areas. The Ogiek have lived in Mau forest for hundreds of years and are the aboriginal East Africans as there are no records showing their coming from elsewhere, and have traditionally occupied Eastern Mau. Their main activity is bee keeping (Sang, 2002). They have deep knowledge in bee keeping and have yearly calendars of bee activities in eastern

Mau. Their beekeeping activities are limited to production and positioning of hives on specific trees. Honey production is the driving force behind bee keeping (Alaazi *et al*, 2010). Honey is one of most important commodities in Ogiek culture and there has been a 40% reliance on honey production in Eastern Mau (Kipkoech *etal*, 2011). Honey production is sustainable for the communities that live close to or in forests, and is able to contribute to food security, poverty alleviation, environmental conservation, health improvement and equity which are essential to attaining national development and millennium development goals (Bradbear, 2009). The ancient Ogiek honey production culture, as well as their ability to conserve *Dombeya goetzenii* K. Schum, *Olea europaea* L. and *Olea hochstetteri* Baker for honey production shows their ability to sustainably exploit the Mau forest ecosystem (Obare and Wangwe, 1998).

The use of honey production and its successful commercialization is compatible with forest conservation. This depends on the enabling conditions like markets for the honey (Sunderlin *et al*, 2005), sufficient information to support honey production, and enhanced product quality (Barbara and Jurgen, 2009). Although Ogiek honey is arguably of the best quality in Kenya, this purported characteristic has not been verified (Alaazi *et al*, 2010). The production of honey for commercial or consumption purposes remains relatively low, yet there is potential in local and international markets (NECOFA, 2013). Other problems facing the incorporation of Ogiek honey enterprise in Mau forest conservation include: lack of information to aid in the prospection for sustainably produced varietal and specialty honeys; lack of floral calendar and documentation of bee flora for apicultural management, lack of classification and profiling of the various honey types and grades to explore more profitable, lack of regulatory frameworks and evaluation of Ogiek honey quality against the international standards. The Ogiek honey production is also affected by lacking an entrepreneurial

approach to bee keeping, honey production and marketing, as well as degradation of habitats (Alaazi *et al*, 2010; Macqueen *et al*, 2014).

The enhancement of Ogiek honey quality, authenticity and production of competitive honey brands in the available local and international markets requires an extensive honey analysis, organoleptic characterization as well as an evaluation against the Standards (*Codex Alimentarus* standard, 2001; Council directive, 110/2001/EC; COMESA/FDHS 002:2004 standards and Kenya Food, drugs and chemical subsidiary legislation Cap 254, part VII) Ogiek honey is necessary. The aforementioned honey standards rely on precise techniques with minimal subjectivity, and approved sampling designs. Melissopalynology studies pollen in honey and is able to reveal information applicable in bee forage conservation, authentication, and labeling of honey. Melissopalynology is useful in the identification of specialty honeys which have premium value and hence increased market share that eventually offers higher return to the beekeepers and consequently incentivize beekeeping. Whereas sensory analysis on the other hand evaluates attributes perceptible by the color, odor, taste, touch and noise (organoleptic characteristics) (Ciappini *et al*, 2013; Piana *et al*, 2004), physico-chemical analysis is concerned with both the physical and chemical aspects of honey (Tchoumboue *et al*., 2007).

Mellissopalynological, physicochemical and organoleptic characterization complements each other in honey quality determination and are essential for honey commercialization. They limit fraud and enable fixing of honey to predefined standard. Melissopalynology when combined with other disciplines in botany like phenology is an essential tool for the development of botanical maps and floral calendars that provide timetables that indicate to the bee keeper the approximate date and duration of the blossoming periods of important nectar and pollen plants (Haftom *et al*, 2013).

Like all other investigations of biological phenomena, this study intends to reduce bias and improve data reliability. The scope of this work is limited to the parameters referred to in the honey quality standards, honey produced by the Ogiek beekeepers during three seasons of the year in Eastern Mau, and analyzed using methodology approved by the Codex *Alimentarus*, 2001; Council directive, 110/2001/EU; ISO 8586-1, 1993; ISO 8586-2; ISO 6658, ISO 8589; 2007, and COMESA 002:2004 standards.

1.2 Problem Statement

Although the Mau Forest Complex Report (2009) has recommended synergy between traditional and scientific knowledge in forest management, conservation of threatened species, as well as participatory forest management to enhance livelihood of the local communities e.g. the Ogieks, Beekeeper Ogieks in Eastern Mau lack the full inventory of melliferous species for purposes of synergizing traditional and scientific knowledge for successful forest management, extensional , technological support (Vlek *et al*., 2014).

Sustainable beekeeping requires a thorough understanding of the flowering period of most of the resourceful plants. Although the flowering periods of various bee plants are extracted in floral calendars, this information has not been documented in the past for reference to complement the Ogiek knowledge of favorite bee forage. This limits capacity building on bee flora by extension workers and precise planning of apicultural activities. There are no records of length of flowering periods for the bee flora, number of flowering plants per month/season and the percentage availability of the biological flora types in dearth and honey flow seasons.

Ogiek honeys are arguably of the best quality as most of the honey in Kenyan market is adulterated (Hansard, 2016). The compositional criteria as well as labelling, description and definition of honey is described by Codex (2001). The declaration of geographical origin of honey limits honey fraud (Louveaux *et al*., 1978). Most trade requirements include labelling

of honey before its sold (Bryant, 2001). A complete pollen spectrum and geographical origin to facilitate the necessary labeling Ogiek honey hasn't determined. In such circumstances the Ogiek honey are vulnerable to mislabeling and honey fraud.

Ogiek, and Africa honey sold as generic blend is unlikely to compete with honey from major exporting countries like China and Argentina (Stubbs, 2011). Honey marketed as specialty honeys which could be unifloral or sustainably produced gives better returns as to incentivize conservation efforts (Stubbs, 2011). The Ogiek honey though has potential for better markets and trade, the prospects and presence for unifloral specialty honeys have not been mellissopalynologically determined (Stubbs, 2011).

Although the Ogiek have attempted to relate various honey produced to their floral sources based on color and taste (Micheli, 2008) there hasn't been a complete algorithmic and objective organoleptic profiling of various Ogiek honeys. There is therefore the risk of developing honey groups that aren't diagnosable of their season or geographical, botanical nor geographical origin. Without the evaluation against standards it's not feasible to suggest remedial measures for any noncompliance.

1.3 Justification

A full inventory of melliferous taxa shall provide information for successful forest management, extensional, technological support for purposes of synergizing traditional and scientific knowledge in beekeeping, forest management, and conservation of threatened species.

Sustainable beekeeping requires a thorough understanding of the flowering period of most of the resourceful plants. Flowering periods of various bee plants in Eastern Mau shall be provided in a floral calendar. This information, which has not been documented in the past shall be available for reference to complement the Ogiek knowledge of favorite bee forage.

The floral calendar shall also enhance capacity building on bee flora by extension workers and precise planning of apicultural activities.

Ogiek honeys are arguably of the best quality as most of the honey in Kenyan market is adulterated. The determination and subsequent declaration of geographical origin of Ogiek honey shall limit honey fraud through mislabeling. A complete pollen spectrum and geographical origin to facilitate the necessary labeling Ogiek honey.

The mellissopalynologically determination of Botanical origin of Ogiek honey shall discover various specialty honeys, which unlike other Africa honey sold as generic blend, the specialty honey shall compete with honey from other regions nationally and internationally and provide better returns and incentives to Ogiek bee keepers. Honey marketed as specialty honeys which could be unifloral or sustainably produced gives better returns as to incentivize conservation efforts.

In the past the Ogiek have attempted to relate various honey produced to their floral sources based on color and taste. This study provides a complete algorithmic and objective organoleptic profiling of various Ogiek honeys. This shall facilitate the development of Ogiek honey groups or classes diagnosable of their season of harvest, as well as botanical and, geographical origin. With the availability of organoleptic profile, there are opportunities for suggesting remedial measures against any noncompliance.

1.4. Objectives

1.4.1 General Objective:

The general objective of this study is to characterize the melliferous taxa, melissopalynological and organoleptic attributes of Ogiek honey in Eastern Mau forest.

1.4.2 Specific Objectives:

(i) To determine the melliferous taxa in Eastern Mau forest.

(ii) To determine the seasonal availability and develop floral calendar for Eastern Mau melliferous taxa.

(iii) To determine the mellissopalynological geographical origin of Ogiek honey in Eastern Mau forest.

(iv) To determine the melisopalynological Botanical origin of various honey types produced by the Ogiek bee keepers in Eastern Mau.

(v) To establish the organoleptic profiles of the Ogiek honeys in the Eastern Mau forest and its compliance with honey standards.

1.5. Research Questions

(i) Which plant families and species are forage by *Apis mellifera* as source of pollen, nectar or both pollen and nectar in Mariashoni, Nessuit and Kapkembu mesoregions of Eastern Mau?

(ii) During which periods of the year are these apiflora in bloom and available as *Apis mellifera* forage?

(iii) Which pollen types form a spectrum to determine the Geographical origin of Ogiek honey in Eastern Mau?

(iv) Are the Ogiek honeys predominantly from single plants (unifloral) or various plant sources (Multifloral)?

(v) What are the organoleptic characteristics of Ogiek honey from Eastern Mau?

CHAPTER TWO

LITERATURE REVIEW

2.1 Mau Forest Complex

2.1.1 Economic Value

Mau forest complex is the largest remaining near continuous montane and indigenous forest in East Africa. The Eastern and Western Mau forests blocks are the largest of the 8 forest blocks that form the Mau forest complex. All the forest blocks are run by KFS except for the Maasai Mau which is a trust land run by the Narok county council (Akotsi *et al*., 2006).

The market value of the goods and services from the Mau forest complex blocks is about Kshs 20 billion, excluding other vital socio economic contribution to the rural urban economies, rural livelihoods, and potential activities in the energy sector (Dodo *et al*., 2006; ICS, 2009). The Mau forest complex is important for the attainment of food self-sufficiency and poverty alleviation in the Lake basin region, and about 5million people depend on it both directly and indirectly. The Eastern and the South Western Mau provide the upper catchments for river flow regulation, flood mitigation, water storage, water purification, recharge of ground water, reduction of soil erosion and siltation, protection of biodiversity and carbon sequestration, (ICS, 2009; UNEP *et al*., 2006). The destruction of the Mau forest has caused irregular river flows, threatened the Maasai Marariver dependent ecosystems, and reduced the capacity of the Sondu Miriu Hydroelectric power plant (ICS, 2009). Mau forest complex is an important bird area and has naturally occurring flora and fauna with option values possibly of higher economic premium e.g. collaborative bioprospecting arrangements regarding the search for naturally occurring biochemicals with commercial value (Kipkoech *et al*, 2011). The Mau forest is extremely rich in biodiversity; there is need for documentation of the Ogiek utilization and systems of coexistence with the forest and nature for decades (Lambrechts *et al*, 2005; NEMA, 2013).

2.1.2 Conservation Status and Efforts

The Mau forest complex is under severe threat of degradation from the forest dwellers and adjacent communities at a 5km radius of the forest boundary (Okemwa, 2014). The degradation is also caused by low forest management capacity, increased population pressure as well as non-involvement of the communities along the Eastern Mau. These factors have been implicated for the loss of ecological services, depletion of wildlife habitat, and decline in the indigenous forest species (Okemwa, 2014). There are legislative and forest policy frameworks including the Kenya forest Act (2005) developed from the Kenya Forest Master plan 1995-2020 as well as the ongoing repossession of the forest areas aimed at the conservation of the Mau forest. Stakeholder forest management approach is now being embraced through the sustainable livelihood and rural development programs (Olang and Kundu, 2001).

Provision of incentives to the local people to adopt best land use has also been recommended. Mau interim coordinating committee has made efforts to work with the Ogieks in the rehabilitation of the Mau forest (ICS, 2009) while Income enhancement projects alongside forest conservation are being adopted by Ministry of Agriculture (IIN, 2013).

2.2 Ogiek

2.2.1 History of the Ogieks

The Ogiek are among the last remaining forest dwellers in Kenya found mainly in the Mau forest and around Mount Elgon. They have lived in the forest for over 100 years. They are the original inhabitants of central Rift valley believed to be the aboriginal East Africans because there is no evidence of them coming from elsewhere (Carrol, 2006). The Ogieks are contemptuously referred to as the “Dorobo” by the Maasai which means poor people who cannot afford cattle and live on hunting. The Ogieks in Kenya have maintained the original cultural traits of the original Ogiek hunter gatherers living in the Mau forest. There are four

main clans of the Ogiek: the Tyepkwererek found in the forest of South Eastern Mau forest from Lake Nakuru. The Moriosonik, Kipchorngwonek, and the Ogiek Optinet found in the Southern part (Micheli, 2008).The Ogiek are found mainly in Nakuru, Narok, and Uasin Gishu counties and are spread in Eastern Mau, Western Mau and Maasai Mau forest blocks (Carrol, 2006).

2.2.2 Honey Production and Conservation by the Ogieks

The Ogiek are highly adapted to the life in the Mau forest. They are knowledgeable environmentalists. Their guidance affirms their moral responsibility of the community to the physical and spiritual laws of nature (Obare and Wagnwe, 1998). Dens of trees in which the tree hyrax reside are sacred to the Ogieks. *Dombeya goetzenii*, *Olea euro*, and *Olea hochstetteri* are some of the tree species used as sources of honey and herbs. Community members are prohibited from cutting these trees. The Ogiek are capable of being totally self-sufficient on the natural products of the forest (Barbara and Jurgen, 2009).

Bee keeping is the main economic activity of the Ogiek. The Ogiek have a honey complex with honey being the most important commodity in their culture. Beekeeping in the Ogiek is limited to positioning of hives on specific trees in the forest and following the natural cycles of the bees and flowers during honey production. The Ogiek distinguish at least eight different kinds of honey depending on the flowers and trees from which the bees collect pollen. The Ogieks have developed a very deep knowledge on of bees and have typical calendars of bee activities. The end of January to March are months of richest harvesting, while in September to October there is average production of honey. This calendar correspond so well with other data present (Carrol, 2006) about the honey harvesting seasons in different regions of the Mau forest (Micheli, 2008).

2.3 *Apis mellifera* Races

The *Apis mellifera* belongs to the subfamily Apinae whose members produce more honey than they consume. They are therefore worthwhile to keep for honey production. There are about ten geographical races of *Apis mellifera* in Africa. Recent reviews show 22 honey bees of the *Apismellifera* worldwide and 10 geographical races in Africa, having specific behavior and morphological characteristics. Different parts of the world adopt different subspecies of *Apis* as those utilizable in the apiaries. *Apis mellifera* is of greatest economic importance. The two dominant *Apis* races are the *A.m.scutelleta* in East Africa from Ethiopia to Southern Africa and *A.m. adansonii* which is predominant in West Africa. Honey bee races in Kenya are *A.m. scutelleta*, *A.m.momnticola*, *A.m.litorea*, and *A.m.nubica* (Raina and Kimbu, 2005)

2.3.1 Foraging Requirements of *Apis mellifera*

The honey bee requires water, resin, nectar, and pollen. The pollen is for growth of the larvae and young adults (Ramesh and Tanya, 2007). Pollen is a major source of protein, fatty substances, minerals, and vitamins and contains 16-40% of all known amino acids (Brodschneider and Crailsheim, 2010). Nectar is major source of carbohydrates and aqueous secretions of sugars. Nectar is obtained from flowers, extra floral nectarines or excretions secreted by plant sucking insects such as Aphids. The honeybee collects water for cooling the hive and dilution of the honey fed to the larvae (Huang, 2010; Pamminger *et al*., 2019).

The *Apis mellifera* colony consists of pollen, nectar, and water foragers. The food quality, weather, and distance determine their foraging behavior. Foraging requires energy and the honeybee considers the net gain of food to the colony. The bees are known to have a foraging range of up to 12 km. Foraging is usually limited to food sources within 3 km range of the hive, with 75% of bees from colony foraging within 1km. Foraging range is also influenced by the race and by the pollen and nectar load. During dearth most tropical bees will go beyond a given distance or elevation. *Apis mellifera* is polylectic as it collects diversity of

pollen for its consumption (Steffan-Dewenter and Kuhn, 2003). This buffers them against nutrient deficiency. Bees tend to practice fidelity by limiting themselves to single species of plant during each visit. Location of pollen and nectar sources is done by social bees as well as foraging bees. Solitary foragers have a regular pattern of visitation unlike the communal foragers. Nectar is generally collected at minimum temperature of 12-14^{0}C. There is no foraging at 8^{0}C, some foraging at 8-16^{0}C; optimal foraging at 16-32^{0}C, and at temperatures above 32^{0}C there is reduction in foraging (British Columbia apiculture fact sheet, 2014; National Honey Board, 2013).

Bee foraging species have been classified according to their main food reward (nectar, pollen or both), qualitative observations of the pollinator behavior, the main flowering season, flower morphology, number of flowers per plant and nectar standing. Bee foragers show innate preferences for certain floral characteristics (Akratanakul, 1990). Some *Helikonia* and *Spathodea* species have toxic pollen while others like *Prunus* have feeding deterrents. The determination of the pollen or nectar visits could be done through observing pollen pellets attached to the bee hind legs, extension of the proboscis to obtain nectar or squeezing the abdomen of the bee to obtain a drop of regurgitated nectar. A sweet taste indicates nectar visit. A single colony can visit different forage. Other sources of information on pollen or nectar visit can be obtained through questionnaire from local bee keepers, published flora, or botanical literature (Hausser, 2002). There are four periods in a colony life cycle: the dearth period, the buildup, the honey flow, and the harvesting season. During dearth there is no much nectar, during build- up there is much forage and the colony expands. Honey flow period is characterized by abundant flowering, nectar production, and increase in hive or colony weight. Most of the plants end of flowering coincide when honey is ready for harvesting (Kajobe *et al*, 2009).

2.4. Melliferous Taxa

The production of honey depends on the abundance of nectaferous plants within easy flight range of the bee colony. After studies on the patterns of nectaferous plant diversity, Awka and Agulu areas in South East Nigeria have been indicated as potential sites for apiculture as a cottage industry and recommended conservation of the nectaferous plants, demarcation and safeguarding of Agulu lake areas as 'bee sanctuaries for Honeybees' (Akunne *et al*., 2016). The knowledge of plants visited by bees is essential in guiding prospective beekeepers in the choice of suitable sites for locating apiaries. It is also essential in the identification of crops that may benefit from pollination by honeybees (Pamminger *et al*., 2019; Dukku, 2013). There are three types of bee flora: plants that only supply nectar, plants that only supply pollen, and plants that provide both (Waykar *et al*., 2014).The identification and registration of honeybee flora in different agroeceological zones and their potential for honey production in an apiary is important for successful honey production to enable beekeepers determine when to carry out various management practices with their colonies. The awareness to maintain the existing bee flora and multiplication of plant species is important for its sustainability (Wubie *et al*., 2014; Coh-Martinez *et al*., 2019). Some of the bee forage lists are based on anecdotal information and generally lack a firm evidence base (Hawkins *et al*., 2015).

2.5 Floral Calendar

A floral calendar is a timetable that indicates to the beekeeper the approximate date and blossoming periods of important honey and pollen plants (Haftom *et al*, 2013). Although the availability of ample bee forage can be determined by observation; hive reserves, forager loads, and pollen residues in the honey samples do give precise record of the bee plants. The assembling of floral calendar and weighing of the hive to monitor the weight changes in bee colony accurately determines the suitability and supporting capacity of an area. Floral

calendar is one of the most important tools of apiculture for an extension worker. It enables him to inform the beekeepers of what to expect on bee forage as well as how to plan the harvesting and colony swarming. Some floral calendars are available in digital versions, and take form of circular charts. Floral calendars of different ecoregions are important bee keeping resources that are still missing. The principle of the construction of the floral calendar involves knowing the area, the plants bee like and their flowering period (Onyango *et al*., 2019). Accuracy of calendar and hence its practical value depends solely on careful recording beginning and end of flowering season of melliferous plant species. The flowering time of a plant species begins from the full opening of the buds till the start of the fruit formation end of flowering. The distribution and type of honey plants as well as their flowering duration varies from one place to another due to topography, climate, and farming practices. Beekeeping cannot develop without an understanding of floral calendar (Akratanakul, 1990).

2.6 Seasonality of Bee Flora

Every region has its own honey flow and floral dearth periods of short and long duration. Such knowledge of bee flora help in the effective management of bee colonies during such periods. Sound information on duration and blooming time is essential for proper beekeeping management. The existence of knowledge on type, density and quality of bee flora in a region are prerequisites for enhancing the efficiency of beekeeping industry and successful beekeeping. Such information enables the beekeepers to utilize bee flora and manage bee colonies effectively (Kumar *et al.*, 2013) it guides prospective beekeepers in the choice of suitable sites for locating apiaries, and identification of crops that may benefit from pollination by honeybees (Dukku , 2013).

For a full understanding of the potential of beekeeping as a sustainable livelihood for the local people, knowledge about flowering phenology of plants and trees potentially foraged by

the bees is indispensable. The honeybee plants provide pollen and nectar as main food sources for honeybees, on the other hand flowering plants depend on bees for pollination and subsequent sexual reproduction. This mutual interaction is particularly important in tropical ecosystems. Success in beekeeping is development is dependent first and foremost on the type and quantity of flora available (Admasu, 2007). The identification and registration of honeybee flora in different agroeceological zones and their potential for honey production creates awareness in the maintenance of existing bee flora and multiplication of plant species is important for its sustainability (Wubie *et al.*, 2014). Flowering sequence can be anticipated and hives moved about, where possible, to exploit nectar flows. The floral calendar of an area however usually varies from year to year since flowering depends on the weather. It serves the most useful purpose of showing the sequence of flowering of various plants in a given area thereby helping to identify the main flowering and dearth periods so that eventually suitable plants could be grown to bridge flowering gaps (Kumar *et al*., 2013).

2.7 Honey

2.7.1 Definition

Honey is the natural sweet substance produced by *Apis mellifera* bees from the nectar of plants or from secretions of living parts of plants or excretions of plant-sucking insects on the living parts of plants, which the bees collect, transform by combining with specific substances of their own, deposit, dehydrate, store and leave in honeycombs to ripen and mature (Council Directive 110/2001; *CodexAlimentarus*, 2001).

According to Foods Drug and chemicals act, Cap 254 part VII (Laws of Kenya, 2004), honey is described as food derived solely from nectar of flowers and other sweet excretions of plants. COMESA 002 (2004) has defined honey as it is in the *Codex Alimentarus*, 2001. The definition of honey by *Codex Alimentarus*, 2001 and COMESA 002 (2004) is correct as different honeys are offered in the market including the *Apis cerana* honey.

2.7.2 Constituents of Honey

Honey consists of a mixture of sugars, mostly glucose and fructose (White, 1975). In addition to water (usually 17-20%), honey also contains very small amounts of minerals, vitamins, proteins, and amino acids. Pollen is a minor, but important component of most honey. Although pollen is carried into the bees' nest (hive) and stored separately from nectar, a few pollen grains find their way into nectar, and eventually into honey. The pollen in honey can be identified using a microscope to give a guide to the plants from which bees collected nectar and pollen. The 'ash' content of honey is mainly mineral trace elements. Minerals present are calcium, copper, iron, magnesium, manganese, potassium, sodium, and chlorides, phosphates, silicates and sulphates. Dark honeys are often very rich in minerals, but variation in the mineral content of different honeys is great. These trace amounts of minerals may be important for human nutrition (Bradbear, 2009).

2.7.3 Categories of Honey

Blossom honey comes from plant nectar; is also referred to as nectar honey. Honeydew Honey is obtained mainly from excretions of plant sucking insects (*Hemiptera*) on the living parts of plants or from secretions of living parts of plants. Monofloral honeyresults from bees foraging predominantly on one type of plant, and is named according to that plant. Common monofloral honey types are clover, *Acacia*, and sunflower honey. Monofloral honey is priced more highly than polyfloral honey (Onyango *et al*., 2019). Light, monofloral honeys like orange blossom or *Acacia* always obtain higher prices than blends of honeys because they look so attractive. Multifloral honey (also known as polyfloral) has several botanical sources, none of which is predominant, for example, meadow blossom honey, and forest honey (*Codex Alimentarus*, 2001; COMESA/FDHS 002, 2004).

Honey may also be categorized according to means of processing; Comb honeys *are* pieces of honeycomb that have not been processed to separate the honey from the beeswax. The

beeswax comb, as well as the honey, is edible. Comb honey always fetches a very good price, as the consumer can be sure that the honey has not been contaminated in any way. Strained honeyis honey obtained by straining honeycombs, to separate the honey from the beeswax. Chunk honeyis a jar of liquid honey with a piece of comb honey placed in it. It is important that the liquid honey is very light and clear, and will not granulate over a long period (*Codex Alimentarus*, 2001; COMESA 002, 2004). Honeys from *Acacia* and *Robinia pseudoacacia* are often used for this. This type of product depends on the type of honey and excellent packaging, and can achieve a very good price. Extracted honeyis honey obtained by centrifuging honeycombs. Pressed honeyis extracted by pressing honeycombs with or without the application of moderate heat. Crystallized or granulated honeyis strained honey that has crystallized. Creamed honeyis strained honey that has been seeded to start crystallization and then stirred to produce a honey of uniform, soft consistency (*Codex Alimentarus*, 2001; COMESA 002, 2004). Honey may be categorized according to intended use (trade categories): Table honeyis honey intended for consumers, to be eaten directly or as a natural sweetener for drinks or in cooking. Industrial or bakers' honeyis honey that does not meet fully all the criteria for table honey, for example, the hydroxymethylfurfural (HMF) content may be higher than 40 mg/kg, In this case, it still qualifies for use in the food industry, for the manufacture of bakery goods, confectionery, breakfast cereals, sauces, tobacco, and products such as honey-roasted nuts and pharmaceutical products (*Codex Alimentarius*, 2001, Bradbear, 2009).

2.7.4 The Value of Honey

Honey is a useful source of high-carbohydrate food, and usually contains a rich diversity of minor constituents (minerals, proteins, vitamins and others), adding nutritional variety to human diets. In many countries, honey is regarded more as a medicine or special tonic, rather than as an every-day food. Honey have medicinal properties that are acknowledged

increasingly by modern medicine. It is widely used as a source of sugars for making honey wines and beers, and in the manufacture of many secondary products like breakfast cereals, bakery goods, and a range of value-added products (Bradbear, 2009).

2.7.5 Role of Honey Production and Bee Keeping

Beekeeping is the management of the honey bee so as to take advantage of the adult foraging. Honey production is the driving force behind bee keeping (Alaazi *et al*, 2010). Beekeeping sustains natural resources and practiced by communities as a source of income and livelihood due to its low startup costs (Bradbear, 2009; Wilfredo *et al*., 2010). Overexploitation of the forest is driven by extreme poverty of forest neighboring communities. Conservation programs through beekeeping extend benefits to communities and enable their entry into the mainstream economies. Involvement of communities through beekeeping a stakeholder centered forest management fosters acceptance and participation compared to the top down approach that has been practiced in the past (Barbara and Jurgen, 2009). To ensure beekeeping benefits the community and subsequently forest conservation, an enhanced product quality and efficient market linkages to incentivize participating communities is necessary. Most angiosperms rely on bees for pollination. The lack of bees as pollinators has been implicated for the decline in production in the Brazilian nuts (*Bertholletiaexcelsa* Bonpl. (Hausser, 2002). While pollinating the forests bees participate in food production and sustenance of the forest ecosystems (Bradbear, 2009; Alfredo *et al*., 2019). Honey production have been used to conserve Black mangrove (*Avicenniagerminans)* (L) L. threatened by man (Burgett, 2000). Bees also improve the quality and quantity of crop and seed yield (Klatt *et al*, 2014). In Nyika national park, Malawi, beekeeping in bee reserves has enabled additional security to departmental staff against the poachers. The Inyonga forest in Tanzania has been one of the least disturbed forests due to the incorporation of bee keeping programs (Hausser, 2002). Elephants are afraid of bees and this has been used in the "Zuia ndovu na *Causirina*"

project in Kwale County, Kenya, in the border of Shimba hills and consequently reducing the human- wildlife conflict in Laikipia (Hausser, 2002; AGROMISA, 2009). Challenges to full exploitation of bee keeping in biodiversity conservation and community empowerment include: lack of enabling regulatory and policy framework, lack of standards, poor quality of honey, lack of an entrepreneurial approach to beekeeping, honey production and marketing (Alaazi *et al*, 2010).

Conservation of natural resources might not appeal to local residents as a desirable goal in its own right, it is thus important to identify a target audience for the message. Bee keepers could be provided with knowledge on bee plants initially as they would be receptive to such a message and consequently act as a link between partners in environmental conservation and local communities. This establishes a framework for negotiating desired outcomes with the affected people in the long run (Vlek *et al.*, 2014).

Apiculture plays a significant role in national economy of a country. It serves as additional source of income to hundreds and thousands of beekeepers in the country. Beekeeping plays an important role in conserving the natural resources and contributes to the globe through environmental protection (Okoth, 2010).Charcoal burning in Mwingi region, Kenya, was successfully reduced by introducing bee keeping as an alternative economic activity and has become a good example for other areas. Apiculture has the potential to improve livelihoods of the local communities and to give them an incentive to participate in the conservation of vital forests. Managed bee colonies are important pollinators. Pollination is a crucial step in re-establishment of deforested areas (Okoth, 2010).

2.7.6 Honey Preparation and Honey Pollen Pollution

Nectar collected by *Apis mellifera* is passed through the esophagus in to the nectar sac which acts as the nectar collecting chamber during transportation. Pollen and debris sucked along

the nectar during foraging is filtered rapidly and the nectar sucked into the honey stomach (Bryant, 2001). In the honey stomach the nectar is moved back and forth in the funnel shaped proventriculus to remove debris. The filtered nectar is either transferred to the workers for further processing or less commonly, fed directly to the brood. By enzyme action and fanning the nectar is finally transformed in to honey (Balasubramanyam, 2011). Pollen contents in the honey are influenced by floral morphological features. Nectar can be polluted through either primary, secondary, or tertiary pollution. The primary pollution is caused mechanically when bees shake the anthers and pollen fall in to the nectar which is eventually carried to the hive. The secondary pollution takes place the moment the nectar arrives in the hive to the moment the comb cells overflowing with honey are capped. Tertiary pollution takes place during honey extraction operations while quaternary pollution occurs due to airborne pollen or anemophilous pollen. Quaternary pollution is much more limited Onyango *et al*., 2019; Ricciardelli, 1988).

2.7.7 Honey Market and Trade

Honey ismarketed as either generic (large volume by *Apis mellifera*) or specialty honey which could be unifloral, come from particular region, has substantial health benefits, meets consumer purchase criteria (organic, fair trade) or sustainably produced assisting on conservation efforts (Onyango *et al*., 2019). Manuka Honey from New Zealand is a specialty honey billed as one of the most expensive honey. Other specialty honeys have been marketed in the auspices of international gorilla conservation in Uganda and Rwanda. Africa honey sold as generic blend is unlikely to compete with honey from major exporting countries like china and Argentina (Stubbs, 2011).

2.7.8 Honey Standards

Codex Alimentarius is run jointly by UN, FAO, and WHO; purposefully to enhance food safety and trade. Worldwide the international standards for honey are laid in *Codex Alimentarius* (Codex, 2001). The EU honey standards are valid for use in trade only in Europe. The *Codex Alimentarius* standard (Codex Standard) guides on all the honey quality factors and their application. It also guides on the labeling, description and definition of honey. The Codex standard is quite similar to the EU directive 110/2001, except that the Codex Standard is more detailed containing reference to other aspects like heavy metals, pesticide contamination, and adulteration. The methods for determination of the quality parameters are defined in Codex Standard while the EU directive 2001/110/EC refers to Codex method without mentioning them explicitly as is to be expected under the principle of subsidiarity. The compositional criteria in both the standards refer to retail honey and there is no special mention to the bakers honey or industrial honey. The COMESA/FDHS 002:2004 Standards are similar to the codex standards except for the alternative methods of analysis that have been included. The Kenyan honey standard has not put levels for some features of honey that are included in the rest of the standards (Laws of Kenya, 2004).

According to *Codex Alimentarius*, 2001 honey essential quality factors, honey sold as such shall not have any food additives nor additions other than honey. Honey shall not have any objectionable sensory characteristics: matter, flavor, aroma, or taint absorbed from foreign matter during its processing and storage. The honey shall not have begun to ferment or effervesce. No pollen or constituent particular to honey may be removed except where this is unavoidable. Honey shall not be heated or processed to such an extent that its essential composition is changed or its quality impaired. Chemical or biochemical treatments shall not be used to influence honey crystallization. In the European Union Council, the same essential composition and quality factors are mentioned but the text formulated differently thus

according to both standards honey should be authentic (Bogdanov and Martin, 2002). The Kenyan honey standard does not explicitly refer to as essential quality factors and unlike the other honey standards e.g. COMESA, CODEX, EU it has only mentioned the maximum values of invert sugar, moisture, sucrose and ash (Laws of Kenya, 2004).

2.8 Melissopalynology

Melissopalynology is the pollen analysis of honey to determine its type, quality, and origin. Melissopalynology is an applied branch of palynology (Attri, 2010). It is one of the most important ways of determining the botanical origin of honey apart from the physicochemical analysis and organoleptic/sensory analysis. Melissopalynology is also referred to as melittopalynology. 'Melissopalynology' is from the Greek word *Melissa* meaning bee and honey (Salonen and Julkunen-Tiito, 2012).

2.8.1Botanical and Geographical Origin of Honey

Melissopalynology is the primary standard and official test used to determine both the botanical and geographical origin of honey. It is also important in revealing the potential resources for apiculture through identification of vegetation units for nectar and pollen sources important for the survival of bee colonies, apicultural research planning, and development (Akratanakul,1990). When used together with field observations involving phenology and floral biology, it provides reliable information on minor and major nectar sources for honey bees at various periods and elevations of honey production (Panseri *et al*, 2013). Melissopalynology is useful in the development of pollen analytical standards, which contributes to quality control and value addition of honey offered to the export market. This in turn limits honey fraud (Louveaux *et al*, 1978; Onyango *et al*., 2019). Because of trade agreements, import tariffs and restrictions, most of the leading honey producing nations require labeling of honey before it is sold. With the use of the marker pollen in honey

melissopalynology is able to effectively judge the nature of the mixing of the native honey and exotic honey (Bryant, 2001).

The study of pollen in honey dates as far back as the nineteenth century. Since this period, several workers have examined the pollen contents of various Swiss, French, African American, India and other European honey samples (Igbe and Obasanmi, 2014). The occurrence of pollen grains in honey can be attributed to their presence in the floral nectar or exogenous sources (Salonen and Julkunen, 2012). Honey pollen profile reflects forest vegetation diversity and species composition of the plants foraged by honey bees. The relative pollen frequency is used in labelling of honey geographical origin. Labelling of honey geographical origin significantly influences honey's commercial value. The pollen profile is used as a traceability tool by food control institutions (Corvucci *et al*., 2015). The European Standard Directive 110/01, defines honey as unifloral when it is from a completely or partially botanical origin including its pollen corresponding to their origin (Ciapinni *et al*., 2013; Bryant, 2001). The pollen from the combination of wind and insect-pollinated taxa found in a honey sample will often produce a pollen spectrum that is unique for the specific geographical region where it was produced (Igbe and Obasanmi, 2014). In general, melisopalynological studies uses random sampling because the main concern is determining the floral origin, purity and broad geographic origins of honey, which do not require long term monitoring (Ponnuchamy *et al*., 2014).

Identification of pollen returned to the hive provides a direct measure of pollen foraging. The pollen within honey provides a longer term overview of plants being used for both nectar and pollen (Kirk and Howes, 2012). These methods are typically used to identify the botanical composition of honey in order to check its geographic origin for food quality and traceability purposes. They have more rarely been used to investigate foraging preferences (Hawkins *et*

al., 2015). The main honey producing countries require accurate labelling of honey before commercialization, including floral classification, traditionally achieved by melissopalynology (Luis *et al*., 2015).The occurrence of pollen grains in honey can be explained either by their presence in the floral nectar or due to exogenous sources (Salonen and Julkunen, 2012). Honey pollen profile reflects forest vegetation, floral diversity and species composition of the plants foraged by honey bees. The relative pollen frequency in honey is used for labelling purposes and to guarantee the geographical origin (Corvucci *et al*., 2015).

The knowledge achieved through melissopalynology, bee botany and nectar plants in beekeeping potential areas facilitate better honey production as well as improves pollination services. Large horticultural undertakings may not flourish in the long run without large scale scientific bee keeping (Singh and Chaturvedi, 2017). Melissopalynology has been extensively used to assess honey correlations with *in situ* climatic parameters such as rainfall and temperature which are important in the context of external factors influencing pollinators and pollination networks (Nascimento and Nascimento, 2012; Ponnuchamy *et al.*, 2014). Melissopalynology makes it is possible to determine adulterated or honey poisonous to children or people with certain diseases. Pollen grains are the essential tools in the analysis of honey (Igbe and Obasanmi, 2014).

Africa honey sold as generic blend is unlikely to compete with honey from major exporting countries like China and Argentina (Stubbs, 2011). Taxonomic identification of bee-collected pollen has the potential to address specific questions related to plant–insect interaction dynamics, habitat use, and habitat and forage quality from both ecological and policy standpoints. This information may go on to influence decisions directed toward evaluating and enhancing pollinator habitat, thus contributing to the future security of plant and bee

populations as well as pollination services. There is need for methods that can quickly, accurately, and efficiently quantify honey bee foraging resources across varying landscapes (Smart *et al*., 2017). Different types of pollen are used to indicate floral nectar sources utilized by bees to produce honey. Relative pollen frequency is often used to verify and label a honey sample as to the major and minor nectar sources. This information has important commercial value because honey made from some plants commands a premium price. Even non-premium grades of honey require certain types of verification because they must be correctly labeled before they are marketed. Identifying and quantifying the pollen in honey samples is one of the best ways to determine the range of nectar types used to produce a honey, and therefore label correctly, based on actual foraging resources. Another reason that pollen analyses of honey are often required is to identify geographical source of origin (Bryant, 2001). The pollen from the combination of wind and insect-pollinated taxa found in a honey sample will often produce a pollen spectrum that is unique for the specific geographical region where it was produced (Igbe and Obasanmi, 2014).

Honey pollen profile reflects forest vegetation, floral diversity and species composition of the plants foraged by honey bees. The relative pollen frequency is used for label purposes and to guarantee the geographical origin, factors that greatly influence honey's commercial value, being also used as a traceability tool by food control institutions (Corvucci *et al*., 2015). The pollen from the combination of wind and insect-pollinated taxa found in a honey sample will often produce a pollen spectrum that is unique for the specific geographical region where it was produced (Igbe and Obasanmi, 2014). Certain species functioning as good geographic markers, were also encountered with low frequencies in samples studied by Novais *et al*., (2013). The low representation of specific pollen types can be used as indicators during the determination of the honeys geographical origin (Baudilio *et al.,* 2002). Data by Novais *et al*., (2013) have indicated that the pollen types with the highest frequency have a botanical

affinity to species that typically have herbaceous or arboreal habits. Presence of frequent or very frequent pollen types in honey samples could be attributed to the ease of availability, abundance of the plant, the quality and quantity of the nectar and pollen, specific nutrients or trace elements provided by the species of interest. An understanding of the reasons for plant targets could provide information on constituents of a balanced *Apis mellifera* diet (Wilson *et al*., 2013; Hawkins *et al*., 2015). Because honey samples may be coming from restricted area, the samples may have high proportion of common pollen types (Baudilio *et al*., 2002). From Shannon weaver diversity index the trophic niche amplitude or pollen niche breadth, the polylectic nature of *Apis mellifera* and trends of temporal specialization in foraging habits can be deduced (Baudilio *et al.*, 2002).

The association of a lower breadth with a greater concentration of collection from a few pollen types (lower evenness) demonstrates tendency towards specialization. The trophic niche of *A. mellifera* in the Atlantic forest of Southern Brazil showed generalist feeding behaviour common to social bees, which demonstrates plasticity in pollen resource use (Suzane *et al*., 2013). Low niche breadth associated with low evenness that characterized some pollen samples demonstrates a trend towards temporal specialization through more intense exploitation of a few floral resources such as Myrtaceae, Asteraceae, Poaceae, and Araceae. Collecting pollen from species like *Eucalyptus* with intense flowering could lead to lower interspecific competition (Suzane *et al.*, 2013). Individuals may specialize on a narrow range of resources, different from those of their conspecific competitors. Such specialization reduce resource-use overlap and competition (Navarro-Lopez and Fargallo, 2015).

In contrast, more species are more reliant on the presence of a particular food resource and typically may satisfy their requirements in only a small subset of habitat fragments (Candida *et al*., 2013). If species differ in their contribution to ecosystem function or services provided

(functional complementarity), from the view point of bee requirement, several plant species are required to supply a bee population because different plant species may provide kinds of food resources (pollen, nectar, and oils) that are important for adult and larva survival thus, plant species are engaged in "resource complementarity". In addition, such resources may be available at different times of the year with the plants that provide resources for bee populations with longer activity seasons being engaged in "phenological complementarity". Calculation of ecological indices such as diversity and evenness, can help characterize the foraging pattern of the species (Novais *et al*., 2013).

2.8.2 Challenges of Melissopalynology

Occasionally melissopalynology has suffered from the incorrect assignment of honey origin poor pollen sedimentation during centrifugation. Some pollen grains appear virtually identical without acetolysis. There are difficulties in identifying the grass pollen and distinguishing some taxa to genus or species level (Onyango *et al*., 2019; Bryant, 2001). Determination of the Botanical and geographical origin of ultra-filtered honey is difficult, making melissopalynology applicable only to strained honey (Louveaux *et al*, 1978). For the determination of the bee friendly species to the highest level of accuracy, the pollen coefficient of each bee species must be determined, yet there are very few coefficient values available for such species. Pollen coefficients have also contributed to some complexities in the interpretation of vegetation regimes (Persano-oddo and Piro, 2004).

Scarcely represented pollen in honey has been traditionally used as discriminators in order to retain certain honey types to certain regions, such criterion doesn’t consider accidental contamination, thus reliance on the rare occurrence does not provide basis for sound classification (Moar, 1985). Melissopalynology like other sciences investigating biological phenomena is also faced with difficulties of variable evaluation (Ricciardelli, 1988).

2.8.3 Progress in Melissopalynology

Several methods have been proposed for the identification of pollen types and precision of the respective pollen concentration (Onyango *et al*., 2019). Many laboratories have adapted minor changes to the original ICBB method. Todd and Vansel (1942) have formed a basis for further development of pollen coefficients of various species. Recently there have been efforts to develop computer aided pollen identification (Stillman and Flenley, 1996).Various standards have now adopted *Codex Alimentarius*, with the Louveaux *et al* (1978) as the source document. Pollen markers originally suggested are now being used in melisopalynological analysis to obtain precise pollen concentration values (Onyango *et al*., 2019; Bryant, 2001).

2.8.4 Reference Slides and Pollen Identification

For accurate analysis of particular honey, an experience in palynology as well as availability of broad based botanically and geographically pertinent pollen reference must be available to the technician from either living or herbarium specimens identified by trained taxonomists, with much efforts focused on known pollen sources. There are few pollen references available for melissopalynologists as well as honey market (Petersen and Bryant, 2011).

2.9 Sensory Analysis of Honey

Sensory analysis is scientific discipline used to examine a product through the evaluation of attributes perceptible by 5 sense organs (organoleptic attributes such as color, odor, taste, touch texture, and noise (Pianna *et al*, 2004; Ligia *et al*, 2014). Sensory perception occurs in three steps; the stimulus hits the sense organ and this is converted to a nervous signal which travels to the brain, the signal is organized and the incoming sensations integrated into perceptions; the response is then formulated based on subject perceptions (Tzia, 2008). Often taste is of major consideration and the industries tend to overlook other sensory perceptions. Sensory evaluation is quantitative science since numerical data are collected to establish the

relationship between product characteristics and human perceptions. Like other analytical procedures, it is concerned with precision, accuracy, sensitivity, and avoiding false position results (Lawless and Heymann, 1998).

2.9.1 Importance of Sensory Analysis

Application of sensory analysis dates back to France Italy and Spain (Gonzalez *et al*., 2010, IHC, 2009). Sensory analysis of honey can facilitate characterization and development of honey products. For the purpose of honey characterization sensory analysis fixes the honey in to a predefined type or standard. This refers primarily to identification of honey as multifloral or unifloral and matching it to a declared origin as per the directive (Council Directive, 110/2001) of the European Union. Sensory analysis is important for determining the floral origin for subsequent quality control practices which ultimately determines consumer preferences toward the product. Sensory analysis compliments the determination of botanical and geographical origin; in sensory terms, honey properties may be described using the senses of human beings (Ciappini *et al*, 2013).

Sensory analysis can discriminate floral honey from honey dews, verify the absence of defects in honey, and honey conformity with honey reference standards (Gonzalez *et al*., 2010). The principal use of sensory analysis include research, quality assurance and as a marketing tool. Reliable results from sensory analysis provide necessary data upon which sound enterprises or business decisions can be made (Lawless and Heymann, 1998).

2.9.2 Sensory Analysis versus Instrumental Analysis

Human senses can detect odorants at lower levels than any instrument (Lawless and Heymann, 2010). Development of instruments to measure aroma, appearance, taste, and texture has a very long history aimed at correlating instrumental and sensory measures to reduce human judgment. The simulation of sensory behavior by instruments cannot match the complex simultaneous activity during eating and chewing. Sensory information is

multidimensional while instrumental information is almost single dimensional. Instruments can be useful in sensory evaluation when there is good understanding of the relationship between instrument measurements sensory perception and consumer behavior which is lacking at the moment (Stăncioiu *et al*., 2014).

Sensory characteristics among honey vary. Honey being a health product, investigation of its sensory characteristics is desirable (Vit, 2013). The Council directive 110/ 2001 requires honey botanical origin to agree with the pollen, physicochemical and sensory characterization .The three analytical techniques are therefore complimentary assays to honey characterization (Farid *et al*, 2011). According to essential honey quality factors in *Codex Alimentarius* (2001), honey should not have any objectionable flavor, taste, and taint. These are sensory features that can only be determined by sensory analysis.

Although fermentation in honey can be determined through physicochemical analysis of the fermentation products, for other characteristics there are no alternative methods. Sensory analysis can reveal presence of botanical components not picked by physicochemical methods as well as melissopalynological analysis that at times alter the typical chemical characteristics, to the extent that honey cannot be marketed as unifloral honey. Small quantities of aromatic honey which are usually not detected in blends by common laboratory analysis can considerably alter the organoleptic characteristics of unifloral honey sensory analysis is the basic criterion for selection of unifloral honey for commercial purposes (Pianna, 2004). Sensory analysis allows differentiation of honey there thus adding value. There is need to know whether the application of sensory methodology, physicochemical and sensory analysis improves the floral origin assignation of honey (Ciappini *et al*, 2013). Many authors have reported different floral markers for honey. Sensory analysis can be used to clear such an ambiguity (Vilma and Petras, 2010).

2.9.3 History, Progress and Challenges in Sensory Analysis

The electronic nose and electronic tongue represent significant advances in the sensory analysis their use is quite dependent on their cost, safety and how well they can correlate with important sensory characteristics so as to offer practical alternatives to human sensory analysis (Lawless and Heymann, 1998).

Sensory analysis in the past has been viewed in the context of technical experts. Companies now evolve away from single technical expert to panel of experts due to product complexity to technical experts. Product complexities limiting the predictionof consumer acceptance. Much interest in sensory analysis in 1950s led to the introduction of the flavor profile alongside quantitative descriptive analysis that does not rely on individual expert but formalized subject screening and training procedures. In 2002 University of California at Davis started offering sensory courses online (Lawless and Heymann, 2010).

Honey sensory analysis was first used in France with traditional techniques by the gounet team (Ciappini *et al*., 2013). In Italy gounets developed the standard traditional methodology including harmonized methodology evaluation form, tasting methods, methods for training and selection of assessors, and sensory description of Italian unifloral honey. Unlike in the first half of the 20th century new and improved sensory analysis methods have been developed using panels of assessors, well defined and controlled experimental protocols as well as statistical techniques for processing of results (Persano-Oddo and Bogdanov, 2004; Pianna *etal*, 2004). A working group established by the IHC to study the sensory analysis application to honey (IHC, 2001) has enabled compilation a glossary referring to all the attributes and terms used for sensory analysis of European unifloral honeys (Persano-Oddo and Bogdanov, 2004). The aroma and odor wheel alongside its descriptors previously developed in Belgium team (Piana *et al.,* 2004) has now been tried out and modified by the working group of IHC, 2001 by adding some attributes of Mediterranean honey. This is

important in the development of standard of terminology for precise consistent description of all possible variations of honey. Terms in the wheel are divided into families and subfamilies. The terms in the aroma and odor wheel enable the communication and product perception as the terms are gradually adapted by consumers (Ciappini *et al*, 2013). The Aroma wheel contains the reference samples of various families and subfamilies. Although with new sensory methods the results are reproducible, the complexity and high costs limit their use in the field of research and development of new product rather than the routine use in the framework monitoring process and quality control (Pianna *et al*, 2004). Great difficulties in the evaluation of intensity and persistence of nasal and retro nasal aromas have been pointed out by trained testers in some studies, it has been considered necessary to improve some of the scales previously developed, grouping some descriptors, and redesigning the profile sheet to include improvements (Lawless and Heymann, 2010).

2.9.4 Sensory Characteristics of Honey

2.9.4.1 Tasting Characteristics

Tasting characteristics refer to all the chemical sensations perceived when small quantity of honey (1-2g) of raw honey at room temperature (18-25^{0}C) is put in the mouth dissolved and swallowed. On a physiological basis taste characteristics may be referred to as gustatutory, olfactory, trigeminal sensations, pseudo thermal effects, or complex sensations (Ciappini *et al*, 2013).

Sweetness is the intensity of sweet sensations when honey is dissolved in the mouth. Differences in sweet intensity are more related to the physical state of the samples whether liquid or crystallized. Acidity is the intensity of acid sensation when honey is put in the mouth while saltiness is the intensity of saltiness perceived when honey is put in the mouth. Bitterness is the intensity of bitter sensation perceived at the back of the tongue after swallowing honey dissolved in the mouth while aroma is the global odor perceived via the

back of the nose when honey is dissolved in the mouth. It is described according to the terminology and references in the odour and aroma wheel (Ciappini *et al*, 2013).

Persistence/aftertaste means the durations of sensations after swallowing. An aftertaste according to ISO 5492(1992) corresponds to a new sensation that appears during the period. Other mouth perceptions are produced by tasting and are not related with olfactory or gustatory sensations. These perceptions include piquancy, astringency, and refreshing, often related to small glucose crystals that absorb heat while melting (Ciappini *et al*, 2013).

2.9.4.2 Crystallization Rate

Honey crystallization is a natural phenomenon that happens when glucose, one of the three main sugars spontaneously precipitates out. The sensory evaluation of this geometrical textural attribute is related to the perception of the size and shape of sugar particles in the honey (Farid *et al*., 2011). This is a non-specific parameter depending on factors apart from the botanical origin (storage and processing) but on some physical parameters (sugar composition, ratio of fructose to glucose or glucose to water) that make it possible to know the granulation rate/crystallization rate of honey. This characteristic can be useful in predicting the future liquid or crystal state of honey. Other physical characteristics in some honey types e.g. texture depend on factors different from botanical origin and have no reference terminology established for them thus cannot be considered as diagnostic parameters (Pianna *et al*, 2004; Ciappini *et al*, 2013).

2.9.4.3 Olfactory Sensation

This is honey odor perceived when sniffing a small (approximately 40 g) in a wine glass (balloon type, 160 ml capacity) at room temperature (18-25^{0}C), just after stirring it with a plastic spoon. The intensity of the odor refers to the overall intensity of sensations perceived when honey is smelled in the above described conditions. The description of odor refers to the terminology and references of honey aroma wheel (Ciappini *et al*, 2013).

2.9.4.4 Visual Characteristic

This is the only characteristic completely related to botanic origin. The color intensity is the degree of lightness or darkness of the honey color when observed on its liquid form. As a reference honey color is considered ranging from very light to very black. In crystallized honey the intensity are from white to almost black through more to less beige tones. The color can vary much following possible types of granulation and processing (Farid *et al*., 2011). Color grading has been used in the honey industry for many years. Honey color is an important characteristic used by producers, packers, and end users alike. Its measurement is vital in quality control process and it is estimated that 75% of industrial users of honey include color specification in their designations. In its natural condition, honey has a continuous range of colors related to mineral content and floral source. Light colored honey have strong flavor. Honey color names include: water white, extra white, white, extra light amber, light amber, amber, dark amber (National Honey Board, 2013). Honey color may be appropriate for classification, in the Botanical origin of honey and is commonly used in international commerce (Farid *et al*., 2011).

2.9.4.5 Principles of Sensory Analysis

Sensory analysis is based on the evaluation of olfactory and gustatory characteristics of honey by assessors trained to identify sensory stimuli on the basis of previously memorized standards (ISO 8586-1, 1993; ISO, 8586-2, 1994) and to quantify them on a unstructured scale of 15 cm (1SO 4121, 2008). Sensory evaluations are carried out according to the conditions and general methodology set down in ISO 6658 (1985) principles developed from psychology and physiology. Since sensation cannot be measured directly, it is important to measure sensitivity on the basis of differential changes by determining the detectable amount of difference between the two stimuli (just noticeable difference= *jnd*) to establish the level of sensation. The *jnd* has found widespread application in sensory analysis in food products

(Ciappini *et al*, 2013). According to the psychophysical law each *jnd* is equal to a unit of sensation. Equal stimulus ratios result in equal sensations ratio.

Log R=k log S (Psychophysical Law) Where;

R=response K=Constant of *jnd* S=stimulus concentration. It has been noted that the perception of the differences between two products was a constant related to the ratio of the difference as per the following equation:

$$K = \frac{\text{Change in R}}{\text{R}}$$

This gives a mathematical relationship can be used to model the connection between acceptance and perceived sensory properties (Tzia, 2008).

2.9.4.6 Complementarity of Melissopalynology, Physicochemical and Organoleptic Analysis of Honey

Although chemometric analysis e.g. HPLC/GC will differentiate between unifloral honeys, it will not differentiate between polyfloral and unifloral honeys. The use of specific honey markers is necessary (Vilma and Petras, 2010). Evaluation of unifloral conformity is determined through organoleptic characterization (Pianna *et al*., 2004) and unifloral markers should be in conformity with the physicochemical and melissopalynological characteristics (Persano-Oddo and Bogdanov, 2004). Sensory analysis compliments the determination of botanical origin and physicochemical characteristics (Gonzalez *et al*, 2010). Melissopalynological quality criteria for unifloral honeys are not valid for all honey and thus at present pollen analysis is used in combination with the sensory and chemical analysis of unifloral honeys (Bogdanov and Martin, 2002). Currently the floral type is judged on the basis of pollen analysis as well as chemical analysis as the pollen content is subject to considerable variation, judgment of honey is based on a combination of several quality criteria. Honey dews/forest or fir honey are therefore labeled on the basis of sensory

judgment and electrical conductivity measures (Bogdanov and Martin, 2002). Pollen analysis differentiates honeys produced in distinctly different geographical and climatic areas; if geographical area is less pronounced; the determination of the pollen spectrum will generally not yield a confident authenticity proof. Melissopalynological methods are based on experience and thus to a certain extent are subjective (Bogdanov, 2011; Onyango *et al*., 2019).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

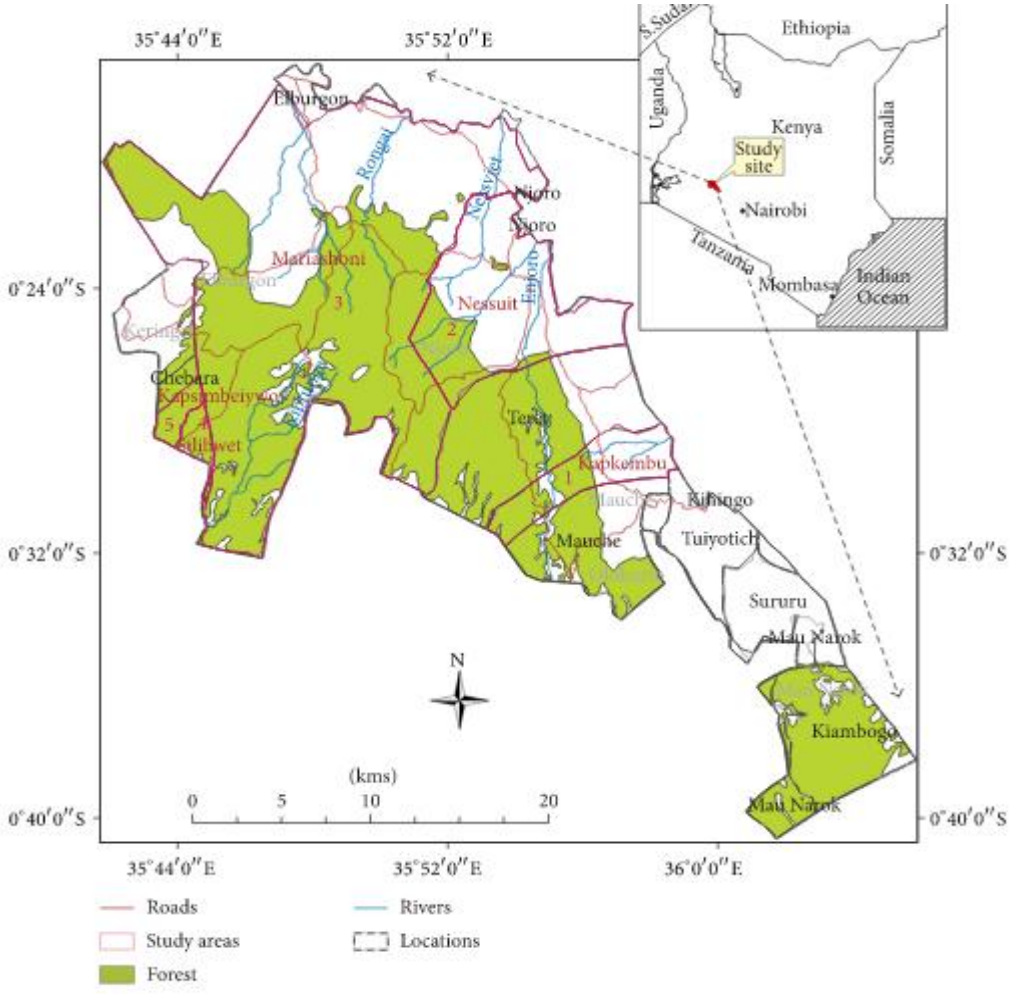

Plate 3.1. Map of study area in Eastern Mau forest Kenya

Eastern Mau is one of the largest blocks in the Mau forest complex. The area is made up of class V vegetation of about 50-75% plant density. There is up to 40% dependence on honey production in Eastern Mau. The study site is located about 50 Km south of Nakuru Town, Kenya. The altitude ranges from 1200 and 2600 m. It is approximately 280 km^2 with the highest number of indigenous forest dwellers dominantly belonging to the Ogiek community. East Mau forest is an important watershed within the Mau Forest Complex, feeding major rivers and streams that make up the hydrological systems of Lake Victoria and inland Lakes

of Nakuru, Baringo and Natron. It hosts endangered mammals (Sang, 2001). The forest ecosystem is therefore an important resource base for the local communities, national and international community. The total forest area has gone down by more than one half due to excision for human settlement in 2001(UNEP *et al*., 2006). The remaining area consists high forest, grassland and planted forest mainly of Cypress and Pines (KFS, 2012). Eastern Mau area terrain ranges from escarpments, hills, rolling land to plains with slopes ranging from 2% above 30% in the foothills. The soil is composed of quaternary and tertiary volcanic deposits. The adjoining settlements have gentle slopes with deep-fertile-volcanic soils suitable for maize, wheat, potatoes, horticultural crops and livestock keeping (Jaetzold and Schmidt, 1982). The area receives trimodial precipitation pattern with the long and intense rains from April to June; short rains in August; and shorter, less intense rains from November to December. Mean monthly rainfall ranges between 30 mm to 120 mm and total annual precipitation of 1200 mm (Kundu, 2007; Okello, 2008). The mean annual temperatures are in the range of 12 -16°C (Kundu, 2007).

3.2 Research Design

Simple stratified random sample was adopted for direct field surveys during the determination of melliferous taxa, development of floral calendar and collection of the 27 Ogiek honey samples. The three mesoregions formed the strata. Direct surveys were used for both determination of melliferous taxa, flowering phenology and seasonal availability, and subsequent development of floral calendar. Honey from three forest strata units were purposively sampled using two main criteria: ethnic composition, presence of indigenous Ogiek community. The following administrative locations were selected: Mariashoni representing an old settlement predominantly occupied by Ogiek indigenous community (65%), Kapkembu – representing a recent settlement with a homogenous community of the

Kipsigis and Ogiek (7.5%) , Nessuit – representing a recent settlement with a heterogeneous population of indigenous (Ogiek, 50%) and immigrant ethnic groups (Langat *et al.*, 2015).

3.3 Melliferous Taxa

Reconnaissance survey was employed to become familiar with the area, to get an insight on the vegetation distribution in the landscape, to observe and locate the possible traverse during the actual study. Stratified random sampling procedure was followed to select the representative sites based on the strata made prior to the survey.

Three transects measuring 5m x 50m were laid out in selected sites representative of the study area and every 120 degrees of an identified hive. In order to retain accuracy, a smaller transect measuring 5mx10m was laid out then replicated 5 times. Plants were categorized as trees when they exceeded 3 m in height, as shrubs when they attained a total height of 1-3m. Plants that grew below 1m in height were taken to be undergrowth layer or herbs in the transects and studied in nested quadrats of 1-2m squared (Vlek *et al*., 2014). This was replicated in Mariashoni, Kapkembu, and Nessuit in Eastern Mau.

3.3.1 Data Collection

Field data was collected through regular monthly visits to the study sites. Each study visit served as pseudo replicates for the site and all observations were made between 0700-1800hrs (wet seasons) and 0700-1830hrs (dry seasons). Primary data was collected through direct identification of bee flora in the region mainly by observing the bee visitation. The flower species was identified as bee plant only after visual confirmation and collection of food by honey bees (Sivaram, 2014). The observation on nectar and pollen source was based on activities performed by honey bees on different flowers. Honey bees with their activity of extending their proboscis into the flowers are considered a nectar source and bees carrying pollen on their hind legs were determined as pollen source. Bees with activities of extending proboscis and carrying pollen are recorded as both pollen and nectar source. Their foraging

behavior was observed for period of 10 minutes. If the success of any foraging attempt was ascertained, the plant was scored as bee foraging species after at least 3 honeybees visited the flowers simultaneously or within observation period (10 minutes) (Okoth, 2010). Binoculars was be used to make observations for high trees and height determined by using clinometers. Plants visited by the honey bees were identified in the field to species level by the Flora of Tropical East Africa. Samples of plants that could not be identified in the field were collected and saved in Herbarium sheets, and subsequently identified in the Department of Botany, Maseno University by taxonomists after comparing with material held in Maseno University Herbarium as well as published reports. Subsequent identification was aided by Flora of Tropical East Africa (2010).

3.4 Seasonal Availability and Floral Calendar of Melliferous Taxa

All the changes in the blossoming of the plants visited by the bees for pollen or nectar were recorded plus their flowering periods from the full opening of the buds till the start of the fruit formation end of flowering by use of binoculars. Each survey area around a bee colony shall be surveyed every week for 12 months in order to record the flowering periods of the plant species according to Akratanakul (1990) method.

3.4.1 Data Collection

A table with 13 columns (plant species and 12 months of the year) was developed. Each of the pollen, nectar or both pollen and nectar plants shall have its row and its flowering moths shaded. Flowering period was delimited as period that extends from the beginning of flowering (5% of open flowers) until the end of lowering. Based on availability of different plants along with their flowering time, a bee floral calendar was developed. This was done for all the melliferous plants.

3.5 Melissopalynology

3.5.1 Geographical Origin

3.5.1.1 Preparation of reference slides

Pollen references were done with various published atlas and reference slides: Maishihah and Kiew (1988); Barth, 1970; Adeonipekun (1989) ; Jailson (2013) ; Ibrahim(2012) ; Anthonysamy and Abdullah (1991), Ejigu *et al*., (2017); Igbe and Obasanmi (2014); Luz *et al*, (2010) ; Moar(1985) ; Nair(2005); Nguemo *et al*., (2016) ; Ponnuchamy *et al*.,(2014) ; Vanessa *et al*., 2014. For plant species not available in various published atlases and references the reference slides were prepared according to Louveaux *et al*., (1978). The pollen were extracted from flowers (fresh or dry) of identified plants in 5x50 m wide belt transects of the bee colonies (hives) of Ogiek beekeepers and visited by the bees for either pollen or nectar. For the purpose of identification the fertile plant specimens were collected with representative plant parts, pressed in between blotting papers and boards, dried in plant drier using 40 watts bulb for four days according to Stace (1989) method and sent to Maseno University herbarium for identification. To get pollen from fresh flowers, the flower buds were collected, kept in zip lock bags into cooler boxers, and let to open in the laboratory to reduce contamination with pollen of other plants, by wind or insect visitors.

The pollen material were acetolyised according to Erdtman, (1960) method by putting into a heat-resistant centrifuge tube and covered with 5 ml of acetic anhydride and sulphuric acid mixture (9:1) prepared by adding the acid, drop by drop, to nine times the volume of acetic anhydride each day. A glass rod was inserted into each tube, and the tube transferred to a water bath at 70°C and heated to a boiling point. The liquid was stirred while boiling and transferred to the centrifuge. After centrifuging (2500 rpm, 10minutes) the reaction mixture was decanted into a reserve receptacle. 10 ml of water-alcohol mixture will be added to the sediment and the tube shaken. After acetolysis and washing transfer, a third of the suspension in the centrifuge tube was transferred to another tube, centrifuged and decanted. 2 ml of

glacial acetic acid, 1 or 2 drops of saturated sodium chlorate solution, and finally 2 or 3 drops of concentrated hydrochloric acid was added to the sediment, the liquid stirred with a glass rod to release the Chlorine. The reaction mixture was centrifuged again, decanted and the sediment washed twice with distilled water. The suspensions of acetolysed pollen grains and of acetolysed and chlorinated grains were then mixed. After centrifuging and decanting once again, the sediment was suspended in five drops of a mixture of glycerine and water (1:1), left for at least 10 min, centrifuged, decanted, and the centrifuge tubes inverted on filter paper. A minute amount of glycerine jelly was fixed on the tip of a platinum needle, and dipped into the pollen-bearing sediment and then transferred to a slide with the jelly and the pollen material adhering to it. The pollen material on the slide was then covered with a clean, cover-glass and a drop of melted paraffin transferred to the margin of the cover-glass with a glass rod to seal the edges. The slide was then gently heated so that the paraffin spreads quickly under the cover glass. The slide was turned upside down to allow small pollen grains and pollen fragments to settle close to the cover-glass. Pollen grains embedded in glycerine are mobile and so slides were sealed in the same way. Fresh material from Cannaceae, Juncaceae, Lauraceae, Maranthaceae, Musaceae and certain species of Zingiberaceae usually become more or less shriveled and wrinkled after acetolysis; so such specimen were only warmed with 2-5% KOH or NaOH solution for a few minutes, instead of acetolysis and their slides sealed with paraffin wax to prevent gelatine from flowing out even if it becomes liquid, and protect the prepared slide against moulds.

3.5.1.2 Honey Sample Collection

Three honey samples were collected from Mariashoni, Kapkembu, and Nessuit) at the end of April, 2016; August, 2016 and December, 2016 from the hives of Bee keeping Ogieks of the Eastern Mau forest region giving a total of 27 samples. Only the honey processed by straining using

fine sieves or cheese-cloth were collected from the beekeepers, placed in sealed food grade screw cup bottles, and transported to the laboratory in cooler boxes. Samples from 3 beekeepers (three replicates) per population substratum were collected. Samples for further analysis were refrigerated at 3 ± 2^0C and stored in dark with screw cup bottles.

3.5.1.3. Honey Sample Preparation

Each laboratory sample of the 27 samples consisting of 100-200 g of honey was transformed into a 10g test sample by thorough stirring. Granulated hard samples were softened by slight warming. Dirty samples were liquefied at 40°C and strained through cheese-cloth.10.0 g of honey was weighed and dissolved in 20 ml of hot distilled water at 39°C.

3.5.1.4 Preparation of Slides

10.0 g of honey will be weighed and dissolved in 20 ml of hot distilled water at temperatures below 40°C. The solution was then be centrifuged for 10 min at 2500 r/min and decanted. The honey sugars will be further completely removed by dispersing again with about 10 ml of distilled water. The solution was poured into a centrifuge tube, and centrifuged for 5 min. The entire sediment was then put on a slide using Pasteur pipettes and spread out over an area about 20 X 20 mm, using a thin glass or platinum rod. After drying by slight heating (not above 40°C), the sediment was mounted with glycerine gelatine, liquefied by heating in a water-bath at 40°C. The sediment constituents remaining in the tube were stirred again with a drop of distilled water, pipetted again, and the used pipette rejected to eliminate the contamination of pollens from other honeys. 20 g was used when the honey sample was poor in pollen, if it is rich in sediment, the residium was spread under two cover glasses.

3.5.1.5 Data Collection

The microscopical identification was based on the identification and counting of pollen grains and other particles in honey. Identification will be made by reference to the literature and to comparative preparations Maishihah and Kiew, (1988) ; Barth(1970) ; Adeonipekun (1989) ; Jailson (2013) ; Ibrahim (2012) ; Anthonysamy, Abdullah, (1991); Ejigu *et al*. (2017) ; Igbe

and Obasanmi (2014) ; *Luz et al*. (2010) ; Moar, 1985;Nair, 2005;Nguemo *et al*., (2016) ; Ponnuchamy *et al*. (2014) ; Vanessa *et al*. (2014).

A complete analysis involving the identification of all pollen grains and other microscopic constituents in the sediment was carried out. Pollen characterisation and identification was done according to the guidelines given by International Commission of Bee Botany. Pollen samples for the analysis were prepared using acetolysis method using Louveaux *et al.* 1978 procedure. 10ml of honey mixed with 20ml of distilled water and centrifuged 5000rpm for 10 minutes. The supernatant was added to the residue and allowed to stay for 5 minutes before centrifuging and decanting. Then 1ml of 10% potassium hydroxide was added to the sediment and boiled for 5 minutes on a water bath at 70^0 C. This process turns the pollen in to light to golden brown in colour. The mixture was centrifuged and Potassium hydroxide removed, the residue containing pollen was mounted on glycerine jelly and observed under a compound microscope with 400X and 1000X magnification.

For pollen grains that were not identified as far as the genus or species, a note was added after the scientific name, to indicate that the term is used in a wider meaning, *Trifolium repens s.l. (sensu lato),* or *Trifolium repens* group, or *Trifolium type* i.e. pollen that are similar to *Trifolium repens* in shape and morphological characteristics but could belong to other *Trifolium* species.\

3.5.2 Botanical Origin

Samples were collected and prepared as in 3.1.4.2, 3.1.4.3, and 3.1.4.4. The extent to which a given honey sample was derived from different plant sources was deduced from the frequencies of the pollen in it. Honey was considered to have been produced mainly from one plant (unifloral honey) if the pollen of that plant is predominant.

3.5.2.1 Calculation and Expression of Results

For pollen grains that could not be identified as far as the genus or species, a note was added after the scientific name, to indicate that the term is used in a wider meaning, *Trifolium repens s.l. (sensu lato),* or *Trifolium repens* group, i.e. pollen that are similar to *Trifolium repens* in shape and morphological characteristics but could belong to other *Trifolium* species.

3.5.2.2 Data Collection

500 pollen grains of each of the 10g honey sample of the 27 collected samples were counted for the determination of relative frequencies. Magnification of 400 to 1000X was used for identifying the various elements in the sediment. The identification and counting of pollen grains was done in groups of 100, following 5 parallel equidistant lines uniformly distributed from one edge of the cover slip (22X22mm) to the other, until 500 grains are counted as shown in the figure 1 below. In each line 100 pollen grains were counted. The matrix provided below was able to guaranteed homogenous examination of the slide.

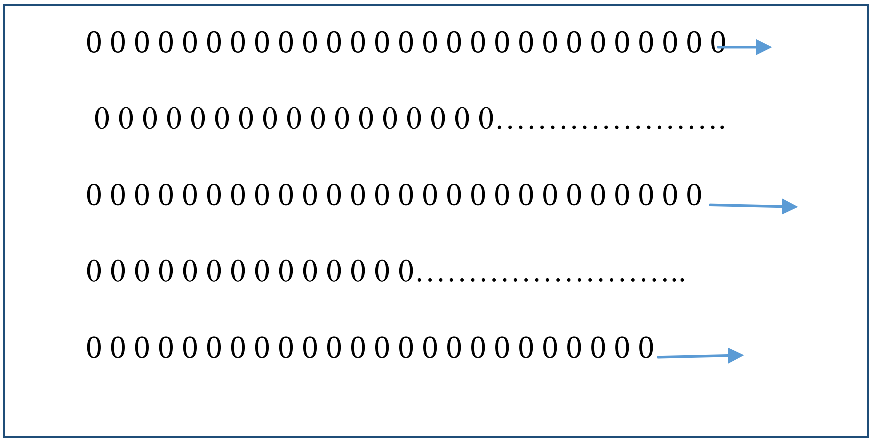

Figure 3.1: Pollen counting Matrix

The total number of the pollen grain in a 10 g sample of Ogiek honey was calculated as follows:

$$PG/10G = +\frac{SX\,npgX\,10}{sxaxp}$$

Where S= Surface area of the of the part containing the sediment of pollen (mm^2)

s=Area of 1 microscope field at the magnification of 100 ($mm^{2)}$

npg=total number of pollen grains counted

p=weight of honey

Pollen density per 10 g was classified in to the following Maurizio classes; below 20,000 (Group I), 20000-100000 (Group II), 100,000-500,000 (Group III), 500,000-1,000,000 (Group IV), and more than 1,000,000 (Group V).

Pollen grain frequencies were estimated according to the following terms: "Very frequent" for grains constituting more than 45% of the total; "Frequent" for grains constituting 16-45% of the total; "Rare" for grains constituting 3-15% of the total and "Sporadic", for grains constituting less than 3%. The frequency classes were described as follows: "Predominant pollen" (more than 45% of the pollen grains counted); "Secondary pollen" (16-45%); "Important minor pollen" (3-15%) and “Minor pollen", (less than 3%). Honey with predominant pollen type was classified as Monofloral honey. For pollen grains that were not identified as far as the genus or species, a note was added after the scientific name, to indicate that the term was used in a wider meaning.The proportion of the HDE to the total frequency of pollen grains from nectar plants were described as follows: Practically none (0.00-0.09); Few (0.10-1.49), Medium quantity (1.50-2.99), numerous (3.00-4.49), Very numerous (>4.50). Estimates of the frequency of pollen grains of anemophilous and other nectar less plants were expressed as follows: "sporadic" (less than 3% of the total); "rare" (3-15%);"frequent" (16-45%); "Very frequent" more than 45%. The identification of pollen types was based on shape, morphological characteristics and size of the pollen grains. Pollen types were identified by using published reference pollen slides, comparative pollen preparations and atlases.

3.6 Organoleptic Characterization

3.6.1 Sensory Analysis Laboratory Standard ISO 8589

Portable sensory booths made of carton boxes were used to simulate suitable, comfortable standardized environment as required by ISO 8589:1988 to facilitate work and production of repeatable results; booths were sufficiently large and comfortable, each booth with accessories, natural lighting, and a sink rinsing drinking water. The booths were placed alongside each other separated by high and wide partitions as to isolate the seated tasters, the booths cardboard material, easy to clean, free from noise, odor, Temp 20^0C-26^0C, 60-70% relative humidity. In order not to affect the results of sensory analysis, additional booths were prepared for preparing samples, shelves for containers and a discussion area. Individual booths were set up so that the assessors work on their own without distraction.

3.6.2 Panel Selection ISO 8586-1, 1993

The value of the panel as the analytical tool in sensory evaluation depended on objectivity, precision, and reproducibility of the judgments of the panelists. For the panel to be used with confidence the ability of the panelists was determined. The panel supervisor selected, trained and monitored the tasters. as described in ISO 8586-1, 1993 "sensory analysis general guidelines for the selection training and monitoring of assessors-Selected assessors 1, and ISO 8586-2, 1994 "Sensory analysis general guidelines for the selection, training and monitoring of assessors-Part 2 experts"

The volunteer panelists were preselected in to equitable number of male (8) and females (8). The criteria for preselection was their availability for participation during 80% or more of the different phases of the panel's work. They were informed of the times for sensory testing, nature of the work and the food to eat. The panel made of the final panelists were subjected to the following selection tests in different sessions.

3.6.3 Basic Tests

Test for basic taste recognition, odor recognition, and descriptions: The presentation was made into strips, soaked, and used according to the substances listed in (Table 3.1).

Table 3.1: Scoring reference substances and odor recognition

Sample	3 points	2 points	1 point
Geraniol $C_{11}H_{18}$	Rose	Flora	Fruit, citrus
Eugenol$C_{10}H_{12}O_2$	Clove	Dentist	Spicy
Anethole $C_{10}H_{12}O$	Anise	Camphorated	Aromatic, spicy
Benzaldehyde C_7H_8O	Almond	Marzipan, macaroons	Sweet
Limonene $C_{10}H_{16}$	Lemon	Citric	Fruit
Aceticacid $C_2H_4O_2$	Acetic acid, vinegar	Dressing	Chemical, pungent
Methylanthranilate $C_8H_9NO_2$	Orange blossom	Floral	Fruit
Valerianic Acid 4 $C_5H_{10}O_2$	Sweat	Animal	Stable
Citral $C_{10}H_{18}O$	Lemon drop	Citrus, lemon	Fruit, candy, chewing gum
Thymol $C_{10}H_{14}O$	Thyme	Spices	Seasoning
Coumarin $C_9H_6O_2$	Clover, honey, vanilla	Sweet milk, coconut	Vegetable, sweet

For both tests, candidates whose scores were greater than or equal to 65% of maximum possible score were selected. For order by strength test (ISO, 8587, 2006) screening assays, the standard arrangement of sweet taste was designed as shown in Table 3. 2 and at least 60% of the correct scores was required.

Table 3.2: Scale for the assessment of current tastes, sweet, sour and bitter

Parameter	Value	Sweet g of sucrose/L	Acid citric acid g/L	Bitter caffeine g/L
Nothing/absent	0	Water	Water	Water
Some/weak	2	50	0.062	0.05
Sensitive	4	100	0.125	0.10
Intense	6	200	0.25	0.20
Very intense	7	350	0.50	0.40

Color vision test was done using the Ishihara (1971) method to detect color blindness. Panelists were presented with printed Ishihara 38 plates with circle of dots random in size and color forming a number or line visible for people with normal color vision, but invisible

(or at least hard to see) for colorblind. The 38 Ishihara color plates comprised: vanishing figure, hidden digit, transformation plate, and qualitatively diagnostic - vanishing plate. Test for description of textures (ISO, 8587 2008): Breakfast cereals as shown in Table 3 were arranged at random and the candidate let to describe their textures. The solid and samples was presented on uniform sizes and in opaque containers respectively. Performance evaluation was done by awarding 3 points for correct description, 2 points for description with general terms; 1 point description with questionable description and 0 for no response. Candidates whose scores were at least 65% after evaluating their individual results were selected.

Table 3.3 Food for the description of Textures

Food	Texture
Breakfast cereals	Crunchy, crisp
Gummy	Rubbery, soft
Cake	Spongy
Raw carrots	Crunchy, hard
Fluid Honey	Smooth, sticky, unctuous
Crystallized honey	Tough, gritty, rough
Sugar	Crystalline, granular, coarse

3.6.4 Sample Preparation and Presentation

A 30 ml quantity of each of the five out the 27 crude honey samples obtained from Eastern Mau was presented at ISO 8589:2007laboratory condition of room temperature from 11-12 am in transparent glass jars (6 cm in diameter and 6 cm in height) perfectly clean, free from odors, flavor and stored at room temperature for at least 2 hours prior to testing. The ratio of the sample to volume of the container was kept at 1/4 to facilitate the liberation of honey odors was presented. The samples were be kept airtight and sealed to retard the dispersion of honey odors and closed while being served. The samples were presented in an anonymous, random/ counter balanced order with a three-random- digit identification code to eliminate bias. Water, bread and apple were used as palate cleansing materials between each tasting (Gonzalez *et al*, 2010). Pattern foods were served in non-returnable containers (glass plates) with every judge receiving desert spoons, paper napkins, whole meal bread without salt and plastic glasses of ½ L to eliminate the ingested remains (Gonzalez *et al*, 2010). The standard

reference food stuffs as provided for in table 3.4 were served to the panelists in non-returnable plates for basic tests for purposes of panel recognition on scent and aromas.

Table 3.4: Families and subfamilies of scents and aromas

Family	Sub family	References
Floral	Subtle	Orange blossom water, rosas
	Heavy	Azahar, jasmine, violet, Jacinto privet
Fruit	Citric	Lemon, orange, bergamot
	Fresh fruit	Strawberry, pear, apple, damascus
	Tropical fruit	Pineapple, banana, cantaloupe
	Processed fruit	Datiles, dried figs, raisins, grape juice, prunes, apple sauce
Warm	Subtle	Beeswax, vanilla, marzipan, honeycomb
	Lactic	Butter, condensed milk, milk candy
	Caramelized	Black sugar, caramel, molasses
	Toasted	Toasted hazelnuts or almonds, instant coffee, coffee beans, toast, malta
	Burned	Toasted bread (some charred)
Aromatic	Spicy	Clove, nutmeg, thyme, oregano, anise, cinnamon, anethole
	Resinous	Pine resin, incense, propolis
	Fresh products	Mint, menthol, eucalyptus essential oil
	Citric	Lemon peel, orange peel
Chemical	Phenolic	Phenol, cresol
	Petrochemical	Tar, plastic, solvent
	Smoked	Smoke cigarette ash
	Acetic	Acetic acid
	Ammonia	Ammonia
	Medicinal	White soap, vitamin B
	Alcoholic	Muscat wine, alcohol
Vegetable	Green	Grass clippings, fresh leaves crushed
	Wet	Wet grass, raw mushrooms, spinach thawed, wet wood, Algae
	Dry	Green tea, cereal straw, dry grass, cereal, bran
	Woody	Cedar wood
Animal	Sulfur	Hardboiled egg (yolk), boiled cauliflower
	Proteic	Dried mushrooms, bouillon cubes, food fish, soy sauce
	Valeric	Sweat, leather, blue cheese, cat urine, fecal

3.6.5 Training of Panelists (ISO, 8586-2, 1994)

The panelists were trained to develop familiarity with the products, their characteristics, and their ability to recognize and identify attributes in order to improve their sensitivity and memory. The training helped them make accurate and consistent judgments as well as develop language awareness in describing the sensory characteristics. The training was conducted in fifteen successive sessions. During the training the panelists were urged to disregard personal preferences and make the evaluation as objective as possible.

The test products were served as illustrative stimuli for the consensus language development. The panel leader worked as a communication facilitator without involvement and interference with panel discussions. References were used for generating sensory terminologies (Ciappini *et al*, 2013). Panelists were requested not to smoke at least 30 min before the test, use any perfume; to fast at least 1hr before the tasting, and must be physically and psychologically well (Tzia, 2008). Training was done till the panel members become familiar with honey and its various attributes. Odor recognition: A variety of honey samples were presented; the panelists then look at them, smelled, touched, tasted and expressed their perceptions. Representative food stuffs of 2 or 3 families of odors were presented as in (Table 3.4) (Pianna *et al*, 2004; IHC, 2001) and a series of elementary taste intensities as in Table 3.5 below.

Table 3.5: Solutions for sorting by sweetness intensity

Intensity	Sucrose [g/L]
1	0.55
2	0.94
3	1.56
4	2.59
5	4.32
6	7.20
7	12.00

Table 3.6: Scale for the assessment of tangerine and smoke odor intensity

		Dilutions in 20 g of commercial glucose syrup	
Parameter	Values	Essence tangerine µ[1]l**	smokeµ[2]l**
absence	0	0	0
weak	2	50	3
moderate	4	100	8
Intense	6	200	20
Very intense	7	350	50

1Essence of mandarins E820486ES Flavor and Fragrance SA

2 Essence of smoke Lir-2463 International Flavors and Fragrances

After training the assessors to recognize odors, they were presented with a series of odor intensities, such as suggested in Table 3.6 above, and urged to express their perceptions. For training of panelists on defects related to caramelized and burned flavor, honey candies were made by mixing 50 grams of honey with 15 grams of sugar and the mixture heated on various durations as indicated in Table 3.7. The candies were then be shaped, picked and dissolved in the mouth followed by perception of the characteristic notes on caramelized /burnt flavor. For training on fermentation, honeys that have developed this effect were used as the reference samples. The panelist only smelled the samples. The panelists quantified the caramelized and burned flavor as well as the fermentation attributes according to the scale shown in Table 3.7

Table 3.7: Scale for the assessment of caramelized/burned odor intensity

Caramelized/Burned Parameter	Values	Time
Absence	0	7 min
Caramelized weak	2	12 min
Intense caramel	4	18 min
Weak burning	6	21 min
Intense burning	7	30 min

Training of panelists on granulity was achieved by constructing a scale of the crystal size was constructed by mixing, glucose syrup (1.722g/L) placed in petri dishes with different types of sugar (Table 3.8). Sugar was added immediately before tasting to avoid dissolution. The amount and size of the particles were seen visually by moving the swirling the sample across the container while the mouth sample will be dispersed against the palate with the tongue. After the training, honey of different degrees of crystallization were presented to the panelists. Other perceptions of the crystals e.g. soluble, insoluble, angular, hard, soft, round or other qualifying items were not quantified when used to describe a sample of honey but only referred to as observations (Ciappini *et al*, 2013).

During training on fluidity**,** portions of various reference mixtures in covered containers as depicted in Table 3.8 were picked at the tip with a spatula, placed 5 cm above the free surface of the sample and the rate at which the sample drops observed (Ciappini *et al*, 2013).

Table 3.8: Scale for the assessment of graininess and fluidity

Graininess		Fluidity	
Product added to 35 g of corn syrup	Point on the scale	G powdered sugar in 20 g of corn syrup	Point on the scale
Nothing	0 -No	10	0 –Does not flow
Powdered sugar, 5 g	1 -Very fine	8	1-It flows very Little
Sweetener, 5 g	2 -Fine	6	2-It flows little
Common sugar, 3 g	3 -Medium	4	3-Fluid
Small crystal brown sugar 3 g	4 -Large	3	4-It flows quite
Glass medium brown sugar 3 g	5 -Coarse	2	5-It flows much
Large crystal brown sugar 3 g	7 –Very coarse	0	7-Extremelyfluid

For purposes of training on persistence, the panelists were exposed to honeys with various durations of sensations after the sample has been removed. For aftertastes, the taste or smell after the product has been removed from the mouth were determined by taking a small sample of honey into the mouth and observation recorded. The panel used the following scale: 0 Intangible (no sensation appears when the stimulus withdraws); 2 Low: less than 30 sec; 4 Medium: about 1 min; 7 Long: about two minutes or more.

During session 10-15 honey samples and controls were presented so that the assessors describe them individually using an evaluation form. Individual performance of each panelist was then be analyzed with each assessor in order to correct errors.

3.6.6 Assessment and Monitoring of Assessors

Once the training was complete and the assessors were able to identify at least 70% of the control samples, the panel analyzed 6 samples by triplicate in balanced order scoring data for each assessor and entire panel using ANOVA (Ciappini *et al*, 2013). Significant variation between panelists was necessary to prove source of bias. Also identify the assessors that significantly deviate from expected performance which must continue with training. Also significant variations between samples were searched, furthermore the presence of significant interactions between assessors and the samples were analyzed to know if one or more of the assessors are using a scale differently from the others. Analysis of each characteristic (average, standard deviation) and repetition of the same sample by each assessor and the average for panel calculated. Presence of outliers indicates the assessors may have not understood the taste assessment instructions (Lawless and Heymann, 2010).

3.6.7 Data Collection

Quantitative Descriptive Analysis (QDA): QDA was applied to the honey evaluation by a trained panel. Comparing with standards previously memorized in the training step, visual,

olfactory, gustatory, and tactile cues were quantified in a series of structured visual scales (ISO 4121, 2008a; ISO 6564, 1985).

Determination: On 16 cm horizontal lines, anchored in 1 cm (minimum) and 15 cm (maximum) representing the continuous scale of 7 points for each attribute, the assessors indicated by a vertical line the perceived intensity for each attribute and sample. Upon completion of the trial, the leader of the panel measured the distance between the anchor and the mark left by the assessor as the measurement result and analyzed statistically. The analysis was complemented by qualitative descriptors for odor and flavor and the mention of other sensations that may be present. The assessors evaluated the honeys one at a time in separate booths without discussion of results nor reference served as intensity standards. Panelists used different parts of the scale to determine the sensory intensities by themselves as result the differences among the products produced by QDA analysis was a relative measurement.

Odour evaluation: The first odor impression was reinforced by smelling of the sample while spreading it on the container walls with a spatula or rotating the container. The process was repeated between 10 seconds. The assessor indicated odor Intensity as well as the family or subfamily to which the odor perception and the distinguished notes belong.

Visual assessment: Both Fluidity and Graininess was evaluated as stated in the training step. The results of each sample was recorded in forms (sample ballots) easily completed and evaluated.

Basic tastes and aroma evaluation: A small amount of honey was placed on the tongue (1 or 2 g) with a disposable spatula and allowed to dissolve for a few seconds without inspiration. The air was then released through the nose, keeping the mouth closed for the aromas to stimulate the olfactory receptors. Total intensity of aroma was evaluated proceeding as for the

smell with concentration on the mouth sensations without distraction by the tactile characteristics for at least 1-2 minutes. The taste and aroma characteristics and other mouth perceptions were then recorded.

Assessment of defects (Caramelized or burnt flavor): 1-2 g of honey sample was dissolved in the mouth and the caramelized or burnt sensation, fermentation, and intensity recorded according to the scales of intensities based on the number of minutes of perception. The defects was then assessed against the memorized families and subfamilies of the aroma and odor (Table 1).

3.7 Data Analyses

The percentage number of taxa in bloom per month was calculated by dividing number of plant species in bloom divided by total number of melliferous plants observed. The quantitative data was checked for normality using the Kolmogorov-Smirnov test.

Quantitative pollen data in Botanical and Geographical origin was subjected to analysis of variance (ANOVA) using

General Linear Model (GLM) in SPSS 20. Fixed factors and Response variable were assigned. Where ANOVA showed significant difference, Tukeys test was done to separate the means. For all tests the level of significance was alpha=0.05 and all values are reported as means.

The percentage of melliferous taxa in bloom were obtained by the formula:

$$\text{Percentage melliferous taxa in bloom/month} = \frac{\text{Number of plants in bloom in a month}}{\text{Total number of plants (86)}}$$

The Jaccards Similarity coefficient/ Jaccards index between two compared honey samples were calculated as follows:

$$\text{Jaccards index} = \frac{\text{Number of pollen types in both honey samples}}{\text{Number of pollen types in either set}} x100$$

Shannon Weaver index was used to determine the diversity of pollen types in various samples of Ogiek honeys. The Shannon =Weaver Index was determined as follows;

Shannon index= $\sum_{i=1}^{s} p \ln p$

Where p is the proportion of individuals of one particular pollen type divided by the total number of individuals found. In is the natural log, ∑= sum of calculations, s is the number of pollen types.

The frequency of occurrence of plant family pollen types were calculated by dividing the number of samples the pollen type present, by the total number of samples (27).

This value was then converted in to percentages. Niche amplitude was derived from variations and ranges obtained from the ShannonWeaverindices. Correlation analysis was carried out for associations between pollen types and seasons and site. Principal component analysis as a multivariate technique was used to transform set of correlated descriptors/variables in to

linear combinations of variables. AFriedman's test as a form of ANOVA was used to compare mean rankings of the organoleptic attributes.

For organoleptic data, ranking was used alongside the Quantitative Descriptive Analysis.

Sensory analysis results was represented using network spider plots and processed statistically using ANOVA. Type II error was minimized by increasing the number of observations in

which the conclusion is based apart from reliable judges (Lawless and Heymann, 1988; 2010). Multivariate statistical techniques was applied to QDA data. Results of sensory analysis of honeys were processed by cluster analysis, and Friedman's analysis of variance using SPSS 20. For cluster analysis a data matrix of 8x10 was prepared from 27

objects(honey samples) and 10 variables (Sites, seasons, pollen types, pollen density, honey types and Shannon weaver

diversity index). The sum of squares for Friedman's test was reduced to Log. Quantitative data collected in Botanical origin was subjected to cluster analysis as outlined by SPSS base 20. The 27 honey samples formed the operational taxonomic units.

The Euclidean distances were computed by the algorithm. For mixed variable, 2-step cluster analysis was used. Pollen density because were large were first converted in to Log before data analysis.

CHAPTER FOUR

RESULTS

4.1 Melliferous Taxa

4.1.1 Melliferous plant species in Eastern Mau

Eighty six (86) bee plants belonging to 36 families were identified. Fabaceae, Compositae and Acanthaceae were the three biggest sources of bee forage, with Fabaceae members forming the biggest proportion of melliferous taxa (24.42%) as shown in Table 4.1. Gramineae largely provided for pollen. The bee forage was contributed by trees, shrubs, herbs, and climbers. All the bee plants listed in the three study sites (Kapkembu, Nessuit, Mariashoni) with similar reward eg Nectar was listed as nectar plant (N), as pollen plant (P) and both nectar and pollen plant (NP) where the reward for foraging was different in different sites.

Table 4.1. Melliferous taxa of Eastern Mau

	Family	Species	Reward	Form
1	Acanthaceae	*Acanthus pubescens* (Thomp ex Oliv.)	N	Herb
2	Acanthaceae	*Asystasia gangetica* (L.)	N	Herb
3	Acanthaceae	*Justicia exigua* S.Moore	NP	Herb
4	Acanthaceae	*Justicia flava* (Vahl.) Vahl.	NP	Herb
5	Acanthaceae	*Odontonema strictum* Kuntze	N	Shrub
6	Agavaceae	*Agave sisaliana* Perrine ex Engelm.	N	Shrub
7	Amaranthaceae	*Achyranthes aspera* L.	N	Herb
8	Amaranthaceae	*Pupalia lappacea* (L.)A.Juss.	N	Herb
9	Anacardiaceae	*Mangifera indica* L.	NP	Tree
10	Anacardiaceae	*Rhus nataliensis* Bernh.	NP	Tree
11	Araliaceae	*Polyscias fulva*J.R. Forst. &G.Forst.	NP	Tree
12	Asphodelaceae	*Aloe secundiflora* Engl.	N	Herb
13	Asteraceae	*Aspilia mossambicensis*(OLiv.) Wild	P	Herb
14	Asteraceae	*Bothriocline fusca* (S.Moore) M.G.Gilbert	P	Herb
15	Asteraceae	*Hellianthus Annuus* L.	P	Herb
16	Asteraceae	*Tithonia diversifolia* Hemsl.	P	Shrub
17	Asteraceae	*Vernonia auriculifera* Hern	NP	Shrub
18	Astercaeae	*Solanecio mannii* (Hook.f.)	P	Shrub

19	Bignoniaceae	*Jacaranda mimosifolia* D.Don	P	Tree
20	Boraginaceae	*Cordia abyssinica* R.Br. ex A.Rich.	NP	Tree
21	Cactaceae	*Opuntia ficus-indica* (L.)Mill.	P	Shrub
22	Capparaceae	*Maerua triphylla* A.Rich.	N	Shrub
23	Caricaceae	*Carica papaya* (L.)	NP	Tree
24	Combretaceae	*Combretum molle* R.Br.ex G.Don.	N	Tree
25	Combretaceae	*Terminalia brownii* Fresen.	P	Tree
26	Convolvulaceae	*Ipomoea batatas* (L.)Lam	N	Climber
27	Curcubitaceae	*Cucurbita pepo* L.	NP	Climber
28	Curcubitaceae	*Mormadica foetida* Schumach	P	Climber
29	Euphorbiaceae	*Croton macrostachyus* Hotchst.	NP	Tree
30	Euphorbiaceae	*Croton megalocarpus* Hutch.	NP	Tree
31	Eurphobiaceae	*Euphorbia hirta* L.	NP	Tree
32	Fabaceae	*Albizia coriaria* Welw. ex Oliv.	NP	Tree
33	Fabaceae	*Acacia brevispica* (Harms) Seigler & Ebinger	NP	Tree
34	Fabaceae	*Acacia elatior* Brenan.	NP	Tree
35	Fabaceae	*Acacia mellifera* (M. Vahl.)	NP	Tree
36	Fabaceae	*Acacia polyacantha* (Willd)	NP	Tree
37	Fabaceae	*Acacia Senegal* (L.)Willd.	NP	Tree
38	Fabaceae	*Acacia tortilis* (Forssk.)	NP	Tree
39	Fabaceae	*Acacia xanthophlea*(Benth.)	NP	Tree

40	Fabaceae	*Crotalaria brevidens* L.	P	Herb
41	Fabaceae	*Delonix regia* (Bojer ex Hook.)	NP	Tree
42	Fabaceae	*Erythrina abyssinica* Lam. ex DC	NP	Tree
43	Fabaceae	*Glircidia sepium* (Jacq.)Kunth ex Walp.	N	Tree
44	Fabaceae	*Leucaena Leucocephala* (Lam.)de Wit	N	Shrub
45	Fabaceae	*Mimosa invisa*[Mart. Ex] Colla	NP	Shrub
46	Fabaceae	*Pentaclethra macrophylla* Benth.	N	Tree
47	Fabaceae	*Phaseolus vulgaris* L.	N	Herb
48	Fabaceae	*Sesbania sesban (L.)Merr.*	N	Shrub
49	Fabaceae	*Tamaridus indica* L.	NP	Tree
50	Fabaceae	*Tephrosia vogelii* Hook.f.	P	Shrub
51	Fabaceae	*Trifolium repens* L.	NP	Herb
52	Fabaceae	*Tylosema fassoglensis* Schweinf.	P	Climber
53	Graminae	*Pennisitem purpureum* Schumach.	N	Herb
54	Gramineae	*Cynodon dactylon* L.	P	Her
55	Gramineae	*Sorghum bicolor*(L.)Moench	P	Herb
56	Gramineae	*Zea mays* L.	P	Herb
57	Lamiaceae	*Leucas deflexa* Hook.f.	N	Herb
58	Lamiaceae	*Ocimum gratissimum* L.	NP	Shrub
59	Lauraceae	*Persea americana* Mill.	N	Climber
60	Malvaceae	*Hibiscus rosa-sinensis* L.	NP	Shrub

61	Malvaceae	*Malvaviscus arboreus* Cav.	N	Shrub
62	Malvaceae	*Sida acuta* Burm f.	NP	Herb
63	Meliaceae	*Melia azedarach* L.	NP	Tree
64	Moraceae	*Morus mesozygia* Stapf.	P	Shrub
65	Moringaceae	*Moringa oleifera* Lam	N	Tree
66	Musaceae	*Musa acuminata* Colla	N	Herb
67	Myrtaceae	*Callistemon citrinus* (Curtis)	NP	Tree
68	Myrtaceae	*E.grandis* (W.Hill)	N	Tree
69	Myrtaceae	*E.resinifera* (Smith)	NP	Tree
70	Myrtaceae	*Psidium Guajava* L.	NP	Shrub
71	Oleaceae	*Jasminum fluminense* L.	N	Climber
72	Oleaceae	*Olea europaea* ssp *Africana* L.	P	Tree
73	Passifloraceae	*Passiflora edulis* Sims.	NP	Climber
74	Proteaceae	*Grevillea robusta* A.Cunn.ex R. Br.	NP	Tree
75	Rhamnaceae	*Zizyphus mucronata* Willd	P	Tree
76	Rosaceae	*Eriobotrya japonica* (Thunb.)Lindl.	P	Tree
77	Rosaceae	*Prunus africana(*Hok.f.)Kalkman	NP	Tree
78	Rutaceae	*Citrus limon* (L.)	NP	Tree
79	Rutaceae	*Teclea nobilis*Hook.f	NP	Tree
80	Sterculaceae	*Dombeya torrida* (J.F.Gmel)	NP	Shrub
81	Tiliaceae	*Grewia bicolor* Juss.	N	Shrub

82	Ulmaceae	*Trema orientalis* L	NP	Shrub
83	Verbenaceae	*Lantana camara* L.	P	Shrub
84	Verbenaceae	*Stachytarpheta jamaicensis* (L.)Vahl.	N	Herb
85	Vitaceae	*Cissus rotundiflora* Vahl.	P	Climber
86	Zygophyllaceae	*Tribulis terrestris* L	P	Herb

Tree species constituted 41.86% of bee forage as shown in Figure 4.1 below. Climbers offered least of the bee forage sources while shrubs and herbs offered bee forage in almost equal proportions 23.26% and 25.58% respectively. Climbers were least foraged at 9.30%.

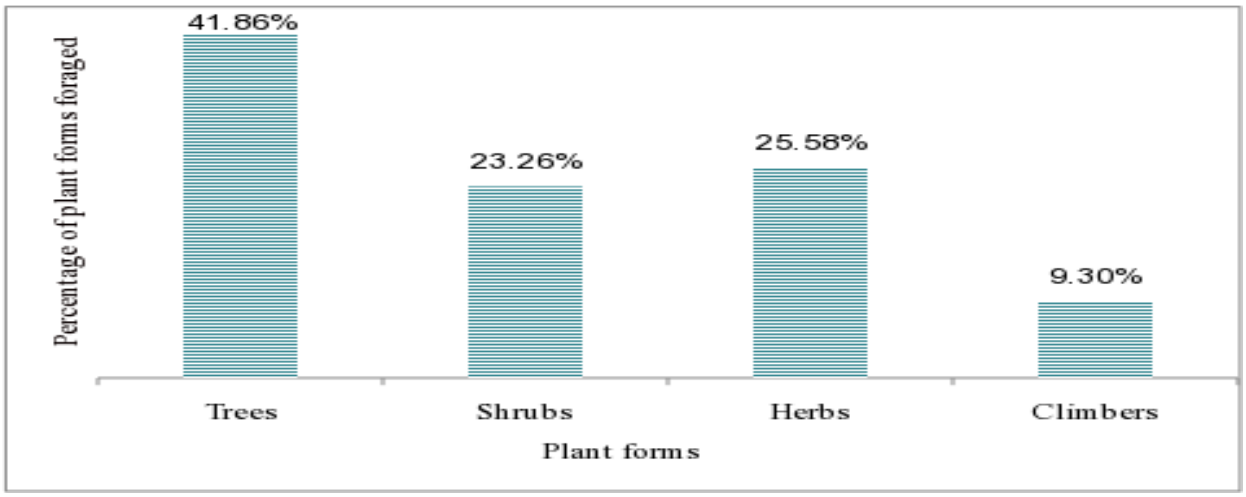

Figure 4.1. Percentage plant forms foraged by *Apis mellifera.*

In Figure 4.2, proportions of plant forms and their contribution as nectar and pollen sources are shown. The tree species provided 66.67% of the both nectar and pollen sources while the climbers offered only 5.13% of the both nectar and pollen sources. Herbs provided for the highest proportion of nectar only sources (40%).

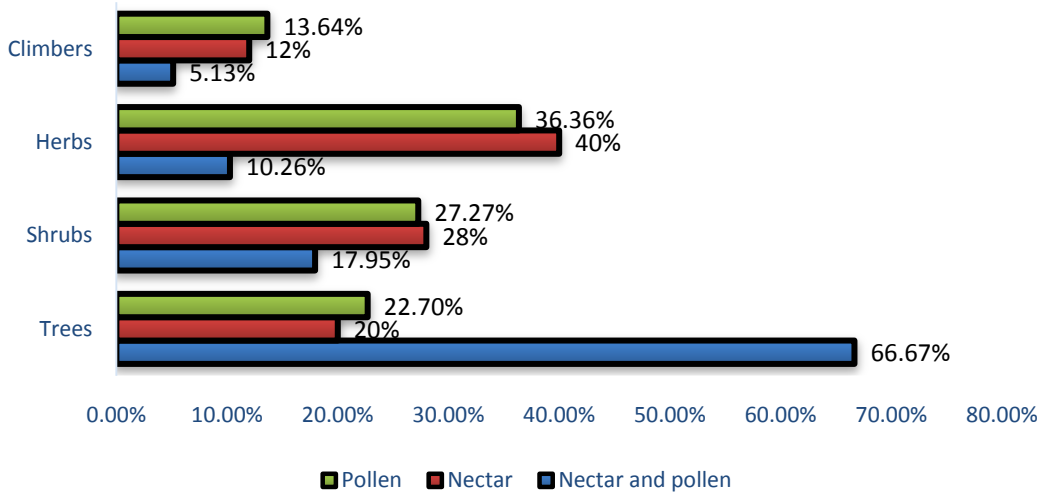

Figure 4. 2. Bee plant forms and their percentage reward of pollen, nectar and both pollen and nectar

4.2. Seasonal Availability and Floral Calendar

In Table 4.2, a continuous availability of bee forage in bloom in various months of the year is shown. The flowering months varied alongside the changing precipitation levels. The variations in flowering were observed within Genus as well as between various Genera. The mean duration in bloom varied from one month to 6 months. Some of the plants flowered more than once during the year, intermittently. Highest proportion of bee plants were observed to flower in April (59.3%) May (44.81%) and June (41.86%). The number of flowering species were lowest in December (11.63%). 54.65% of the plants flowered for 1 season, 36.05% for 2 seasons, 4.65% 3 seasons, 4.65% for the whole year.

Table 4. 2. Floral calendar for melliferous plant taxa in Eastern Mau

Family	Species	Months in bloom	Duration	Seasons
Acanthaceae	*Acanthus pubescens* (Thomp ex Oliv.)	April-May, September-October	4	C
Acanthaceae	*Asystasia gangetica* (L.)	January-June	6	B
Acanthaceae	*Justicia exigua* S.Moore	July-September	3	B
Acanthaceae	*Justicia flava* (Vahl.) Vahl.	April-May, July-September	5	C
Acanthaceae	*Odontonema strictum* Kuntze	February-March, July-August	4	C
Agavaceae	*Agave sisaliana* Perrine ex Engelm.	January, September-November	4	C
Amaranthaceae	*Achyranthes aspera* L.	February-June,	5	B
Amaranthaceae	*Pupalia lappacea* (L.)A.Juss.	March-May, August, November-December	6	D
Anacardiaceae	*Mangifera indica* L.	January, June-September	5	B
Anacardiaceae	*Rhus nataliensis* Bernh.	March-May	3	B
Araliaceae	*Polyscias fulva*J.R. Forst. &G.Forst.	April-May, September-October	4	C
Asphodelaceae	*Aloe secundiflora* Engl.	January, May, October-December	5	C
Asteraceae	*Aspilia mossambicensis*(OLiv.) Wild	May-July	3	B
Asteraceae	*Bothriocline fusca* (S.Moore) M.G.Gilbert	April-June	3	B
Asteraceae	*Hellianthus Annuus* L.	May-July	3	B
Asteraceae	*Tithonia diversifolia* Hemsl.	April-May, July	3	C
Asteraceae	*Vernonia auriculifera* Hern	January-April, October-December	7	C
Astercaeae	*Solanecio mannii* (Hook.f.)	March-May	3	B
Bignoniaceae	*Jacaranda mimosifolia* D.Don	May-September	5	B

Boraginaceae	*Cordia abyssinica* R.Br. ex A.Rich.	January-March, May-August	7	C
Cactaceae	*Opuntia ficus-indica* (L.)Mill.	April-May	2	A
Capparaceae	*Maerua triphylla* A.Rich.	April-June, October	4	C
Caricaceae	*Carica papaya* (L.)	May-July,	3	B
Combretaceae	*Combretum molle* R.Br.ex G.Don.	February-July, October-December	9	C
Combretaceae	*Terminalia brownii* Fresen.	April	1	A
Convolvulaceae	*Ipomoea batatas* (L.)Lam	May-June, August	5	C
Curcubitaceae	*Cucurbita pepo* L.	March-May	3	B
Curcubitaceae	*Mormadica foetida* Schumach	April-June,	3	B
Euphorbiaceae	*Croton macrostachyus*	March-May	3	B
Euphorbiaceae	*Croton megalocarpus*	July-November	5	B
Eurphobiaceae	*Euphorbia hirta*	March-May, July-August	5	C
Fabaceae	*Albizia coriaria* Welw. ex Oliv.	January-May	5	B
Fabaceae	*Acacia brevispica* (Harms) Seigler & Ebinger	January-December	12	E
Fabaceae	*Acacia elatior* Brenan.	February-May, September-October	6	C
Fabaceae	*Acacia mellifera* (M. Vahl.)	January-March	3	B
Fabaceae	*Acacia polyacantha* (Willd)	January, April-May,	3	C
Fabaceae	*Acacia Senegal* (L.)Willd.	February-April, July-September, November	7	C
Fabaceae	*Acacia tortilis* (Forssk.)	August-December	5	B
Fabaceae	*Acacia xanthophlea* (Benth.)	May-June, September-November	5	C
Fabaceae	*Crotalaria brevidens* L.	May-July	3	B

Fabaceae	*Delonix regia* (Bojer ex Hook.)	January, May-July	4	B
Fabaceae	*Erythrina abyssinica* Lam. ex DC	January-February	2	A
Fabaceae	*Glircidia sepium* (Jacq.)Kunth ex Walp.	January-February	2	A
Fabaceae	*Leucaena Leucocephala* (Lam.)de Wit	January-December	12	E
Fabaceae	*Mimosa invisa*	April-October	7	B
Fabaceae	*Pentaclethra macrophylla* Benth.	March-April, June-July	5	D
Fabaceae	*Phaseolus vulgaris* L.	April-May, August-September	4	C
Fabaceae	*Sesbania sesban (L.)Merr.*	March-May, August-September	5	C
Fabaceae	*Tamaridus indica* L.	March-June,	4	B
Fabaceae	*Tephrosia vogelii* Hook.f.	April	1	A
Fabaceae	*Trifolium repens* L.	March-July	5	B
Fabaceae	*Tylosema fassoglensis* Schweinf.	March	1	A
Graminae	*Pennisitem purpureum* Schumach.	February-April, August-September	5	C
Gramineae	*Cynodon dactylon* L.	January-February	2	A
Gramineae	*Sorghum bicolor*(L.)Moench	April-June	3	B
Gramineae	*Zea mays* L.	April-June	3	B
Lamiaceae	*Leucas deflexa* Hook.f.	July-October	4	B
Lamiaceae	*Ocimum gratissimum* L.	January, May	2	C
Lauraceae	*Persea americana* Mill.	April-June, August-September	5	C
Malvaceae	*Hibiscus rosa-sinensis* L.	February-April, August, October-November	6	D
Malvaceae	*Malvaviscus arboreus* Cav.	January-December	12	E

Malvaceae	*Sida acuta* Burm f.	March-May	3	B
Meliaceae	*Melia azedarach* L.	June-October	5	B
Moraceae	*Morus mesozygia* Stapf.	March-May	3	B
Moringaceae	*Moringa oleifera* Lam	January, June-August	4	B
Musaceae	*Musa acuminata* Colla	May-July	3	B
Myrtaceae	*Callistemon citrinus* (Curtis)	June-August	3	B
Myrtaceae	*E.grandis* (W.Hill)	May-July	3	B
Myrtaceae	*E.resinifera* (Smith)	January-December	12	E
Myrtaceae	*Psidium Guajava* L.	March-July	5	B
Oleaceae	*Jasminum fluminense* L.	April-May	2	A
Oleaceae	*Olea europaea* ssp *Africana* L.	April-June, November-December	5	C
Passifloraceae	*Passiflora edulis* Sims.	May	1	A
Proteaceae	*Grevillea robusta* A.Cunn.ex R. Br.	January-May, August-September	7	C
Rhamnaceae	*Zizyphus mucronata* Willd	August-September	2	A
Rosaceae	*Eriobotrya japonica* (Thunb.)Lindl.	January-February, November	3	C
Rosaceae	*Prunus Africana (*Hok.f.)Kalkman	January-April, August-September	6	C
Rutaceae	*Citrus limon* (L.)	January-February, June-August	5	C
Rutaceae	*Teclea nobilis*	May	1	A
Sterculaceae	*Dombeya torrida* (J.F.Gmel)	May, August-October	4	C
Tiliaceae	*Grewia bicolor* Juss.	January-April	4	B
Ulmaceae	*Trema orientalis* L	June-August	3	B

Verbenaceae	*Lantana camara* L.	January,March-May, July	5	D
Verbenaceae	*Stachytarpheta jamaicensis* (L.)Vahl.	April-May, September-October	4	C
Vitaceae	*Cissus rotundiflora* Vahl.	Feb-March, July	3	C
Zygophyllaceae	*Tribulis terrestris* L	March-May,September-November	6	C

Key: N= Nectar= Pollen, NP=Nectar; A- 1 season less than 2 months, B- 1 season more than 2 months, C-Two seasons, season, D- Three seasons, E-Year round. The flowering pattern ranged from one season (1month) to year round (12 months).

Trees had the highest mean number of forage species per month (13.75) throughout the year followed by the shrubs (7.83), herbs (6.42) and climbers (1.75) respectively as shown in Figure 4.3 below. The highest number of forage species (17) were recorded in trees, in April. There were only 10 plant species that flowered in December and 51 plant species flowering in April. Highest proportion of bloom of bee plants was observed during the rainy season. There was observed a steady trend of reduction of availability of bee plants towards the dry periods ofNovember and December that coincided with drought.

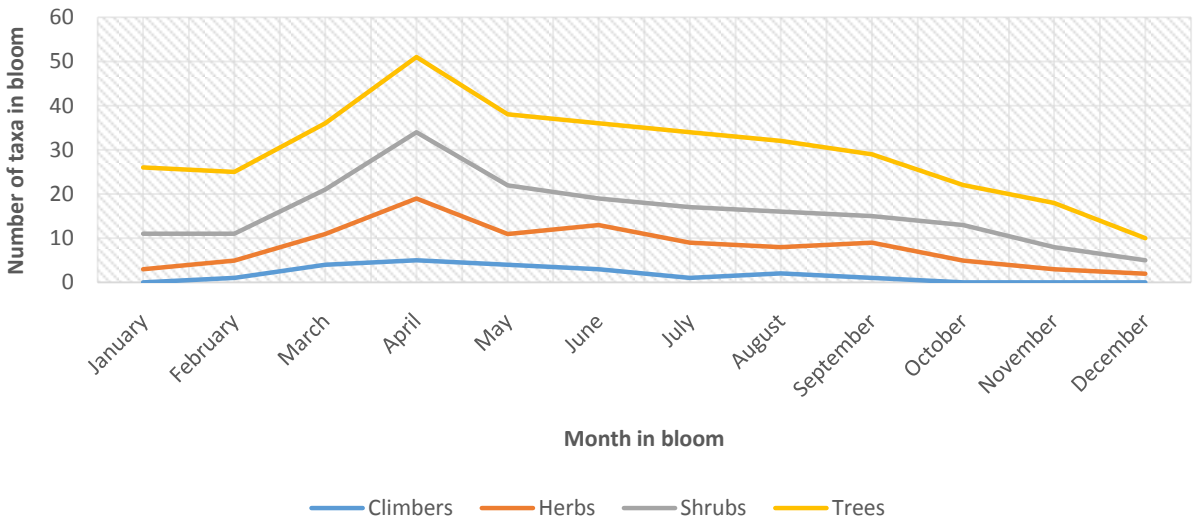

Figure 4.3: Number of plant taxa in bloom across the year

In Figure 4.4., the flowering patterns of bee plants are shown. There were very limited proportion of bee plants that bloomed year round. Most bee plants foraged for one season >2months or two seasons with very few flowering for one season less than 2 months. Climbers formed the largest proportion (37.5%) of bee plants foraged for one season less than 2 months. No climber was foraged for three seasons or year round. 10% of the shrubs flowered year round. Its only shrubs and trees that flowered year round. Most of the bee

plants flowered for two seasons and for one season greater than 2 months. Three season flowering pattern was observed in trees, shrubs and herbs.

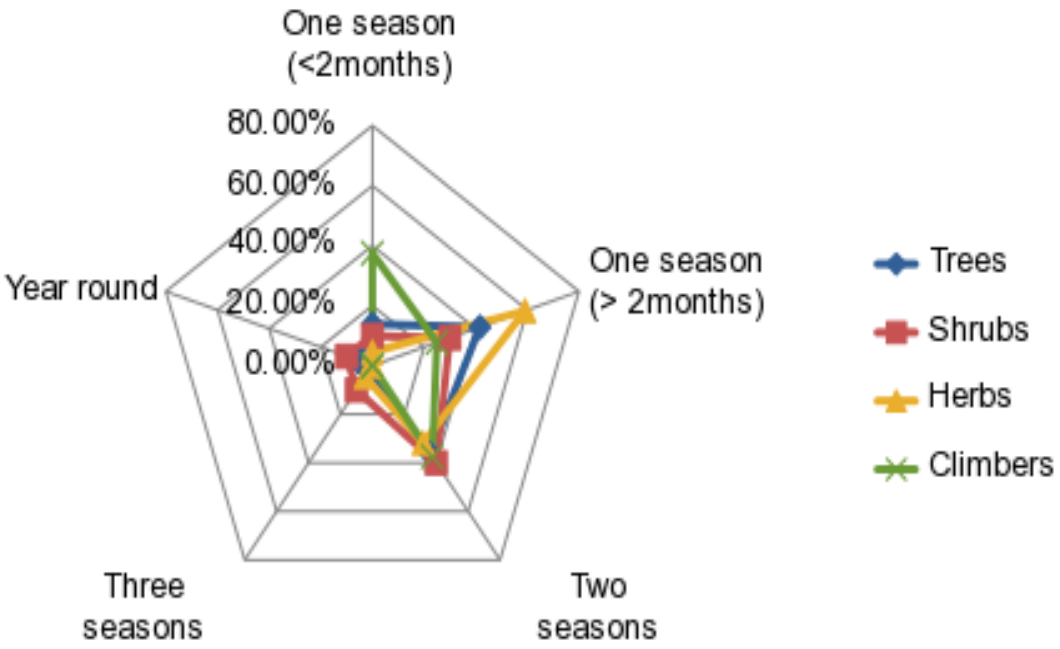

Figure 4.4: Flowering patterns for different plant forms.

4.3 Geographical Origin

Table 4.3. shows frequency of occurrence of pollen types in the 27 Ogiek honey samples studied. Fabaceae pollen types existed in 100% of the honey samples. The lowest frequency of occurrence was 3.7%, one honey sample. Fabaceae included 19.7% of the total pollen contributed by various taxa.

Table 4.3. Frequency of occurrence of pollen types from various taxa

Family	% of total types	Frequency of occurrence (%)	Pollen types
Acanthaceae	6.6	55.6	*Asystasia gangetica (L.), Asystasia gangetica ,Acanthus pubescens ,Justicia exigua ,Justicia flava ,Odontonema strictum*
Agavaceae	1.3	22.2	*Agave sisaliana*
Amaranthaceae	2.6	48.1	*Achyranthes aspera, Pupalia lappacea*
Anarcardiaceae	2.6	33.3	*Mangifera indica,Rhus nataliensis*
Araliaceae	1.3	7.4	*Polyscias fulva*
Asphodelaceae	1.3	37.0	*Aloe secundiflora*
Asteraceae	6.6	88.9	*Aspilia mossambicensis, Bothriocline fusca, Hellianthus Annuus, Tithonia diversifolia,Vernonia auriculifera*
Bignoniaceae	1.3	7.45	*Jacaranda mimosifolia*
Borognaceae	1.3	59.3	*Cordia abyssinica*
Cactaceae	1.3	3.7	*Opuntia ficus-indica*
Capparaceae	1.3	11.1	*Maerua triphylla*
Caricaceae	1.3	18.5	*Carica papaya*
Combrateceae	2.6	48.1	*Terminalia brownii, Combretum molle*
Convolvulaceae	1.3	22.2	*Ipomoea batatas*
Cucurbitaceae	2.6	7.4	*Cucurbita pepo, Mormadica foetida*
Euphorbiaceae	2.6	51.9	*Croton spp., Euphorbia hirta*

Fabaceae	19.7	100.0	*Acacia spp.,Albizia coriaria,Crotalaria brevidens,Delonix regia,Erythrina abyssinica,Glircidia sepium,Leucaena Leucocephala,Mimosa invisa,Pentaclethra macrophylla,Phaseolus vulgaris,Sesbania sesban, Tamaridus indica,Tephrosia vogelii,Trifolium repens,Tylosema spp.,*
Gramineae	5.3	22.2	*Cynodon dactylon,Pennisitem purpureum,Sorghum bicolor,Zea mays*
Lamiaceae	2.6	18.5	*Leucas deflexa,Ocimum gratissimum*
Lauraceae	1.3	7.4	*Persea americana*
Malvaceae	2.6	22.2	*Malvaviscus arboreus,Sida acuta*
Meliaceae	1.3	11.1	*Melia azedarach*
Moraceae	2.6	3.7	*Morus mesozygia*
Moringaceae	2.6	3.7	*Moringa Oleifera*
Musaceae	1.3	7.4	*Musa acuminate*
Myrtaceae	3.9	59.3	*Callistemon citrinus,Eucalyptus spp., Psidium Guajava*
Oleaceae	2.6	11.1	*Jasminum fluminense, Olea europaea*
Passifloraceae	1.3	3.7	*Passiflora edulis*
Pinaceae	1.3	7.4	*Pinus type*
Proteaceae	1.3	22.2	*Grevillea robusta*
Rhamnaceae	1.3	7.4	*Zizyphus macronata*
Rosaceae	2.6	14.8	*Eriobotrya japonica,Prunus Africana*
Rutaceae	2.6	7.4	*Citrus limon,Teclea nobilis*
Sterculaceae	1.3	14.8	*Dombeya torrida*

Tiliaceae	1.3	11.1	*Grewia bicolor*
Ulmaceae	1.3	7.4	*Trema orientalis L*
Verbenaceae	1.3	25.9	*Lantana camara*
Vitaceae	1.3	3.7	*Cissus rotundiflora*
Zygophyllaceae	1.3	3.7	*Tribulis terrestris*

Table 4.4. shows the various frequency classes and range of the various pollen types recorded in various honey samples The highest frequency of occurrence was 85.2% while the lowest was 3.7%.11 species including *Opuntia ficus-indica, Cucurbita pepo, Mormadica foetida, Crotalaria brevidens, Delonix regia, Pentaclethra macrophylla , Sorghum bicolor, Morus mesozygia, Moringa Oleifera, Jasminum fluminense, Passiflora edulis, Eriobotrya japonica, Citrus limon, Teclea nobilis, Tribulis terrestris,* were only observed in one honey sample each.The very frequent pollen types were *Vernonia auriculifera* (55.6% of the samples), *Cordia abyssinica* (59.3%) , *Acacia* spp (85.2% of the samples).

Table 4.4: Frequency classes and range of pollen types in honey samples studied.

Frequency class	Frequency Range (%)	Number of types	Proportion of types	Species
<10% (Rare)	3.7{4.0}7.4	36	47.4%	*Justicia exigua, Pupalia lappacea,Rhus nataliensis,Polyscias fulva, Hellianthus Annuus, Jacaranda mimosifolia, Opuntia ficus-indica, Cucurbita pepo, Mormadica foetida, Euphorbia hirta,Crotalaria brevidens, Delonix regia, Pentaclethra macrophylla,Phaseolus vulgaris ,Tephrosia vogelii ,Tylosema spp., Pennisitem purpureum, Sorghum bicolor, Zea mays,Ocimum gratissimum, Persea americana,Sida acuta,Morus mesozygia, Moringa Oleifera, Musa acuminata, Callistemon citrinus, Jasminum fluminense, Passiflora edulis, Pinus type, Zizyphus mucronata, Eriobotrya japonica, Citrus limon,Teclea nobilis,Trema orientalis, Lantana camara, Cissus rotundiflora, Tribulis terrestris,*
10-20% (Infrequent)	11.1{14}18.5	21	27.6%	*Asystasia gangetica , Acanthus pubescens, Justicia flava ,Odontonema strictum, Bothriocline fusca, Maerua triphylla, Carica papaya, Terminalia brownii, Erythrina abyssinica, Glircidia sepium, Sesbania sesban,Tamaridus indica,Cynodon dactylon, Leucas deflexa,Malvaviscus arboreus,Melia azedarach, Psidium Guajava, Olea europaea, Prunus africana, Dombeya torrida, Grewia bicolor,*

20-50% (Frequent)	22.2{29.0}40.7	16	21.1%	*Agave sisaliana , Achyranthes aspera, Mangifera indica,Aloe secundiflora, Aspilia mossambicensis,Tithonia diversifolia,Combretum molle, Ipomoea batatas, Croton spp., Albizia coriaria, Leucaena Leucocephala ,Mimosa invisa,Trifolium repens , Eucalyptus spp., Grevillea robusta, Lantana camara*
>50% (Very Frequent)	55.6{67.0}85.2	3	3.9%	*Vernonia auriculifera, Cordia abyssinica, Acacia* spp.

Table 4.5 shows how the number of pollen types in the 27 honey samples varied between various seasons and the three sites of Kapkembu, Nessuit and Mariashoni. The number of pollen types ranged from 8 (MA-S3-DE, NE-S3-DE) to 15(MA-S1-AP, MA-S2-AP, MA-S3-AP) the mean pollen types was 11.307. The highest number of pollen types was observed in honey samples collected in April and August. The number of pollen types ranged from (10-15) in April; (11-15) in August; and (8-11) in December. Variations were observed on the number of pollen types in samples collected during various seasons and sites.

Table 4.5: Number of pollen types in various honey samples collected from Eastern Mau

Sample	Site	Season	Pollen Types
KA-S1-AP	Kapkembu	April	13
KA-S2-AP	Kapkembu	April	10
KA-S3-AP	Kapkembu	April	12
MA-S1-AP	Marioshoni	April	15
MA-S2-AP	Marioshoni	April	15
MA-S3-AP	Marioshoni	April	15
NE-S1-AP	Nessuit	April	11
NE-S2-AP	Nessuit	April	12
NE-S3-AP	Nessuit	April	12
KA-S1-AU	Kapkembu	August	12
KA-S2-AU	Kapkembu	August	13
KA-S3-AU	Kapkembu	August	12
MA-S1-AU	Mariashoni	August	12
MA-S2-AU	Mariashoni	August	11
MA-S3-AU	Mariashoni	August	15
NE-S1-AU	Nessuit	August	14
NE-S2-AU	Nessuit	August	12
NE-S3-AU	Nessuit	August	13
KA-S1-DE	Kapkembu	December	11
KA-S2-DE	Kapkembu	December	10

KA-S3-DE	Kapkembu	December	10
MA-S1-DE	Mariashoni	December	9
MA-S2-DE	Mariashoni	December	10
MA-S3-DE	Mariashoni	December	8
NE-S1-DE	Nessuit	December	10
NE-S2-DE	Nessuit	December	8
NE-S3-DE	Nessuit	December	11

In table 4.6 the pollen type variation in seasons are shown. The mean number of pollen types (Table 4.6) were highest in April (12.78), and lowest in December (9.67). There was highest deviation in pollen types within the samples in April (1.86) and lowest in (1.12).

Table 4.6: Pollen type means and variations of honey samples collected in various seasons in Eastern Mau.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
April	9	12.8	1.86	.62	11.4	14.2	10.0	15.0
August	9	12.7	1.22	.41	11.7	13.6	11.0	15.0
December	9	9.7	1.12	.37	8.8	10.5	8.0	11.0
Total	27	11.7	2.02	.39	10.9	12.5	8.0	15.0

Table 4.7 shows pollen type variation in regions. The number of pollen types ranged from 8 to 15. The highest number of pollen types was observed from Mariashoni mesoregion (15). The mean number of pollen types was highest (12.2) in Mariashoni and 11.4 in both Kapkembu and Nessuit.

Table 4.7: Pollen type means and variations of honey samples collected in various regions in Eastern Mau.

	N	Mean	SD	Std. Error	95% Confidence Interval		Min.	Max.
					Lower bound	Upper bound		
Kapkembu	9	11.4	1.24	.41	10.5	12.4	10.00	13.0
Mariashoni	9	12.2	2.86	.95	10.0	14.4	8.00	15.0
Nessuit	9	11.4	1.74	.58	10.1	12.8	8.00	14.0
Total	27	11.7	2.02	.39	10.9	12.5	8.00	15.0

Table 4.8 shows the level of diversity of pollen types based on Shannon Weaver diversity of pollen types. The diversity of pollen in honey varied in various seasons and honey samples. Ranged from 1.215 to 3.332.

Table 4.8: Shannon Weaver diversity index of pollen types in honey samples collected from Eastern Mau region

Sample	Site	Season	Shannon Weaver diversity index
KA-S1-AP	Kapkembu	April	3.036
KA-S2-AP	Kapkembu	April	2.708
KA-S3-AP	Kapkembu	April	2.936
MA-S1-AP	Mariashoni	April	2.832
MA-S2-AP	Marioshoni	April	1.925
MA-S3-AP	Marioshoni	April	2.276
NE-S1-AP	Nessuit	April	2.524

NE-S2-AP	Nessuit	April	2.370
NE-S3-AP	Nessuit	April	2.191
KA-S1-AU	Kapkembu	August	2.191
KA-S2-AU	Kapkembu	August	2.205
KA-S3-AU	Kapkembu	August	2.146
MA-S1-AU	Marioshoni	August	2.736
MA-S2-AU	Marioshoni	August	1.215
MA-S3-AU	Marioshoni	August	1.839
NE-S1-AU	Nessuit	August	1.936
NE-S2-AU	Nessuit	August	2.832
NE-S3-AU	Nessuit	August	2.020
KA-S1-DE	Kapkembu	December	3.332
KA-S2-DE	Kapkembu	December	2.168
KA-S3-DE	Kapkembu	December	2.168
MA-S1-DE	Marioshoni	December	2.639
MA-S2-DE	Marioshoni	December	1.677
MA-S3-DE	Marioshoni	December	2.431
NE-S1-DE	Nessuit	December	2.164
NE-S2-DE	Nessuit	December	1.475
NE-S3-DE	Nessuit	December	2.736

In Table 4.9 the mean Shannon Weaver Index had the highest value (2.53) in honey samples collected in April. The maximum Shannon Weaver index (3.04) was also observed in April.

The mean Shannon weaver index was highest in April (2.53). December was relatively a drier month than any other season, the Shannon weaver index was higher than in honey samples collected in August. The overall mean Shannon weaver diversity index was 2.32 across all seasons and sites of sample of collection. Although there was no significant variation of Shannon Weaver index with regard to sites and seasons. There was more variation between than within the sites and seasons. Maximum Shannon Weaver index was observed in a sample collected in April (3.04) and in Kapkembu (3.33). Biggest range of Shannon Weaver index (1.48-3.33) with regard to season was observed in December.

Table 4.9: Mean values and standard deviation of Shannon Weaver index in different seasons of honey collection

Season	N	Mean	S. D	95% Confidence Interval for Mean		Min.	Max.
				Lower bound	Upper bound		
April	9	2.53	.37	.12	2.25	1.93	3.04
August	9	2.12	.48	.16	1.76	1.22	2.83
December	9	2.31	.56	.19	1.88	1.48	3.33
Total	27	2.32	.49	.09	2.13	1.22	3.33

Biggest range of Shannon Weaver index (1.22-2.83) with regard to sites was observed in Marioshoni (Table 4.10) Maximum and minimum Shannon weaver index across sites recorded was 3.33 and 1.22 respectively. The mean Shannon weaver index was 2.32 across all mesoregions.

Table 4.10: Mean values and standard deviation of Shannon Weaver index in different mesoregions of honey collection

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower bound	Upper bound		
Kapkembu	9	2.54	.46	.15	2.19	2.90	2.15	3.33
Mariashoni	9	2.17	.55	.18	1.75	2.59	1.22	2.83
Nessuit	9	2.25	.42	.14	1.93	2.57	1.48	2.83
Total	27	2.32	.49	.09	2.13	2.52	1.22	3.33

Table 4.11 shows Jaccards similarity index of pollen types between Ogiek honey samples in Eastern Mau forest. Jaccards similarity index ranged from 0.00 to 0.588 based on pair wise comparison between individual honey samples collected from the 3 mesoregions. The highest Jaccards similarity was observed in a comparison between (NE-S3-8) and NE-S1-8) within same site, Nessuit but different samples obtained from different colonies in different sites, but same period of August. Maximum dissimilarity was observed in samples from different seasons/months as well as sites. On average the most similar honey sample to the rest was (MA-S1-AP=21.9%) while the least similar to the rest of the samples was (KA-S2-AP).

Table 4.11: Jaccards similarity index of pollen types between Ogiek honey samples in Eastern Mau forest.

	Jaccards Index		
Sample	Min	Max	Average
KA-S1-4	0.000[MA-S2-12]	0.471 [KA-S3-4]	0.174
KA-S2-4	0.000[NE-S3-12]	0.375 [NE-S2-4]	0.134
KA-S3-4	0.000[MA-S2-12]	0.471 [KA-S1-4]	0.177
MA-S1-4	0.353[KA-S1-4]	0.500[NE-S3-4]	0.219
MA-S2-4	0.217[KA-S1-4]	0.318[MA-S1-4]	0.165
MA-S3-4	0.273[KA-SI-4]	0.318[MA-S1-4]	0.210
NE-S1-4	0.000[MA-S2-12]	0.368[MA-SI-4]	0.210
NE-S2-4	0.042[NE-S1-8]	0.412[KA-S3-8]	0.181
NE-S3-4	0.000[MA-S2-12]	0.500[MA-S1-4]	0.195
KA-S1-8	0.038[MA-S1-4]	0.250[KA-S2-8]	0.153
KA-S2-8	0.080[MA-S1-4]	0.278[NE-SI-12]	0.185
KA-S3-8	0.048[MA-S2-12]	0.412[NE-S2-4]	0.214
MA-S1-8	0.048[MA-S2-12]	0.333[KA-S3-8]	0.195
MA-S2-8	0.048[KA-S1-12]	0.316[MA-S1-8]	0.202
MA-S3-8	0.042[KA-S1-12]	0.316[KA-S3-8]	0.184
NE-S1-8	0.040[NE-S3-12]	0.588[NE-S3-8]	0.184
NE-S2-8	0.000[NE-S3-12]	0.350[NE-S1-8]	0.170
NE-S3-8	0.000[NE-S3-12]	0.588[NE-S1-8]	0.184
KA-S1-12	0.042[MA-S3-8]	0.313[KA-S2-12]	0.161
KA-S2-12	0.043[MA-S3-8]	0.429[KA-S3-12]	0.177
KA-S3-12	0.042[MA-S2-4]	0.429[KA-S2-12]	0.199
MA-S1-12	0.100[KA-S1-4]	0.357[KA-S3-12/NE-S1-12]	0.203
MA-S2-12	0.000[KA-S1-4/KA-S3-4/NE-S1-4/NE-S34]	0.250[KA-S3-12/NE-S1-12]	0.135
MA-S3-12	0.167[KA-S1-4/KA-S2-8]	0.385[KA-S3-12]	0.203
NE-S1-12	0.150[KA-S1-4]	0.357[MA-S1-12]	0.210
NE-S2-12	0.045[MA-S1-4]	0.267[MA-S2-8]	0.145
NE-S3-12	0.000[KA-S2-4/NE-S2-8/NE-S3-8]	0.333[MA-S1-12/NE-S1-12]	0.146

A correlation analysis showed a positive significant correlation between pollen types and pollen density in the honey samples (Table 4.12). There was a negative significant correlation of -0.657, (α=0.05) between the number of pollen types and seasons in which the honey samples were collected.

Table 4.12: Correlations between number of pollen type and other variables of honey collected from Eastern Mau forest, Kenya.

Statistic	Variable x	Variable y	Correlation coefficient	Sig. (2-tailed)
Pearson	Pollen types	Shannon Weaver	0.047	0.815
Pearson	Pollen types	Pollen density	0.679**	0.000
Spearman's rho	Pollen types	Sites	0.12	0.953
Spearman's rho	Pollen types	Seasons	-0.657**	0.000
Spearman's rho	Pollen type	Honey types	0.407*	0.037

4.4 Botanical Origin

Table 4.13 shows the pollen density and honey types from honey samples from Eastern Mau Highest and lowest pollen density were observed respectively from Mariashoni (Log 5.205) and Kapkembu (Log 4.680) mesoregion.

Table 4.13: Pollen density and honey types from honey samples from Eastern Mau

Sample	Site	Season	Log (Pollen Density)
KA-S1-AP	Kapkembu	April	4.961
KA-S2-AP	Kapkembu	April	5.004
KA-S3-AP	Kapkembu	April	5.009
MA-S1-AP	Marioshoni	April	5.192
MA-S2-AP	Marioshoni	April	5.205
MA-S3-AP	Marioshoni	April	5.194
NE-S1-AP	Nessuit	April	5.032
NE-S2-AP	Nessuit	April	5.008
NE-S3-AP	Nessuit	April	5.063
KA-S1-AU	Kapkembu	August	4.892
KA-S2-AU	Kapkembu	August	4.890
KA-S3-AU	Kapkembu	August	4.921
MA-S1-AU	Marioshoni	August	5.121
MA-S2-AU	Marioshoni	August	5.119
MA-S3-AU	Marioshoni	August	5.130
NE-S1-AU	Nessuit	August	4.953
NE-S2-AU	Nessuit	August	4.919
NE-S3-AU	Nessuit	August	4.990
KA-S1-DE	Kapkembu	December	4.764
KA-S2-DE	Kapkembu	December	4.680
KA-S3-DE	Kapkembu	December	4.692
MA-S1-DE	Marioshoni	December	4.898
MA-S2-DE	Marioshoni	December	4.888
MA-S3-DE	Marioshoni	December	4.893
NE-S1-DE	Nessuit	December	4.746
NE-S2-DE	Nessuit	December	4.820
NE-S3-DE	Nessuit	December	4.886

In Table 4.14 the mean pollen density was highest in April and lowest in December. The pollen density in December was the least varied amongst the three study sites.

Table 4.14: Mean Pollen density (Log) of honey samples in different months of honey sample collection

Month	N	Mean	Std. Deviation	Minimum	Maximum
April	9	5.07	0.10	4.96	5.21
August	9	4.99	0.10	4.89	5.13
December	9	4.81	0.09	4.68	4.90
Total	27	4.96	0.15	4.68	5.21

A post hoc analysis was carried out as shown in Table 4.15 below. There was significant variation in the mean pollen density between samples. The significant variation (α=0.05) arose between April and December samples, and August and December honey samples.

Table 4. 15: Tukeys HSD Post-hoc multiple comparison of pollen density(Log) between honey samples collected in different months from Eastern Mau forest.

Statistic	(I) Season	(J) Season	(I-J) Mean difference	Sig.	95% Confidence interval	
Tukeys HSD	April	August	0.08	0.19	-0.03	0.19
	April	December	0.27*	0.00	0.15	0.37
	August	April	-0.08	0.19	-0.19	0.03
	August	December	0.19*	0.00	0.07	0.30
	December	April	-0.27*	0.00	-0.37	-0.15
	December	August	-0.19*	0.09	-0.30	-0.72

* The mean difference is significant at 0.05 level.

There was a significant variation (α=0.05)between the pollen densities of honey samples collected from various mesoregions as shown in Table 4.16. The variation was contributed by honey samples collected from Mariashoni and Kapkembu.

Table 4.16: Tukeys HSD Post-hoc multiple comparison of pollen density between honey samples collected from different mesoregions of Eastern Mau forest.

Statistic	(I) Mesoregion	(J) Mesoregion	(I-J) Mean difference	Sig.	95% Confidence interval	
Tukeys HSD	Kapkembu	Mariashoni	-0.20*	0.05	-0.35	-0.06
	Kapkembu	Nessuit	-0.07	0.49	-0.21	0.08
	Mariashoni	Nessuit	0.14	0.07	-0.01	0.28
	Mariashoni	Kapkembu	0.20*	0.05	0.06	0.35
	Nessuit	Mariashoni	-0.14	0.07	-0.28	0.01
	Nessuit	Kapkembu	-0.07	0.49	-0.08	0.21

* The mean difference is significant at 0.05 level.

Table 4.17 shows pollen type frequencies and botanical honey types in Eastern Mau forest. It shows the Botanical Origin of each of the 27 Ogiek honey samples. 8 monofloral honey samples were observed. Five honey samples lacked the secondary pollen types. Unifloral honey samples were observed from the three mesoregions of Eastern Mau forest. 50% of the unifloral honey were collected in April (2016). Botanical origin from predominant pollen types were *Acacia* spp type, *Eucalyptus* type, *Croton* spp. type, *Albizia coriaria* type, *Cordia abyssinica* type, and *Vernonia auriculifera* type. The extent of predominance ranged from (47.1%-66.40%), there was bifloral honey observed in MA-S1-DE sample (*Vernonia auriculifera* type and *Croton* spp. type, 46.0% and 47.50% respectively). Secondary pollen ranged from (16.4%-43.4%). All honey samples were floral honey. 29.63% were unifloral honey while the rest were multifloral/heterofloral honey. Unifloral honey was observed from the three mesoregions of Eastern Mau forest.50% of the unifloral honey were collected in April during the main bloom, 37.5% in August, and 12.5% in December. 50% of the samples were collected from Mariashoni(April-3, August-1), 37.5% from Kapkembu (August-2 and December-1), and 12.5% from Nessuit (April). Apart from Predominant pollen type there

were secondary pollen, importantminor or minor pollen. Secondary pollen ranged from (16.4%-43.4%),

Table 4.17: Pollen type frequencies classes in honey samples collected in Eastern Mau.

Sample	Predominant pollen	Secondary pollen	Important minor pollen	Minor pollen
KA-S1-AP		*Vernonia uriculifera* (18%) ,*Cordia abyssinica* 17.50%), *Acacia* spp (33.6%). *Albizia coriaria* (20%)	*Eucalyptus* spp.(4.70%), *Grevillea robusta* (3.90%),	*Asystasia gangetica* (0.50%), *Achyranthes aspera* (0.10%), *Malvaviscus arboreus* (0.10%), *Moringa Oleifera* (0.10%), *Prunus africana* (0.40%), *Cissus rotundiflora* (0.90%)
KA-S2-AP		*Acacia* spp (30%), *Grevillearobusta* (16.4%),	*Cordia abyssinica* (15%), *Albizia coriaria* (14%), *Achyranthes aspera* (5%)	*Achyranthes aspera* (5.0%), *Sida acuta* (0.8%), *Meliaazedarach* (0.60%), *Lantana camara* 0.60%)
KA-S3-AP		*Vernonia uriculifera* (24.10%) *Acacia* spp (36%), *Psidium Guajava* (17%),	*Eucalyptus* spp.(13.50%),	*Achyranthes aspera* (2.40%), *Moringa Oleifera* (0.10%), *Jasminum fluminense* (0.80%),*Olea europaea* ssp *Africana* (0.70%), *Pinus* type (0.70%), Grevillea *robusta* (2.80%), *Prunus africana* (0.60%), *Lantanacamara* (0.80%)
MA-S1-AP	*Acacia* spp.(65%)		*Vernonia auriculifera* (4.00%), *Cordia abyssinica* (9.00%), *Erythrina abyssinica* (3.00%), *Trifolium repens* (4.00%),	*Odontonema strictum* (0.6%), *Achyranthes aspera* (0.5%) *Aloe secundiflora* (0.3%), *Terminalia brownii* (0.40%), *Ipomoea batatas* (0.2%), *Euphorbia hirta* (0.60%), *Tamaridus indica*

			Eucalyptus spp. (9.00%), *Grevillea robusta* (6.00%),	(0.30%), *Zea mays* (0.70%),
MA-S2-AP	*Acacia* spp.(55.8%)	*Tithonia diversifolia* (17.80%)	*Asystasia gangetica* (5%), *Erythrina abyssinica* (6.00%), *Leucaena Leucocephala* (3.50%), *Sesbania sesban* (3.40%), *Grevillea robusta* (4.00%)	*Achyranthes aspera* (0.7%), *Rhus nataliensis* (0.6%), *Vernonia auriculifera* (0.60%),*Terminalia brownii* (0.30%), *Euphorbia hirta* (0.40%), *Cynodon dactylon* (0.20%), *Zea mays* (0.30%), *Grewia bicolor* (1.40%)
MA-S3-AP	*Eucalyptus* spp.(56.50%)	*Aspilia mossambicensis* (16.8%)	*Vernonia auriculifera* (3.40%), *Cordia abyssinica* (4.10%), *Acacia* spp.(3.40%), *Albizia coriaria* (6.00%), *Erythrinaabyssinica* (7.00%),	*Odontonema strictum* (0.30%), *Aloe secundiflora* (0.40%) , *Leucaena Leucocephala* (0.30%), *Tamaridus indica* (0.40%), *Cynodon dactylon* (0.30%), *Sorghum bicolor* (0.50%), *Prunus africana* (0.40%), *Grewia bicolor* (0.20%)
NE-S1-AP	*Croton* spp.(60%)		*Achyranthes aspera* (3.7%), *Cordia abyssinica* (4.10%), *Acacia* spp. (5.90%), *Glircidia sepium* (4.00%), *Trifoliumrepens* (3.50%)	*Vernonia auriculifera* (0.60%), *Terminalia brownii* (0.60%), *Ipomoea batatas* (0.40%), *Callistemon citrinus* (0.90%), *Olea europaea* (0.60%)

NE-S2-AP		*Albizia coriaria* (19.50%), *Leucaena Leucocephala* (17.80%), *Tamaridus indica* (18.00%)	*Vernonia auriculifera* (9.60%), *Cordia abyssinica* (10.70%), *Croton* spp. (11.10%), *Grevillea robusta* (9.90%)	*Asystasia gangetica* (0.5%), *Odontonema strictum* (0.7%), *Achyranthes aspera* (0.3%), *Sida acuta* (1.30%), *Lantana camara* (0.60%)
NE-S3-AP		*Acacia* spp. (24.00%)	*Cordia abyssinica* (10.50%), *Albizia coriaria* (11.00%), *Sesbania sesban* (13.00%), *Trifolium repens* (8.70%)	*Odontonema strictum* (2.6%), *Achyranthes aspera* (2.6%), *Ipomoea batatas* (0.90%), *Tamaridus indica* (0.60%), *Malvaviscus arboreus* (0.80%), *Eucalyptus spp. (2.30%)*
KA-S1-AU	*Albizia coriaria* (47.10%)	*Mangifera indica* (17.4%), *Terminalia brownii* (23.00%), *Croton* spp. (16.30%)	*Sesbania sesban* (8.20%)	*Acacia* spp.(0.50%), *Asystasia gangetica* (0.6%), *Polyscias fulva* (0.3%), *Bothriocline fusca* (2.00%), *Hellianthus Annuus* (2.90%), *Jacaranda mimosifolia* (2.70%), *Maerua triphylla* (0.30%), *Carica papaya* (1.70%)
KA-S2-AU	*Cordia abyssinica* (56%)	*Acacia* spp. (18.60%)	*Justicia exigua* (6%), *Rhus nataliensis* (3.8%), *Combretum molle* (8.00%), *Albizia coriaria* (4.30%)	*Asystasia gangetica* (0.6%), *Pupalia lappacea* (0.3%), *Aloe secundiflora* (0.7%), *Opuntia ficus-indica* (0.70%), *Carica papaya* (0.20%), *Croton* spp.(0.60%), *Glircidiasepium* (0.20%)

KA-S3-AU		*Mangifera indica* (27.00%), *Vernonia auriculifera* (34%)	*Justicia flava* (7%), *Cordia abyssinica* (13%), *Croton* spp. (10.00%), *Albiziacoriaria* (4.50%)	*Odontonema strictum* (0.5%), *Achyranthes aspera* (0.7%), *Aloe secundiflora* (0.3%), *Aspilia mossambicensis* (2.10%), *Carica papaya* (0.50%), *Lantana camara* (0.40%)
MA-S1-AU	*Croton* spp. (50.20%)		*Mangifera indica* (4.00%), *Vernoniaauriculifera* (12.60%), *Cordia abyssinica* (8.30%), *Acacia* spp. (14.00%)	*Justicia flava* (0.70%), *Mormadica foetida* (0.40%), *Persea americana* (2.90%), *Trifolium repens* (3.00%), *Psidium Guajava* (2.70%), *Citrus limon* (0.50%), *Lantana camara* (0.70%)
MA-S2-AU		*Vernonia auriculifera* (30.00%), *Acacia* spp. (29.00%)	*Mangifera indica* (14.50%), *Mimosainvisa* (14.80%), *Trifolium repens* (3.60%)	*Aspilia mossambicensis* (0.50%), *Tithonia diversifolia* (2.80%), *Combretum molle* (0.60%), *LeucaenaLeucocephala* (2.70%), *Psidium Guajava* (0.70%), *Lantana camara* (0.80%)
MA-S3-AU		*Cordia abyssinica* (30.00%), *Albizia coriaria* (28.50%)	*Mangifera indica* (8%), *Vernoniaauriculifera* (14.5%), *Acacia* spp. (7.7%)	*Justicia flava* (0.70%), *Achyranthes aspera* (0.6%), *Tithonia diversifolia* (2.80%), *Ipomoea batatas* (0.40%), *Crotalaria brevidens*(0.30%), *Delonix regia* (2.70%), Tylosema spp.(0.80%), *Ocimum gratissimum* (2.30%), *Lantana camara* (0.70%)

NE-S1-AU	*Dombeya torrida* (43%), *Mangifera indica* (28%)	*Hellianthus Annus* (7.00%), *Cordiaabyssinica* (13.00%)	*Acanthus pubescens* (0.7%), *Aspilia mossambicensis* (1.60%), *Tithonia diversifolia* (1.60%), *Maerua triphylla* (0.40%), *Carica papaya* (0.50%), *Ipomoea batatas* (0.30%), *Acacia* spp.(2.00%), *Glircidia sepium* (0.60%), *Trifolium repens* (0.40%), *Callistemon citrinus* (0.90%)
NE-S2-AU	*Acacia* spp. (26.00%), *Eucalyptus* spp. (22.60%)	*Cordia abyssinica* (12.00%), *Maerua triphylla* (0.90%), *Mimosa invisa* (9.00%), *Morus mesozygia* (10.00%), *Passiflora edulis* (0.80%), *Dombeya torrida* (11.00%)	*Acanthus pubescens* (1.50%), *Achyranthes aspera* (1.8%), *Aspilia mossambicensis* (1.30%), *Tithoniadiversifolia* (2.70%)
NE-S3-AU	*Eucalyptus* spp. (30.60%)	*Mangifera indica* (13.4%), *Cordia abyssinica* (12.00%), *Acacia* spp. (9.20%), *Trifoliumrepens* (14.00%), *Dombeyatorrida* (13.00%)	*Acanthus pubescens* (0.7%), *Justicia flava* (0.60%), *Aspilia mossambicensis* (2.00%), *Hellianthus Annus* (2.80%), *Jacaranda mimosifolia* (0.80%), *Carica papaya* (0.30%), *Ipomoea batatas* (0.60%)

KA-S1-DE	*Croton* spp. (66.40%)	*Acacia* spp. (28.80%), *Leucasdeflexa* (19.00%)		*Agave sisaliana* (0.4%), *Pupalia lappacea* (0.7%), *Bothriocline fusca* (0.60%), *Cynodon dactylon* (0.30%) *Malvaviscus arboreus* (0.40%), *Eucalyptus* spp. (0.80%), *Dombeya torrida* (0.60%), *Tribulis terrestris* (0.50%)
KA-S2-DE		*Acacia* spp. (27.10%),	*Croton* spp. (13.60%), *Leucaena Leucocephala* (14.50%), *Tephrosia vogelii* (14.10%), *Eucalyptus* spp. (13.80%), *Teclea nobilis* (14.80%)	*Aloe secundiflora* (0.60%), *Bothriocline fusca*(0.70%), *Leucas deflexa* (0.50%), *Zizyphus mucronata* (0.30%)
KA-S3-DE		*Acacia* spp.(43.40%)	*Combretum molle* (16.8%), *Croton* spp. (20.00%), Mimosa invisa (11.50%)	*Aloe secundiflora* (2.50%), *Bothriocline fusca* (0.80%), *Phaseolus vulgaris* (1.70%), *Eucalyptu*s spp. (2.00%), *Zizyphus mucronata* (0.70%),*Trema orientalis* (0.60%)
MA-S1-DE	*Vernonia auriculifera* (46%), *Croton* spp.(47.50%)		*Acacia* spp. (1.30%), *Ocimum gratissimum* (0.50%), *Grewia bicolor* (0.50%), *Trema orientalis* (0.70%)	*Agave sisaliana* (1.4%), *Aloe secundiflora* (1.20%), *Combretum molle* (0.90%)

MA-S2-DE	*Bothriocline fusca* (38%), *Tithonia diversifolia* (40%)	*Leucaena Leucocephala* (13.50%), *Mimosa invisa*(1.80%), *Tylosema* spp.(0.50%), *Persea americana* (0.30%), *Melia azedarach* (1.40%)	*Agave sisaliana* (2.1%), *Aloe secundiflora* (0.70%), *Combretum molle* (1.7%)
MA-S3-DE	*Acacia* spp.(36.10%), *Eucalyptus* spp.(27.40%)	*Vernonia auriculifera* (9%), *Combretum molle* (13.00%), *Croton* spp.(11.00%)	*Mimosa invisa* (2.10%), *Melia azedarach* (1.20%), *Pinus*type (0.20%)
NE-S1-DE	*Acacia* spp.(43.00%)	*Vernonia auriculifera* (14.50%), *Cordia abyssinica* (13.80%), *Combretum molle* (13.20%), *Mimosa invisa*(13.50%)	*Justicia exigua* (0.6%), *Agave sisaliana* (0.8%), *Aloesecundiflora* (0.30%), *Tephrosia vogelii* (0.60%), *Pennisitem purpureum* (0.20%), *Leucas deflexa* (0.10%)
NE-S2-DE	*Combretum molle* (31.00%), *Acacia* spp.(35%), *Leucaena Leucocephala* (31.40%)		*Agave sisaliana* (0.6%), *Polyscias fulva* (0.7%), *Aspiliamossambicensis* (0.40%), *Eriobotrya japonica* (0.30%)

NE-S3-DE	*Vernonia auriculifera* (43%), *Combretum molle* (40.00%)	*Croton* spp.(13.10%)	*Cucurbita pepo* (0.20%), *Agave sisaliana* (0.50%), Aloe *secundiflora* (0.70%), *Pentaclethra macrophylla* (0.60%), *Phaseolus vulgaris* (0.40%), *Pennisitem purpureum* (0.40%), *Malvaviscus arboreus* (0.80%), *Musa acuminata* (0.30%)

Table 4.18 represents communalities of principal components. Sites, seasons, pollen types, pollen density, honey types and Shannon weaver diversity index were well represented in the common factor space. 86% of extracted factors in pollen density explain more of the variance of honey samples. Only 53% of honey type explain the variation in honey samples.

Table 4.18: Communalities of principal component analysis

	Initial	Extraction
Sites	1.00	.61
Season	1.00	.76
Pollen types	1.00	.74
Pollen density(Log)	1.00	.86
Honey type	1.00	.53
Shannon Weaver	1.00	.56

Table 4.19 explains variance in the principal component analysis. The number of principal components, 6 are as many as the number of variables whose communalities have been explained. Principal component 1explains up to 44.07% of the variance and has the highest Eigen value 2.64. Principal Component 2 accounts for 23.6% of total variance and an Eigenvalue of 1.416. Component 1 and 2 had Eigenvalues above 1 and both cumulatively accounted for 67.67% of the total variance. Successive principal components accounted for less and less variances.

Table 4.19: Total variance explained for the principal component analysis

	Initial Eigen values			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	2.64	44.07	44.07	2.64	44.07	44.07	2.62	43.58	43.58
2	1.42	23.60	67.67	1.42	23.60	67.67	1.45	24.10	67.67
3	.76	12.74	80.41						
4	.66	10.92	91.33						
5	.34	5.70	97.04						
6	.18	2.97	100						

The scree plot (Figure 4.5) has graphed the eigenvalue against the component number. The first two components have the highest eigenvalues with each successive component explaining smaller and smaller amounts of total variance. The principal components analysis has redistributed the values of correlation matrix using eigenvalue decomposition to redistribute the variances to first component extracted.

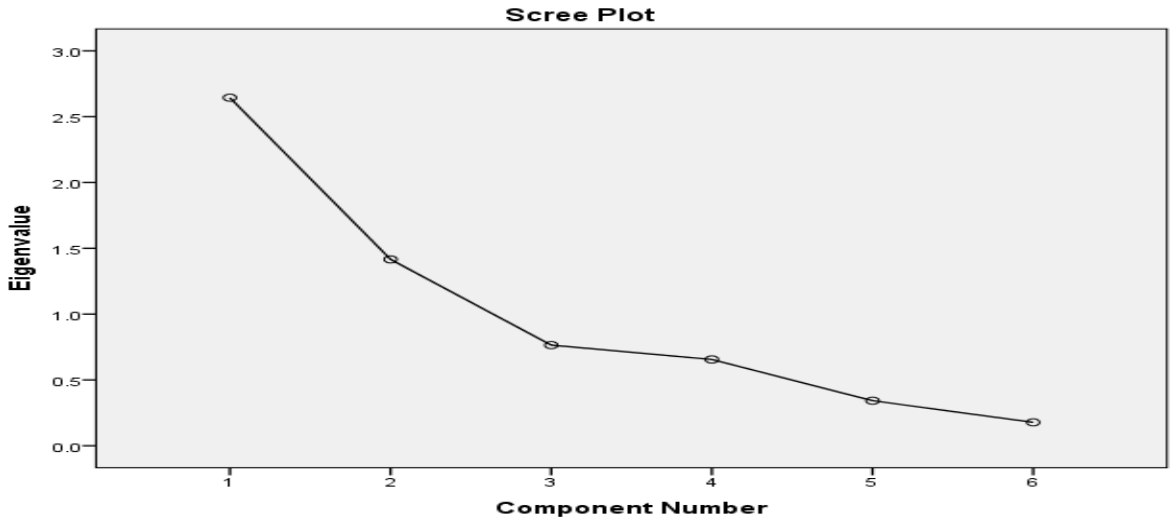

Figure 4.5: Scree plot of components against Eigen values

Table 4.20 below shows the component loadings, the correlations between the six variables the principal components. Pollen density, Season, pollen types, honey types are more

correlated to the principal component 1, while sites and Shannon Weaver diversity index were more correlated to principal component 2. Two components have been extracted.

Table 4.20: Component matrix of principal component analysis

	Component 1	Component 2
Pollen density(Log)	.88	-.31
Season	-.87	
Pollen types	.86	
Honey type	.59	.42
Sites		-.78
Shannon Weaver		.73

Figure 4.6. Shows component plot in rotated space. The principal component analysis of the pollen density, seasons, pollen types, honey types, sites and Shannon Weiner index disclosed two principle components. Pollen density, seasons, pollen types, honey types contributed to the first principal component.

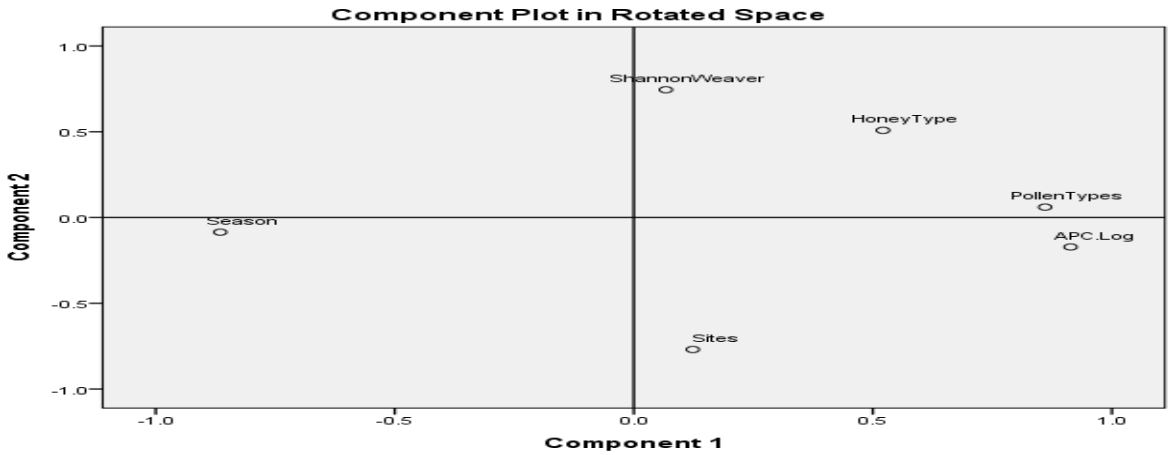

Figure 4.6: Saturation of variables in axes of first two principal components.

A Hierarchical Cluster analysis for the 27 honey samples was performed as shown in Figure 4.7. Clusters were created from the cluster analysis algorithm. The clusters had mixture of honey samples from various regions except for all samples collected from Mariashoni in

April that formed an isolated single cluster, with all samples (MA-S1-AP, MA-S2-AP, MA-S3-AP) unifloral honey. Honey samples KA-S2-DE, KA-S3-DE, NE-S1-DE, and NE-S2-DE, all collected in December formed a cluster. The clusters did not exclusively bring together honey samples of a given type, of given plant origin, or season of collection.

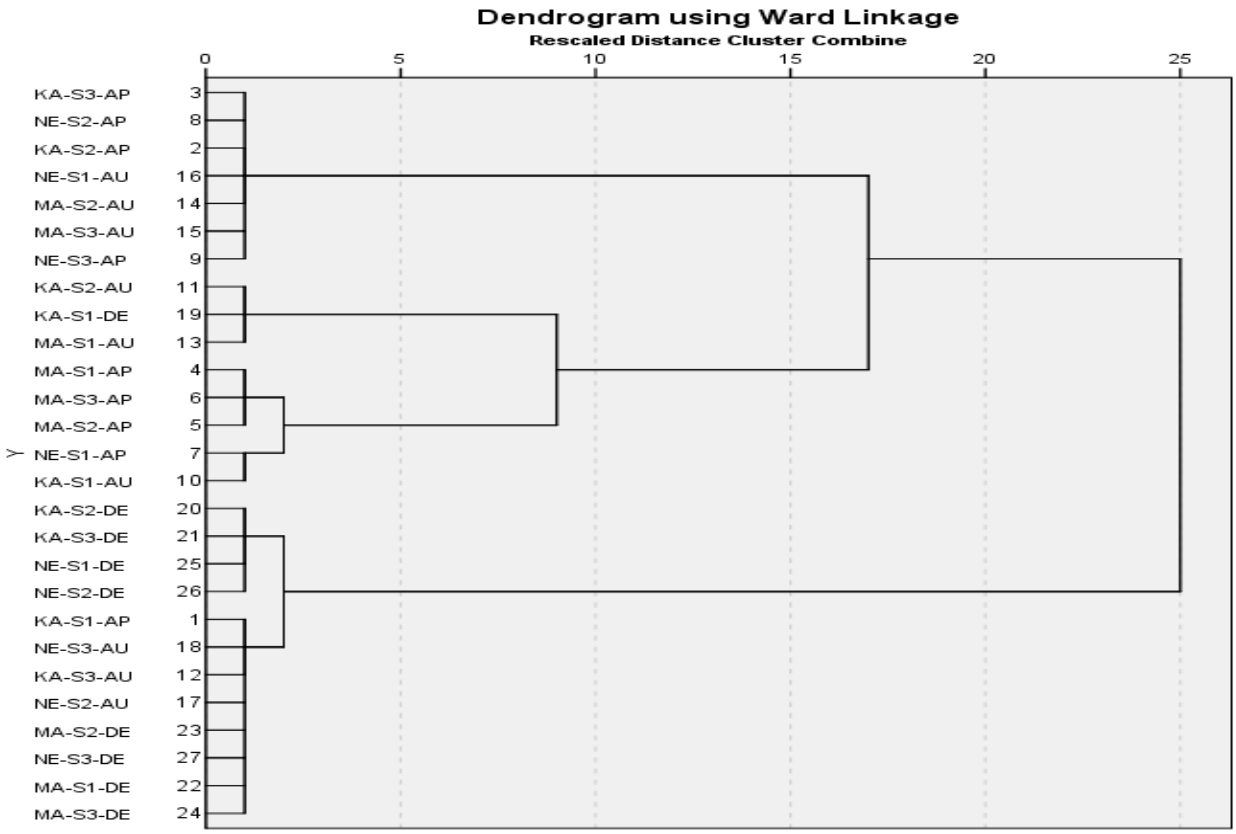

Figure 4.7: Dendrogram from cluster analysis of 27 honey samples from Eastern Mau forest.

4.5 Organoleptic Characterisation

Mean organoleptic rankings for the 8 monofloral honey samples were established as shown in Table 4.21. All honey samples had normal colours. The colours were light amber, amber and extra light amber in 3, 3, and 1 sample respectively. Both *Acacia* honey samples were light amber. *Croton* honey were amber and light amber. There was no common colour for honeys harvested from the same season, place or of a given botanical origin. The highest colour

intensities were observed in *Cordia* and *Croton*honey. The highest odour intensity and persistence was observed in *Albizia* honey. Floral fresh aroma was the most dominant. All *Acacia* honey had floral fresh aroma family. Highest aroma intensity was observed in *Albizia* honey. While highest aroma aftertaste was observed in *Eucalyptus*spp. honey. All honey samples had sweet taste,*Eucalyptus* honey had the sweetest taste intensity. Acidity was generally low ranging from 0-2. Majority having no acidity. The graininess ranged from 0 (absent) to 2 (fine). 50% of the honey samples showed fine graininess. *Eucalyptus,Acacia*and Cordia honey was the grainiest.

Table 4.21: Mean ranks of organoleptic characteristics of Eastern Mau unifloral honeys derived from visual analog scales

VARIABLE	MA-S1-AP	MA-S2-AP	MA-S3-AP	NE-S1-AP	KA-S1-AU	KA-S2-AU	MA-S1-AU	KA-S1-DE
Botanical origin	*Acacia* Honey	*Acacia* Honey	*Eucalyptus* honey	*Croton* Honey	*Albizia* Honey	*Cordia* Honey	*Croton* Honey	*Croton* Honey
Colour (Normal)	Light amber	Light amber	Amber	Amber	Extra light amber	Amber	Amber	Light amber
Colour Intensity	5.2	5	5.6	6	4.2	6.3	5.6	5
Odour intensity	4.5	5	4	3	5.4	4	3.5	4
Odour persistence	3.5	5.5	3.8	4	6	4.5	3.9	4.2
Aroma (Family)	Floral fresh fruit/ fruit	Floral fresh fruit/floral	Fresh/refreshing	Floral fresh fruit/fruit	Floral fresh fruit/floral	Woody/Resinous	Warm/ subtle	Warm/ subtle
Aroma (Subfamily)	Pear apple	Orange blossom	Eucalyptus	Pear Apple	Orange blossom	Propolis	beeswax	beeswax
Aroma (Intensity)	5	5.4	6.1	6	6.7	6.3	5.6	6.2
Aroma aftertaste	5	5.9	6.2	4	6	5	4.8	5
Taste (Sweet) Intensity	5.3	5.4	5.9	0.6	5	4.3	5.2	4
Acidity	0	0	2	0	1	1	0	1
Texture /graininess	1	2	2	1	1	2	0	1

Table 4.22. gives a Friedman's analysis of variance for the organoleptic characteristics of the 8 monofloral honey samples. There was a significant variation in the organoleptic characteristics except in odour persistence. The *Albizia* and *Cordia* honey samples collected in August from Kapkembu differed significantly in colour intensity. NE-S1-AP (*Croton honey*) differed from all the other seven monofloral honey samples in the sweet taste intensity. There was no significant difference among *Croton* honey in any of the organoleptic characteristics. The highest variation was observed in the fluidity amongst honey samples (Friedman's Q=645.46) and aroma intensity (Friedman's Q=239.5). The two *Acacia* honey samples from different sites in Mariashoni (MA-S1-AP, MA-S2-AP) differed significantly in aroma intensity.

Table 4.22: Friedman one way repeated analysis of variance by ranks of organoleptic variables (N=12, df=7, LSD=23.52, X^2 =14.07)

Parameter	Mean Rank	Mean Range	Log_{10}. SS	Friedman's Q	Pair wise comparison
Colour intensity	5.36	4.20-6.30	4.53	142.18	(KA-S1-AU*KA-S2-AU)
Odour intensity	4.18	3.00-5.40	4.32	36.68	(NE-S1-AP*KA-S1-AU)
Persistence	4.46	3.80-5.50	4.37	0.08	No significant difference.
Aroma intensity	5.91	5.00-6.70	4.61	239.50	(MA-S1-AP*MA-S2-AP), (MA-S1-AP*KA-S1-AU),(MA-S3-AP*KA-S1-AU)
Aroma aftertaste	5.24	4.00-6.20	4.51	122.57	(NE-S1-AP*MA-S3-AP),(NE-S1-AP*KA-S1-AU)
Sweetness/Taste intensity	4.46	0.57-5.85	4.41	33.89	NE-S1-AP*all other 7 samples)
Acidity	0.63	0.00-2.00	3	310.00	(MA-S3-AP*MA-S1-AP),(MA-S3-AP*MA-S2-AP),(MA-S3-AP*KA-S1-AU),(MA-S3-AP*MA-S1-AU)
Texture/Graininess	1.25	0.00-2.00	3.36	292.00	(MA-S1-AU*KA-S2-AU)
Fluidity	7.71	6.00-9.70	4.84	645.46	(MA-S1-AU*MA-S1-AP),(MA-SI-AU*MA-S2-AP),(MA-S1-AU*MA-S3-AP)

Spider plots were developed as shown Figure 4.8. Highest variation in *Acacia* honeys was observed in odour persistence. Acidity and texture was absent and moderate respectively in Acacia honeys. There less dispersion in fluidity, texture and acidity in monofloral honeys studied. Maximum dispersion was observed in odour persistence (*Acacia* honey samples), fluidity (*Croton* honey samples), and odour persistence (*Eucalyptus*, *Albizia*, *Cordia* honey).

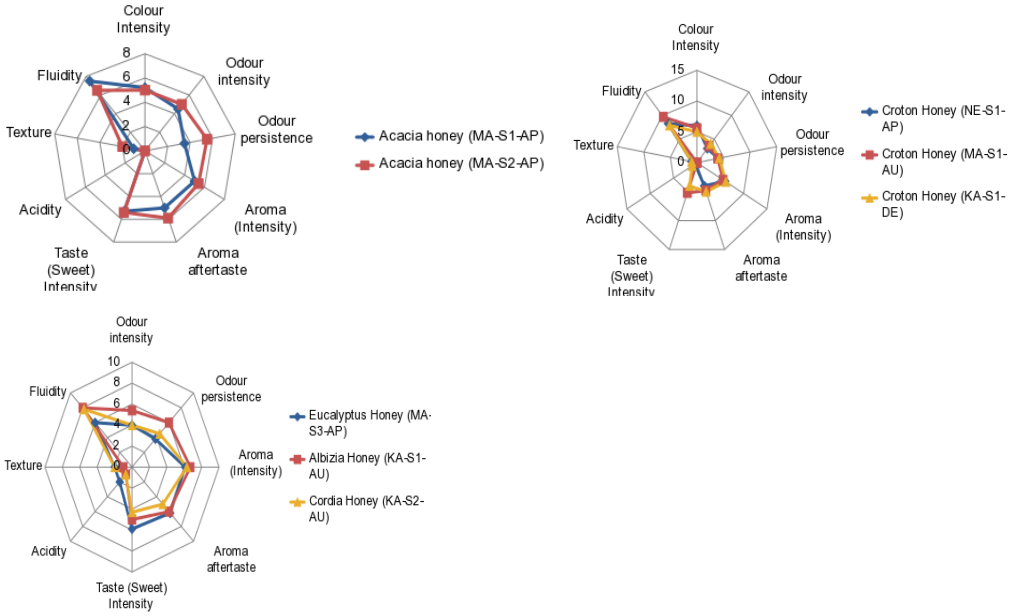

Figure 4.8: Spider plot of the various sensory attributes of the monofloral honey samples from Eastern Mau forest, Kenya.

ATwo-step cluster analysis performed for the 8 monofloral honey samples. Variable importance were extracted and represented in Figure 4.9. The most important variable in predicting the monofloral honey type is the odour persistence. Aroma/aftertaste was the least important organoleptic trait in differentiating the monofloral honey studied. 70% of the organoleptic characteristics had less than 0.5 predictor importance. Odour intensity, aroma/odour family, and odour persistence had predictor importance of more than 0.5.

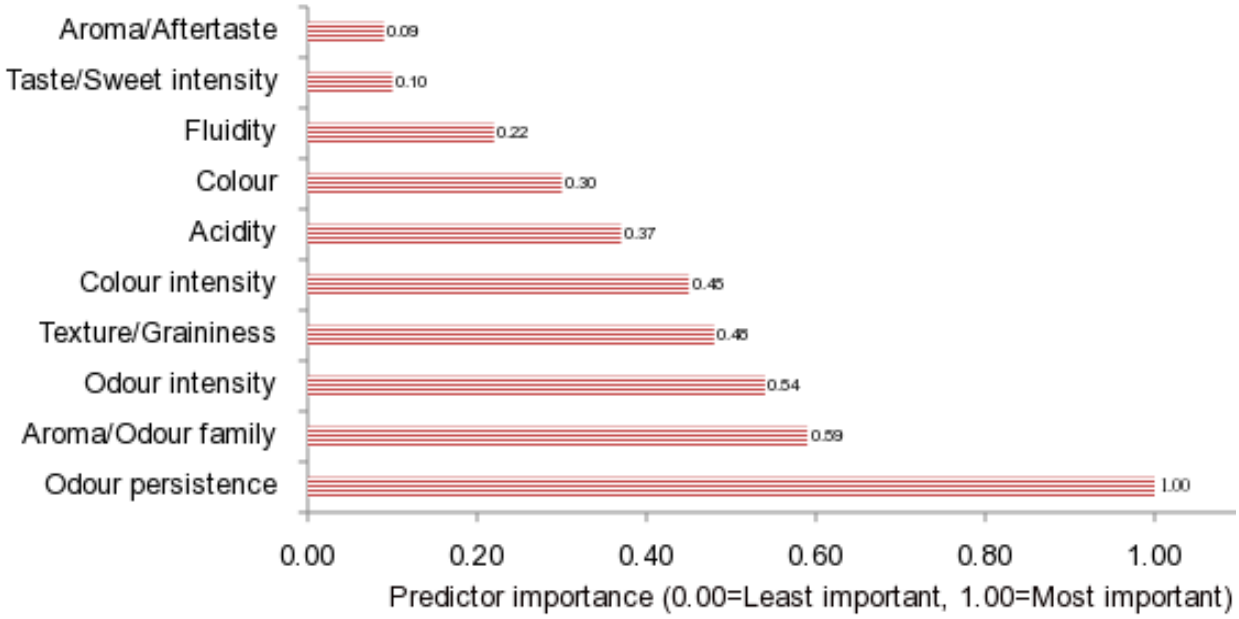

Figure 4.9: Two step cluster analysis predictor importance for the organoleptic characteristics of unifloral honeys.

The two step cluster analysis grouped the monofloral honey samples into 3 clusters. The *Acacia* honey fell in to cluster 1 and 2. All *Croton* honey grouped together in cluster 1. Cluster members included honey samples from different botanical origin.

Table 4.23: Two step cluster membership of unifloral honey samples of varied pollen predominance

Honey sample	Botanical Origin	Predominant Pollen Content	Cluster Membership
MA-S1-AP	*Acacia sp.*	65%	1
MA-S2-AP	*Acacia sp.*	55.80%	2
MA-S3-AP	*Eucalyptus sp.*	56.50%	3
NE-S1-AP	*Croton sp.*	60%	1
KA-S1-AU	*Albizia sp.*	47.10%	2
KA-S2-AU	*Cordia sp.*	56%	3
MA-S1-AU	*Croton sp.*	50.20%	1
KA-S1-DE	*Croton sp.*	66.40%	1

CHAPTER FIVE

DISCUSSION

5.1 Melliferous Taxa

Results of melliferous taxa are comparable to the Akunne *et al*. (2016) reporting 83 melliferous species in Akwa and Agulu environs, South East Nigeria. Results on the contribution of various plant forms is in consort with Devi and Mattu (2017) who reported honeybees as using trees, shrubs, herbs and cultivated crops as sources of pollen and nectar. Asteraceae, Acathaceae, Fabaceae, Gramineae, Euphorbiaceae, and Myrtaceae recorded 47.67% of the total population of bee plants .The studies are in consort with Nuru *et al*., (2017). Similar results were also reported by Ejigu *et al* (2017) with herbs, trees, shrubs being source of forage for the bees. Herbaceous plants that grow as weeds on cultivated field, neglected open land, wastelands and as ornamentals are important source of bee forage because they grow and flourish in a short period and their seeds are collected easily and sown for the next growing season. Short flower shedding time may be only used for colony build up (Kifle et *al*, 2014). The density value for herbaceous plant species for the Fabaceae and Asteraceae have been reported in higher altitudes by Wubie *et al*., (2014) ranging from 1500m to 2200m in Ahmara region Ethiopia. Such higher plant frequencies have been attributed to adaptation to the study area and local climate.

Trees contributed the most significant pollen sources. This was both in form of providing for both Nectar and pollen, and as purely pollen sources. This is in agreement with studies by (Taha,2015) who reported trees to represent the most important pollen sources, offering more than 80.00% of the total amount of collected pollen. Studies by (Dukku, 2013) further reported major honey sources trees species. The contribution of Fabaceae in this study support earlier observations reported by Vlek *et al.,* (2014) that showed similar trends of distribution, but further determined *Justicia* spp as of higher importance than *Leucas* species

in the undergrowth. In general trees are more productive in nectar secretion than herbs due to their larger biomass, dense flowers, deep roots and resistance to moisture stress. Moreover in most trees, flowers are not colourful and are expected to secrete more nectar and strongly attract sufficient pollinators. Herbaceous plants have conspicuous colours and may not need to produce large amount of nectar (Nuru *et al*., 2017). This study is largely comparable to Larinde *et al* (2014) in which Asteraceae, Anarcardiaceae, Rutaceae, Lamiaceae, and Cucurbitaceae were equally reported as bee plants. *Apis mellifera* was showed some level of constancy by visiting a majority of the trees and shrubs for pollen and nectar as earlier suggested by Larinde *at al*., (2014) which reported *Apis mellifera* while studying bee flora in Southern Nigeria to be constant on plant food source that are rewarding in terms of nectar and pollen. Wubie *et al*., (2014) in the study of honey plants revealed that the herbs, trees, and shrubs supplied varied floral rewards.This was further observed in this study where the different plant forms supplied various forage rewards with highest number of trees supplying both pollen and nectar at the same time.

The number of various families and species foraged by *Apis mellifera* are different from reports by Haragude *et al* (2016), 100 species; Devi and Mattu (2017), 219 species; Villanueva-Gutierrez *et al*., (2015), 168 plant species; Dukku (2013), 61 species; and Akunne *et al*., (2016), 83 melliferous plant species. Generally high number of footage agrees observations of Iler *et al.*, (2013) that *Apis mellifera* is a generalist visiting a range of blooming flowers.

In previous studies (Carroll, 2006) in Nandi hills,*Persea americana*, *Dombeya torrida*, *Grevillia robusta*, *Musca* spp, *Carica papaya*, *Phaseolus vulgaris*, *Coffea arabica*, *Eucalyptus saligna*, *Croton macrostachyus* and weeds were identified as bee plants. In Molo: *Dombeya goetzentii*, *Zea mays*, *Callistemon citrinus*, *Eucalyptus saligna*, *Vernonia* spp,

Croton megalocarpus, *Artemesia tridentata*, *Dahlia pinnata*, *Fuchsia* spp, *Raphanus raphanistrum.* In Kirinyaga: The main nectar bearing trees in the area are *Coffea* spp, *Musa* spp), *Grevillia robusta*, *Persea americana*, *Macadamia tetraphylla*, *Mangifera indica*, *Croton* sp, *Carica papaya*, *Phaseolus vulgaris*. Flowering *Zea mays* is an important source of pollen. Mwea division : *Grevillea robusta*, *Acacia mellifera*, *Eucalyptus saligna*, *Acacia lahai*, *A. seyal*, *A. abyssinica*, *A. brevispica*, *A. gerrardii*, *Azadirachta indica*, *Calliandra calothyrsus*, *Callistemon citrinus*, *Cajanus cajan*, *Kigelia africana*, *Carica papaya*, *Musa* sp., *Phaseolus* sp., *Mangifera indica*, *Psidium guajava* and *Macadamia tetraphylla* (Carroll, 2006). In Kakamega forest, honey production is reliant on the flowering of forest trees and other plants including *Leucaena leucocephala*, *Musa* spp, Isungusa (Luyhia), Isirimoi (Luyhia), and Iludolio (Luyhia). The flowering of *Croton megalocarpus* (Musine, Luyhia) is an indicator of when to harvest honey. In Transmara *Olea africana*, *Thunbergia alata*, *Scutia myrtina*, *Cordia moncica*, *Acacia seiberiana* have been reported as bee plants (Carroll, 2006). Some of the bee plants are reported for the first time *Cissus rotundiflora* (Vitaceae), *Trema orientalis* (Ulmaceae), *Maerua triphylla* (Capparaceae), *Aloe secundiflora* (Asphodelaceae), *Tribulis terrestis* (Zygophyllaceae) and Polyscias fulva (Araliaceae) in Eastern Mau forest studies (Carroll, 2006).

A differentiated foraging by *Apis mellifera* for different rewards was observed in this study. This agrees with reports by Akunne *et al* (2016) which revealed that generally the honey bee visitation and exploitation of the plant species varied from one species to another. High number of the plant species producing nectar alone and both nectar and pollen is an indication of honeybees sustainable colony performance and productivity. The variation in plant types based on their floral reward also agrees with the findings of Waykar and Baviskar (2014) that there are plants that supply nectar, pollen and plants that provide both. The trend in bee plant reward agrees with report by Waykar and Baviskar (2014) in order of both nectar

and pollen, nectar, and pollen. Colour, odour, and morphology of flowers determine the preference of honey bees for a particular nectar or pollen source and there is high reliance on a few species (Villanueva-Gutierrez *et al*., 2015). Plant species that only offer pollen as a reward vary tremendously in their floral displays including anther and corolla colours, suggesting that visual cues might be useful for bees to learn. Anther and corolla colours may allow bees to discriminate among pollen rewarding plants species (Muth *et al*., 2016; Devi and Mattu (2017).

The results of this study are comparable to the study by Nuru *et al*., (2017). Asteraceae, Leguminoseae, Lamiaceae, Acanthaceae, and Malvaceae accounted for the majority (35%) of the total bee forage species of the region (Nuru *et al*., 2017), while in this study Asteraceae, Acathaceae, Fabaceae, Gramineae, Euphorbiaceae, and Myrtaceae recorded 47.67% of the total population of bee plants even though in this study there were only a total of 86 plant species studied, in Nuru *et al*., (2017) up to 111 speceis were observed. This could be attributed to the variation in the ecological distribution of bee floral resources and periods of availability according to the flowering times as reported by Abou-Shaara (2015). Bees also collect nectar and pollen from many different plant species. Production of pollen and nectar may vary in various ecological zones. Plants considered a major nectar source in one region may only be a minor source in others. Yearly variations may also cause minor honey plants to occasionally yield heavily, or major plants to yield poorly (Haragude *et al*., 2016). Abundance, distribution and diversity of nectar and pollen plants vary from place to place due to variation in topography, climate and farming practices. Slight variation in nectar resources across areas are common, and this may not pose serious challenge to profitable apiculture (Akunne *et al*, 2016). Forage use patterns have also shown that it is not simply the number of good pollen and nectar species that occur in the area that determine forage use but also their abundance (Hutton-Squire, 2014). Despite the fact that some annuals provide quick

and abundant bee forage, perennial herbs and shrubs are superior bee forage, compared to annuals perennials are generally richer sources of nectar because of their longevity and provide more or less dependable food source year after year. However heavily wooded areas in the forest ecosystem are not always suitable for honey bees although the bees are able to forage on high canopies (Mwangi *et al*., 2012).

Section of plants being the major bee plants has been reported by Crane (1990) where only six plant species served as major nectar sources in the region of study. Larinde *et al*., (2014) while studying ecological zones in Southern Nigeria reported the foraging of members of the families Asteraceae (23.810%), Anarcardeaceae (9.523%), Rutaceae (9.523%), Lamiaceae (4.762%), and Curcubitaceae (94.762%) by *Apis mellifera* for nectar and pollen. Although the same families were foraged by the *Apis mellifera* in Eastern Mau, in this study Fabaceae, was the most visited followed by Asteraceae, and then Acanthaceae. The variations could be attributed by constancy of *Apis mellifera* on plant food source that are rewarding in terms of nectar and pollen as reported by Omoloye and Ayansola (2006). High frequency by Compositae is in conformity with similar results obtained by Olusola and Oluwatoyin (2009) that Asteraceae had the highest pollen and being of great importance to bees for production of honey. In the families studied, only few of members were foraged. This is in consort with Dukku (2013) that reported 2 or 1 species in the Sudan Savanna zone of North Eastern Nigeria. Akunne *et al*. (2016) also reported other families apart from Asteraceae, Euphorbiaceae, Verbeneceae, and Malvaceae to be represented scantily.

Rosaceae (*Prunus* spp) have been reported as bee forage by Decourtye *et al* (2010) as creating favourable landscapes for *Apis mellifera*.Villanueva-Gutuerez (2015) while studying the Yucatan Peninsula reported up to 168 bee forage plants species including with Gramineae among the families that contributed the largest number of species. Investigations by Devi and

Mattu (2017), Haragude et *al*., (2013), Vlek *et al.*, (2014) similarly reported *Sorghum vulgare* and *Zea mays* and*Cynodon dactyon* as pollen sources. Similar results have also been reported by Wubie et *al*., (2014) in which all grass plants were recorded as only pollen sources. *Ipomoea batatus* (Convolvulacae)as a bee plant confirms previous studies by Devi and Mattu (2017) while preparing floral calendar for adjoining areas of Himachal Pradesh. *Ipomoea batatas* (L.) Lam was repoted as both pollen and nectar plant, however in this study was recorded as a nectar plant.

Justicia flava (Acanthaceae) observed in this study had been earlier reported (Mwangi *et al*., 2012) in Kakamega and surrounding farmlands. However farmers rarely notice the plants as source of forage for bees but as source of firewood and as boundaries. Tree and shrub bee plants may require farmer intervention compared to freely growing herbs eg *Justicia flava* (Mwangi *et al*., 2012). *Sida acuta* (Malvaceae)has been reported as both nectar and pollen plant by Akunne *et al.*, 2016. Studies by Akunne *et al*., 2016 has similarly reported *Psidium guajava* (Myrtaceae) as both nectar and pollen plant and *Lantana camara* and*Stachytarpheta jamaicacensis* (Verbenaceae) as both nectar and pollen forage. Honey prooduction is made possible by *Eucalyptus* in South Africa; in the Western Cape alone, two thirds of honey production is supported by *Eucalyptus*. *Eucalyptus cladocalyx* is one of the best nectar yielding and is said to be number one honeybee forage in South Africa. Not only do *Eucalyptus* species provide high quality nectar necessary for good honey production, they also play a critical role in strengthening honeybee colonies which can then be used for agricultural crop pollination (Hutton-Squire, 2014).

This study has reported of Fabaceae being the most visited. Similar results have been reported by Forman *et al* (2003), legumes being the most frequently visited plant species due to their long flowering periods of the multi- annual flowering pattern species and their being

attractive. Fabaceae have been reported as bee forage by Decourtye *et al*. (2010). Despite these reported benefits, the slow growth of some legumes may be a limiting factor in some cases because an absence of flowers in the first year (Decourtye *et al*., 2010). Bee forage taking a long time for blooming to shedding are very important for honey production (Kifle *et al*., 2014). Despite the long term value of perennial legumes to honey plants, farmers always prefer the annual species due to their low cost. In bee pastures such concerns have been addressed with mixture of annual, biannual and perennial plants (Decourtye *et al*., 2010). Studies by Hutton-Squire (2014) on the relationship between honey-bee and its forage did reveal that *Citrus* spp (Rutaceae),*Medicago sativa* and*Lucerne* spp as valuable nectar and pollen sources. *Persea americana* (Lauraceae), though reported as a bee plant by Ish-Am and Eisikowitch (1993), the flower is shallow, greenish yellow, and the nectar is fully exposed. The pollen and nectar though easily collected, are not very attractive to bees. The flower has lacks landing platform and is somewhat small for the honey bees. The inflorescence is too sparse to be visited as a unit, and seem to have difficulties holding tightly to the single flower (Okoth, 2010).

5.2 Floral Calendar

Eastern Mau is characterized by a trimodial rain pattern with the long and intense rains from April to June; Short rains in August; and short less intense rains from November to December (Langat *et al*., 2015). The peak flowering in the number of bee plants therefore coincided with periods of high precipitation. Low number of flowering species duringless intense rainfall has been reported in studies in Baringo (Vlek *et al*., 2014) where most bee plants bloomed with April/May rains and showers in August. In December, the least proportion of bee plants flowered, similar results were observed in Baringo by (Vlek *et al*., 2014) where only one species flowered out of the 20 bee plants recorded. There is a general scarcity of flowering during the hot, dry months of December to January while flowering of

undergrowth plants eg *Pupalia lappacea* that beekeepers reported supplies bees with nectar when there is sufficiently heavy rainfall (Vlek et al., 2014). Less than average rainfall at the beginning of the year have been reported to reduce the number of plants that flower as well as the floral abundance (Dukku, 2013; Akunne et al, 2016). Most of the plants flowering during this time are reported to be perennial trees in similar studies in Arabuko Sokoke forest, Kenya. (Okoth, 2010).

More abundant flowering of insect pollinated species has been observed during the wet season in Indian dry tropical forest. This trend has also been observed with studies in Costa Rica, where small trees and shrubs flowered mainly during the wet season. Need to avoid competition and to synchronize flowering with the availability of pollinators could be attributed to flowering during the dry season (Okoth, 2010). Waykar and Baviskar (2015) in studying bee plants in Nasik District India reported very few plants flowering during the summer period characterised with low precipitation and high temperatures as high as 35^0C. Similar trends were also reported by Dukku (2013) where 59% of the plants flower during the nectar flow period and 41% during the dearth period.

Pupalia lappacea, Aloe secundiflora, Leucaena leucocephala, Malvaviscus arboreus, Acaciabrevispica, Vernonia auculifera, Acacia tortilis, Combretum molle, Eucalyptus resinifera, Olea europea flowered during the month of December characterised by less precipitation and high temperatures as reported by Langat *et al*., (2015).*Acacia brevispica* and *A.tortilis* always have individuals in a right physiological state to flower about every second month whenever light showers fall by chance outside the regular rainy seasons of the year. *A.tortilis* is considered an important pollen plant in lowlands. Beekeepers in Baringo have considered *A.brevispica* and *A. senegal* as important bee plants, possibly based on frequent flowering (Vlek *et al*., 2014). Plants like *A.tortilis* have been observed to flower

during dry season, in leafless stages and secrete considerable amount of nectar from stored carbohydrates of the previous season. Short and intermittent flowering patterns have also been observed by Nuru *et al*., (2017). The high preferences of honey bees towards *A.tortilis* may be attributed to inflorescence which consists of relatively dense flowers and longer florets which may reduce the honey bee access to its nectar. The preference of honeybees towards different plant species has been attributed to the floral morphology and chemistry of nectar (Nuru *et al*., 2017). *Acacia* spp. flower even during the dearth period, the blooms overlap and provide forage throughout the year. This is further enhanced by its abundance (Dukku, 2013).

This study reported intermittent flowering in three seasons observed in 4 species. Predominat flowering pattern (sub annual) was also observed with flowering occurring more than once a year, often irregularly. Bee flora have in similar studies shown intermittent flowering eg four seasons for *Amaranthus hybridus* and some with flowering period as short as 2 weeks eg *Oldenlandria* spp (Okoth, 2010). Our results on varied seasonal availability are comparable to Waykar *et al*., (2014) where Flowering was observed up to period of 12 months. In this study 82 plant species (95.34%) flowered for at least 2 months. This is in agreement with studies of Arabuko Sokoke by Okoth (2010) reporting up to 82 plant species (majority) flowering for a period of at least 2 months while up to 12 species including *Grewia bicolor*, *Lantana camara*, and *Hibiscus*spp flowered for at least 6 months. While Okoth (2010) reported 1 month flowering in *Oldenlandia*spp., this study recorded up to 4 species flowering for only one month and no bee plant flowering for 4 seasons. Variation in seasonal ability has also been observed by Haragude *et al*., (2016) where *Hibiscus rosasinensis*, *Prosopsis juliflora*, and *Azadirachta indica* flowered throughout the year, in two different seasons and for only one month respectively.

The seven *Acacia*species recorded in this study provided bloom throughout the year with varying flowering periods. This characteristic overlap of *Acacia* species have been reported in the past studies by Dukku (2013) reaffirming their importance in the family Fabaceae. The blooming of the Fabaceae, especially *Acacia* spp overlap providing forage throughout the year. They also flower concurrently but vary in terms of peak flowering within a season. All of these phenomena may be considered as adaptations by species to avoid competition for pollinators and minimize heterospecific pollen transfer among related species (Dukku, 2013). *Acacia mellifera, A.tortilis* and *A.brevispica*, among the 20 plants have been reported as important for nectar, pollen, and both nectar and pollen provision (Vlek *et al*, 2014). *A.brevispica* have been reported in both studies to flower all year round. The results of this study are comparable to results by Waykar and Baviskar (2015) as well as Larinde *et al*., (2014) reporting *Lantana camara* to have flowered for 5 months intermittently in 3 seasons; *Asystasia gangentica* and *Euphorbia hirta* flowering for relatively long periods (6 and 5 months respectively) and *Citrus lemon* flowering for 2 seasons. Vlek *et al* (2014) while studying the bee plants of Baringo reported most trees to be flowering between May and November. This is in contrast with the results of this study where at least 13 tree species were in bloom every month from January to September contributing the highest number proportion of bee plants.

In Arabuko Sokoke 82 plant species were recorded as flowering for a period of at least 2 months. Only 18 species were crop species while the rest were secondary colonizers of the formerly forested regions. Reduced precipitation at the beginning of the year limits bloom as well as the floral abundance. Most of the plants flowering during this time are perennial trees (Okoth, 2010). Studies by Larinde *et al* (2014) have also identified*Aspilia*spp and *Tridax procumbens* to flower year round with every month there are different plant species that serve as pollen and nectar sources.

5.3 Geographical Origin

The plant families found in this study corroborate reports that Africanized bees in the neotropical region forage primarily on members of Asteraceae, Anacardiaceae, Euphorbiaceae, Lamiaceae, Fabaceae, Moraceae, Myrtaceae, Arecaceae, Rubiaceae (Poderoso *et al*., 2012).

Varying genera of native herbs, shrubs, grass and trees have been identified by Agwu *et al*, (2013), climbers, sedges, epiphytes (Ponnuchamy et al., 2014), morphotypes which were further confirmed by Amakpea *et al*. (2015) with perennial plants being reported as the main pollen and nectar sources for bees in the tropical areas. The predominance of the woody strata and herbaceous taxa in savannah zone have been observed during the dry rainy season respectively. In the dry season, bees select flowering plants on the top of the canopy trees, with a few herbs foraged. During the rainy season, the bees exploit preferably big trees, and frequently visit some shrubs and herbs as well (Amakpea *et al*., 2015). In the rainy season, bees are very selective and exploit the flowering trees and shrubs in priority while in areas where grassland occupies a vast surface, herbaceous are more numerous (Nguemo *et al*, 2011). These observations are in contradiction with findings of Nguemo *et al*., (2016) whose data revealed that all the biological types are foraged by bees during the two seasons, with herbs were most exploited during the two seasons. The presence of the melliferous minor plants and less exploited melliferous plants were great indicators of the geographical origin of honey from the zone (Nguemo *et al*., 2016).

Apis mellifera highly prefer trees followed by herbs (Shubharani *et al*., 2012; Sharma, 2011) .The dominance of tree species (53.84 %) from honey samples have been reported by Aswini (2013). This is explained by their larger number of flowers than bushes, shrubs and crop plants unless the latter are growing in large continuous areas. In Nigeria and the Sudanian woody savanna, bees forage practically only on trees (Nguemo *et al*., 2016). Bees show a

strict avoidance of exotic food resources and prefer native species. This has been reported in spite of the abundance of exotic and ornamental species (Aswini, 2013). Foraging of honey bees on plants with different habit (trees, herbs, shrubs) indicate that height of the plant is not a barrier to bees for collecting pollen and nectar as they are found to visit both the tall trees eg *Cocos nucifera* and small plants such as *Mimosa pudica*. Similar studies conducted have concluded that height of the trees is not a barrier to *Apis mellifera* who forage on *Tridax procumbens*, which are a few centimeters in height, along with tall trees such as *Eucalyptus guineensis* in regions of Nigeria. *Apis mellifera* therefore satisfy their dietary requirements from the preferred sources in and around the apiary irrespective of the plant height (Aswini, 2013).

The frequency of occurrence of many species in Asteraceae and Fabaceae were also reported in honey samples from many regions of Turkey as well as in other countries. The degree of selectivity of bee flora seems to be influenced by floral morphology, plant phenology, climatic factors and also by the length of their tongue (Cenet *et al*., 2015). Presence of frequent or very frequent pollen types in this study could also be attributed to the availability as well as abundance of the plant, the quality and quantity of the nectar and pollen, specific nutrients or trace elements provided by the species of interest. An understanding of the reasons for plant targets could provide information on constituents of a balanced *Apis mellifera* diet. Along with the frequent foraged species, there are a kind of plants found only in one or two honey samples (Wilson *et al*., 2013, Hawkins *et al*., 2015). In our results only three pollen types are reported as very frequent, in broad contrast to 9 and 21 pollen types reported by Ana and Francisco (2014), and Laura and Cynthia (2018) respectively. Although very frequent pollen types were not present in honey samples, it is interesting to note that the number of pollen types contributing to various frequency classes: frequent, infrequent and rare pollen types was relatively equal (Jailson *et al*., 2013). Some pollen types from less

common plants occurred in one or the other honey samples. This suggests a previous learning process due to intrinsic preferences of each colony, or different competition levels in the search for pollen sources. These circumstances may occur in a non-uniform vegetation regarding plant species, with short blossom periods (Luz *et al*, 2010). Although some pollen typesdid not record a frequency greater than 10% in at least one of the samples in this study, this could imply their periodic significance in the composition of pollen spectra (Jailson *et al*., 2013). Certain species functioning as good geographic markers, were also encountered with low frequencies in samples studied by Jailson et al., (2013). The low representation of specific pollen types can be used as indicators during the determination of the honeys geographical origin (*Baudilio et al.*, 2002).

Contrary to our findings, not all frequency classes have been represented in other studies (Samir *et al*., 2007; Jailson *et al*., 2013), with no very frequent pollen types observed in Autumn honeys (Samir *et al*., 2007). No pollen types occurred in 100% of the samples. Similar results have been documented (Rasic *et al*., 2018; Vanessa *et al* 2014; Laura and Cynthia, 2018; Jailson *et al*., 2013), with highest frequencies of occurrence being 95%, 79.4% and 94% respectively. Highest frequency for pollen types was observed in family Fabaceae followed by Asteraceae by Sunita and Mattu (2018). This corroborates well with our results where *Acacia* sp. (Fabaceae), *Cordia abyssinica*, and *Vernonia auriculifera* (Compositae) were very frequent. Frequent and very frequent pollen types in this study were majorly from tree pollen types. This supports the argument that there are certain key plant taxa that are particularly important to the honey bees, although *Apis mellifera* is considered to be supergeneralists in their foraging preferences as earlier asserted by Hawkins*et al*., (2015). Herbaceous species including Trifolium spp., non-native and invasive species that have been recorded as frequent by (Hawkins *et al*., 2015), have also been observed in this study in the frequent presence of herbaceous*Achyranthes aspera*.

Data by Jailson *et al*., (2013) have indicated that the pollen types with the highest frequency have a botanical affinity to species that are typically herbaceous or of arboreal habits. Our results indicate otherwise with the most frequent in general associated with trees and shrub related pollen types as seen in *Eucalyptus* sp., *Croton* sp., *C.abyssinica*, and *Acacia* sp.The increased representation and constant presence of pollen from certain species eg *Eucalyptus*, *Cordia*, and *Acacia* species as reflected in their very frequent occurrence could be attributed to their abundant blossomsand is consistent with other studies (Luz *et al*., 2010). *A. mellifera* displayed some preferences for foraging on herbs which include the majority species of Poaceae and Asteraceae. Similar results were earlier reported by Suzane et *al*., (2013).

Various honey studies from different regions have documented contrasting numbers of pollen types across the area of study. Up to 50 pollen types (Ashoke, 2014; Cenet *et al*., 2015; Agwu *et al*., 2013). Between 50 to 80 pollen types have been reported by Sunita and Mattu (2018), Ponnuchamy *et al*., (2014) and over 100 pollen types (Francois *et al*., 2017; Laura and Cynthia, 2018). Although the number of pollen types may be contrasting, the results of this study are comparable to studies by Sunita and Mattu (2018) who reported 84 pollen types and Laura and Cynthia (2018) and Ponnuchamy *et al*., (2014) whose number of pollen types were referable to 43 and 41 botanical families respectively. West Bengal, India (25 pollen types, 19 families) (Ashoke, 2014); 27 pollen types in Turkey; Sunita and Mattu (2018) has reported 84 pollen types belonging to 41 different families. Plants with a broad taxonomic range composed of 46 families have also been reported by (Hawkins *et al.*, 2015), while 32 pollen types have been identified by Agwu *et al*. (2013). 114 and 142 pollen types reported by Laura and Cynthia, 2018 and Francois *et al*., (2017) respectively are relatively higher than that observed in this study. The results of this study corroborates well with earlier observations of Samir et al., (2007) that honey bees foraged on more than 10% of the total angiosperm flora

of the area. Richness of pollen types also demonstrates great diversity of flora visited by Apis *mellifera* (Samir *et al*. (2007).

While a range of , 1-10 (Boff *et al*., 2011), 4 to 7 pollen types in Argentina (Ciapinni *et al*., 2013), 4-9 pollen types (Ashoke, 2014), 6-21pollen types throughout the year (Suzane *et al*, 2013).This is in contrast with studies by (Cenet *et al*., 2015) which reported a pollen type range from 7 to 12. Pollen diversity ranged from 11-29 (Ana and Francisco, 2014). Number of pollen types per sample varied between 11-47 (Caccavari and Guillermina, 2016), 16 pollen types (Sunita and Mattu, 2018), 17-26 (Agwu *et al*., 2013); Highest richness 56 types and lowest in December 11 types (Laura and Cynthia, 2018). Higher average number of pollen types in honey samples were reported as 17, (Laura and Cynthia, 2018; Ana and Francisco, 2014), 26 (Caccavari and Guillermina (2016), 28.52 (Laura and Cynthia, 2018). The more the pollen type, the more diverse the source of nectar collection, and the more the richness of the honey. The broad presence of pollen type in large number of samples show preference for nectar from these plants attributed to their production of sweet nectar inviting to the honey bees (Ige and Apo, 2007). Going by pollen diversity classification according to Yedemonhan (2009) cited in Francois *et al.*, (2017), 100% of the honey samples in this study are classified as relatively rich honey (with 5-15 species). The number of pollen types is smaller in monofloral honeys than in multifloral honeys (Caccavari and Guillermina (2016). The pollen richness observed in this study is proof that *A.mellifera* uses a broad spectrum of pollen resources, characteristic of polylectic bee species. Generalist foraging habit based on the number of pollen types was observed. Such foraging habit is characteristic of many bee species of Apidae (Suzane *et al*, (2013).

Our results corroborate with other reports (Maria and Andreas , 2007; Giovanna *et al*, 2012; Boff *et al*., 2011, Francois *et al*., 2017; Nguemo *et al*., 2016; Ponnuchamy *et al*., 2014) in

which the number of pollen types varied based on seasons, years, or months. Such variations, according to (Ponnuchamy et al., 2014) makes it possible for honey samples and taxa groups be well delineated based on locations, years or months and classification of additional pollen spectra, low overall replicability notwithstanding. Apart from the temporal variation in the number of pollen types, other studies have reported variation in biological type foraged by bees (Nguemo et al., 2016), variation due to time, frequency and species richness (Boff et al., 2011), number of pollen types due to regions or sites, even within the same zone (Ashoke, 2014). The results of this study correlate well with the floral rewards of nectar and pollen in chronological terms, giving proof that in different periods during the year, certain flowers can be either be nectaferous or polleniferous, while in other periods both floral resources are available (Mathew *et al*., 2018). Pollen spectra equally comparable between months or year (Ponnuchamy *et al*., 2014) demonstrates the complexity of ecological and environmental phenomena in shaping the foraging of bees in a heterogeneous landscape, implying a substantial variation from year to year or season to season in terms of the pollen contents of honey produced in the same hive.

The variation in the number of pollen types could implicate *Apis mellifera* for selection of botanical sources according to diversity of surrounding vegetation, resource availability, seasonality, interractions with other bees, and hive requirements, bee dietary preferences in relation to flowering periods, flower colour and or morphology, or nectar distribution and dynamics (Giovanna *et al*., 2012). Most pollen types were collected during spring because the brood population was expanding and pollen was needed as a protein source for growth (Maria and Andreas, 2007). Bees collect pollen mainly from plants with large population sizes near colonies. Surrounding vegetation significantly affects the amount of pollen collected and the number of pollen types collected. Although the number of taxa earlier recorded in an area would be high, the honeybees only utilise around 50% of them (Maria and Andreas, 2007). In

other reportsit was demonstrated that the pollen that the bees utilise in the study areas did not exceed 25% of the taxa recorded by previous studies in the region (Hawkins *et al*., 2015).

It is suggested, by Aswini (2013) that during dearth season because of rains, the foraging range of plants for the nectar and pollen is limited, while on the onset of honey flow season, *Apis mellifera* collect nectar and pollen from a wide range of plants. This phenomenon is reflected in the honey samples of honey flow season. A significant difference ($P \leq 0.05$) (Chi square test) in the spectrum of families and species of bee-plants exploited between the rainy and the dry seasons have been reported by Nguemo *et al*., 2016), with about 85% and 40% of pollen types identified in the honey of rainy season, and dry season respectively in honey samples from the Sudano-Guinean highland, Cameroon. Our results are contrary to those obtained by Bastos *et al*. (2003) in studying honey samples from four sites in Brazil, where the spectra of melliferous plants identified in honey of dry season were always more diversified compared to the rainy season. Similarly, in studying honeys of the phytogeographical zones in Benin, Francois *et al*., (2017) reported such differences, though not significant rises or decreases, independence of pollen grains in the honeys to the seasons of a given zone was deduced. Differences could be attributed to floristic richness of a given area. Low richness in rainy season could be the reason to either absence of numerous species in bloom (Francois *et al*., 2017).

The trophic niche amplitude in this study is lower than (2.19, 0.36-2.55) reported by Jailson *et al*., (2013) but higher than (0.75-2.53,1.78) reported by Rasic *et al*., (2018), 1.5 by Jailson *et al*., (2013), and 1.59-3.0(1.41) (Suzane *et al*., 2013) 0.15 and 2.25 (Candida *et al*. (2013).The mean Shannon weaver index was higher than 1.6 reported by Jailson *et al*., (2013) and 1.67 by Suzane *et al*., (2013). In this study the foraging habit of *Apis mellifera*, as reflected in the pollen type diversity was characterized as polylectic with a more homogenous

use of flora progressively from April, August through December. Similar trends have been reported by Jailson *et al*., (2013). Contrary trends have been reported by Melissopalynological studies in Balterra, Brazil by Jailson *et al*., (2013) in which pollen niche size derived from Shannon Weaver index showed a trend of decreasing homogeneity from February (0.6) to 2.1(October), and similar results by (Suzane *et al*., 2013) where Shannon Weaver index ranged from 1.17 (April) to 2.16 (December). Greater range of trophic niche associated with the greater richness and evenness of pollen types coincide with an improved weather in the various study areas (Suzane *et al*., 2013; Onyango *et al*., 2019). Basing on observations from honey samples from East Croatia by Rasic *et al* (2018).It would be expected that Shannon Weaver index increases alongside species richness. An index rangedfrom 0.75 (9 pollen types) to 2.53 (25 pollen types). This however was contradictory in our study. It would therefore be inferred that the number of pollen types solely does not determine the extent of Shannon Weaver diversity. Other factors could be the number of families from which pollen types are derived. It is possible that a single family could contribute maximum number of pollen types hence a reduced diversity (Onyango *et al*., 2019).

Bee species with narrowest niches (H'=0.15) have shown food specialization on *Cordialeucocephala* (Boragnaceae) as previously reported by Candida *et al*., (2013). Recent research have suggested individual ecological specialization. In this work, the trophic niche breadth of *Apis mellifera* utilized floral resources in a highly seasonal environment with flowering of many plants limited to the wettest parts of the year resulting in lower availability of floral resource of bees during the dry season. A wider trophic niche coupled with longer periods of activity is expected during wet periods of great bloom than in August and December with less bloom (Candida *et al*., 2013). The Shannon Weaver indices have revealed distinct diets of *Apis mellifera* colonies and complementarity in use of available

floral resources in the Eastern Mau environment. Such segregation in trophic niches may have resulted from a combination of factors such as existence of several levels of preference/fidelity of the bee species for specific plants, temporal of spatial fluctuations in resource abundance, duration of blooming period, length of the adult bee activity period, and differences in the community capacity about food resources among different bee species (Candida *et al*. 2013). The high number of pollen types with low representation in the pollen spectra contributes to increasing the value of the Shannon weaver diversity index (Onyango *et al*., 2019) A high variety of pollen reflect the dispersion rate of the forager workers and therefore demonstrate that the foraging habits of these species are polylectic (Jailson *et al*., 2013). As a generalist,*Apis mellifera* may use several food resources and have a higher probability of meeting resource needs in a larger number of habitat fragments than do specialists, with little relationship between plant phylogeny and resource use Candida *et al*., (2013). Generalistforaging can also be adaptive in more unfavorable and or unpredictable environments by increasing the capabilities of foraging and probability for expansion by colonization of new habitats, hence ensuring persistence. Generalist strategies increase competition and foraging efficiency and as a result, a reduction on biomass intake compared to more specialist strategies (Navarro-Lopez and Fargallo, 2015).

Our results of Jaccards similarity Index are distant from those reported by Vanessa *et al.*, (2014). Similarity ranged from 35% to 72%. Nine out of the 11 studied municipalities (Group B) had a similarity of about 0.24, while the rest of the samples had the highest similarity index of 0.48; sharing 10 pollentype (Ana and Francisco, 2014). Observed differences in similarity are attributable to low frequency pollen types in a region, and quantity of pollen types in samples. Honey samples with high quantity of pollen types display the highest similarity forming an axis of about 50% similarity. Dissimilarity occur among the pollen sources between the flowering periods and not among the main pollen types

in the monthly samples. This incidence could indicate the difference in blossom phases and the phenological plant development in the colony surroundings (Luz *et al*, 2010) or foraging behaviour of colonies (Dukku, 2013).

Similar correlation have been noticed between the population size of the taxa and the respective weight contribution of the foraged pollen types (Maria and Andreas, 2007). A correlation analysis between pollen density and pollen types of honey samples during three seasons revealed that there was no significant positive correlation between pollen density and pollen types in dearth season and brood rearing season, 0.03 and 0.12 respectively. A negative correlation, not statistically significant was recorded during honey flow season (-0.06) (Aswini, 2013). These associations are attributable to the fact that rain during dearth season limits honey bees foraging from a wide range of plants for nectar and pollen consequently low pollen density in honey samples collected. In the onset of rainy season *Apis mellifera* collects pollen and nectar from a wide range of plants which is reflected in the honey samples (Chaturvedi and Temsunungla, 2008). Beekeepers have also been reported to provide sugar syrup and artificial food during dearth season thus decreasing the pollen count into honey. Samples studied by (Boudilio *et al*., 2002) reported high number of families and pollen types were represented in each honey sample whether multifloral or monofloral. The number of pollen types in monofloral honeys hardly differed from multifloral samples making it difficult to find a relation between the kind of honey and its pollen richness.

5.4 Botanical Origin

The quantity of pollen in a given honey sample of honey gives a clue to the determination of its purity and genuineness. Pollen counts of honey samples in this study indicate that the honey samples were undiluted (Agwu *et al*, 2013). The more the pollen content, the more the preference for nectar from these plants attributable to their sweet nectar to the honey bees (Ige and Apo, 2007). High pollen content also reflects richness of pollen grains and

abundance of polleniferous species (Laura and Cynthia Fernandes, 2018). Higher pollen density in forested areas Thiruvananthapuram district have been reported by (Aswini, 2013) citing Nair (2005). The variation in pollen density between and within the locations during various seasons may be attributed to the diversity and richness of bee flora in different locations as well as bee forage preference of bees within various locations (Aswini , 2013), an argument that has been supported by other studies (Bhargava et al. 2009; Shubharani *et al*. 2012).

Brood rearing season have coincided with honey samples rich in maximum mean pollen density across sites, while the dearth season record lowest mean pollen density (Sadia *et al*., 2008; Nair, 2005). This is expected since pollen is a significant ingredient for bee nutrition, brood development and for maintenance of a healthy bee colony and a source of proteins, amino acids, carbohydrates, vitamins and hormones. In order to meet the dietary requirements of the brood, foraging bees will collect ample quantity of pollen which results in higher pollen density during brood rearing season. The importance of pollen as major source of protein to the brood has been also reported from the studies conducted by Sadia *et al*. (2008). Absolute pollen count ranging from 908 to 62844/g higher than our results have been reported (Boudilio *et al*., 2002). Extreme values of 7055 to 546,558/10g (Ana and Francisco, 2014) and 19,388 to 950,347 reported by Novais (2013). While studying the honey pollen in Delta state, Igbe and Obasanmi (2014) recorded pollen counts ranging from 10,409 to 712,634, while pollen grain counts ranged from 532 to 1033, (Agwu *et al*., 2013).

Honey samples studied by (Novais, 2013; Alicia, 2008; Ana and Francisco, 2014) as in this study, also never fell in class V. There are no consistent classes that honey samples fall. This is in consort with the findings of most honey samples being categorized as falling in Class II, (Novais, 2013), III (32.3%) and IV (35.3%), Laura and Cynthia Fernandes, (2018) and I

(23.8%) and II (61.9%) by Ana and Francisco, (2014). Similar results have been reported by Samir *et al*. (2007). In contrast, 62% of honey samples with values between 16 and 2067 were reported by Boudilio *et al*., (2002).

Most of the minor pollen taxa types were herbaceous or members of the graminacious types. The predominant and secondary pollen types were mainly from trees and shrubs. The contribution of pollen types were coinciding much with their bloom. More unifloral honeys than multifloral honeys have been reported by (Ana and Francisco, 2014; Baudilio *et al*. 2002; Rasic *et al*, 2018). While other studies (Alicia, 2008; Ashoke, 2014; Sunita and Mattu, 2018) more multifloral than unifloral honeys were recorded. Eastern Mau complex endowed as it is with a rich and varied floristic complex has the natural potential for establishing an organised bee keeping industry for the production of commercial quantities of single source (Unifloral honeys). Frequency classes extracted in this study made it possible to evaluate the periodic contribution of each pollen type to the composition of the pollen spectrum of a sample. Thus predominant pollen types have a high botanical affinity for plant species with a more significant monthly contribution to the composition of a given spectrum. Predominat types were present in a fewer samples than the other frequency classes. The pollen spectrum in a sample isnot sufficient to determine the botanical origin of the honey (Molan , 1998). This is because one must assume that no honey is completely unifloral and that the amount of pollen and nectar produced by plants varies according to different factors linked to seasonality, climate, soil conditions among others. Pollineferous plant species can also contaminate the honey and mask other species sub represented which could be good nectar suppliers as well as important indicators of the regional provenience of honey (Novais, 2013).

The types/plants that are either predominant or secondary pollen types raise a possibility of producing single source honey on commercial scale (Samir *et al*., (2007). Honey analysis by

Luz *et al*., (2010) observed *Mimosa scabrella, Myrcia* type, and *Sorocea* types as the predominant pollen types. Similarly in our results, only a number of types were predominant. Preferences of floral sources during the major part of the time was demonstrated in spite of the strong anthropic influence. Polliniferous variety, is indicative of the potential for monofloral as well as heterofloral pollen production (Luz *et al*., 2010).

Although some plants taxa were prominent in the pollen spectrum in terms of their high frequencies in our results, bees tended to continue collecting from minor pollen taxa that provide small amounts of food. Such minor contributorplants become alternative sources of trophic resources for the colony and are particularly useful when other providers of pollen and nectar are saturated by other pollinators or are diminished. Moreover a priori, those secondary or minor sources could over time occupy central position in the food supply (Novais, 2013). While this study recorded 6 pollen types as predominant (at least 45%), 13 types (Alicia, 2008), 10 types (Ana and Francisco, 2014) demonstrating variation on extent of predominance in samples of various origin. *Trifolium* type (Fabaceae) and *Eucalyptus* type (Myrtaceae) accounted for the monofloral honey. With 31% of pollen types corresponded to native flora (Alicia, 2008).

Predominant pollen types *Prunus* sp., *Eucalyptus camaldulensis,* and Rutaceous member observed in this study have also been reported by (Sunita and Mattu, 2018), *Eucalyptus saligna, Terminalia mantaly,* and *Parthenium*spp (Asteraceae) was recorded as predominant and secondary pollen (Ashoke, 2014). Predominance in pollen contribution could be attributed to widespread presence or spontaneous flowering as seen in *Parthenium* as well *Eucalyptus saligna* and *Terminalia mantaly* which were much foraged during the two seasons (Ashoke, 2014). Helianthus type (Asteraceae) have also been reported in Boudilio *et al*., (2002) as a predominant type. Predominant and important minor pollen were significantly

higher in rainy season compared to the dry season in results by Nguemo *et al.* (2016). Predominance has also been associated by period of abundant flowering (February to November) of the speceis *Mikania cordifolia* . In periods of high abundance of flowers,*Apis mellifera* can show high foraging activity in few floral sources. Meanwhile in seasons of reduced availability of floral resources, the bees have to search for resources in a greater number of plant species, which would in turn be reflected in the abundance of pollen types under consideration (Laura and Cynthia, 2018).

Studies by Nguemo *et al.* (2016) seem to corroborate well with our results as it was observed that during the rainy season, the pollen of *Mimosa* sp. was dominant and that of *Eucalyptus* which was not at the blooming peak period during this season, was classified as occasional isolated pollen. The accessory pollen was represented by *Eucalyptus* sp. Certain predominant pollen type in our study (*Eucalyptus* type, *Acacia*, *Croton* type) were also reported as secondary, important minor and minor pollen in different honey sampled from different sites. Similar trends were reported by Sunita and Mattu, (2018). According to Novais, (2013), it is possible that predominat pollen types eg *Myrcia* (Myrtaceae) from their results, could be from plants which flower throughout the year, but collected only part of the year. It could be hypothesized that months with low frequency of such pollen types represent flowering periods of alternative or more attractive sources of nectar or pollen for the bees. The predominant types Eg *Acacia* spp. observed in our studies were in bloom for a long period indicating that species related to this pollen type flower throughout much of the year. Such predominat pollen types could flower with different intensities at different months and their presence also affected by diversity of nectar sources (Mathew *et al*., 2018). The Secondary pollen types: *Erythrina* sp., *Eucalyptus camaldulensis*, *Citrus* sp., *Callistemon citrinus*, *Psidium guajava*, *Acacia* sp., *Terminalia* sp., *Moringa oleifera*, Important minor pollen: *Mangifera indica*, *Eryhthrina* sp., *Ipomoea* sp., *Zizyphus* sp., *Hibiscus* sp., and members of

Cucurbitaceae, Apocynaceae, Rosaceae, Meliaceae, Poaceae, Euphorbaceae present in different honey samples studied by Sunita and Mattu (2018); *Zea mays* and *Trifolium* reported by Cenet *et al*., (2015) while studying the honey samples of Turkey are in consort with the taxa reported in our studies. *Mimosa pudica* (Fabaceae) and *Zizyphus* type (Rhamnaceae) have also been reported by Ana and Francisco (2014) as accessory pollen are in agreement with their observed contribution in our results. That Convolvulaceae, Anacardiaceae, Fabaceae and Acanthaceae are also preferred as minor source of pollen and nectar (Aswini, 2013) is in agreement with the present study.

The selection of a small number of key variables in principal component analysis increases the reliability of mathematical classification, eliminates features with minor information and allows a visual examination of the data set by two dimensional plot of the key features. Principal component analysis was applied to autoscaled data in studies by Kuchla *et al*., (2015), data analysis showed 73.51% of the total variance was explained by the first two components. The first principal component (PC1 with 43.29% of total variance) was strongly influenced by 3 variables, while for the second principal component (PC2 with 30.22% of the total variance) 2 variables were more important. Similar results were observed in this study where 44.07% of total variance was explained by the first principal component, with 67.67% being explained by the first 2 principal components.

Cluster analysis have given a distinct discrimination of honeys with a wider geographical and botanical origin. Although proven to be very useful, honeys coming from restricted area makes discrimination on the basis of geographical and botanical origin limited. The application of cluster analysis classification is further justified especially when presence of one pollen type has been used as a discriminator amongst honey samples and to relate a certain honey type to certain geomorphological zone. This, however does not take note of

accidental contamination. As such, reliance of rare occurrences can not provide basis for sound classification (Boudilio *et al*., 2002).

It would be expected that honeys harvested during one season group in to specific clusters. Four clusters did not conform to the seasonality of collection. Similar results have been observed in previous studies (Samir *et al*., 2007, Ana and Francisco, 2014). Three clusters did not conform to the seasonality of collection (Samir *et al*., 2007). This could be attributed to the long flowering period of part of the taxa and the varied frequency of occurrence of pollen in honey from different areas during the same season (Samir *et al*., 2007). Classes obtained by cluster analysis have been reported to be composed of both unifloral honeys, multifloral honeys, and mixture of both monofloral and multifloral honeys (Boudilio *et al*., 2002), and with varying similarity magnitudes (Ana and Francisco, 2014). Similar trends were observed in this study.

Fewer clusters than the sites from which the samples were collected were observed in this study. Similar trends were reported by Samir *et al*. (2007), attributed to border effect. Honey Samples collected closer to each other geographically (samples 20, 21, 25, and 26) from adjacent Nessuit and Kapkembu mesoregions, were classified within the same cluster due to similar pollen composition. A cluster analysis of the taxa using presence/absence data, also grouped honey samples of five geomorphological zones into four classes based on their pollen composition (Poderoso *et al*., 2012). In studies by Samir et al. (2007) in West India, a K means clustering of honey samples showed that though samples are collected in 3 different seasons , from different areas, most of the Summer and Autumn honeys have similar floristic composition (Boudilio *et al*., 2002). A similar trend was observed in this study in which April honey samples and December honey samples were clustered together separately. Cluster analysis by Boudilio *et al*. 2002) generated a dendrogram of seven classes. Infrequent pollen

contributed to the determination of the class in the honey samples. Presence of pollen types associated with endemic species show the use of native vegetation by honey bees corroborating the importance of these pollen types as geographic markers for honey samples from a region (Ana and Francisco, 2014).

5.5 Organoleptic Characterisation

Unifloral honeys differ from each other, among other features, in volatile organic composition which influences remarkably the individual sensory characteristics of each honey type (Christy *et al*., 2011). *Acacia* honeys in this study were of light amber colour and with floral fresh aroma. Honeys from same floral source were observed to have similar sensory attributes by Janaina *et al.* (2016). There was a significant variation in the organoleptic characteristics of the honey samples except for odour persistence. The differences between the sensory profiles of honeys highlight the blossom effect on the product's volatile composition. The maintenance of the same volatile compound profiles in honeys from the same floral origin was previously reported by Bicchi *et al*. (1983), who observed the same chromatographic profile of volatile compounds of honeys from the Piedmont region in different harvest years. The qualitative diversity was evident in honeys of different botanical origins. However, these profiles were not uniform for all samples from the same blossom as earlier observed by Jerkovic and Kus (2014). This could be attributed to the fact that because by definition, honey could be considered monofloral when it contained 45% pollen from the same plant. Thus, the honey can maintain the same mellissopalynological classification even if 55% of the pollen composition varies, which will result in different compositional profiles (Jerkovic & Kus, 2014).

The accumulation of phytochemicals and the precursors of volatile components, including carbohydrates, phenols and volatile organic compounds, depends on the climatic conditions and soil characteristics. Differences between honeys with the same botanical origin produced

by different species in different regions are presumably associated with different nectar or pollen compositions, which have the strongest effects on the chemical composition of the honey (Jerkovic & Kus, 2014). Generally, only partial similarities between the volatile constituents of nectar, flower extracts, and honeys have been found. Differences between honey and flower extracts are expected because the honey aroma compounds are constituents of various flower and plant parts (Jerkovic & Kus, 2014), the volatile compound profiles mostly varied from sample to sample in studies by Ana *et al*. (2018). Honeys from same floral source were observed to have similar sensory attributes. The sensory characteristics of honey vary according to maturation time and weather (Jananina *et al*., 2016; Gabriela, 2006). *Acacia* honey has shown highest sensory quality in studies of Romanian honey (Plostcutanu and Uliescu, 2018). Honey from similar locations were observed to differ in sensory profiles eg Colour intensity, aroma intensity, sweetness intensity and, acidity. This is due to the fact that honey has distinct and unique flavours related to the origin of the location (local sensory uniqueness). Different sensory profiles ofhoney from similar locations have also been reported in studies by Plostcutanu and Uliescu (2018).

The differences in the volatile fraction compositions of monofloral honeys greatly affect the individual sensory characteristics of each type of honey. Volatile compounds, which primarily account for food aroma and flavor, are present in honey at very low concentrations as complex mixtures of different chemical classes, including monoterpenes, norisoprenoids, sesquiterpenes, benzenoids, alcohols, esters, ketones and aldehydes (Silva *et al*., 2016). Volatile composition and sensory impression of honey samples are greatly influenced by the Geographic origin, an important quality factor closely correlated with the chemical and sensory characteristics of honey. Generally, volatile organic compounds (VOCs) could be derived from the plant or nectar source, transformation of plant compounds by the bee metabolism, heating or handling during honey processing and storage, from microbial or

environmental contamination (Christy *et al*., 2011). *Eucalyptus* honeys are an important unifloral honey commercialized worldwide. Honey from different species of *Eucalyptus* trees displaying wide variations in the sensorial characteristics. The aroma of *Eucalyptus* honey has long been investigated and attributed to hydroxycetones, sulfur compounds, dike tones, norisoprenoids, alkanes, aliphatic compounds, and monoterpenes as characteristic compounds in their composition (Maria *et al*., 2014). Sensory evaluation have revealed significant differences in taste and aroma between the 27 samples studied. Adulterated honey samples have a less intensive aroma or do not have aroma at all (Sedik *et al*., 2018). Sweet, aromatic, resin, wax aroma notes have been reported in *Cordia* honey by Ligia *et al*. (2014). Consumers preferless, honeys with lower aroma intensity (Plostcutanu and Uliescu, 2018). Fruity, chemical and fermented notes were not reported in studies by Gabriela (2006). The acids in honeys cause different aromas that range from spicy to rancid depending on the length of the molecule's carbon chain. Short-chain acids, including acetic acid, have spicy flavors and aromas, whereas long-chain acids are associated with a rancid aroma (Ana *et al*., 2018).

There was low honey acidity level observed in this study. Honey acidity may be caused by either its mineral content or bacterial activity during the product maturation stage (Pasini *et al*., 2013). This derives from the organic acids of different nectar origins, and D-glucose oxidase enzymatic activity, which catalyzes the conversion of D-glucose into gluconic acid (Belay, 2013). A negative correlation has been reported (r=-0.63) between acidity and colour. Honey with less intense amber colour have more intense acid taste (Janaina *et al*., 2016). Our results are in the contrary in that *Cordia* honey with more intense amber colour showed highest levels of acidity. *Acacia* honeys did not show any acidity contrary to studies by Plostcutanu and Uliescu (2018) in which *Acacia* honey recorded high scores for all the investigated attributes.

Average colour score for this study are comparable to studies by Plostcutanu and Uliescu (2018) in which the average honey colour score was 5, ranging from 5-8.4. High honey colour scores have been given by *Acacia* monfloral honey (8.6) in studies by Plostcutanu and Uliescu (2018), in this study highest colour intensity was observed in Cordia honey (6.3). According to Janaina *et al*. (2016), honey with less intense amber colour have more intense aroma. Colour in liquid honey varies from clear and colorless to dark amber or black. The various honey colours are basically nuances of yellow amber. Colour varies with age, botanical origin, and storage conditions. Less common honey colours eg reddish undertones (Chest nut), greyish (*Eucalyptus*) and greenish (honey dew) have been reported. Once crystalized honey turns lighter in colour because the glucose crystals are white (Krell, 1996). *Croton* honey have been reported with highest proportion (33.15%) glucose (Ligia *et al*., 2014). Some of the honeys reportedly "as white as milk" in some parts of East Africa are finely crystalized honey, almost water white (colourless) in their liquid state (Krell, 1996). Previous studies have reported honey colour intensity varying according to pH, mineral content, and exposure to light, storage time and enzymatic reactions. Dark honeys show having a high content of phenolic compounds and flavonoids (Tlemcani *et al*., 2018). Honey colour have also provided major contribution to first principal component in studies by Jananina *et al*. (2016). Extra light amber, white/amber, dark amber, light amber for Croton honey have been reported (Ligia *et al.*, 2014).

A significant variation in fluidity was observed. This was the attribute with highest variation amongst honey samples. Freshly extracted honey is a viscous liquid. The viscosity depends on honey composition and particularly with its water content (Krell, 1996). Honey with lower water content have been reported to be of high viscosity attribute (Janaina *et al*., 2016). Honey from different origins have been reported as following Newtonian behaviour. However results indicating for non-Newtonian behaviors

(thixotropic/dilatancy/pseudoplasticity) for some honeys have also been published (Stelmakiene *et al*., 2012). Dilatancy has been reported in Nigerian, *Eucalyptus* honeys. Rheology of honeys may inform something about its composition. Thixotropy is thought to be associated with proteins in honey, whereas the presence of high-molecular weight dextran in honey can cause dilatancy. Newtonian behaviour usually is expected for a concentrated solution of low molecular weight compounds, indicating absence of macromolecules and/or particles in suspension. Unusual non-Newtonian pseudoplastic behaviour in honeys can signify the addition of foreign substances to honey such as molasses or starch. The variation observed in honey viscosity is greatly affected by composition parameters, such as water, sugar and protein contents, which change with the geographical and botanical origin of each honey (Fransisco *et al*., 2014).

Highest graininess was shown equally among *Eucalyptus*, *Acacia* and *Cordia* honey. The crystallization as well as graininess could be attributed to fructose-glucose and glucose-water ratio in the honey composition (White, 1978; Fransisco *et al*., 2014). Fructose-glucose ratio is an important parameter for the prediction of crystallization tendency of honey. Honey samples that do not crystallize for a long time, have a fructose-glucose ratio higher than 1.33 (White, 1978). Fructose-glucose ratio less than 1.11, honey crystallizes quickly. Glucose-water ratio may be used to evaluate the honey propensity to crystallize. Glucose -water ratio above 1.7 means a high probability of the honey to crystallize (Fransisco *et al*., 2014). *Cordia* honey was liquid with crystals, of powdery texture and crystalline nature in studies by Ligia *et al.* (2014), this was comparable to our results in which *Cordia* honey had fine graininess. Our two step cluster analysis results show that the most important variable in predicting the monofloral honey type is the odour persistence. Odour intensity, aroma/odour family, and odour persistence had predictor importance of more than 0.5 and contributed to the largest proportion of honey variability. This is in contrast to reports by Gabriela (2006) in which

principal component analysis indicated that colour, honey flavour, and sweet taste defined most of the variability.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

(i) Eastern Mau has 86 melliferous plant species from 39 plant families. Fabaceae, Asteraceae, Acanthaceae, Myrtaceae, Euphorbiaceae, and Gramineae contribute the majority of the bee plants in Eastern Mau forest.

(ii) The floral calendar of Eastern Mau has a year-long bee plant mosaic.

(iii) The Geographical Origin of Eastern Mau honey can be determined by a 76-pollen type spectrum.

(iv) Botanical Origin of Unifloral honey in Eastern Mau is predominantly *Acacia*, Eucalyptus, *Croton, and Albizia, Cordia,* and *Vernonia* pollen types while multifloral honey is by a range of 8 to 15 pollen types.

(v) The organoleptic characteristics of the unifloral honeys from Eastern Mau are within the acceptable limits as stipulated regulations and are most distinguishable with use of odour persistence.

6.2 Recommendations

(i) The value of the 86 melliferous plant species should be shared with the Ogiek bee keepers in extension programs.

(ii) The floral calendar should be translated in to local Ogiek dialect for further use in beekeeping while Ogiekbee keepers should harvest their honey end of May which coincides with the end of honey flow period

(iii) The pollen spectrum denoting the Ogiek honey Geographical origin should be shared with honey traders to eliminate mislabeling and fraud in Ogiek honey industry.

(iv) The monofloral honey should be marketed and sold as premium brands to incentivize the conservation of plants that produce them.

(v) The organoleptic profiles of the Ogiek honeys should be used alongside the Botanical and Geographical origin as an identity of quality and source.

6.3 Further Research

(i) The factors that influence the preferences for various melliferous taxa by *Apis mellifera*.

(ii) The consonance of the floral calendar and the local Ogiek beekeeper knowledge about the flowering seasons and periods of bee plants.

(iii) The effect of climatic and anthropogenic conditions influence on the pollen spectrum determining the Geographical origin.

(iv) How plant density and diversity affects the production of monfloral honey.

(v) The physicochemical factors that affect the organoleptic characteristics of Eastern Mau forest honey.

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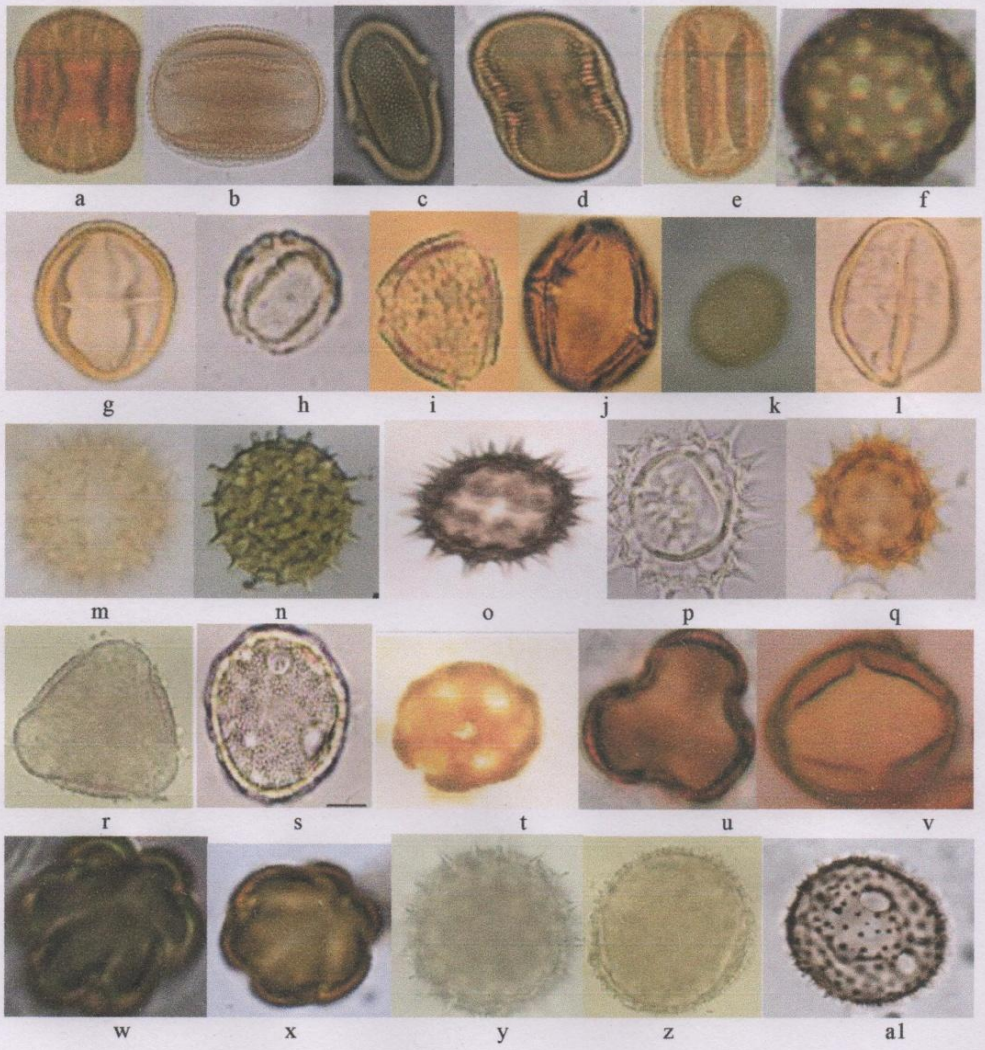
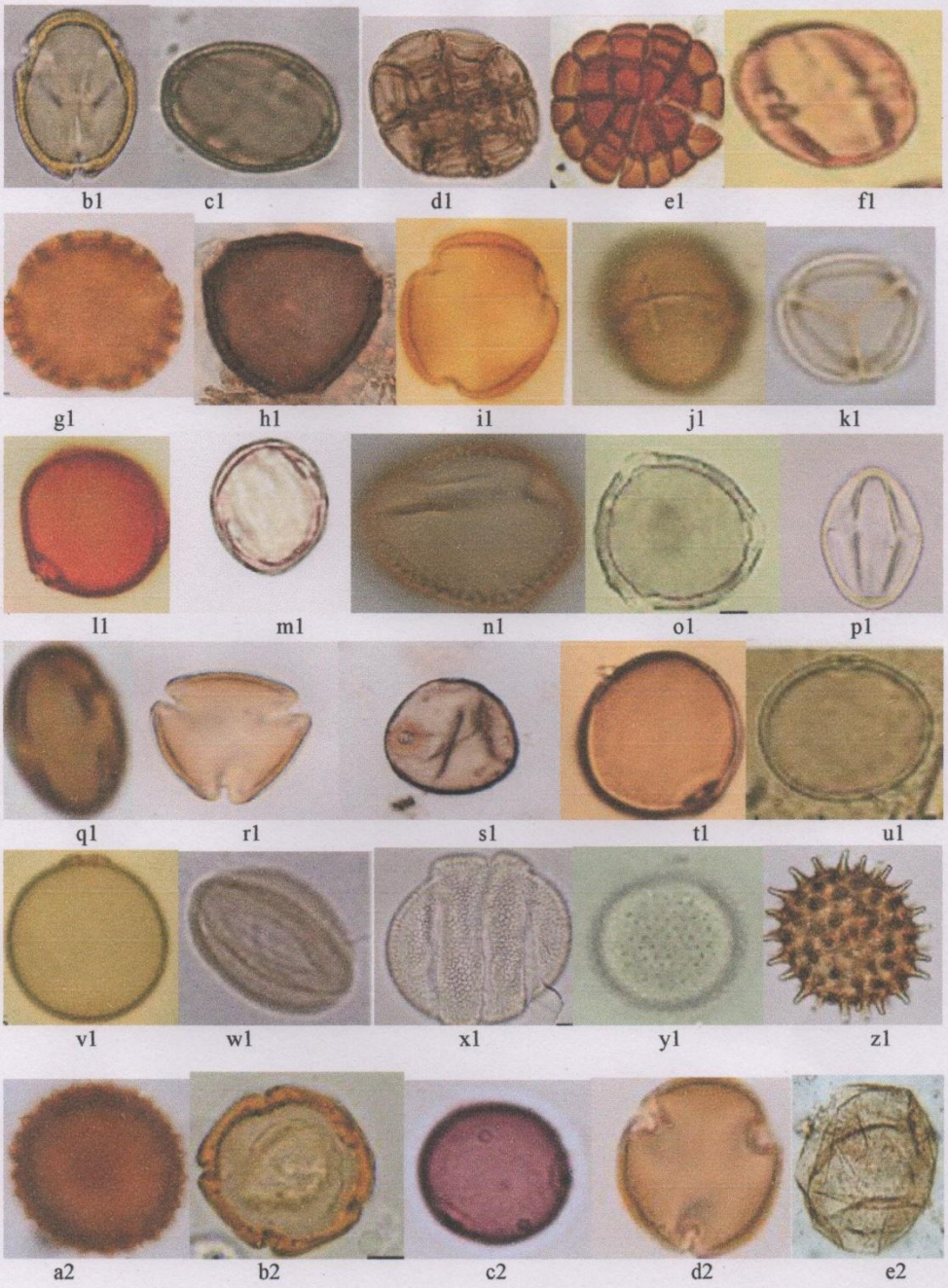
APPENDICES

Appendix 1: Pollen types observed in various honey samples from Eastern Mau Forest, Kenya

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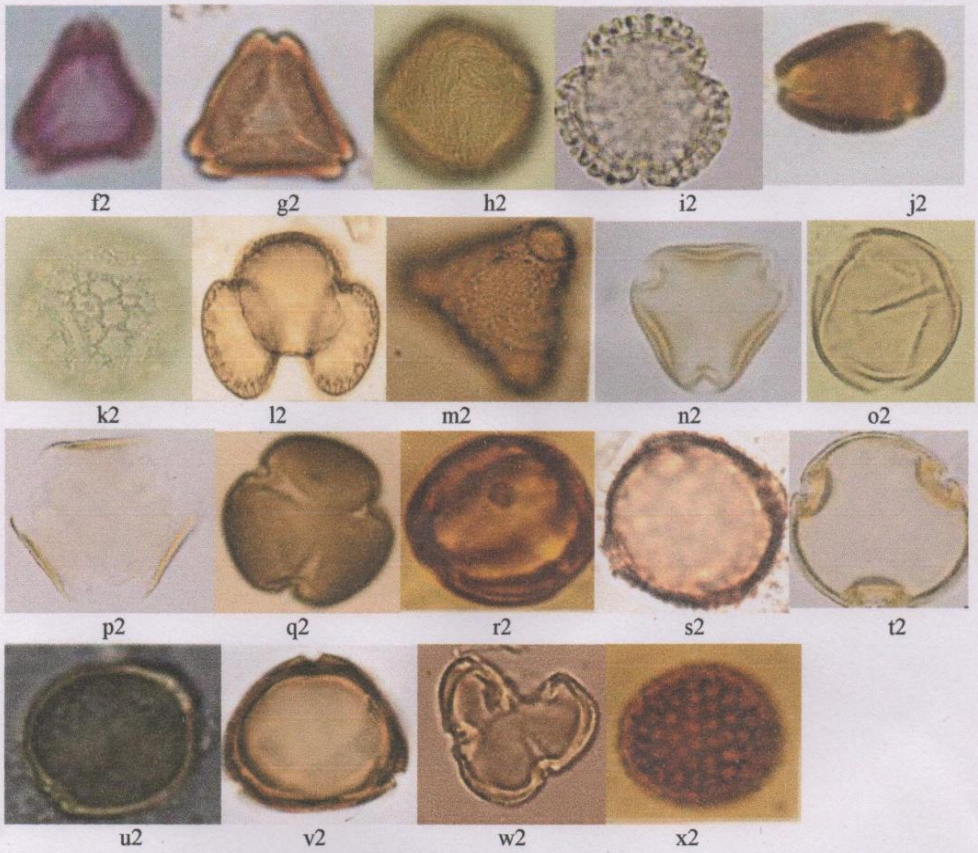

Key: The pollen types arranged in order of the names below.

a-*Asystasia gangetica (L.)****;b-****Acanthus pubescens;* ***c-****Justicia exigua ;* ***d-****Justicia flava* ***; e-****Odontonema strictum ;* ***f-****Agave sisalana;****g-****Achyranthes aspera;* ***h-****Pupalia lappacea;****i-****Mangifera indica;****j-****Rhus nataliensis;****k-****Polyscias fulva;****l-****Aloe secundiflora;****m-****Aspilia mossambicensis;****n-****Bothriocline fusca;****o-****Hellianthus Annuus;****p-****Tithonia diversifolia;****q-****Vernonia auriculifera;****r-****Jacaranda mimosifolia;****s-****Cordia abyssinica;****t-****Opuntia ficus-indica;****u-****Maerua triphylla;****v-** *Carica papaya;****w-****Terminalia brownii;****x-****Combretum molle;****y-****Ipomoea batatas*

z-Cucurbita pepo;

a1-*Mormadica foetida;****b1-****Croton spp.;****c1-****Euphorbia hirta;****d1-****Acacia spp.;****e1-****Albizia coriaria;****f1-****Crotalaria brevidens;****g1-****Delonix regia;****h1-****Erythrina abyssinica;****i1-****Glircidia sepium;j1-Leucaena leucocephala;k1-Mimosa invisa;l1-Pentaclethra macrophylla;m1-Phaseolus vulgaris;****n1-****Sesbania sesban;****o1-****Tamaridus indica;****p1-****Tephrosia vogelii;****q1-****Trifolium repens;****r1-****Tylosema spp.;****s1-****Cynodon dactylon;t1-Pennisitem purpureum;u1-Sorghum bicolor;v1-Zea mays;* ***w1-****Leucas deflexa;****x-****Ocimum gratissimum;****y1-** *Persea americana;* ***z1-*** *Malvaviscus arboreus;*

***a2**-Sida acuta;**b2**-Melia azedarach;**c2**-Morus mesozygia;**d2**-Moringa Oleifera;**e2**-Musa acuminata;**f2**-Callistemon citrinus;**g2**-Eucalyptus spp.;**h2**- Psidium guajava;**i2**- Jasminum fluminense;**j2**- Olea europaea;**k2**-Passiflora edulis;**l2**-Pinus type;**m2**-Grevillea robusta;**n2**-Zizyphus mucronata;**o2**-Eriobotrya japonica;**p2**-Prunus africana;**q2**- Citrus limon;**r2**-Teclea nobilis;**s2**-Dombeya torrida;**t2**- Grewia bicolor;**u2**-Trema orientalis L;**v2**- Lantana camara;**w2**-Cissus rotundiflora;**x2**-Tribulis terrestris.*