

ANNUAL DIVERSITY OF HONEY BEE POLLEN SOURCES IN TWO PUMPKIN GROWING LANDSCAPES, MACHAKOS COUNTY, KENYA

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Abstract—Multi-floral foraging sources for honey bee (*Apis mellifera* L.) have been threatened by landscape changes and unsustainable farming practices. In East Africa, the biodiversity of forage resources that could support honey bees, especially in agricultural lands, remains least explored. This study investigated pollen diversity for honey bees in Yatta and Masinga Sub-counties in Machakos County, Kenya. Honey bee hives were installed on eight pumpkin (*Cucurbita maxima* Duchesne ex Lam) farms (one hive per farm) in two varying landscape vegetation classes (low and medium) based on normalized difference vegetation index (NDVI). Pollen traps were installed at the hive entrance and pollen pellets were retrieved fortnightly for subsequent identification. Approximately 115 pollen types were identified. The pollen pellets were associated with 63 plant families and 109 plant families in low and medium NDVI classes, respectively. The predominant source of pollen for honey bees in low NDVI class included the plant families Poaceae (5,526 pellets), Asteraceae (3,176 pellets), Combretaceae (1,327 pellets), Acanthaceae (1,122 pellets), Amaranthaceae (960 pellets), Boraginaceae (951 pellets), Typhaceae (889 pellets), Guaduelleae (809 pellets) and Loranthaceae (588 pellets). In medium NDVI, most pollen was sourced from plant family Asteraceae (3,605 pellets), Malvaceae (1,572 pellets), Poaceae (1,538 pellets), Combretaceae (1,468 pellets), Salvadoraceae (1,354 pellets), Solanaceae (1,011 pellets), Asphodelaceae (885 pellets), Fabaceae (882 pellets), Euphorbiaceae (685 pellets) and Myrtaceae (546 pellets). The diversity of pollen types varied between the NDVI classes and across months. Although honey bees sourced diverse pollen required for the dietary balance of the colony, there was variability across landscape types and months.

Keywords—*Apis mellifera*, multi-floral; normalized difference vegetation index (NDVI); pollinator; pollen diversity

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INTRODUCTION

Honey bees (*Apis mellifera* L.) play vital roles in pollination provision, which is critical in agricultural productivity and supporting plant reproductive success. Pollinators contribute to the stability of natural ecosystems and agricultural

landscapes. Pollination is the transfer of pollen from the male parts (anther) of a flower to the female part (stigma). However, successful pollination should not only lead to pollen deposition on the stigma but also its acceptance, growth and onward fertilization leading to seed and fruit production. For this to occur, a synchrony

of various actions is necessary such as having pollen from same plant species, deposition of mature pollen, a ready and receptive stigma and available agent to move the pollen. The honey bees carry pollen with their hairs and deposit them to the stigma incidentally (Konzmann et al. 2019). They are responsible for pollinating many types of fruits and vegetables and apart from pollination services, honey bees are managed to produce an array of hive products such as honey, wax, bee bread, royal jelly, bee venom and propolis, products which have various uses in the food and pharmaceutical industries (Pasupuleti et al. 2017).

The availability of floral resources is critical for ensuring adequate nutrition to support normal growth, reproduction, brood rearing and survival of honey bee colonies (Keller et al. 2005; Brodschneider & Crailsheim 2010). The main sources of food for honey bees come from the flowering plants on which they forage for pollen and nectar (Kleinert & Giannini 2012). Pollen is the primary sources of protein, energy and other dietary needs for brood and adults in the honey bee colony (do Carmo Zerbo et al. 2001; Brodschneider & Crailsheim 2010; Donkersley et al. 2017). Additionally, pollen provides essential nutrients that boost the immune response (Alaux et al. 2010), especially against pests and diseases (Noordyke & Ellis 2021). This implies that high pollen diversity of honey bee forage is important in improving overall colony resistance to various pests and diseases (Antúnez et al. 2017). However, pollen from diverse floral sources can have varied levels of nutrients such as amino acids, minerals, lipids and vitamin content (Stanley & Linskens, 2012). Pollen is stored in hives in form of bee-bread while nectar is processed to become honey, both products being consumable by humans (Kroyer & Hegedus 2001).

Honey bees employ different foraging techniques to access their main floral rewards (pollen and nectar) (Dyer 2002). Many plants that produce flowers, including pumpkin (*Cucurbita pepo* L.), have evolved morphological traits such as brightly colored petals and floral scents to attract a target group of pollinators, including honey bees. Some plant families, such as Asteraceae have pollen that are spinous while Malvaceae have pollen with echinations or prolongations, which allow and promote pollen transfer during the visits

by pollinators to achieve cross-pollination crucial for reproduction in many plants (Dyer 2002).

Honey bees exploit different plant species including pumpkin to collect and store pollen and nectar. Reportedly, the quantity of pollen produced also varies across plant species and within species (Goodman 2003; Filipiak et al. 2022). The quantity and diversity of pollen collected by honey bees is an indicator of a healthy foraging habitat, describing the floral resources in terms of their quality to support the health and sustenance of a colony (Da Luz et al. 2021) although, pollen sources and quantity produced may vary spatially across seasons or by landscape (Lau et al. 2019; Simanonok et al. 2020; Malagnini et al. 2022). Information on foraging habitats is critical in determining the quality of honey bees products such as honey and provides data to beekeepers to improve the market value of beehive products (Barth et al. 2010). Foraging habitat information can also inform beekeepers and farmers about the honey bee forage plant species to bolster their conservation in a region for pollination services or help in making critical decisions such as selecting suitable locations for beehive installations (Modro et al. 2009). Unfortunately, changes in land cover can lead to reduced abundance and diversity of pollinators due to the loss of floral resources (pollen, nectar and resins) (Patrício-Roberto & Campos, 2014). For example, higher pollination services have been associated with highly diverse habitats with increased levels of natural cover (Jakobsson & Ågren 2014). Reportedly, honey bee colonies engage in high foraging specialization that positively correlates with habitat heterogeneity because they are likely to forage on key flowering species, especially in increased semi-natural habitat cover (Pardee et al. 2023).

Knowledge of the floral resources that honey bees use across the year is an essential component of developing a honey bee forage plan in a landscape. This knowledge can be obtained using different approaches, including analysis of pollen pellets carried by returning foragers (Köppler et al. 2007; Gorelick et al. 2017), analysis of pollen stored in nests or hives (Ramanujam & Kalpana 1992) and direct observation of foragers in the field through video monitoring or other observation methods (Richard et al. 2011). Identification of pollen pellets from honey bee foragers provides a measure of

pollen foraging by the honey bees, while pollen found in honey indicates plants being used by honey bees for both pollen and nectar (Kirk & Howes 2012). Pollen found in honey is also used to classify the botanical composition of honey to determine the geographic origin for food quality and traceability (Hawkins et al. 2015). The occurrence of pollen in honey can be explained either by their presence in the floral nectar or exogenous sources (Salonen & Julkunen -Tiitto 2012). The pollen profile of honey reflects forest vegetation, floral diversity and species composition of the plants foraged by honey bees (Corvucci et al. 2015). However, pollen pellets from the returning honey foragers indicate peak pollen foraging periods and actively flowering plants at that time.

Pumpkins are an important food and economic crop, globally; Haščík et al, (2022) estimates its global production at 22,900,826 tons. Africa alone produced 2,793,530 tons which is comparatively low than the first two leading countries in the world: China (8,427,676 tons) and India (5,655,994 tons) while Kenya produced 28,150 tons (Haščík et al. 2022) which is far lower than the leading African countries in the production of pumpkin such as Algeria (420,135 tons) (Haščík et al. 2022). The government of Kenya under the Ministry of Agriculture's Kenya Agricultural Livestock and Research Organization (KALRO) has continued to promote the production and consumption of crops such as pumpkin owing to their value for food and nutrition security, fighting hunger and hidden hunger in rural communities, and for diversification of incomes by farmers. Pumpkin is a crop that is highly dependent on insect pollination services (Klein et al. 2007; Giannini et al. 2020). Honey bees are known to be the main pollinators of pumpkin in Kenya and the effort by the government of Kenya to promote the use of insect pollination services in farming systems requires that farmers keep honey bees. However, most crops have short flowering windows and cannot provide honey bees with sufficient food needs throughout the year, underlining the need to adopt a landscape-wide bee forage management approach. Therefore, the present study investigates diversity of pollen collected by honey bee foragers to map honey bees' forage resources across different months of the year and varying landscapes in Machakos County, Kenya.

MATERIALS AND METHODS

DESCRIPTION OF THE STUDY SITE

The study was carried out in smallholder farmer-managed pumpkin fields in Yatta (2°18'0" S and 38°13'0" E) and Masinga Sub-Counties 0°56'31" S and 37°37'33" E) in Machakos County in Kenya within low and medium landscape vegetation productivity classes based on satellite-derived normalized difference vegetation index (NDVI) (Fig. 1). Machakos County covers a total area of 6,208 km² and lies at an elevation of 790 m to 1,594 m above sea level. The average annual rainfall of the County is between 500 mm and 1,250 mm, where October to November is the main rainy season (Mwangi & Mundia 2014).

COMPUTATION OF NORMALIZED DIFFERENCE VEGETATION INDEX

As described by Gorelick et al. (2017), rainfall data from the Climate Hazard Group Infrared Precipitation with Station (CHIRPS, University of California, Santa Barbara, USA) was used at a 5 × 5 km spatial resolution to determine the exact dry and wet seasons in 2019 for the study area. Sentinel - 2 (S2) satellite images were then used to compute the normalized difference vegetation index (NDVI) in the cloud-based Google Earth Engine platform (GEE, Alphabet, Mountain View, USA). One hundred and ninety-five S2 images were acquired for both the wet (February to May, 99 images) and dry (June to August, 96 images) seasons. We then created a composite image for each season using the multi-date S2 median reflectance pixel values at 10 m spatial resolution. A detailed description of the processing steps is found in Adan et al. (2021). Using the equation below, we calculated the NDVI for dry and wet composite images based on red and near-infrared bands as $NDVI = (NIR - red) / (NIR + red)$, where NIR and red are reflectance values at near-infrared and red bands 8 and 4 of S2, respectively. NDVI values for wet and dry seasons were reclassified into two vegetation productivity classes (low and medium) using the unsupervised K-means clustering method (Adan et al. 2021). The ranges of NDVI values for each class for the dry season were 0.320 - 0.077 (low), 0.077 - 0.133 (medium) and 0.133 - 0.619 (high), while the NDVI ranges for the wet season were 0.373 - 0.158 (low), 0.158 - 0.249 (medium) and 0.249 - 0.730 (high). Subsequently, a multi-season composite classified map was created

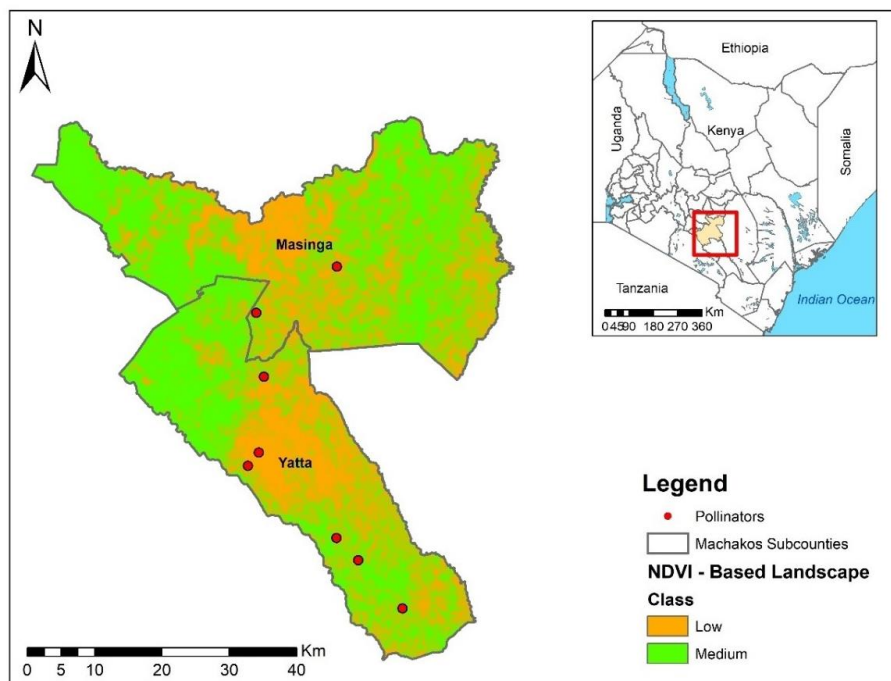


Figure 1. Distribution of pumpkin farms in Yatta and Masinga Sub - Counties, Machakos County. NDVI = normalized difference vegetation Index.

by combining the outputs of the wet and dry season classifications based on the cluster values for both seasons (Adan et al. 2021).

SOURCE AND INSTALLATION OF HONEY BEE COLONIES

Honey bee colonies housed in standard Langstroth hives with a naturally mated active egg-laying queen were obtained from the International Centre of Insect Physiology and Ecology (*icipe*) apiary, Nairobi, Kenya. Sites for installation of the hives were categorized using low and medium NDVI on the established landscape types with at least 25 km distance between the farms. Colonies were installed in four pumpkin farms (one colony/farm) in each NDVI class, yielding a total of eight farms. The colonies were allowed to acclimatize to the conditions of their respective new environment for a week before the onset of data collection.

POLLEN SAMPLING AND PROCESSING

The pollen traps were attached to the entrance of a hive at 8:00 am and left for 48 h before collecting the pollen. The samples of pollen pellets trapped from returning honey bee foragers were retrieved every two weeks for a year (from May 2020 to June 2021, covering both rainy and dry seasons). Collected pollen pellet samples were transferred into sterile 5 mL vials. The vials were immediately placed in a cooler box after pollen collection and transported to the palynology and

palaeobotany laboratory for analysis at the National Museums of Kenya (NMK), Nairobi, Kenya.

Pollen samples were weighed in the laboratory using a precision weighing balance. Using a spatula, a representation of three to four pollen with different colours was placed in 5 mL vials containing water and then mixed using a vortex mixer (ZX3, Velp Scientifica Usmate Velate, City, Italy). Five mL of 10% KOH was added to remove organic materials. The samples were placed in a hot bath for 5 min to catalyse the process. Samples were then centrifuged for 3 min at 3000 rpm, the KOH was decanted and then the samples were washed three times with distilled water to further remove KOH. Five mL of glacial acetic acid was added to dehydrate the samples which was followed by addition of the acetolysis mixture (9 parts of acetic acid and 1 part of sulphuric acid). About 5 mL of the acetolysed mixture was then added and placed in a hot bath for 3 - 4 min. Samples were then centrifuged and the acetolyses mixture was decanted followed by a buffering procedure using acetic glacial acid to prevent overreaction during the distilled water washing process. Finally, 2-3 drops of glycerin were added to each sample followed by fuschin dye and samples were mounted on a slide for microscopic identification, counting and photography. Pollen residues were mounted on permanent microscopic

slides covered with cover slides, dried, sealed using colourless nail polish, and labelled as described by Barth et al. (2010). Only 115 of 133 collected pollen samples were successfully identified following comprehensive laboratory analysis.

POLLEN ANALYSIS

Pollen collected by honey bees was classified according to sources, then quantified and grouped into four types according to their proportion as predominant pollens (>45%), secondary pollens (16-45%), important minor pollens (3-15%) and minor pollens (<3%) according to Louveaux et al. (1978). The samples were mounted in the glycerine medium and pollen identification was done using an Axioscop microscope (Carl-Zeiss, Thornwood, USA). Morphological characteristics such as apertures and colpi were examined at x400. The pollen polar axis (P) and equatorial diameter (E) were measured to determine the quantitative traits of pollen. At least 500 pollen pellets were counted per sample using the transect method as described by Tamic et al. (2011). Pollen types were identified taxonomically to genus level while others to family level and species level (Vincens et al. 2007) based on the palynological reference collection (e.g., Bonnefille 1971) at the palynology and paleobotany laboratory at NMK. Pollen samples identified under the Axioscop microscope were compared with plants collected in surrounding areas where NIR and red are reflectance values at near-infrared and red bands 8 and 4 of S2, respectively (Bosco & Da Luz 2018). The pollen identified was classified according to raw palynological spectra nomenclature proposed by Von Der Ohe et al. (2004).

ESTABLISHMENT OF A FLORAL CALENDAR

We established floral calendars using pollen that occurred as predominant pollen (>45%) and secondary pollen (45 - 16%). The categorized frequencies were color-coded and mapped on the months. The floral calendars for low and medium NDVI were established separately.

DATA ANALYSIS

A generalized linear mixed effect model was used to determine statistical variation of pollen number among the plant families (pollen sources), between the two NDVI classes and across the months. Plant families, NDVI and months were

used as fixed variables while farm was used as a random variable.

The Shannon -Wiener diversity index was calculated based on the different pollen samples. For landscape composition, the Shannon-Wiener index for pollen reflects both the richness and evenness of pollen samples, with lower values indicating a lower diversity in pollen sample composition.

The relative abundance, diversity and evenness across different months and between the two NDVI classes were determined using the Shannon - Wiener diversity index (H') (Al-Fedaghi 2012):

$$H' = -\sum[(p_i) \times \ln(p_i)],$$

where: p_i = proportion of individuals of its species in a whole community; $p_i = n/N$; n = frequency of a particular plant family; and N = total number of all sampled plant families. Subsequently, the evenness index (J), which compares the similarity of the population size of each family, was calculated according to Kiros (2018):

$$J = H'/H_{\max},$$

where $H_{\max} = \ln$ (total number of families). The species richness was determined by counting the number of individual species represented under each season and month. The datasets were analyzed using R software version 4.0.1, R Core Team (2020).

RESULTS

The sources of pollen collected by honey bees varied significantly across plant families ($\chi^2 = 164.109$, $df = 70$, $p < 0.001$) but not across months ($\chi^2 = 11.08$, $df = 11$, $P = 0.43$) or between the two NDVI classes ($\chi^2 = 0.087$, $df = 1$, $P = 0.76$). There was a significant effect on pollen sources resulting from the interaction of NDVI and month ($\chi^2 = 18.66$, $df = 10$, $P = 0.044$). Honey bees foraged on 61 and 106 plant families in low NDVI and medium NDVI, respectively (Fig. 2). Generally, there was a higher diversity of forage plant families providing more than 45% pollen for honey bees in low NDVI compared to those in medium NDVI across the year. For low NDVI, plant families that provided most pollen to honey bees included: Asteraceae, Poaceae, Typhaceae, Combretaceae, Acanthaceae, Boraginaceae and Amaranthaceae while families

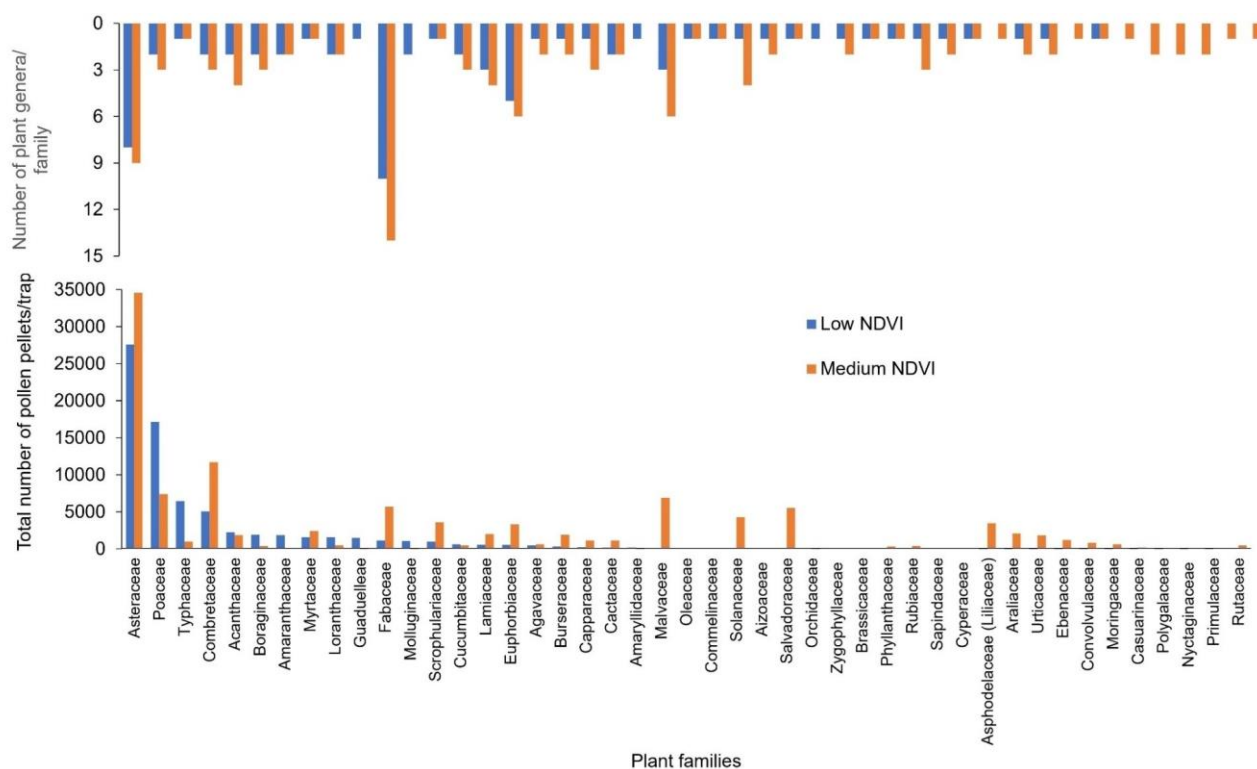


Figure 2. Plant families and total number of pollen pellets per beehive, and number of plant genera per family, in Machakos County, Kenya. NDVI = normalized difference vegetation index.

Asteraceae, Poaceae, Fabaceae, Asphodelaceae, Solanaceae, Scrophulariaceae, Malvaceae, and Salvadoraceae were key sources of pollens in the medium NDVI. Based on pollen analysis, families Fabaceae, followed by Asteraceae, had the highest number of genera represented in both low (10 and 8, respectively) and medium (14 and 9) NDVI, respectively (Fig. 2).

POLLEN TYPES, THEIR ABUNDANCE AND DIVERSITY

There was a temporal difference in the collection and use of pollen by honey bees across the two NDVI classes. In low NDVI, predominant pollen (>45%) flora was recorded in April (*Vernonia* spp.), May (*Typha* spp.) and September (*Ageratum* spp.) while in medium NDVI, predominant pollen (>45%) sources were recorded in January (*Vernonia* spp.), March (*Salvadora* spp.) and November (*Aloe* spp.). Some of the most common pollen types are illustrated in Fig. 3.

The abundance, Shannon diversity index, species richness, and species evenness is illustrated in Fig. 4. Generally, honey bees collected more pollen pellets in medium NDVI (67,125 pollen pellets) than in low NDVI (45,758 pollen pellets). In the medium NDVI, the highest amount of pollen

pellets was collected in March (9,689 pollen pellets), while the least amounts of pollen pellets were collected in February (4,527 pollen pellets) and April (1,714 pollen pellets). The highest diversity of pollen sources was recorded in August ($H' = 2.4$), September ($H' = 2.4$) and May ($H' = 2.3$) compared to other months. Likewise, the highest numbers of plant families foraged by honey bees were observed in August (42 families), May (37 families) and September (36 families). The lowest diversity ($H' = 1.5$ and $H' = 0.9$) of pollen sources was collected from 18 and 21 plant families in January and March, respectively (Fig. 4).

In the low NDVI class, the pollen pellets collected by honey bees were the highest in May (11,357 pollen pellets) and least in November (1,046 pollen pellets). The highest diversity of pollen sources ($H' = 2.2$) was observed in March, while the lowest diversity of pollen sources ($H' = 0.2$) was recorded in both October and November. Overall, honey bees had more pollen sources with a generally high abundance and diversity in the medium NDVI than in the low NDVI. Honey bees in the low NDVI landscapes faced more variable and potentially unpredictable conditions with several months of the lowest abundance of pollen

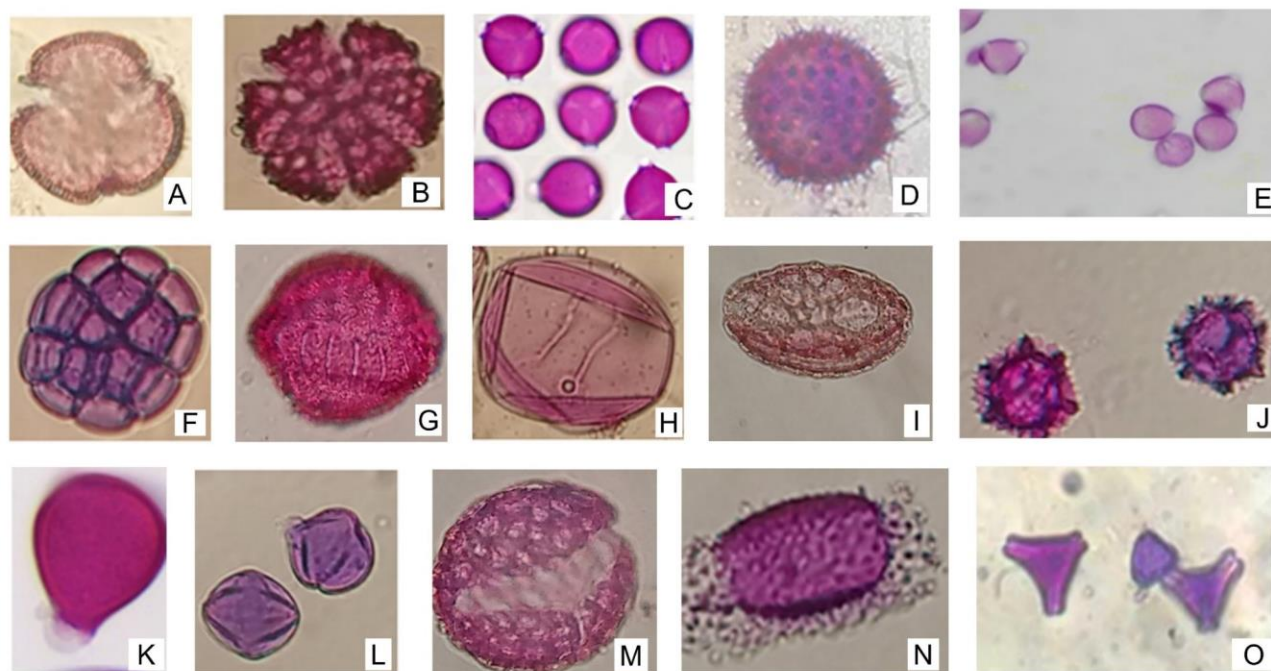


Figure 2. Photomicrographs of some pollen types collected by *Apis mellifera* from Yatta and Masinga Sub-Counties of Machakos County, Kenya. A) Euphorbiaceae: *Euphobia* spp. B) Lamiaceae: *Ocimum* spp. C) Fabaceae: *Phaseolus* spp. D) Asteraceae: *Bidens pilosa*. E) Urticaceae: *Urtica dioica*. F) Fabaceae: *Acacia* spp. G) Rubiaceae: *Spermacoce* spp. H) Poaceae: *Zea mays*. I) Agavaceae: *Agave* spp. J) Asteraceae: *Vernonia* spp. K) Solanaceae: *Solanum lycopersicum*. L) Solanaceae: *Solanum incanum*. M) Fabaceae: *Delonix* spp. N) Commelinaceae: *Commelina* spp. O) Loranthaceae: *Tapinathus bangwensis*.

(March, June and October) and low diversity of pollen sources (April, July and October) (Fig. 4).

FLORAL CALENDAR

The floral calendar for low and medium NDVI consists of 11 and 12 families, respectively (Fig. 5). In the low NDVI class, three plant genera (*Bidens* spp., *Vernonia* spp., and *Ageratum* spp.) provided pollens to honey bees for 11, 10 and 8 months of the year, respectively. In the medium NDVI class, there was one family (Poaceae), four genera (*Vernonia* spp., *Syzigium* spp., and *Terminalia* spp.), and *Bidens* spp., that provided pollens for 12, 7, 7, 8 and 10 months of the year, respectively. Also, the results showed that the amount of pollen types varied across months in the low NDVI class and medium NDVI indicating seasonal flowering phenology of most plants (Fig. 3, 4).

DISCUSSION

The ability of honey bees to collect nectar and pollen to be processed into honey and bee bread is crucial for the survival, prosperity and reproduction of their colonies (Brodschneider & Crailsheim 2010). In this study, the amount and

types of pollen collected by honey bees varied between landscapes and across months. This illustrates the ecological context experienced by the foraging honey bees in low and medium-vegetation productivity landscapes based on the NDVI. Honey bee sourced pollens from 61 and 103 plant families in low and medium NDVI, respectively. The most harvested pollen types were from the plant families: Acanthaceae, Asteraceae, Amaranthaceae, Combretaceae, Myrtaceae and Poaceae in low NDVI and Asteraceae, Combretaceae, Malvaceae, Myrtaceae, Salvadoraceae, Solanaceae and Poaceae in medium NDVI. Although Cucurbitaceae pollen was always available on the study site farms throughout the year from wild and managed sources, honey bees did not collect pollen from pumpkin particularly in January, February, March and August in the low NDVI class and May and July in the medium NDVI. Honey bees effectively pollinate the genus *Cucurbita*, but they rarely take *Cucurbita* pollen back to the hive because the pollen is too large, oily, and spiny to pack easily into the honey bee corbicula possibly contributing to the low presence of pumpkin pollen in the returning honey bee

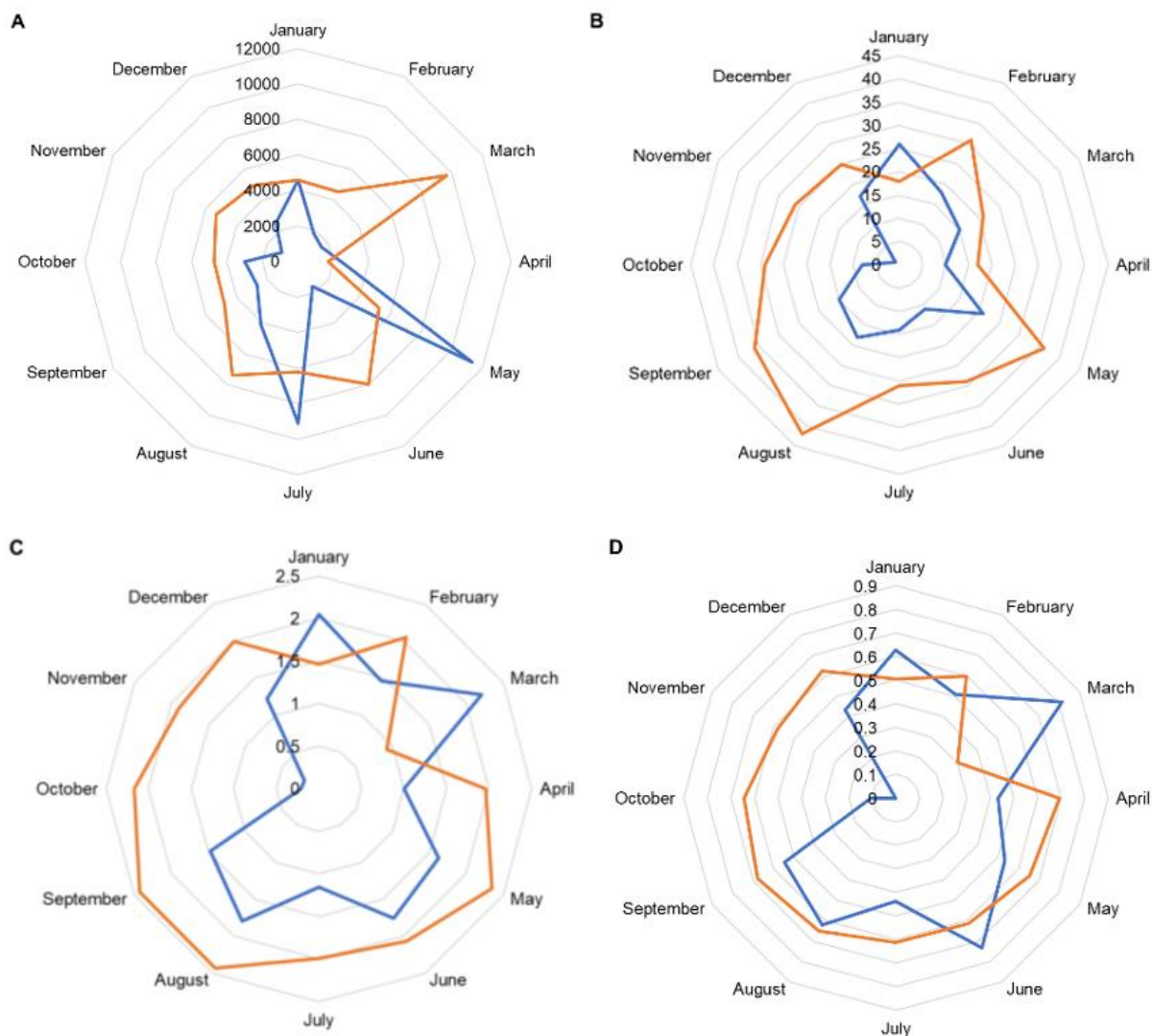


Figure 3. Abundance and diversity indices for the pollen samples collected by honey bees in Machakos County in the low and medium NDVI landscapes throughout the year. The indices shown are abundance (A), species richness (B), Shannon diversity indices (C), and evenness (D) of pollen samples. Different normalized difference vegetation index (NDVI) classes are indicated by differently coloured lines (blue - low NDVI; orange - medium NDVI).

foragers (Konzmann et al. 2019). Also honey bees may visit pumpkin flowers and provide pollination services on the farms while returning with none or some of the pumpkin pollen to the hive (Brochu et al. 2020).

Findings by Guantai et al. (2019) and Onyango et al. (2019) also showed that the family Asteraceae was the most used floral resource by honey bees in a mountainous region of Kenya while Capparaceae, Combretaceae and Asteraceae families were reported as the most used floral resource in semi-arid and arid regions of Kenya (Ochungo et al. 2021). These observations indicate the effect of landscapes on the foraging resources.

Honey bees gathered multi-floral pollen pellets from 3 - 35 plant families in low NDVI and 9 - 40 plant families in medium NDVI, reflecting the availability of flowering plants across the months and varying landscapes in Machakos County. The variation in the pollen collected from certain plants across months corresponds to their blooming period. The plant genera *Barleria*, *Ageratum*, *Bidens*, *Vernonia*, *Zea*, *Terminalia*, *Delonix*, *Astragalus*, *Syzygium*, *Solanum* and *Salvadora* provided pollen in most months of the year. The amount of pollen collected by the honey bees is dependent on the density of the flora, distance to the hive and competing flora (Elliott et al. 2021). However, the

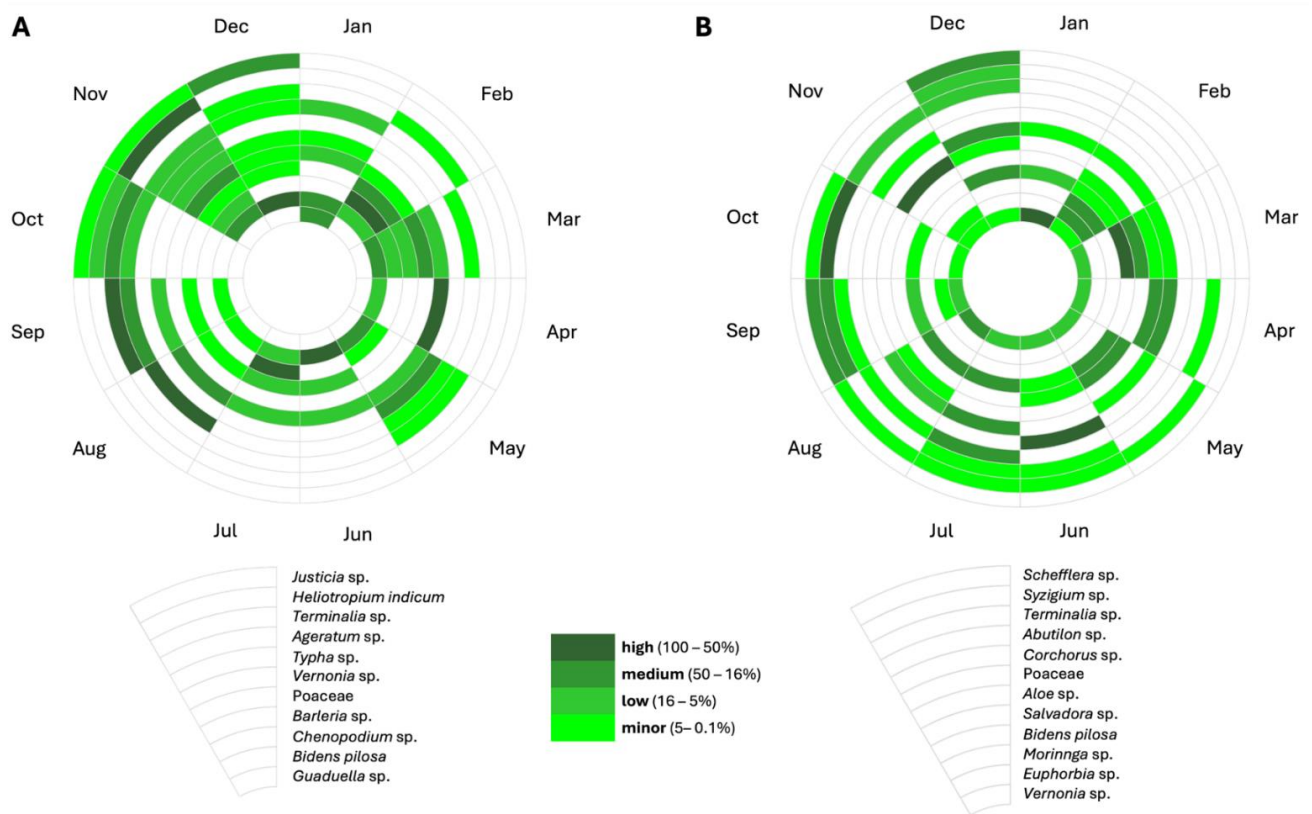


Figure 4. Floral calendar of plant taxa used for pollen collection by honey bees in the low (A) and medium (B) NDVI = normalized difference vegetation index (NDVI) landscapes in Machakos County in Kenya. Taxa (one family, 18 genera, two species) included in this calendar had an abundance of more than 16% of all pollen collected for at least one month. The abundance is colour-coded.

distance to the hive and competing flora were not investigated in our study.

The variation of pollen collected by bees is associated with the floral calendar of different plants in specific landscapes. We observed *Chenopodium* spp. found in the low NDVI provided predominant pollens (>45%) in February in croplands. In the medium NDVI, the predominant pollens were from *Vernonia* spp. (>45%) in January in the grassland while *Bidens pilosa* provided predominant pollens in March in both the hedges and grasslands. These findings show how the different plant species provide pollen to honey bees in various months of the year indicating a difference in the proportion of cropland, grasslands, hedges and natural vegetation in the low and medium NDVI landscapes. Similar observations on pollen diversity and varied proportions of vegetation cover were reported by Ochungo et al. (2021). Most of the plant species recorded in this study such as *Vachelia* spp., *Terminalia brownie*, *Solanum incanum*, *Grewia* spp., *Aspilia mosambicensis*, *Cassia diambotia*, *Cassia semea*,

and *Euphorbia* spp. flower after the rainy seasons of October-December and March-May and are commonly the predominant plants in semi-arid areas of eastern Kenya, including Mwingi (Abdel-Rahman et al. 2015). In another study in Machakos County, out of 124 plant species identified through pollen analysis, the most predominant species were *Terminalia* spp., *Cleome* spp. and *Vachelia* spp. (Ochungo et al. 2021). This demonstrated that a floral calendar may be specific to an area.

Any negative change to the provision of sufficient quantities of pollen required by honey bees across the year may force honey bees to abandon their hives in search of alternative sources of pollen. Therefore, efforts to enhance conservation and protection of the multi-floral sources across months in each landscape will help to retain honey bees at a particular locale, if other factors that threaten bee existence are managed. Conserving these pollen sources is critical for honey bee health and production in the region as well as for preserving pollination services for flowering crops such as pumpkin.

CONCLUSION

This study shows that there was a high diversity of pollen throughout the months of the year in both low and medium NDVI landscapes. Honey bees collected pollen from multiple plants, although more diverse bee forage sources were recorded in the medium NDVI than in low NDVI, further studies are warranted to study the impact of this difference on colony vitality and beehive products such as honey and bee bread from these two landscapes. Plants from the taxa *Ageratum* spp., *Barleria* spp., *Bidens pilosa*, Poaceae (grasses and *Zea mays*), and *Vernonia* spp. acted as sources of pollen for honey bees in most months of the year. We encourage farmers to adopt agri-environmental practices to increase the abundance and diversity of flowering plants in places where they want to set apiaries to optimize hive productivity and honey bee pollination services for their crops.

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AUTHOR CONTRIBUTION

Conceptualization, T.D., H.M.G.L., M.K., M.M.G., K.R., R.N.K., and M.W.N.; Methodology, M.W.N., M.K., K.R., R.N.K., M.M.G., T.D., E.M.A.-R., M.A., and H.M.G.L. Formal analysis, M.W.N., and E.R.O.; Supervision, M.K., K.R., and M.M.G.; Investigation, M.K., M.A., R.N.K., and M.W.N.; Writing -original draft, M.W.N.; Writing, review and editing, M.W.N., M.K., T.D., M.M.G., H.M.G.L., E.M.A.-R., M.A., E.R.O., K.R., and R.N.K.; Project administration, M.K., and T.D. All authors contributed critically to the drafts and gave final approval for publication.

DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

DATA AVAILABILITY STATEMENT

Please contact the corresponding author for data requests.

REFERENCES

- Abdel-Rahman E, Makori D, Landmann T, Piironen R, Gasim S, Pellikka P, Raina S (2015) The Utility of AISA Eagle Hyperspectral Data and Random Forest Classifier for Flower Mapping. *Remote Sensing*, 7(10), 13298–13318. <https://doi.org/10.3390/rs71013298>
- Adan M, Abdel-Rahman EM, Gachoki S, Muriithi BW, Lattorff HMG, Kerubo V, Landmann T, Mohamed SA, Tonnang HEZ, Dubois T (2021) Use of earth observation satellite data to guide the implementation of integrated pest and pollinator management (IPPM) technologies in an avocado production system. *Remote Sensing Applications: Society and Environment*, 23, 100566. <https://doi.org/10.1016/j.rsase.2021.100566>
- Alaux C, Ducloz F, Crauser D, Le Conte Y (2010) Diet effects on honey bee immunocompetence. *Biology Letters*, 6(4), 562–565. <https://doi.org/10.1098/rsbl.2009.0986>
- Antúnez K, Invernizzi C, Mendoza Y, vanEngelsdorp D, Zunino P (2017) Honey bee colony losses in Uruguay during 2013–2014. *Apidologie*, 48(3), 364–370. <https://doi.org/10.1007/s13592-016-0482-2>
- Barth OM, Barreto CF, Vilela CG, Baptista Neto JA (2010) Pollen analysis revealing the paleoenvironment of a 3520 year BP old sediment in the Guanabara Bay, Rio de Janeiro, Brazil. <https://www.arca.fiocruz.br/handle/icict/26072>
- Bonnefille R (1971) Atlas des pollens d’Ethiopie, principales espèces des forêts de montagne. *Pollen et Spores*, 13(1), 15–72. https://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=GEOD_EBRGM72227162

- Bosco LB, Da Luz CFP (2018) Pollen analysis of Atlantic Forest honey from the Vale do Ribeira Region, state of São Paulo, Brazil. *Grana*, 57(1–2), 144–157. <https://doi.org/10.1080/00173134.2017.1319414>
- Brochu KK, van Dyke MT, Milano NJ, Petersen JD, McArt SH, Nault BA, Kessler A, Danforth BN (2020) Pollen defenses negatively impact foraging and fitness in a generalist bee (*Bombus impatiens*: Apidae). *Scientific Reports*, 10(1), 3112. <https://doi.org/10.1038/s41598-020-58274-2>
- Brodschneider R, Crailsheim K (2010) Nutrition and health in honey bees. *Apidologie*, 41(3), 278–294. <https://doi.org/10.1051/apido/2010012>
- Corvucci F, Nobili L, Melucci D, Grillenzoni FV (2015) The discrimination of honey origin using melissopalynology and Raman spectroscopy techniques coupled with multivariate analysis. *Food Chemistry*, 169, 297–304. <https://doi.org/10.1016/j.foodchem.2014.07.122>
- Da Luz CFP, Chaves SADM, Cano CB (2021) Botanical and geographical origins of honey samples from Pantanal (Mato Grosso and Mato Grosso do Sul states, Brazil) certificated by melissopalynology. *Grana*, 60(3), 189–216. <https://doi.org/10.1080/00173134.2020.1815831>
- do Carmo Zerbo A, Lúcia R, Silva de Moraes M, Regina Brochetto-Braga M (2001) Protein requirements in larvae and adults of *Scaptotrigona postica* (Hymenoptera, Apidae, Meliponinae): Midgut proteolytic activity and pollen digestion. *Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology*, 129(1), 139–147. [https://doi.org/10.1016/S1096-4959\(01\)00324-4](https://doi.org/10.1016/S1096-4959(01)00324-4)
- Donkersley P, Rhodes G, Pickup RW, Jones KC, Power EF, Wright GA, Wilson K (2017) Nutritional composition of honey bee food stores vary with floral composition. *Oecologia*, 185(4), 749–761. <https://doi.org/10.1007/s00442-017-3968-3>
- Dyer FC (2002) The Biology of the Dance Language. *Annual Review of Entomology*, 47(1), 917–949. <https://doi.org/10.1146/annurev.ento.47.091201.145306>
- Elliott B, Wilson R, Shapcott A, Keller A, Newis R, Cannizzaro C, Burwell C, Smith T, Leonhardt SD, Kämper W, Wallace HM (2021) Pollen diets and niche overlap of honey bees and native bees in protected areas. *Basic and Applied Ecology*, 50, 169–180. <https://doi.org/10.1016/j.baae.2020.12.002>
- Filipiak M, Walczyńska A, Denisow B, Petanidou T, Ziółkowska E (2022) Phenology and production of pollen, nectar, and sugar in 1612 plant species from various environments. *Ecology*, 103(7), e3705. <https://doi.org/10.1002/ecy.3705>
- Giannini TC, Alves DA, Alves R, Cordeiro GD, Campbell A J, Awade M, Bento JMS, Saraiva AM, Imperatriz-Fonseca VL (2020) Unveiling the contribution of bee pollinators to Brazilian crops with implications for bee management. *Apidologie*, 51(3), 406–421. <https://doi.org/10.1007/s13592-019-00727-3>
- Goodman L (2003) Form and function in the honey bee. International Bee Research Association. <https://www.cabdirect.org/cabdirect/abstract/20033184686>
- Gorelick N, Hancher M, Dixon M, Ilyushchenko S, Thau D, Moore R (2017) Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment*, 202, 18–27. <https://doi.org/10.1016/j.rse.2017.06.031>
- Guantai MM, Kasina M, Mueke J, Matolo N, Martins D, Gemmill B (2019) Spatio-Temporal Delivery of Floral Resources in Highly Fragmented Farmlands. *African Journal of Horticultural Science*, 15, 1–12. <https://journal.hakkenya.net/index.php/ajhs/article/view/29>
- Haščík P, Čech M, Čuboň J, Bobko M, Kačániová M, Arpášová H (2022) Effect of supplemental flax and pumpkin pomace on meat performance and quality of Ross 308 broiler chickens' meat. *Slovak University of Agriculture in Nitra*. <https://doi.org/10.15414/2022.9788088279150>
- Hawkins J, De Vere N, Griffith A, Ford CR, Allainguillaume J, Hegarty MJ, Baillie L, Adams-Groom B (2015) Using DNA Metabarcoding to Identify the Floral Composition of Honey: A New Tool for Investigating Honey Bee Foraging Preferences. *PLOS ONE*, 10(8), e0134735. <https://doi.org/10.1371/journal.pone.0134735>
- Jakobsson A, Ågren J (2014) Distance to semi-natural grassland influences seed production of insect-pollinated herbs. *Oecologia*, 175(1), 199–208. <https://doi.org/10.1007/s00442-014-2904-z>
- Keller I, Fluri P, Imdorf A (2005) Pollen nutrition and colony development in honey bees: Part 1. *Bee World*, 86(1), 3–10. <https://doi.org/10.1080/0005772X.2005.11099641>
- Kirk WD, Howes FM (2012) Plants for bees: A guide to the plants that benefit the bees of the British Isles. (No Title). <https://cir.nii.ac.jp/crid/1130000794509455744>
- Kiros S (2018). A preliminary study on bird diversity and abundance from Wabe fragmented forests around Gubre sub-city and Wolkite town, Southwestern Ethiopia. *International International Journal of Avian & Wildlife Biology*, 3(4). <https://doi.org/10.15406/ijawb.2018.03.00116>
- Klein AM, Vaissière BE, Cane JH, Steffan-Dewenter I, Cunningham SA, Kremen C, Tscharntke T (2007) Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society B: Biological Sciences*, 274(1608), 303–313. <https://doi.org/10.1098/rspb.2006.3721>

- Kleinert ADMP, Giannini TC (2012) Generalist Bee Species on Brazilian Bee-Plant Interaction Networks. *Psyche: A Journal of Entomology*, 2012, 1–7. <https://doi.org/10.1155/2012/291519>
- Konzmann S, Koethe S, Lunau K (2019) Pollen grain morphology is not exclusively responsible for pollen collectability in bumble bees. *Scientific Reports*, 9(1), 4705. <https://doi.org/10.1038/s41598-019-41262-6>
- Köppler K, Vorwohl G, Koeniger N (2007) Comparison of pollen spectra collected by four different subspecies of the honey bee *Apis mellifera*. *Apidologie*, 38(4), 341–353. <https://doi.org/10.1051/apido:2007020>
- Kroyer G, Hegedus N (2001) Evaluation of bioactive properties of pollen extracts as functional dietary food supplement. *Innovative Food Science & Emerging Technologies*, 2(3), 171–174. [https://doi.org/10.1016/S1466-8564\(01\)00039-X](https://doi.org/10.1016/S1466-8564(01)00039-X)
- Lau P, Bryant V, Ellis JD, Huang ZY, Sullivan J, Schmehl DR, Cabrera AR, Rangel J (2019) Seasonal variation of pollen collected by honey bees (*Apis mellifera*) in developed areas across four regions in the United States. *PLOS ONE*, 14(6), e0217294. <https://doi.org/10.1371/journal.pone.0217294>
- Louveaux J, Maurizio A, Vorwohl G (1978) Methods of Melissopalynology. *Bee World*, 59(4), 139–157. <https://doi.org/10.1080/0005772X.1978.11097714>
- Malagnini V, Cappellari A, Marini L, Zanotelli L, Zorer R, Angeli G, Ioriatti C, Fontana P (2022) Seasonality and Landscape Composition Drive the Diversity of Pollen Collected by Managed Honey Bees. *Frontiers in Sustainable Food Systems*, 6, 865368. <https://doi.org/10.3389/fsufs.2022.865368>
- Modro AFH, Silva IC, Luz CFP, Message D (2009) Analysis of pollen load based on color, physicochemical composition and botanical source. *Anais Da Academia Brasileira de Ciências*, 81(2), 281–285. <https://doi.org/10.1590/S0001-37652009000200014>
- Mwangi W, Mundia CN (2014) Assessing and monitoring agriculture crop production for improved food security in Machakos County. 5.
- Noordyke ER, Ellis JD (2021) Reviewing the efficacy of pollen substitutes as a management tool for improving the health and productivity of western honey bee (*Apis mellifera*) colonies. *Frontiers in Sustainable Food Systems*, 5, 772897. <https://www.frontiersin.org/articles/10.3389/fsufs.2021.772897/full>
- Ochungo P, Veldtman R, Kinyanjui R, Abdel-Rahman EM, Muli E, Muturi MNK, Lattorff HM G, Landmann T (2021) Pollen diversity and protein content in differentially degraded semi-arid landscapes in Kenya. *Journal of Apicultural Research*, 60(5), 828–841. <https://doi.org/10.1080/00218839.2021.1899656>
- Onyango P, Nyunja R, Opande G, Fedha Sikolia S (2019) Inventory, reward value and diversity of *Apis mellifera* nectariferous and polleniferous forage in Eastern Mau forest, Kenya. *International Journal of Scientific and Research Publications (IJSRP)*, 9(2), p8608. <https://doi.org/10.29322/IJSRP.9.02.2019.p8608>
- Pardee GL, Ballare KM, Neff JL, Do LQ, Ojeda D, Bienenstock EJ, Brosi BJ, Grubestic TH, Miller JA, Tong D (2023). Local and landscape factors influence plant-pollinator networks and bee foraging behavior across an urban corridor. *Land*, 12(2), 362. <https://www.mdpi.com/2073-445X/12/2/362>
- Pasupuleti VR, Sammugam L, Ramesh N, Gan S H (2017) Honey, Propolis, and Royal Jelly: A Comprehensive Review of Their Biological Actions and Health Benefits. *Oxidative Medicine and Cellular Longevity*, 2017, 1–21. <https://doi.org/10.1155/2017/1259510>
- Patrício-Roberto G, Campos M (2014) Aspects of Landscape and Pollinators—What is Important to Bee Conservation? *Diversity*, 6(1), 158–175. <https://doi.org/10.3390/d6010158>
- Ramanujam CGK, Kalpana TP (1992) Tamarindus indica L: An important forage plant for *Apis florea* F in south central India. *Apidologie*, 23(5), 403–413. <https://doi.org/10.1051/apido:19920503>
- Richard PSS, Muthukumar SA, Malleshappa H (2011) Relationship between floral characters and floral visitors of selected angiospermic taxa from Kalakad Mundanthurai Tiger Reserve, Southern Western Ghats, India. <https://www.cabidigitallibrary.org/doi/full/10.5555/20113311303>
- Salonen A, Julkunen-Tiitto R (2012) Characterization of two unique unifloral honeys from the boreal coniferous zone: Lingonberry and mire honeys. *Agricultural and Food Science*, 21(2), 159–170. <https://journal.fi/afs/article/view/4931>
- Schmidt JO, Thoenes SC, Levin MD (1987) Survival of Honey Bees, *Apis mellifera* (Hymenoptera: Apidae), Fed Various Pollen Sources. *Annals of the Entomological Society of America*, 80(2), 176–183. <https://doi.org/10.1093/aesa/80.2.176>
- Simanonok MP, Otto CR, Smart, MD (2020) Do the Quality and Quantity of Honey Bee-Collected Pollen Vary Across an Agricultural Land-Use Gradient? *Environmental Entomology*, 49(1), 189–196. <https://doi.org/10.1093/ee/nvz139>
- Stanley RG, Linskens HF (2012) *Pollen: Biology Biochemistry Management*. Springer Science & Business Media.
- Tamic T, Aupinel P, Odoux JF, Loublier Y, Chabirand M (2011) Optimisation d'une méthode de dénombrement de grains de pollen adaptée à l'étude de l'alimentation de l'abeille domestique. *Polen*, 21, 51–55. <https://revistas.usal.es/index.php/polen/article/download/9292/10338>

Vincens A, Lézine AM, Buchet G, Lewden D, Le Thomas A (2007) African pollen database inventory of tree and shrub pollen types. *Review of Palaeobotany and Palynology*, 145(1–2), 135–141. <https://doi.org/10.1016/j.revpalbo.2006.09.004>

Von Der Ohe W, Persano Oddo L, Piana ML, Morlot M, Martin P (2004) Harmonized methods of melissopalynology. *Apidologie*, 35(Suppl. 1), S18–S25. <https://doi.org/10.1051/apido:2004050>

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