FLOWERING PHENOLOGY OF HONEYBEE FORAGE PLANTS IN PUMPKIN FARMS IN MACHAKOS COUNTY, KENYA

MARYSTELLA NANG'ONI WEKHANYA, MSc (Plant Ecology)
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DECLARATION

This thesis is my original work and has not been presented for a degree in any other University or any other award.

Signature …………………………. Date …………………

Marystella Nango'ni Wekhanya MSc (Plant Ecology)
I84/CE/38117/2017
Department of Plant Sciences

Supervisors

We confirm that the candidate carried out the work reported in this thesis under our supervision. We have read and approved this thesis for examination.

Signature …………………………. Date …………………

Prof. Rebecca Karanja,
Department of Plant Sciences,
Kenyatta University.

Signature …………………………. Date …………………

Dr. Muo Kasina,
Food Crop Research Center, Kenya Agricultural and Livestock Research Organization (KALRO), Kabete, (NARL), Nairobi.

Signature …………………………. Date …………………

Dr. Mary Mwari Guantai,
Department of Phytosanitary Services,
Kenya Plant Health Inspectorate Service (KEPHIS).

DEDICATION

This work is dedicated to the Almighty God, my husband Cyrus Gakuo, our children Tony, Chris, Arthur and college friends who have been an inspiration.

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ABBREVIATIONS AND ACRONYMS

ASALs	Arid and Semi-Arid lands
DHEA	Dehydroepiandrosterone
FAOSTAT	Food and Agriculture Organization Statistical Database
GDP	Gross Development Product
GENSTAT	General Statistical Software
GLMM	Generalized Linear Mixed-effect Model
HCDA	Horticultural Crop Development Authority
ICIPE	International Centre of Insect Physiology and Ecology
ISAAA	International Service for the Acquisition of Agri-Biotech Application
KALRO	Kenya Agricultural and Livestock Research Organization
KDHS	Kenya Demographic and Health Survey
KEPHIS	Kenya Plant Health Inspectorate Service
NACOSTI	National Council of Science, Technology, and Innovation
NDVI	Normalized Difference Vegetation Index
NSRC	National Sericulture Research Centre

ABSTRACT

Pollinator reservoirs can augment pollination of flowering crops and increase agricultural crop production. Despite this recognized importance, there is a critical knowledge gap concerning the biodiversity of pollinator forage resources within croplands and their utilization by honeybee (*Apis mellifera*). Pumpkin (*Cucurbita maxima* L.), a member of the Cucurbitaceae family, is an economically important food crop globally contributing to household food security. As a pollinator-dependant crop, its production remains low, a constraint largely attributed to an insufficient supply of pollinators. Therefore, the main objective of the study was to determine the annual floral resource structure and its utilization by honeybee pollinators within pumpkin growing farms in Yatta and Masinga sub-counties, Machakos county. To achieve this, four specific objectives were established: to determine the abundance and diversity of flowering plants present in pumpkin farms; to determine the phenology of the non-pumpkin flowering plants utilized by honeybees; to determine the diversity of pollen sources deposited within beehives; and to determine if there is pollination inhibition in pumpkin flowers due to foreign pollen. The study was conducted starting in November 2019 to August 2020. Data was collected on 32 pumpkin-growing farms that were differentiated using Normalized Difference Vegetation Inddex whereby (16 farms were in low NDVI and 16 farms in medium); NDVI is a measure of vegetation greenness and density. Flowering plants abundance and diversity data were collected in the middle of the farm using one quadrat 2 m x 2 m and a belt transect 4 m x 50 m was used to collect data from the middle of the pumpkin farm towards the exit of the farm (non-crop area). Data within the belt transect was collected at intervals of after every one meter. Data were analyzed using the Shannon-Weiner Index. The phenology of non-pumpkin plants utilized by honeybees was determined using monthly plant data that was used to develop a floral calendar. Identification and classification of plants and pollen pellets collected from the beehives was carried out at the National Museum of Kenya. Results revealed thirty five percent of the plants within the sampled areas remained actively flowering throughout the sampling period, serving as alternative forage sources for pollinators. The abundance of plant species varied between NDVI classes and across months; one hundred and forty-two plant species were recorded. A significantly higher abundance of plant species was recorded in low NDVI farms; 6,765 plants compared to 4,399 plants recorded in May. Pollen analysis revealed one hudred and fifteen pollen species from different plant families and the families frequently visited by honeybees were Asteraceae, Solanaceae and Typhaceae. Areas with higher vegetation density and diversity indicated by medium NDVI support a rich array of flowering plants. This translated to greater pollinator forage diversity, as evidenced by the finding that A. mellifera foraged from sixty-one plant genera in low NDVI farms, whereas they utilized one hudred and three plant genera in medium NDVI farms. In both NDVI, the predominant pollen (more than fourty five percent) sources were from Chenopodium spp in low NDVI and Vernonia spp in medium NDVI. Analysis of pollen deposited on pumpkin stigmas revealed that the number of pollens deposited on the stigma differed significantly among the major group of plants ($\chi2 = 8938.30$, df = 9, $p < 0.0001$). This means that despite honeybees foraging on diverse non-pumpkin plants, pollen deposited on stigmas originated from pumpkin. In conclusion, the study shows that there is abundance and diversity of non-crop flowering plants within and around the pumpkin farms that act as reservoirs for pollinators. Information on the phenology of key pollinator forage plants will serve as a vital tool for on-farm management of pollinators by farmers. This will ensure a continuous supply of pollinators and consequently enhance pumpkin yields.

CHAPTER ONE

INTRODUCTION

1.1 Background information

Agricultural production in Kenya has dropped in the recent past with a low performance of 2.9% in 2013 (ROK, 2014). Majority of Kenyans practice smallholder farming which is an important basis of livelihood, food and employment. Smallholder farming significantly accounts for 75% of total output (ROK, 2020) and the production of major food crops has been generally low due to depressed rainfall and unpredictable rainfall patterns (MOA, 2013). Declining food production, high population growth and limited arable land are concerns in improving agricultural productivity in Kenya (MOA, 2009). The arid and semi-arid lands (ASALs) parts of Kenya with about 3.2 million people have increased chronic food insecurity and poor nutrition (ROK, 2011).

Pumpkin (*Cucurbita maxima* L.) under the family Cucurbitaceae, genus Cucurbita which also includes gourds, melons, squash, courgettes and cucumber. It is one of the largest vegetable crops of herbaceous plant that is native to North America (Rakcejeva *et al*., 2011). The family comprises about 850 species in 118 genera (Schaefer and Renner, 2011). The plants are characterized by vines that grow several meters long with tendrils. They have large, deeply lobed leaves and fleshy fruit, approximately 70% flesh (McCormack, 2005). Pumpkin is adapted to a range of agro-ecological zones in Kenya and has huge potential for food production, but this has not been adequately appreciated nor fully exploited. Pumpkin is superior in health qualities and dietary diversity compared to exotic foods such as wheat and rice. It is low in calories and a rich source of vitamin A, vitamin C, potassium and proteins (Tammy, 2008). The fruits and leaves are used as vegetables; seeds are roasted as snack rich in protein, carbohydrates and oil containing unsaturated fatty acids (Karanja *et al*., 2013) and it has various medicinal uses (Nyabera *et al*., 2021).

Pumpkin is a creeping plant with a stem that can grow to more than 10 meters long, an annual, monoecious and with a short-lived perennial root. It is a warm seasoned crop that grows at a temperature range of between 18^{o}C- 27^{o}C. It takes 90-120 days to mature after planting and the fruit matures between 120-180 days after flowering. It is monoecious with the female flowers being more elongated (6-12 cm) than the male flowers (3-5 cm). The color of both flowers varies from yellow to pale orange (Chomicki *et al*., 2020). According to Anusree *et al*., (2015), pumpkins reproduce sexually through cross-pollination. The staminate flowers produce pollen grains with large granules and are pollinated by bees. The honeybees visiting flowers collect pollen or nectar and, in the process, carrying pollen alongside them from the anthers to the stigma of the same plant species, thereby, initiating the process of fertilization (Matsuk *et al*., 2008).

Pumpkins are cultivated in good, well-drained soil during the warm season. They grow on a global scale of around 3 million hectares, yielding 27.832 million tons. They are ranked among the eight leading vegetable crops, globally (FAOSTAT, 2015). The global production of *Cucurbita* species in 2019 was 22,900,826 million tons (FAOSTAT, 2019). The world's largest global producers of cucurbits are China (58%, 8,427,676 million tons), India (4%, 5,655,994 million tons), Ukraine (1,346,160 million tons), and Russia (1,195,611 million tons) (FAOSTAT, 2019). Cucurbit production in Africa is estimated at 2,793,530 million tons; with Algeria (420,135 million tons), followed by Egypt (406,778 million tons), Malawi (368,025 million tons) and South Africa (270,486 million tons) being the main producers (Figure 1.1) (FAOSTAT, 2019; Hosea *et al*., 2021). The production of pumpkin in Kenya remains low with smallholder farmers producing less than the potential of 20 tons per hectare (HCDA, 2013). Farming of pumpkin is ranked second together with Jute mallow (*Corchorus olitorius*) in popularity in western Kenya (Nelly and Godfrey, 2012). According to Nelly and Godfrey (2012), green leafy vegetables, such as pumpkin leaves, are good sources of vitamins, proteins, and minerals, and it can reduce malnutrition in children, lactating and pregnant mothers.

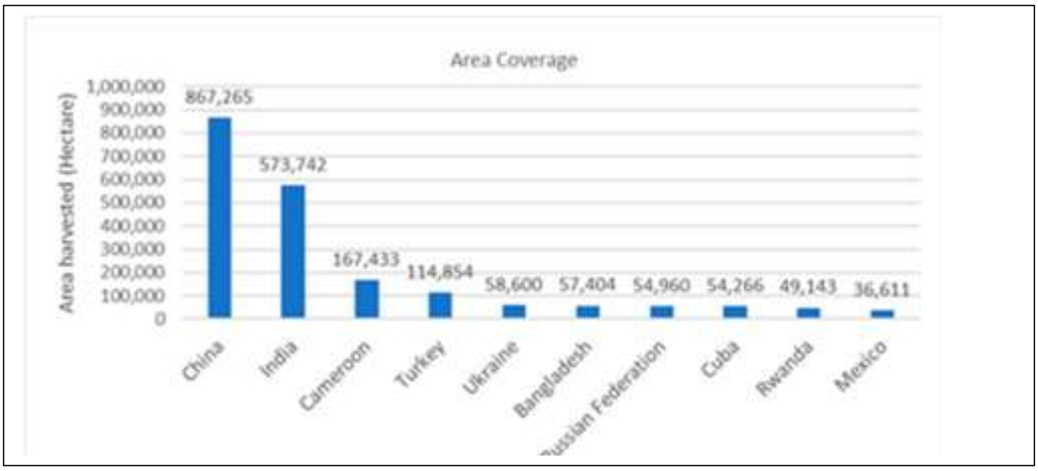

Figure 1.1: Bar graph showing countries that produce pumpkin in hectare.

In Kenya, agriculture is the backbone for the economy (Bryan *et al*., 2013) and horticulture is among the primary subsectors contributing to food security. The horticultural crops cultivated in Kenya include vegetables such as French beans (*Phaseolus vulgaris* L.); spinach (*Spinacia oleracea* L.), tomatoes (*Solanum lycopersicum* L) and pumpkin (*Cucurbita maxima* L.) among other crops. The production of pumpkins in Kenya increased in 2009 from 888 hectares with revenue of KES 482,453,000 to 1,342 hectares in 2013 with revenue of KES 874,966,284 (Ndegwa, 2016). They are produced in Kakamega, Siaya, and Machakos Counties mainly for local consumption and it is ranked as the sixth food crop in Kisii and Busia Counties (Choi, 2015). Nutrient analysis of pumpkins grown in Kenya has revealed that they have appreciable levels of crude fat, carbohydrates and high levels of minerals like potassium, iron, sodium, and pro-vitamin A, which are good for animal and human health (Karanja *et al*., 2014).

Pumpkin crop requires insect pollinators to transfer pollen grains from anthers to stigma for fruit development and seed set (Ali *et al.*, 2014), as shown in (Figure 1.2). For successful pumpkin production, several honeybee visits are important to the female flower for efficient pollination about 8 - 12 visits per female flower within the few hours when the flower opens (Njoroge, 2005) but such bees require sustained forage resources to sustain their population even when pumpkins are not flowering. Pumpkins are short cycle crops, they take 3- 4 months to mature after seed planting and the flower opens only for a day 6 hours between 6:00 AM and 11:00 AM (Lima *et al*., 2022)

Figure 1.2: Honeybees visiting flowers of (*Cucurbita maxima*) and (*Abutilon hirtum*).

The yearly availability of floral resources ensures presence of honeybees and other key pollinators in the farmlands, therefore increasing pollination of pollinator-dependent crops (Guantai *et al*., 2019). It is therefore important to have a diversity of wild flowering plants close to their nesting sites for pollination efficiency. Pollination efficiency is fruit formation or seed production per unit time because of pollination agents for example insects and wind (Ne'eman *et al*., 2010). Therefore, evaluating the availability of pollen, nectar and other floral resources in pumpkin farms is crucial for managing pumpkin productivity.

Honeybees forage normally seeks floral resources such as pollen and nectar. They store pollen as food (mainly protein and vitamins) for their brood, while nectar is converted into honey as a source of energy. Honeybees (*Apis mellifera* L.) usually forage for short distances from the nest's location. However, without floral resources, the bees can travel long distances within approximately 6000 m radius from their colonies (Hagler *et al*., 2011). Colonies foraging distance is influenced by factors such as colony strength, food resources, weather and the time of the day. The more the diversity of flowering plants across seasons, the better the conditions for bees and the higher the pollination efficiency (Martins, 2015). Different insect pollinators have different pollination efficiency which is important for yield improvement (Walters and Taylor, 2006). Honeybees have the ability detect and evaluate the sugar concentration in plants' nectar and will preferably forage the sweeter nectar (Borst, 2012). Pumpkin flowers produce nectar with a sugar concentration of 35-50%, which is within the preferential sugar concentration of between 30% and 50%; this range is preferred by honeybees (Vidal *et al*., 2006); hence the flowers are very attractive to the bees.

However, managed honeybees can avoid pumpkin flowers if they feel it provides fewer resources than other co-flowering plants (Petersen *et al.*, 2013). This study aimed to determine the floral resources within and near pumpkin farms for the pollinators and document their phenology, pollen preference, and sources of foreign pollen that can lead to the contamination of pumpkin pistilate flowers.

1.2 Statement of the Problem

Globally, abundance of insect pollinators in the past decades has declined, while the demand for food produced from insect-pollinated crops has increased tremendously (Goulson *et al*., 2015). Previous studies indicate that local floral resources for pumpkin pollinators were declining due to land fragmentation and the destruction of natural habitats (Munyuli, 2011). This is done by farmers who continuously open land for cultivation without maintaining the undisturbed areas. Fragmentation causes a reduction of foraging and nesting sites for honeybees leading to a reduction in their populations (Kasina, 2012). Guantai *et al*., (2019) established that Kenya's pumpkin production remains low due to insufficient pollination caused by dwindling abundance and diversity of bee species, among other factors.

Studies by Goulson *et al*., (2015) have also shown that pesticides contribute to colony losses; insecticides and fungicides that are used during the blooming season directly affect forager bees and contaminated pollen and nectar brought to the colonies, their metabolites have been identified inside colonies (Evans *et al*., 2009). This decline disadvantages farmers because pumpkins only set fruit if insects pollinate them, and the fruit quality is improved by increased pollinator activity (Nicholls and Altieri, 2013). Additionally, flowering plants that may have potential of enhancing pollinator activity in the pumpkin farmlands are not well documented.

In Yatta and Masinga sub-counties, there was a paucity of data on non-pumpkin flower resources such as pollen and nectar for bees when the pumpkins are not flowering or when it closes its flowers in the afternoon periods. The floral calendar of these flowering plants had not been developed for this study area. These data gaps were the drive behind the need to establish the sources of floral resources for pumpkin pollinators. Data from this research can be used by farmers to determine the alternative floral resources for pumpkin pollinators throughout the year and provide insights into their management and conservation.

1.3 Justification

Food productivity in Machakos county is generally associated with inadequate rainfall coupled with unpredictable weather (Machakos county Integrated Development Plan, 2017). Therefore, farmers prefer to grow short-cycle, drought-tolerant crops such as pumpkins for food security and income generation (Nabhan, 2013). Pumpkins are relatively affordable compared with other food items and therefore can serve as a good food source for poor households (Hosen *et al*., 2021). In addition, it is a hardy crop and can be stored for over eight months after harvesting (Grubben and Chigumira-Ngwerume, 2004).

Pumpkins are highly dependent on insects for pollination, especially honeybees hence the need to document alternative floral resources for the honeybees during on and off seasons of pumpkin flowers (Mallinger and Liburd, 2021). Due to the scarce pumpkin-bee data, there is a need for an ecological survey to document alternative floral resources for the honeybees during on and off seasons of pumpkin in Machakos county. The resultant, information has been used to develop floral calendar within and around the pumpkin farms. This calendar will be valuable to farmers for management of pollinators (especially honeybees) for maximization of their pollination services.

1.4 Research questions

i) What is the abundance and diversity of flowering plants within pumpkin farms in Masinga and Yatta sub-counties?

ii) What is the phenology of honeybee flowering plants within and around pumpkin farms in Masinga and Yatta sub-counties?

iii) What is the diversity of pollen sources collected by honeybees, and how does this diversity vary seasonally, within Masinga and Yatta sub-counties?

iv) Does the deposition of non-self-pollen on pumpkin flowers in Masinga and Yatta sub-counties lead to a measurable inhibition of successful pumpkin pollination?

1.5 Hypotheses

i) The abundance and diversity of flowering plants is similar within pumpkin farms in Masinga and Yatta sub-counties.

ii) There is no difference in phenology of flowering plants found within and around pumpkin farms in Yatta and Masinga sub-counties.

iii) There is no significant annual difference in the diversity of pollen sources for honeybees in Masinga and Yatta sub-counties.

iv) There is no significant pollination inhibition from foreign pollen grains deposited on pumpkin flowers in Masinga and Yatta sub-counties.

1.6 Objectives

1.6.1 General objective

To determine the annual floral resource structure, pollen preference, inhibition, and utilization by honeybee pollinators in Machakos county for enhanced pumpkin productivity.

1.6.2 Specific objectives

i. To determine the abundance and diversity of flowering plants in pumpkin farms at Masinga and Yatta sub-counties.

ii. To develop the phenology of plants foraged on by the honeybees within and around pumpkin farms in Masinga and Yatta sub-counties.

iii. To determine the diversity of pollen sources collected by honeybees across the year in Masinga and Yatta sub-counties.

iv. To determine if there is pollination inhibition due to deposition of non-self-pollen on pumpkin flowers in Masinga and Yatta sub-counties.

1.7 Significance of the study

The findings of this study provide the farmers with a clear inventory of the annual floral resources available to support honeybee pollinators all year round. This information will equip the farmers with knowledge on how to support honeybee pollinators around their farms through planting bee friendly flora.

Data from this research will also be used to determine the alternative floral resources for pumpkin pollinators throughout the year and provide insights into their management and conservation. This will result to increased pumpkin yield that could translate to an enhanced source of income for the farmers and contribute to reducing poverty and malnutrition.

1.8 Scope of the study

Pumpkins were initially cultivated in Argentina, North Mexico and Chile then spread worldwide to Europe, Asia, Western America and Africa. In East Africa, pumpkins were introduced together with paw paws (*Asimina triloba* L.), pineapples (*Ananas comosus* L.), and watermelons (*Citrullus lanatus* L.) by explorers and traders of the European age after 1492 (Robert and William, 1992). Pumpkins are commonly grown in temperate regions with long growing seasons. They have been reported to grow in diverse conditions including humid, arid and semi-arid conditions (Seymen *et al.*, 2019).

This study focussed on flowering plants utilized by honeybees which are the main pollinators of pumpkins. The data gathered will be used to develop to determine the abundance and diversity of flowering plants, develop floral calendars, and determine pollination inhibition in pumpkin flowers in Yatta and Masinga sub-counties.

1.9 Conceptual framework

The conceptual framework illustrates a summary of the relationships between flowering plants, honeybees, land use patterns and their socio-economic implications within agricultural settings specifically focusing on pumpkin farms in Masinga and Yatta sub-counties. It is comprised of dependent variables, independent variables and moderating variables. The independent variables are factors that affect the dependent variables, they include floral density and floral diversity; and land use/habitat fragmentation. The dependent variables are as follows, crop yield, food and nutritional security, income and gross domestic products while the mediatory variables are honeybee food availability, honeybee density and diversity, and pollination.

The availability of floral resources/ honeybee food (pollen and nectar) is determined directly by the floral density and diversity of flowering plants both within and surrounding pumpkin farms. Adequate floral resources are important for sustaining healthy honeybees in terms of their density and diversity.

However, land use practices such as habitat fragmentation for farming can negatively impact bee habitats and the overall landscape. Fragmentation can lead to reduced floral resources and suitable nesting sites, consequently lowering honeybee density and diversity. A robust population of diverse bees (high bee density and diversity) is essential for an efficient pollination process, which includes the transfer of pollen from the male flowers to the female pumpkin flowers. This process can potentially be hindered by factors such as the deposition of non-self-pollen on pumpkin flowers, leading to pollination inhibition.

A successful pollination process directly influences crop yield, specifically pumpkin yield in this study. Higher and more consistent crop yields contribute significantly to food and nutritional security at the household and community levels. Increased crop production also translates into higher income for farmers, on a broader scale; it contributes to the agricultural sector's share of Gross Domestic Product (GDP) (Figure 1.3).

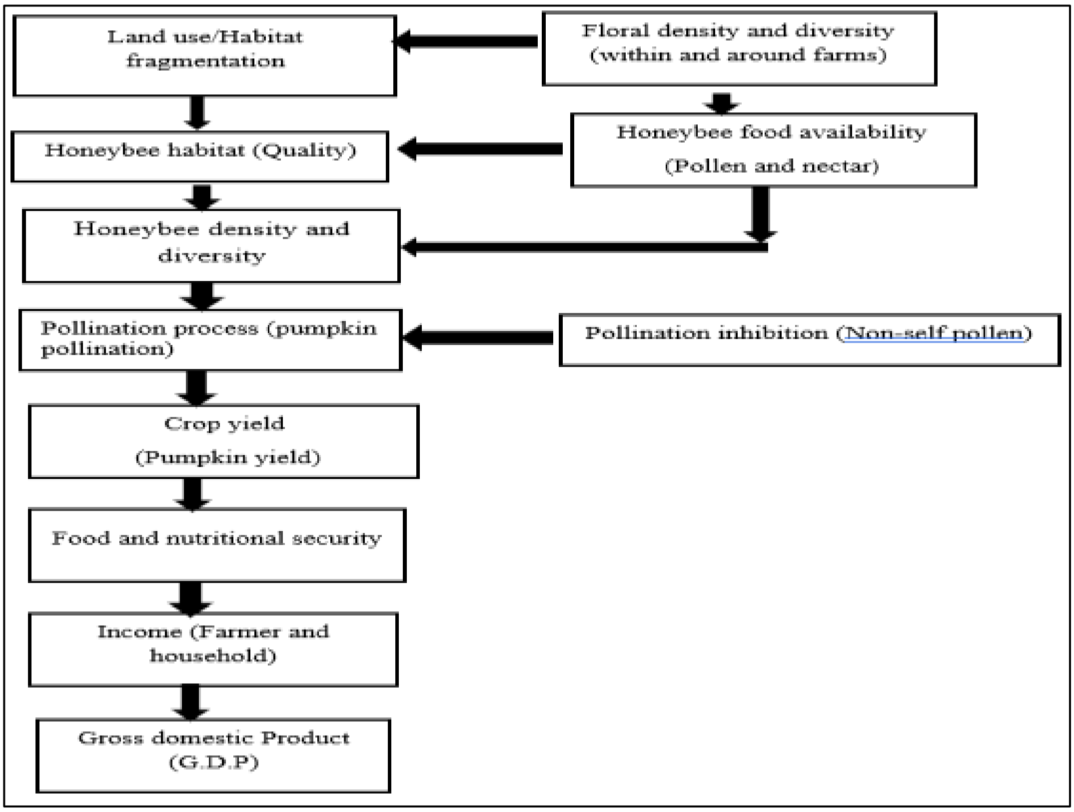

Figure 1.3: Conceptional framework. Arrows ➡ showing directional influence
Schematic presentation of the author

CHAPTER TWO

LITERATURE REVIEW

2.1 General description of pumpkins

2.1.1 Background information

Pumpkins were initially cultivated in Argentina, North Mexico and Chile then spread worldwide to Europe, Asia, Western America and Africa. In East Africa, pumpkins were introduced together with paw paws (*Asimina triloba* L.), pineapples (*Ananas comosus* L.), and watermelons (*Citrullus lanatus* L.), by explorers and traders of the European age after 1492 (Robert and William, 1992). Pumpkins are commonly grown in temperate regions with long growing seasons.

Global production of pumpkin is estimated at around 27.832 million tons per year grown on around 3 million hectares. The leading global pumpkin producer is China with about 58% produced India 20%, Ukraine 4% and Russia 4%. Turkey is in tenth position with approximately 0.6 million tons, accounting for 2 percent of global production (Figure 2.1) (FAOSTAT, 2017). In Germany, pumpkins are popular; consumption increased by 60% between 2003 and 2010 (FAO, 2010). It's annual production of 48,000 tons on 1800 hectares amounts to a value of 36 million Euros wholesale in Germany (Schäfer and Blanke, 2012). In Africa, pumpkin is grown as a vegetable for its leaves and seeds in Nigeria, Zimbabwe, Malawi, Zambia, Uganda, South Africa and Kenya (Opajobi *et al*., 2011).

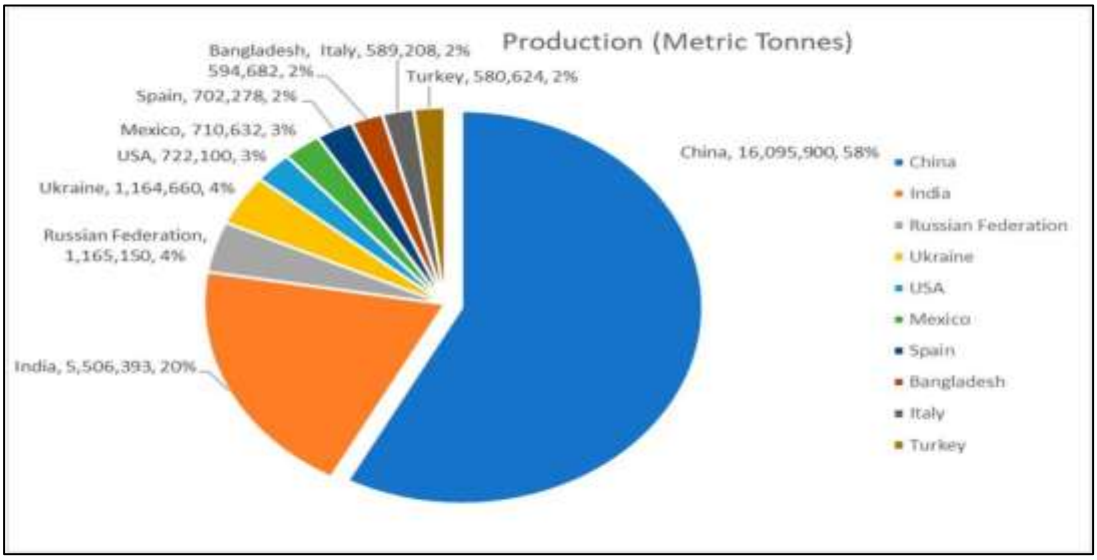

Figure 2.1: Pie chart showing the top 10 countries that produce pumpkins and their yields in percentage.

Pumpkin is an important indigenous vegetable in Kenya for food security, income and livelihoods of smallholder farmers. Its production has increased in the country in the last five years (Ndegwa *et al*., 2016) (Table 2.1). A report by HCDA (2020) indicates that there has been an incredible upward trajectory in pumpkin production in Kenya. For instance, in 2017, pumpkin production in terms of the area was 1,293 hectares with annual production of 21,993 million tons estimated at KES. 568,311,788 which increased to 1,755 hectares with 35,829 million tons' annual production estimated at KES. 813,596,889 in 2018 (HCDA, 2020). It has a huge potential for food production and security because it is widely adapted to various agro-ecological zones in Kenya, but its production remains relatively low with smallholder farmers producing less than the potential of 20 tons per hectare. Pumpkin farming is practiced in Western, Central, and Eastern regions. In Kenya pumpkins are grown in many areas including drylands such as Machakos county.

Table 2.1:Pumpkins production in Kenya, 2009 - 2013

Year	Production area (Ha)	Quantity (000' kg)	Yield (kg/ Ha)	Value (Ksh.)
2009	888	18,973	21,366	482,453,000
2010	979	20,769	21,215	52,919,000
2011	1,046	20,588	19,683	532,452,500
2012	1298	24,702	19,031	783,943,650
2013	1342	28,150	20,976	874,966,284

2.1.2 Classification and morphology of pumpkin

Pumpkins (*C. maxima* Duch.) are some of the most genetically varied groups of food plants (Rakcejeva *et al*., 2011). They belong to the same family (Cucurbitaceae) as the gourd, melon, cucumber, and squash (Karanja *et al.*, 2013). Cucurbita maxima are the widely cultivated species after acorn squash (*Cucurbita pepo* Duch.) In Kenya the varieties that are widely grown include butternut squash (*Cucurbita moschata* L.) and *C. maxima* (squash pumpkin) (Fedha, 2014). According to Wu *et al*. (2007), the family has several species, but only three are economically important, namely, *C. maxima* Duch., and *C. moschata* Duch. and *C. pepo* as they can adapt to different climatic conditions in different agricultural regions. Pumpkins are herbaceous plants usually growing in the form of vines producing several branches that can grow up to 30 feet long. The leaves are usually dark green, with prominent veins, fine hair, and divided into five lobes with serrated margins; they also have long-running, bristled stems that grow several meters long (McCormack, 2005).

Pumpkin flowers are yellow or orange; they are usually monoecious and have nectar that attracts both pollinators such as honeybees (Alfawaz, 2004). The ratio of male lowers to female flowers is approximately 20:1 (PROTA, 2018). Both staminate and pistillate flowers grow between 1 - 3 cm in diameter. The pistillate flowers are borne singly on the main stem with a large inferior ovary of pistillate flower resembles a miniature fruit while the male flower has three staminate with free filaments and the anther is usually supported by a long-twisted organ. The flower opens for a single day and abort rapidly if not adequately pollinated (Buchmann and Nabhan, 2012). The fruit is a large berry with variable in shapes: globular, cylindrical and ovoid and the colours range from white, orange, yellow, green or grey due to its wide genetic background. It contains approximately 70% flesh that varies from yellow to orange. The fruit has many seeds that are obovoid and flattened with a white in colour and has an average weight of between 4- 34 kg. Improved hybrid seed that are well taken care yield 30 tons per hectare (FAOSTAT, 2019). Notably the leaves, fruit, seeds, stems, and roots are all edible. The average yield of leaves is 20 tons per hectare during a harvest period of two months (Grubben and Chigumi 2004).

2.1.3 Optimal growth conditions for pumpkins

Pumpkins are warm season crops that grow at an altitude of between 1,000 m to 2,500 m above sea level in the tropics (PROTA, 2018). They are hardy, warm-season, and drought-tolerant plants adapted to harsh climatic conditions of temperature ranges between 18°C to 27°C and an average rainfall of between 700 mm to 1,250 mm (MOA, 2007a). If leaves and parts of the vines are removed, they quickly re-grow secondary vines to replace the lost ones (Keller *et al.*, 2018). They can be cultivated in almost any nutrient-rich, well-drained soil. They are sensitive to acidic conditions but grow well in slightly acidic soils with a pH value range of 5.5 - 7.0. Medium and well-decomposed manure is suitable for the pumpkins and squashes to grow but for optimal growth during vegetative phase, the recommended fertilizer applications are: 50-100 kg/ha of N, 20-40 kg/ha of P and 40-80 kg/ha of K (Mendlinger *et al.*,1992). However, pumpkins are sensitive to waterlogging and excessive humidity due to high probability of disease development (FAOSTAT, 2019). They are grown on raised beds (15 cm - 20 cm high) by direct seeding or occasionally transplanting. Seeds are planted to a depth of 2 cm - 4 cm for maximum yield, 2 - 3 seeds are planted per hill and thinned to a single healthiest seedling. Grass mulch is used at times for weed control, to keep fruit clean and for moisture conservation (Grubben and Ngwerume, 2004).

Pumpkins are warm-seasoned crops, but they are also cultivated in Europe. Their successful cultivation in the various European climatic zones, from the Mediterranean south to the temperate and continental north, requires adaptation to the regional climatic changes. In cooler European regions, farmers often start seeds indoors on windowsills or in greenhouses to ensure adequate warmth for germination before transplanting. The optimal growth temperatures ranging from 20°C to 35°C (OMAFRA, 2022). Consistent temperatures below 10°C results to stunt growth, while sustained temperatures above 35°C can negatively impact pollen viability and fruit set. Planting outdoors in most European regions is delayed until after the "Ice Saints" (mid-May in Central Europe) when the risk of late spring frosts has passed (Fryd, 2024). Central and Northern Europe example Poland, United Kingdom and Germany, they have shorter and cooler summers necessitating starting seeds indoors and transplanting hardened-off seedlings after the last frost. The farmers also plant early maturing varieties for successful yields (Fryd, 2024).

2.1.4 Nutritional value and uses of pumpkins

Pumpkins have significant nutritional and medicinal importance (Matin *et al.,* 2022). They have various essential nutrients such as carbohydrates, vitamins, proteins and fatty acids (Bashirl *et al*., 2025). Pumpkin leaves, vines, fruits and seeds are consumed as vegetables (James and Okon, 2014). A study by Karanja *et al*., (2014) on the nutritional composition of pumpkin (*Cucurbita maxima*) revealed that its seeds contained varying amounts of carbohydrates ranging from 8.66% to 27.35%.

They also contain zinc, polyunsaturated fatty acids and phytosterols-β-sitosterol that are used in the treatment of benign prostate hyperplasia (Tsai *et al*., 2006). They possess antioxidant capabilities, as highlighted by research conducted by Lee *et al*., (2015); Chen and Huang (2019). The seeds exhibit a dehydroepiandrosterone (DHEA) blocking action that is important in preventing prostate cancer (Dotto and Chacha, 2020; Gossell-Williams et al., 2006). Pumpkin seeds also are said to treat kidney stones (Agrawal and Shahani, 2021); this is due to the high phosphorus level. They have inhibitory effects on kidney stone formation, reducing the risk of kidney stone development. They are anti-inflammatory too, reducing arterial cholesterol by reducing susceptibility of patients to stroke and heart attack (Asgary *et al*., 2018; Woldesenbent, 2020). These properties have implications for cardiovascular health, reducing inflammation, supporting healthy blood clotting. The unsaturated fatty acids in pumpkin oils enhance maintenance of healthy blood vessels, nerves, and tissues (Djuricic and Calder, 2021).

Pumpkins are a source of tocopherols, which are important for protecting cells from oxidative damage (Rezig *et al*., 2012). Magnesium, phosphorus, calcium, manganese, copper, and zinc are essential elements (Batool *et al*., 2022) which play crucial roles in various physiological functions, such as bone health, enzyme activities, and immune system support. Additionally, delta-7-sterols are a type of phytosterol present in pumpkins and are known for their potential cholesterol-lowering properties (Kumari *et al*., 2020). The anti-diabetic potential of pumpkin explored by Ceclu *et al*. (2020) suggest that pumpkin aid in managing blood sugar levels and improving insulin sensitivity, which are crucial factors for diabetes management. Pumpkins are also reported to reduce the risk of muscular degeneration, a serious eye problem usually resulting in blindness (Provesi and Amante, (2015).

Pumpkin leaves juice is used to increase the hemoglobin levels rapidly in the human body during the treatment of anemia. A study reported that dietary intake of the leaf could prevent garlic-induced haemolytic anemia in rats (Obho, 2004). These studies provide the scientific justification for the common practice among pregnant women in Nigeria who take the leaf juice on a regular basis. Pumpkin fruit is also good for weaning children from the age of 6 months because of its diverse nutrients like carbohydrates that provide the baby with energy. It has dietary fiber that aids in digestion, vitamin B and C for immunity and minerals like potassium, iron and magnesium that are essential for the growing child (Usha *et al*., 2010). It is also ideal for young children due to its soft texture hence easy to digest, low in allergenic potential hence safe first food for a child and it can be prepared in various ways (Capra *et al*., 2024). According to horticulture crop validated report (2010), pumpkin farming and consumption in Kenya has increased because of its medicinal properties (Karanja *et al.*, 2013). Considering this wealth of nutrients, pumpkins emerge as a valuable addition to the diet.

2.2 Abundance and diversity of flowering plants in pumpkin farms

The productivity of many agricultural crops like pumpkins is reliant on pollinators and the presence of pollinators is linked to the availability of adequate floral resources. Flowering plants are the main source of nectar and pollen, which are essential for the survival, growth and reproduction of pollinator populations like honeybees (*A. mellifera*) (Oluoch, 2012). Agricultural landscapes, however, have dynamic environments mostly characterized by changes in land use, habitat fragmentation of habitats and simplification of floral communities due to monoculture practices. The changes affect the diversity, quantity and quality of variety of floral resources available to pollinators both within cultivated fields and in the surrounding non-crop areas (Kasina *et al*., 2012)**.** Flowering plants provide floral resources; nectar a source of carbohydrates and energy for honeybee and pollen a source of proteins, lipids, vitamins and minerals. Diversity of flowering plants ensures availability of floral resources crucial for colony health, brood rearing and immune function. A diverse floral community provides a buffer against the failure of any single plant species, ensuring continuous forage availability across the year in different seasons. It also supports a wider array of pollinator species, and this contributes to ecosystem resilience. Abundant floral resources attract pollinators into the agricultural landscape and retain them within the vicinity of target crops, thus enhancing pollination services.

There is a concern on the specific composition, abundance, and seasonal availability of flowering plants within and around pumpkin farm ecosystems in many smallholder farmers. From literature review, it is evident that there is no empirical data that identifies the specific species of flowering plants that contribute floral resources to honeybees especially when pumpkins are not flowering. This study aimed to addressing this critical knowledge gap by systematically identifying and quantifying the abundance and diversity of flowering plants within and around pumpkin farms in Masinga and Yatta sub-counties, thereby providing foundational data for understanding pollinator support in agriculture.

2.3 Alternative floral resources for pumpkin pollinators

2.3.1 Floral phenology

Phenology is the timing of recurring biological phenomena such as flowering and its relationship to environmental factors. According to Ebeling *et al*., (2008), pollinator visits increase with the number of flowers, abundance and diversity of flowering plant species. It was also observed by Ebeling *et al*., (2008) that the existence of an attractive plant species only temporally improves stability in the frequency of pollinator visits. Farms with high diversity of plants have enhanced, stabilized frequent and varied flower visitations. A high floral abundance translates to more resource for pollinators contributing to temporal variability. Previous studies by Martin (2015) reported that wild flowering species of Ocimum, Leucas, Bidens, and Commicarpus are attractive to bees. Therefore, areas adjacent to natural habitats containing some of these bee plants are key for the conservation of insect pollinators for crop improvement through pollination because they will serve as alternative floral resources for pumpkin crop when it is not in bloom.

The floral resources of the pollinators can be managed by establishing field margins, hedgerows around the farmlands (Guantai, 2019) and sowing a mixture of grass species and other plant species such as *Agrostis capillaris* and *Festuca rubra*, which develop into grasslands with a variety of flowering plants (Critchley *et al*., 2006). They provide annual resources to pollinators because they do not produce flowers simultaneously

(Moonen and Marshall, 2001). The aim of the study is to generate a floral calendar for honeybee plants within and around pumpkin farms. This will provide essential empirical data to understand resource availability dynamics identifying potential temporal mismatches between floral resources and pollinator demand and ultimately informative strategies for sustainable pollinator management that will improve agricultural productivity.

2.3.2 Floral calendar of flowering plants

A floral calendar is a timetable that shows a complete chronological period of flowering plants (Bhalchandra *et al*., 2014). The data collected for the development of the floral calendar includes the identity and abundance of the flower visitors, the time of the day, the time in seconds taken by an individual pollinator on the flower per visit and the number of flowers present on the plant. Floral calendars are useful because they help in proper management of apiaries.

The floral calendar developed in this study has provided information on when there is abundance of pollen and nectar flow for the honeybees which is dictated by presence of high number of flowering plants. This is helpful to the farmers since they can manage the colonies to build up strength population for maximum honey production. The calendar can also guide on optimal time for honey harvesting and knowledge on when natural forage is scarce so that the honeybees can be provided with supplements like water. Studies by Bhalchandra and Baviskar (2017) on the floral calendar found 29 agricultural plants and 23 wild plant species useful for beekeeping. Mulwa *et al*. (2019) determined the floral calendar of the avocado plant by observing the tree on the farms for one week throughout the blooming period. According to Brodshneider *et al*., (2019), trees are the main source of pollen in spring, with approximately 59.7% of analysed pollen followed by herbs. Studies by Ayansola and Davies (2012) show that plants do not flower at the same in a year, nectar and pollen becomes available throughout the year for maximum utilization by the bee.

In crop pollination and agricultural productivity, the floral calendar is important because gaps in floral resources availability have been identified hence a recommendation for development of interventions such as planting pollinator flora such as members of family Asteraceae. These interventions will allow all year-round food security for the pollinators. Using the peak visitation times, the farmers will be advised by the agricultural extension officers on the correct timings of application of pesticides and when to avoid so that the pollinators are not affected when they are active. The calendar is vital because by understanding the flowering times of both crops (like pumpkins) and surrounding wild plants, farmers can better assess the synchrony between crop blooming and pollinator activity. This helps to ensure sufficient pollinators are present when the crop flowers. The calendar will also encourage the integration of diverse flowering plants within and around farms such as field margins, cover crops, hedgerows to support pollinators throughout the year. This diversified landscape will enhance overall farm resilience and productivity.

For ecological and climate change studies the calendar will contribute to a deeper understanding of plant biodiversity within an ecosystem and how different species contribute to the overall floral resource base. Honeybees foraging for floral resources visit a variety of flowering plant species cover up to eight kilometres radius all year-round forage (Aina and Owinibi, 2011). Pollen is analysis identifies floral resources estimate the major sources of its floral resources. According to De Vere *et al*. (2017), honeybees do not forage on all flowering plants in a habitat. For example, honeybees in Austria have been noted to forage on a broader spectrum of pollen sources (Wood *et al*., 2018). To identify plants that provide pollen and nectar, data on botanical names and floral descriptions are important for developing a record of flowering plants, hence an annual floral calendar (Ayansola and Davies, 2012). In summary, a floral calendar is a very important tool for sustainable land management, pollinator conservation, and optimal agricultural yields by providing specific information about the most critical resource for many ecosystems, which are the flowers.

Despite the crucial role of consistent floral resources for honeybee health, colony productivity, and the subsequent pollination services essential for crops like pumpkin, there is a significant knowledge gap in a precise, year-round floral calendar for honeybee forage plants within and immediately surrounding smallholder pumpkin farms in Masinga and Yatta sub-counties.

2.4 Diversity of pollen sources collected by honeybees

Insect pollination constitutes a mutual relationship between the insect pollinators and the plant; as pollinating insects receive floral rewards after visitation for their growth and development the plant benefits in terms of fertilization (Venturini *et al*., 2017). Moreover, the yield and quality of a crop is affected by insect pollinators; cowpeas yield increased due to pollination by carpenter bee (Stephanie *et al*., 2015). Cross-pollination by abiotic vectors like insects is important because it improves the quality and quantity of fruit (Greenleaf and Kremen, 2006). The pumpkin crop wholly depends on pollinators including honeybees (*A. mellifera* L.), squash bees (*Peponapis pruinosa* Say), and bumble bee (*Bombus impatiens* Cresson) (Shuler *et al*., 2005) According to Artz and Nault (2011), *A. mellifera* L. *P. pruinosa* Say and *B. impatiens* Cresson comprise 99% of be visiting to pumpkin flowers.

Additionally, the number of bees visiting the pumpkin flowers has a direct effect on fruit set, fruit weight and number of seeds produced (Walters and Taylor, 2006). Notably, lack pollination by insects would cause more than 95% fruit misshaping (Klein *et al.*, 2009). Honey bees (*A. mellifera*) collect nectar and pollen from a wide variety of plant species for the health, development, and overall productivity of a honeybee colony (Di pasquale *et al*., 2016). Pollen is the main source of proteins, amino acids, lipids, vitamins, and minerals for honeybees while nectar provides carbohydrates /energy.

Diversity of diet of pollen from multiple floral sources ensures that the honeybees receive all the necessary macronutrients and micronutrients required because some pollen have more amino acids or lipids than others. Single-source pollen diet can lead to nutritional deficiencies, weakened immune responses, and reduced colony fitness (Minahan *et al*., 2024). Pollen is used by honeybees for: larval development, development of hypopharyngeal glands in nurse bees to produce royal jelly that is essential for feeding larvae and the queen and improved immune system for bees making them more resilient to parasites like *Varroa destructor*, stressors like pesticides and diseases (Mohamed *et al*., 2023). A Variety of pollen sources from flowering plants also ensures a continuous supply of essential nutrients, especially during critical periods such as colony build-up, major honey flows, and preparation for dearth seasons. Healthy and well-nourished honeybee colonies are more robust and can deploy more efficient foraging forces, these results to more effective pollination of surrounding crops, including pumpkins, leading to improved fruit set, yield and quality.

According to a study by Vali *et al*. (2022), pollen diversity collected by honeybees can be affected by various factors such as: the richness and abundance of flowering plant species within a honeybee's foraging range of 3-5 kilometers from the hive; this includes cultivated crops, wild vegetation (bushes, trees, grasses), weeds, and garden plants. The flowering phenology of different plant species also dictates what pollen is available at any given time of year, foraging preferences by honeybees, colony needs such as high protein demand during brood rearing can influence foraging choices, environmental conditions like temperature, humidity, wind, and rainfall can affect flower availability, nectar and pollen production, and bee foraging activity, thereby influencing the diversity of collected pollen. Land use practices such as monoculture farming, habitat degradation, deforestation, and pesticide use can significantly reduce floral diversity and, consequently, the diversity of pollen collected by bees.

Diversity of pollen sources collected by honey bees is assessed through palynological analysis of pollen loads collected by foraging bees (using pollen traps at hive entrances) or from honey samples. This involves microscopic identification of pollen grains based on their unique morphological characteristics. Newer techniques like DNA metabarcoding are also emerging for high-throughput identification. Different sources of pollen for honeybee health is important because honeybees play a key role in crop pollination but there is no data to quantify the monthly or seasonal variation in the diversity and abundance of pollen and specific botanical origins of pollen collected by honeybees. This knowledge will be essential for developing targeted and effective management strategies that ensure adequate and diverse nutritional resources for honeybees in pumpkin-dominated agricultural landscapes. This will not only support honeybee populations but also enhance the critical pollination services they provide to pumpkin production contributing to food security and farmer livelihoods.

2.5 Pollination inhibition and its implications on pumpkins and flowering crops

Pollination inhibition is a genetic mechanism where pollen from another flower is not allowed to germinate or develop a pollen tube on the pistil of another flower. Many crops have flowers that are androgynous; therefore, pollen must be moved from the anthers to the stigma for fertilization and fruit set to take place (Frankel and Galun, 2012). Pollination inhibition affects the production of fruits quantity and the quality and fruit weight (Aminatum *et al*., 2019). Pollinators rarely visit a single plant species exclusively, and most plant-pollinator interactions appear generalized. Enhanced plant species richness is directly related to high diversity of pollinators due to available pollen and nectar resource over space and time (Kwaiser and Hendrix, 2008).

2.5.1 Pollination inhibition on alternative flowering crops

Flowering crops that are entomophilous form the bedrock of global food security and agricultural economies. Approximately 75% of leading global food crops and 35% of global food production volume benefit from animal pollination (Klein *et al*., 2007; IPBES, 2016). According to Aminatun *et al*. (2019), foraging insects on the anthers and stigmas of flowers of chili plants can affect the quality of fruits and hence the plant's productivity due to pollen inhibition (Bugnon *et al*., 1997). Insects that often visit tomato plant flowers also visit chili plants, which can cause contamination (Fajarwati *et al*., 2016). Flowers of plants with a high susceptibility to pollination inhibition take more time to fruit, and their maturation is usually late and harvesting because they bloom later than the other plants without pollination inhibition.

Pollination inhibition in flowering crops can arise from a complex interplay of ecological, environmental, physiological, and anthropogenic factors. These includes mismatch between the peak flowering period of a crop and the peak activity period of its most effective pollinators can lead to a pollination deficit. This can be influenced by climate change altering phenological patterns (Memmott *et al*., 2007). Alternative, more attractive or abundant floral resources exist nearby like highly rewarding wild plants may make the pollinators exhibit preference, diverting their attention from the target crop leading to insufficient visitation rates (Brittain and Potts, 2011).

Allelopathic interference can also cause pollination inhibition where by some non-self-pollen species release inhibitory compounds that negatively affect the germination of compatible pollen, even if the non-self-pollen itself does not germinate (Weston and Duke, 2003). Anthropogenic factors also significantly contribute to pollination inhibition: application of ppesticides especially during flowering, directly kill pollinators or impair their foraging, navigation, and pollen transfer abilities (Goulson *et al*., 2015). Herbicides can eliminate floral resources in field margins. Improper agronomic practice like excessive nitrogen fertilization or inappropriate irrigation can indirectly affect flower quality or pollinator activity.

2.5.2 Pollination inhibition in pumpkins

Successful reproduction in insect-pollinated crops, such as pumpkin (*C. maxima* L.), is mainly dependent on efficient pollination that is the transfer of viable pollen from male anthers to receptive female stigmas. Pollination efficacy directly affects fruit set, fruit quality, and ultimately, crop yield. There are various factors that can disrupt this process leading to pollination inhibition. Inhibition can be displayed as a reduced rate of successful pollen transfer, compromised pollen germination and tube growth, or subsequent fertilization failure, resulting in lower yields or aborted fruits (Abrol, 2012; Free, 1993).

Pollination in pumpkins rely exclusively on insect vectors, mainly honeybees due to their heavy and sticky pollen (Vickery and Kremen, 2019) and they require multiple bee visits per female flower to ensure adequate pollen deposition for optimal fruit development (Stephen and Wein, 1992. Inhibition can occur due to low pollinator density like honeybees and squash bees within the foraging range of pumpkin farms that can lead to inadequate flower visitation rates. This can be exacerbated by habitat loss, pesticide use, and scarcity of diverse floral resources in the surrounding landscape (Kremen *et al*., 2002). Also, pollinator foraging activity is highly sensitive to weather conditions; extreme temperatures (both very low and very high), strong winds and heavy rainfall can reduce bee flight and foraging time, thereby limiting pollen transfer during the critical short window of flower receptivity (Michener, 2007).

Even with adequate pollinator visitation, the quality and quantity of pollen, stigma's receptivity can also inhibit successful fertilization. Some pollen may be transferred but the female flower might not receive the optimal number of viable pollen grains required for complete fertilization of all ovules. This often results in misshapen, small, or partially developed fruits (Free, 1993). Environmental stressors such as severe drought, heat stress, extreme nutrient deficiencies can affect the viability of pollen produced by male flowers, rendering it incapable of germination.

Pollination inhibition may also involve the deposition of pollen from plant species other than pumpkin onto pumpkin stigmas. While pumpkin flowers are not typically self-incompatible in the strict botanical sense, the presence of foreign pollen can potentially lead to inhibition through several mechanisms like stigmatic clogging due to high density of non-self-pollen grains on the stigma surface physically block access for pumpkin pollen affecting pollen landing and germination (Murphy and Llewellyn, 2011). Pollination inhibition has a potential impact on crop productivity. There is no documented knowledge on impacts of non-pumpkin pollen from other floral resources on the reproduction success on pumpkins in Yatta and Masinga sub-counties. Understanding this specific mechanism of inhibition is important for developing targeted interventions, such as tailored habitat management to promote desired pollinators and reduce undesirable pollen transfer flowers strategies and sustainable agricultural practices for optimized agricultural productivity particularly in small-holder farming systems where crop yields are often constrained by multiple interacting environmental and biological factors.

CHAPTER THREE

STUDY AREA, MATERIALS AND METHODS

3.1 Description of the study area

Machakos county is in the southeastern part of Kenya and lies between latitudes 0º45' and 1º31' South and longitudes 36°45' and 37°45' East approximately 60 kilometers southeast of Nairobi city. It borders several other counties: Kiambu and Nairobi to the west, Embu to the north, Kitui to the east, Makueni to the south. The county covers an area of approximately 6,208 square kilometers and it is sub-divided into eight sub-counties: Mwala, Machakos town, Mavoko, Kathiani, Matungulu, Kangundo, Masinga and Yatta with Masinga bordering Embu and Kitui, and Yatta extending towards Kitui Figure 3.1 (Machakos county Annual Development Plan 2025-2026).

The climate of the county is over 84% ASALS with mean annual temperatures range from 18°C to 29°C, the rainfall is bimodal with an annual mean rainfall of 450 mm - 800mm. It has two distinct rainy seasons: long rains fall in March – May and short rains fall in October - December hence two cropping seasons per year. The soils are heterogeneous, poorly consolidated, fragile and susceptible to erosion. The dominant soil types are luvisols (sandy-clay, brown-red brown) and black cotton. It has diverse terrains ranging from relatively flat plains to hilly and undulating areas. The altitude range is from approximately 400 - 2100 metres above sea level (ASL). It has numerous seasonal rivers that contribute to the Athi river system (Wamalwa *et al*., 2023).

The dominant vegetation is savannah grassland and riverine vegetation; with the following common trees: *Acacia spp*., *Commiphora spp*., *Combretum spp*., *Balanites aegyptiaca* and variety of shrubs. It is not characterized by large wildlife population but has various bird species, reptiles and small mammals (Ambani, 2011). The county has a total population of 1.42 million people (as per 2019 Kenya Population and Housing Census) with 264,500 households, and majority of the indigenous communities are Akambas community (KNBS, 2014). The main socio-economic activity is small scale mixed agriculture where horticultural crops and food crops are grown and livestock like chicken, cows and goats reared.

The research study was undertaken in Yatta and Masinga sub-counties, the major pumpkin-growing regions in Machakos county in October 2019 -March 2020 long rains to April -August 2020 short rains (Wekhanya *et al.*, 2025). Yatta and Masinga have small-scale farmers who practice mixed farming (crops: maize, sorghum, millet and pigeon peas and livestock: cows, and goats) with low investment for agricultural production, like pumpkin farming.

Yatta sub-county has a total land area of 1059 km^2 and lies at a latitude of 0° 03′ and 1°12′ South and a longitude of 37°47′ and 38°57′ East (Jaetzold and Schmidt, 2006). It is in the agro-climatic zone IV, categorised as semi-arid land. The mean annual temperature of ranges from 17 ºC - 24 ºC with a bimodal rainfall pattern. The soils are well-drained, moderately deep to very deep, dark red brown to dark yellow-brown, and sandy-clay to clay, with more moisture storage capacity and low availability of nutrients (Karuku *et al*., 2018). The altitude of the sub- county is between 700 - 800 metres above sea level with a population of 172,583 persons as per the 2019 Kenya Population and Housing Census.

Masinga sub-county has a total area of 1,402.8 km^2 and lies at a latitude of 0.9757° South and a longitude of 37.6037° East. It is an ASALs in the Eastern part of Machakos county and receives an annual rainfall average of 500 - 700 mm per year (GOK, 2008). The temperatures are between 29 - 36°C, but at times can rise to 40°C.The altitude is 1,183 M above sea level and the total population of the sub-county is 148,522 persons. The socio-economic activities of both Yatta and Masinga sub-counties are farming, sand harvesting, and rearing of livestock. Irrigation practices are done by the population that resides near Masinga Dam. The crops cultivated for food include millet, maize, sorghum, pigeon peas, green grams, cowpeas, and pumpkins locally known as ‘ilenge’, while the cash crops include cotton, sunflower, and castor (Figure 3.1).

Some farmers in Yatta and Masinga sub-county also practice bee keeping for production of honey locally known as ‘uki’ and other bee products. The local community (Akamba) have a rich and long-standing tradition of honeybee keeping which is significant for cultural, dietary and medicinal uses (Lemba *et al*., 2012). Low rainfall that causes crop failure and food insecurity has resulted to some farmers shifting to apiculture that exerts less pressure on land use and water (Mutua *et al*., 2023). Apiculture in Machakos county has generated an annual average income of Kenyan Shillings 15,166.67 (USD 150) (Bett, 2017).

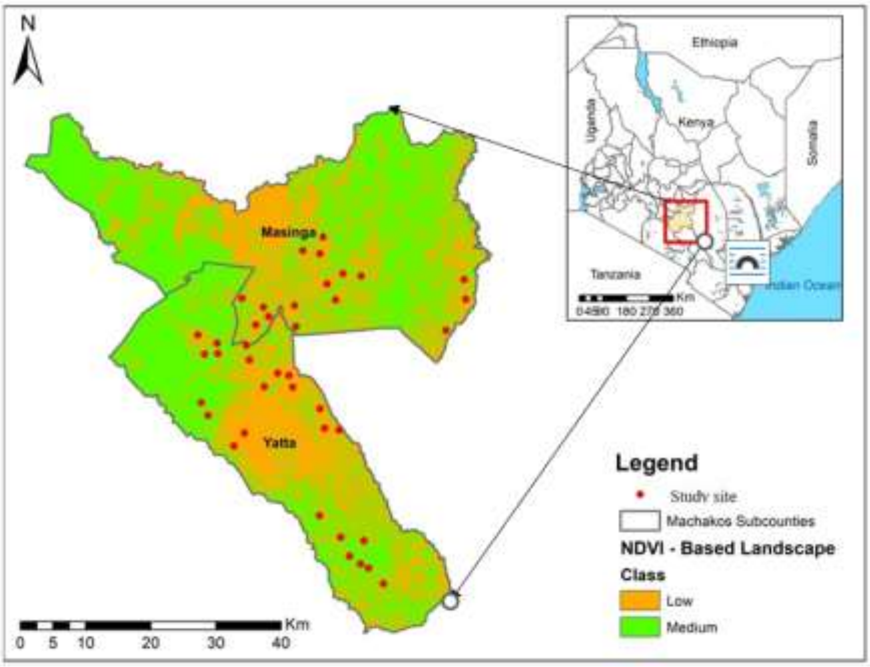

Figure 3.1: Map of the study area showing distribution of pumpkin farms in Yatta and Masinga sub-counties, Machakos county.

3.2 Normalized Difference Vegetation Index.

Normalized difference vegetation index (NDVI) is a numerical indicator that quantifies vegetation greenness, density, and health using remote sensing data, typically acquired by satellites or drones. Vegetation, such as shrubs and grasslands, displays moderate NDVIs, while high NDVI indicates dense vegetation cover (Boit and Odima, 2017). Yatta and Masinga have two NDVI; mainly medium and low NDVI (Figure 3.1). As described by Almeida et al., (2024), 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).

S2 images totaling to 195 images were acquired for both the wet (February to May, 99 images) and dry (June to August, 96 images) seasons. A composite image for each season using the multi-date S2 median reflectance pixel values at 10 m spatial resolution was created. A detailed description of the processing steps is found in Adan et al. (2021). Using the equation below, the NDVI for dry and wet composite images based on red and near-infrared bands was calculated for Machakos County.

$$NDVI = \frac{NIR - red}{NIR + red}$$

where NIR and red are reflectance values at near infrared and red bands 8 and 4 of S2, respectively. Data on NDVI is obtained using satellites orbiting the earth which carry multispectral sensors that capture reflected light from the earth's surface in various spectral bands, including red and near-infrared. The raw data are usually in the form of Digital Numbers (DNs) which are then converted to reflectance values. 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) for Yatta and Masinga sub-counties.

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 by combining the outputs of the wet and dry season classifications based on the cluster values for both seasons (Figure 3.2) (Adan *et al.*, 2021).

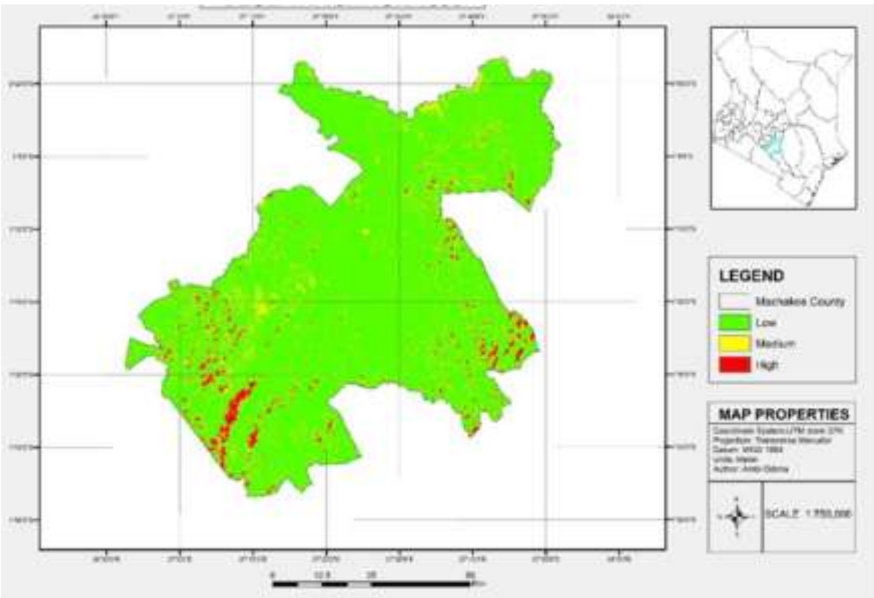

Figure 3.2: Map of Machakos County showing the various NDVI areas

3.3 Materials and Methods

3.3.1 Determination of abundance, diversity and floral calendar of flowering plants in pumpkin farms at Masinga and Yatta sub-counties.

Remote sensing method was used to identify 32 farmers who have designated pumpkin area within their farms. Out of the 32 farms in Yatta and Masinga sub-counties, 16 farms were in low NDVI and 16 in medium NDVI and they were used for data collection. The low and medium NDVI classes were spread across the target sub-counties; Yatta and Masinga. The Farmer's crop size area was a minimum of 600 m^2 and in each farm/field, plots measuring 20 × 30 m used for growing pumpkins were demarcated. Each farmer was supplied with 150 pumpkin seeds (Dora F1 Hybrid, Safari Seeds, Nairobi, Kenya), which were sown directly in the soil at a spacing of 2 × 2 m and a depth of 3-4 cm. Certified hybrid seeds were used in the research because they produce higher yields due to hybrid vigor, they were also found to be resistant to diseases and low adaptable to low rainfall a challenge faced by farmers in Machakos County.

The seeds were sowed then three weeks afterwards; the crops were top-dressed with 15 g/plant of 17-17-17 NPK fertilizer. The farmers were given the NPK fertilizer because it is a balanced compound with nitrogen for vegetative growth of the pumpkin, phosphorous for strong root system that allows the plant to maximize absorption of water, nutrients, flowering and fruit set. The work of Potassium is to help the pumpkin plant in the transportation of sugars to the developing pumpkin fruit resulting in larger, firmer pumpkins with better storage qualities.

The research was conducted in two pumpkin growing seasons (October 2019 - March 2020 long rains; April - August 2020 short rains). After the pumpkin seeds germinated, data collection was done in the farms/field regularly by visits to the study sites. The data was collected once per week on floral patterns within and around the farms from January-February 2020 and June-August 2020 which were the dry seasons while wet season was March-May 2020. The number of plants both flowering plants/crops and non-flowering within and around pumpkin farms was recorded weekly throughout the year to determine the seasonal variations in flowering patterns in plants and the season when there is plenty of floral resources, number of plants actively flowering, number of flowers and colour of flowers. Also, data on flower visitors on different flowering plants were recorded with details on their names, the number present in each flowering plant and the time taken by the flower visitor on flowers within 5 minutes was recorded in 2 m × 2 m quadrat and 4 m × 50 m belt transect. The quadrat was used to obtain qualifiable data in the pumpkin farms and belt transect was used because it is continuous. Data on the gradual change of plants from the middle of the farmlands toward the exit where there are non-crop plants was recorded.

Random sampling design was used hence data was collected by establishing 2 m × 2 m quadrat and 4 m x 50 m belt transect by use of a tape measure in the middle of the farm. The quadrat was placed in the middle of the pumpkin farm; plant within the quadrat counted and recorded. The belt transect was established in the middle of the farm then gradually moved towards the exit of the farm at intervals of 1 m where there were no crops. Then data was recorded in the data collection worksheet within the belt transect 4 m x 50 m and quadrat. Data on different plants within the quadrat and belt transect were assessed, counted and recorded from the middle of the pumpkin farmland towards the edge of the farm where there are non-crops.

The quadrat was also placed in the middle of the farm and data on plants collected within the quadrat. The identity of the flowering plants (common and scientific name) was done by observation of morphological characteristics and by use of expert knowledge, online botanical databases, plant identification apps and digital floras such as iNaturalist, PlantNets and information/data was recorded in a data sheet. Plant samples that were not identified in the farms/field were collected, carefully pressed and dried according to standard herbarium procedures and taken for identification at the National Museums of Kenya (NMK) herbarium by a plant taxonomist. The data collected was used to determine the abundance and diversity of plants and development of the floral calendar in the pumpkin farms in Yatta and Masinga sub-counties.

3.3.2: Determination of the diversity of pollen sources collected by honeybees

Farmers for this study were selected based on several factors: location of their farms within the defined study boundaries and farmers actively cultivating pumpkins (Cucurbita maxima) on their land during the intended study period because pumpkin was the focal crop pollination study. The farmers also voluntarily accepted to participate in the study, provide informed consent and commit to allowing researchers access to their farms for data collection activities. This was to ensure ethical compliance, secure necessary permissions and facilitate consistent data collection. The farms were reasonably accessible for regular, scheduled visits throughout the study period, considering road conditions and travel time within Masinga and Yatta sub-counties. Once the farms were established, purposive sampling was used to identify a pool of farmers who met the criteria of pumpkin growers with bees.

Stratified random sampling was used to compare different NDVI (low and medium). Honeybee hives were installed on portable stands in the identified farms on the periphery of the farm (Figure 3.5 A-B). Honeybee colonies housed in standard Langstroth hives single boxes with seven to ten fully occupied frames with a naturally mated active egg-laying queen were obtained from the International Centre of Insect Physiology and Ecology (ICIPE) apiary, Nairobi, Kenya for the research. 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. Honeybee colonies were installed in four pumpkin farms (one colony/farm) in each NDVI class, yielding to a total of eight farms (Figure 3.3). The honeybee hive colonies were numbered, and the coordinates of each bee colony marked using a Global Position System (GPS).

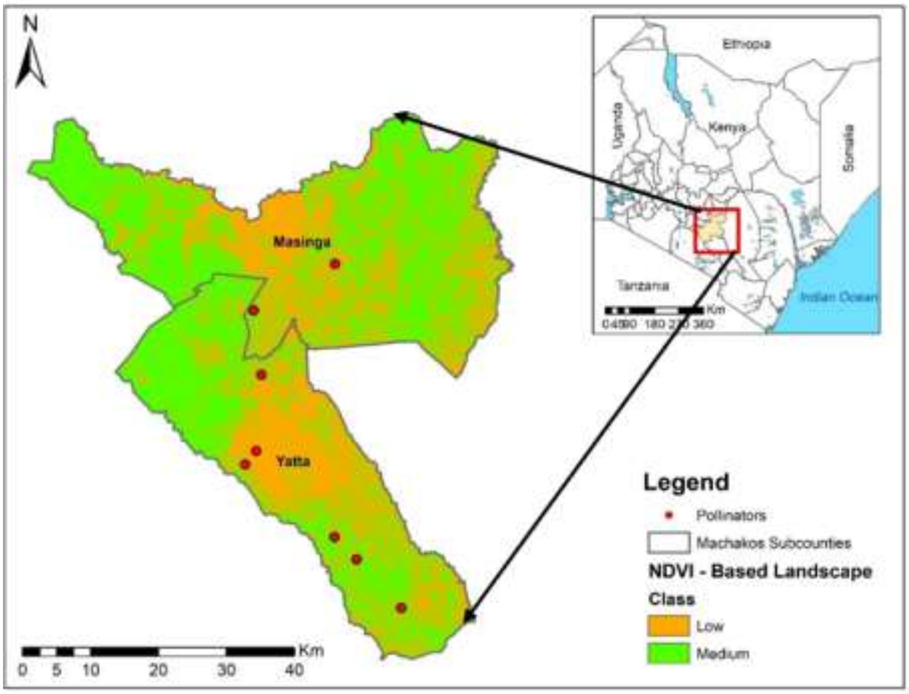

Figure 3.3: Map of the study area showing distribution of farms with honeybee hives in Yatta and Masinga sub-counties, Machakos county.

The colonies were allowed to acclimatize to the conditions of their respective new environment for a week before the onset of collection of pollen samples. Data collection was done by attachment of pollen traps at the entrance of each hive at 8:00 am and the trap left for 48 hours before removing the pollen traps from the honeybee hives (Figure 3.5 C-D). A pollen trap is a specialized device used in beekeeping to collect pollen pellets that foraging honey bees carry on their hind legs (in structures called corbiculae or "pollen baskets") as they return to the hive. A pollen trap is a specialized device used in beekeeping to collect pollen pellets from foraging honeybees carrying on their hind leg (corbiculae). It is fitted to a honeybee hive at the hive entrance, designed with a series of small openings or a grid (often a mesh screen). As returning pollen-laden worker bees attempt to re-enter the hive through these restricted openings, the pollen pellets on their legs are gently dislodged and fall into a collection tray located beneath the grid (Figure 3.4).

Figure 3.4: Photo of pollen traps attached at the entrance of a bee hive

Samples of pollen pellets trapped from returning forager honeybee basket were retrieved every two weeks for a year (from May 2020 to June 2021, covering both rainy and dry seasons (Figure 3.5 E-F). Pollen pellet samples collected were transferred into well labelled sterile vials (Figure 3.5 G) which were immediately placed in a cooler box then sent to palynology and paleobotany for laboratory processing and identification at the National Museums of Kenya (NMK), Nairobi, Kenya (Figure 3.5 H).

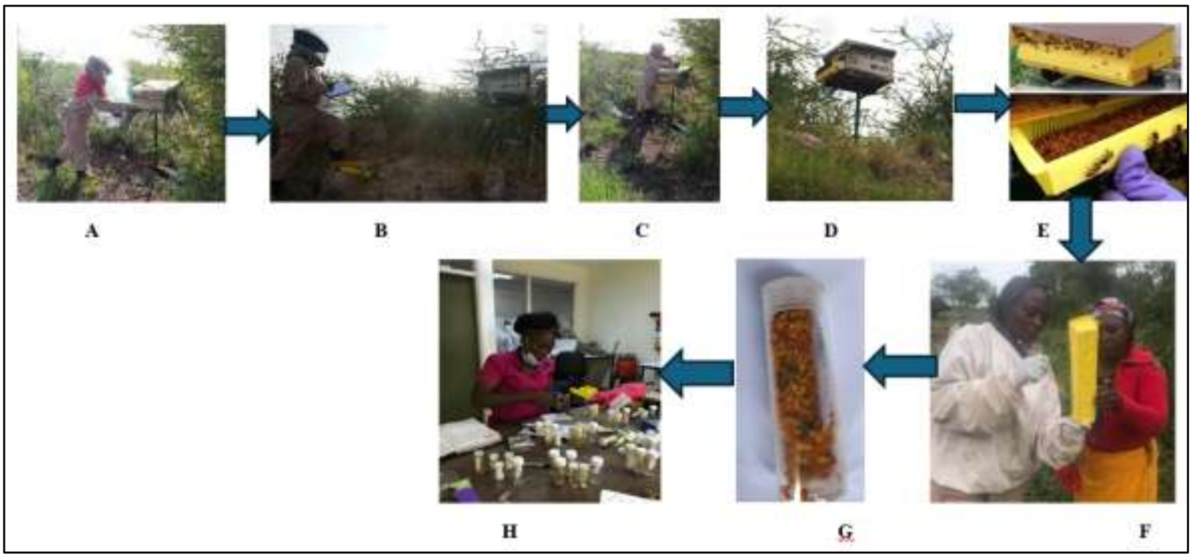

Figure 3.5: Photos shows installation of honeybee hive, pollen traps placed on the honeybee hive, removal of pollen trap with pollen pockets from honeybee hive, G-Vial with pollen

In the laboratory the following apparatus were used for pollen processing: pair of forceps, weighing balance, centrifuge, dissecting needles, micropipette, and vials like the micro centrifuge tubes), microscope slides (for initial check) and a camera (for documenting the pollen). Pollen samples collected from the pollen trap were sorted according to colour using a spatula in groups of four or five pollen pockets. The following pollen processing procedure was used according to Scaifer (1998) methodology. The procedure included:

- The pollen was weighed using a precision weighing balance and placed in 5 mL vials containing water and then mixed using a vortex mixer (ZX3, Velp Scietifica Usmate Velate, City, Italy) (Figure 3.6 A-C).
- Organic materials were removed by the addition of 5 mL of 10% potassium hydroxide.
- The samples were placed in a hot bath for 5 minutes to catalyze the process and then centrifuged for 3 minutes at 3000 rpm (Figure 3.6D); the potassium hydroxide was decanted, and the samples were washed three times with distilled water to further remove potassium hydroxide.
- About 5 mL of glacial acetic acid was added to dehydrate the samples which were followed by the 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 water bath for 3 - 4 minutes.
- 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 (Figure 3.6 E).
- Two-three drops of 50% glycerin were added to each sample followed by fuschin dye (Figure 3.6 F-G) and pollen residues mounted on permanent microscopic

slides covered with cover slides, dried, sealed using colorless nail polish and labelled as described by Barth *et al*., (2010) Figure 3.6 H).

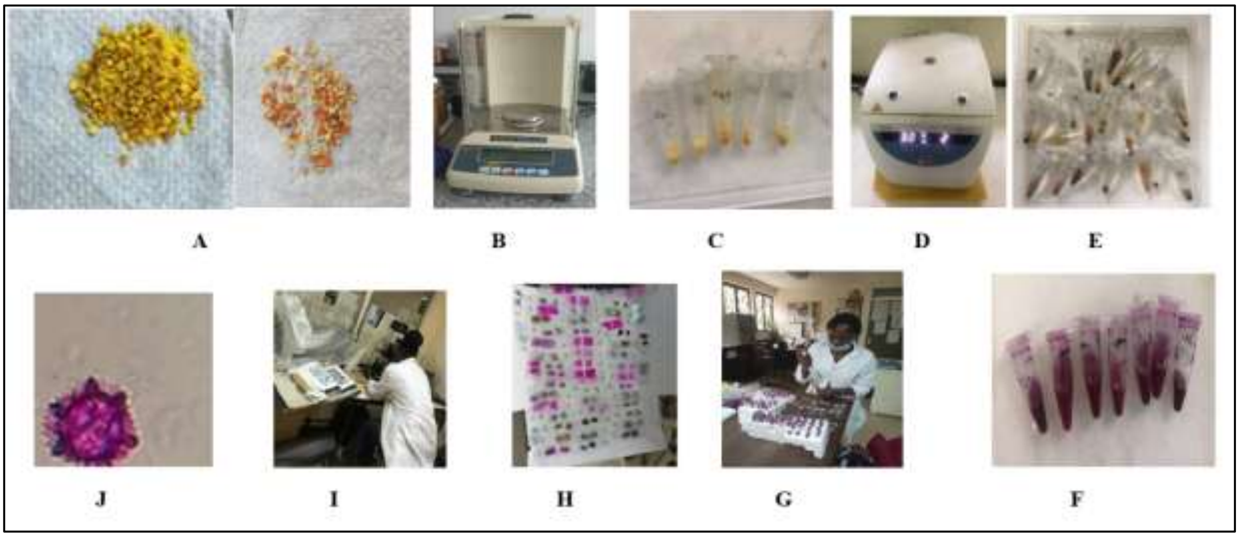

Figure 3.6: Photos showing laboratory processing of pollen samples

Only 115 of 133 collected pollen samples were successfully identified following comprehensive laboratory analysis. For identification of pollen collected by honeybees in the laboratory; pollen 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). 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 (example 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 and Da Luz 2018). The pollen identified was classified according to raw palynological spectra nomenclature proposed by Von Der Ohe *et al*., (2004). Pollen samples identified under the microscope were compared with plants collected in surrounding areas where the honeybee hives were located (Bosco and Luz, 2018) 2015). The pollen pockets were identified to the lowest taxonomic level for example genus and species (Vincens *et al*., 2007) and palynological databases (Bonnefille, 1971; Koelzer *et al*., 2023). The pollens were identified following the "pollen" nomenclature according to Oddo *et al*., (2004).

3.3.3: Determination of pollination inhibition in pumpkin flowers

Matures flowers were selected for the collection of the stigma and anthers. A total of 60 pumpkin flowers were identified, the anther and stigma collected from the flowers. Timing for honeybees entering a flower was done during the active hours of the honeybees. Immediately after the honeybee left the flower, the anthers and the stigma were carefully removed from the flower using a dissecting needle they were transferred into a clean, labeled micro-centrifuge tube and if the pollen was loose; it was carefully brush it into the tube. The tubes were labeled with the following details: full scientific name (genus, species, and author), collection date and collection locality (GPS coordinates/farm) (Kearns and Inouye. 1993). They were then taken to the palynology laboratory for analysis to determine foreign pollen (Figure 3.7).

Additionally, the number of honeybees visiting the pumpkin flowers and the time taken in flower was recorded between 07:00 AM-11:00 AM. The flower parts samples were collected from pumpkin plants in the selected 32 pumpkin farms (Figure 3.7 A-B). In the laboratory, the flower parts (anther and stigma) were stored in the freezer overnight before analysis. The pollen grains were brushed off from the stigma and the anther onto separate petri dishes using a soft brush. The pollen was then placed in an eppendorf tube, distilled water (1,000 µL) was added, mixed by vortexing, centrifuged, and discarded. Approximately 1,000 µL of 70% ethanol was added, mixed thoroughly, centrifuged, and the ethanol discarded. About 50 µL of 20% fructose solution was mixed thoroughly with the pollen.

The resultant solution was pipetted, and a single droplet was placed on a microscope slide. The slide was dried by use of a slide dryer. A droplet of fuchsin solution was added, then the slide dried, and the addition of a droplet of glycerine followed this. A cover slip was placed on the slide and set aside to dry. A permanent slide was made, labelled, placed in a microscope, and viewed under 40 × magnifications. The pollen grains were observed at different angles and orientations, and their digital images were recorded. These digital images were compared to the reference pumpkin pollen library to identify the alternative pollen sources for honeybees acting as possible contaminants of pumpkin's total reproductive sites, ultimately affecting fertilization and fruit set of pumpkins.

A B C

Figure 3.7: Photos showing honeybees in pumpkin flower**,** sample of pumpkin stigma and anther

3.3.4 Data management and statistical analysis

Quantitative datasets were recorded and tabulated on broad data sheets (Appendix. Data collected includes inventory of plants (species, number of plant species, sum of plants species with flowers, sum of plants species without flowers, and total number of flowers), flower visitors (species names, forage plants, and time taken on flowers) in 2 m × 2 m quadrat and 4 m × 50 m transact belt per month, NDVI class and seasons. The data was formulated, computed and tabulated using Microsoft excel program analyzed in R-software version 4.5.0 (R-Core Team, 2025). Plant frequency data was subjected to a generalized linear mixed-effect model (GLMM). In this model, the plant, NDVI, and time of assessment (months) were explanatory variables, while farm sites were used as random variables.

Data analysis on the abundance and diversity of flowering plants; floral calendar of honeybee plants within and around pumpkin farms; diversity of pollen sources collected by honeybees across the year, were analysed using Shannon-Wiener diversity index and poisons regression; the relative abundance, species richness, species diversity, species evenness across different months and seasons in 2 m × 2 m quadrat; 4 m × 50 m transact belt in the two seasons, two NDVI classes, two study sites (Yatta and Masinga) were determined using the following formula (Al-Fedaghi, 2012):

$$H' = -\sum_{i=1}^{R} p_i \ln(p_i)$$

Where *H'* is the Diversity Index, *Pi* is the proportion of each species in the sample, and ln (*Pi*) is the natural logarithm of *Pi*.

The relative abundance (or *Pi*) of plants was determined as follows:

$$Relative\ abundance = \frac{n}{N}$$

Where *n* was the abundance of a particular plant species, and *N* was the total number of all sampled plant species. The evenness of plant species compares the similarity of the population size of each species. Evenness Index (*J'*) was calculated using the ratio of observed diversity to maximum diversity using the formula (Kiros *et al*., 2018):

$$J' = \frac{H'}{Hmax}$$

Where H' is the Shannon Wiener Diversity index and H_{max} is the natural log of the total number of species. Shannon-Wienner diversity analysis was also applied in assessing the diversity of pollen sources for honeybees.

Datasets on pollen inhibition were also subjected to Poisson regression analysis with NDVI and plant family acting as fixed variables. The effect of NDVI classes, observation period (months), and pollinator groups on the number of pollinators was determined. For each pollen sample, the Shannon diversity index, richness and evenness were calculated across landscape composition and month.

CHAPTER FOUR

RESULTS

4.1 Inventory of plant species in Yatta and Masinga sub-counties

A total of 90 flowering plant species were observed within and around the pumpkin farmlands (Fig. 4.1 and Appendix 1). The results revealed 42 flowering plant families in both low and medium NDVI in Yatta and Masinga sub-counties. The most predominant families with the most species were Fabaceae, Asteraceae, Lamiaceae, Solanaceae, Malvaceae (Figure 4.1).

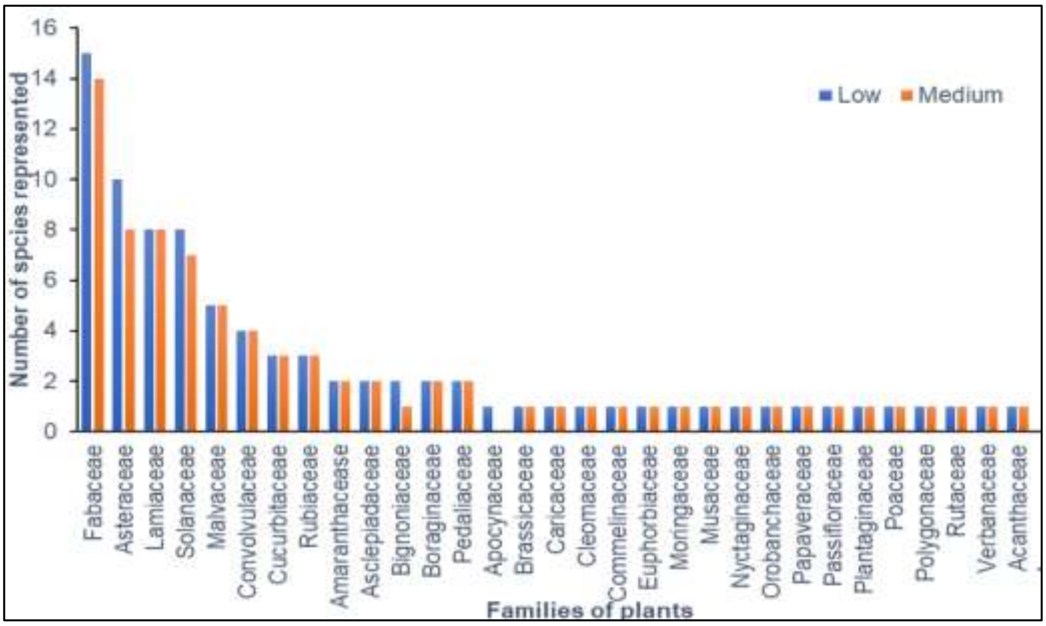

Figure 4.1: Number of flowering plant families in study sites

4.2 Diversity and abundance of plants within and around pumpkin farms

The frequency of plants observed differed significantly among plant type species ($\chi2$ = 451.72, df = 141, p< 0.001), between the NDVI classes ($\chi2$ = 44.79, df = 1, p < 0.001) and across the months ($\chi2$ = 353.06, df = 7, p < 0.001) in the quadrat. Likewise, the frequency of plants observed differed significantly among the plant species ($\chi2$ = 439.98, df = 131, p < 0.001), between the NDVI classes ($\chi2$ = 4.87, df = 1, p =0.027) and across the months ($\chi2$ = 321.45, df = 7, p < 0.001) in 4 m × 50 m belt transect.

The frequency of flowering plants in Masinga sub-county was high in the months of January, February, May and June in medium NDVI. In low NDVI the frequency was high only in the month of July. The frequency of flowers was high in the months of February, April, May, June and August in medium NDVI while in the low NDVI the frequency was high in the month of march low NDVI (Figure 4.2).

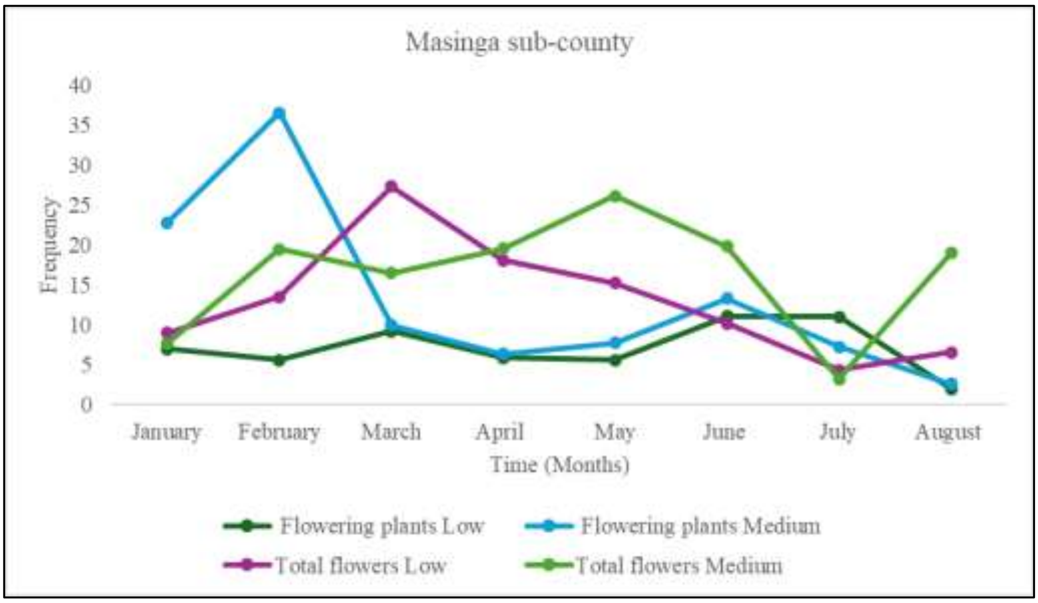

Figure 4.2: Frequency of flowering plants and total number of flowers in Masinga.

In Yatta sub-county, the frequency of flowering plants was high in the months of February, June and July in medium NDVI. In low NDVI the frequency was high in the month of March. In medium NDVI the frequency of flowers was high in the months of January, April, May, July and August while in the low NDVI the frequency was high in the months of February, March and June (Figure 4.3).

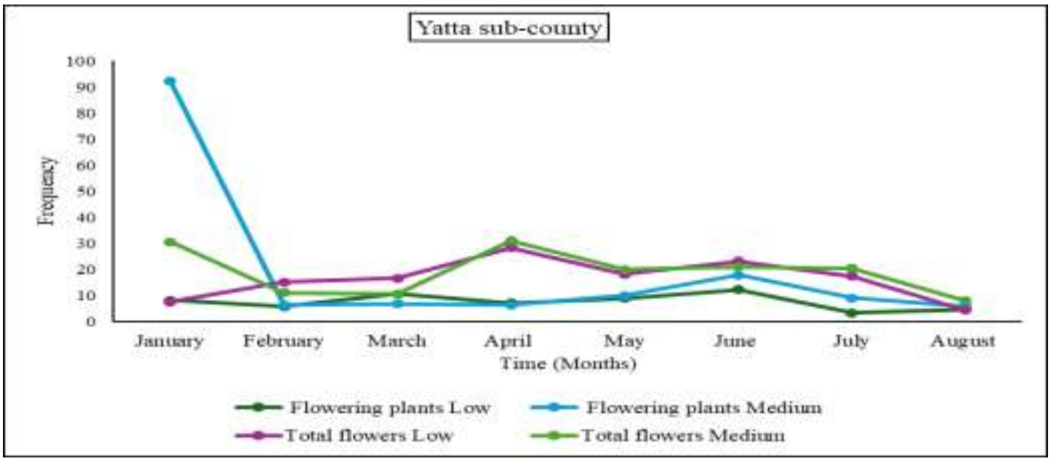

Figure 4.3: Frequency of flowering plants and total number of flowers in Yatta.

Quadrat data revealed that plant diversity varied throughout the months. In Masinga sub-county, high plant abundance, species richness and species evenness were recorded in the month of March (17,551 plants, 520.90 plants respectively), high diversity was in the month of May H' 3.30 in medium NDVI. In Yatta sub-county, high plant abundance was recorded in the month of March (5,789 plants), high species richness and diversity recorded in the month of June (40, H' 3.30 respectively) in low NDVI. Species evenness (J) was high in medium NDVI in the month of January (J 0.92) in Yatta sub-county (Table 4.1). No data was collected in January in low NDVI, Masinga sub-county due to logistic factors.

Belt transect results recorded the highest abundance of plants in both NDVI classes, across the months. The highest plant abundance, species richness and diversity were recorded in medium NDVI (17608 plants in February, 47, H' 3.32 in April respectively). High species evenness was recorded in low NDVI in March (J 0.89) and June (J 0.89) (Table 4.2).

Table 4.1: Species abundance and diversity of plants in the quadrat

Sub-county	NDVI	Characteristics	January	February	March	April	May	June	July	August
Masinga	Low									
		Abundance	–	965	1173	983	1068	682	255	363
		Species richness	–	10	10	16	22	10	10	11
		Shannon-Weiner diversity (H')	–	1.97	2.07	2.39	2.48	2.08	1.80	1.54
		H' Max	–	2.30	2.30	2.77	3.09	2.30	2.30	2.40
		Species Evenness (J)	–	0.86	0.90	0.86	0.80	0.90	0.78	0.64
	Medium									
		Abundance	2621	17551	7953	6515	8516	9634	1684	2278
		Species richness	19	31	52	38	48	38	39	40
		Shannon-Weiner diversity (H’)	2.32	2.72	3.07	2.93	3.30	2.99	2.71	2.93
		H' Max	2.94	3.43	3.95	3.64	3.87	3.64	3.66	3.69
		Species Evenness (J)	0.79	0.79	0.78	0.80	0.85	0.82	0.74	0.79
Yatta	Low									
		Abundance	980	2103	5789	4087	7937	6175	999	934
		Species richness	34	26	35	29	38	40	38	36
		Shannon-Weiner diversity (H’)	3.04	2.71	2.83	2.93	3.03	3.13	2.67	2.40
		H' Max	3.53	3.26	3.56	3.37	3.64	3.69	3.64	3.58
		Species Evenness (J)	0.86	0.83	0.80	0.87	0.83	0.85	0.73	0.67
	Medium									
		Abundance	39	2718	2265	1215	1908	1956	506	428
		Species richness	2	22	18	16	26	22	9	14
		Shanon-Weiner diversity (H’)	0.64	2.74	2.56	2.34	2.83	2.80	1.69	2.20
		H' Max	0.69	3.09	2.89	2.77	3.26	3.09	2.20	2.64
		Species Evenness (J)	0.92	0.89	0.89	0.84	0.87	0.91	0.77	0.83

Table 4.2: Species abundance and diversity of plants in the belt transect

Sub-county	NDVI	Parameters	January	February	March	April	May	June	July	August
Masinga	Low									
		Abundance	–	965	1173	1064	973	633	239	363
		Species richness	–	10	9	21	15	10	9	10
		Shannon-Weiner diversity (H')	–	1.97	1.96	2.47	2.34	2.06	1.75	-0.95
		H' Max	–	2.30	2.20	3.04	2.71	2.30	2.20	2.30
		Species Evenness (J)	–	0.86	0.89	0.81	0.86	0.89	0.80	-0.41
	Medium									
		Abundance	2622	17608	7952	8710	6638	9994	1896	1860
		Species richness	21	32	43	47	37	38	39	29
		Shannon-Weiner diversity (H')	2.41	2.73	2.88	3.32	2.90	3.02	2.83	2.59
		H' Max	3.04	3.47	3.76	3.85	3.61	3.64	3.66	3.37
		Species Evenness (J)	0.79	0.79	0.77	0.86	0.80	0.83	0.77	0.77
Yatta	Low									
		Abundance	1434	11652	12802	10968	6011	10391	1845	1124
		Species richness	29	38	46	48	39	41	45	38
		Shannon-Weiner diversity (H')	2.73	2.80	3.13	3.13	3.18	3.24	3.21	2.77
		H' Max	3.37	3.64	3.83	3.87	3.66	3.71	3.81	3.64
		Species Evenness (J)	0.81	0.77	0.82	0.81	0.87	0.87	0.84	0.76
	Medium									
		Abundance	39	3358	2261	1910	920	1991	506	462
		Species richness	2	24	18	27	17	22	9	14
		Shannon-Weiner diversity (H')	0.64	2.82	2.56	2.86	2.43	2.83	1.66	2.25
		H' Max	0.69	3.18	2.89	3.30	2.83	3.09	2.20	2.64
		Species Evenness (J)	0.92	0.89	0.89	0.87	0.86	0.91	0.75	0.85

In low NDVI, Popcorn cassia (Senna didymobotria) was the most abundant plant species (55.8%), followed by wild basil (Ocimum suave willd.) (20.2%). In medium NDVI, passion fruit (*Flora edulis*) was the most abundant (33.6%,) followed by wild basil (*Ocimum suave*) (30.2%) (Figure 4.4).

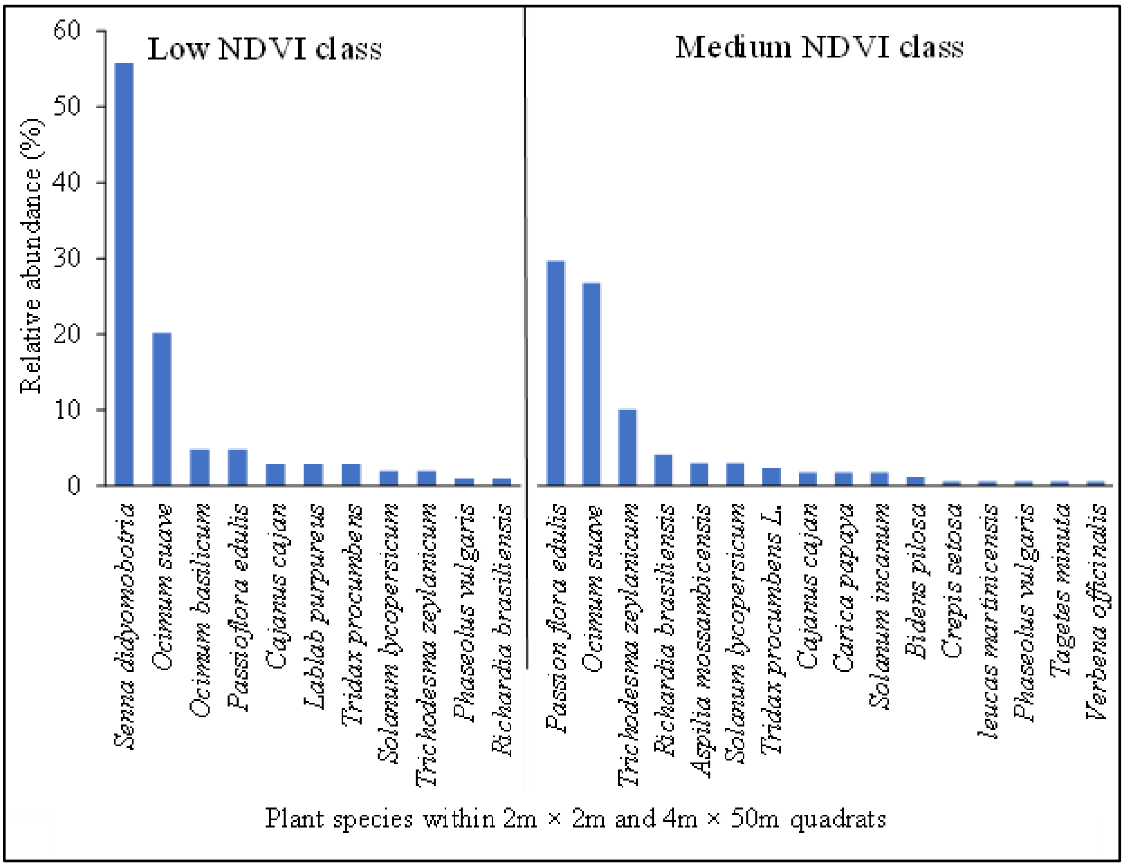

Figure 4.4: Relative abundance of plant species in low and medium NDVI

The total number of observed plants varied significantly across the NDVI classes (χ^2 = 122.9, df = 1, P < 0.001), month (χ^2 = 11654.0, df = 5, P < 0.001) and families of plants (χ^2 = 18406.6, df = 69, P < 0.001). The not-flowering plants did no varied significantly across NDVI classes (p>0.001).

4.3 Phenology of honeybee plants within and around pumpkin farms

The floral calendar of plant species indicated variations in the total number of plants, flowering plants, and flowers produced across the months and NDVI classes. The calendar for low and medium NDVI consists of 11 and 12 families, respectively. Flowering plants and flowers were observed throughout the study period; in medium NDVI, the peak months of flowering plants and flowers were February (11,000 flowering plants, 6,000 flowers), March (2,000 flowering plants, 3,000 flowers) and July (4,000 flowering plants, 4,000 flowers) as illustrated in Figure 4.5.

In low NDVI, the study revealed more flowering plants in the months of: February (5,000 flowering plants, 10,000 flowers), March (6,000 flowering plants, 15,000 flowers), April (14,000 flowers) and June (3.000 flowering plants, 4,000 flowers) (Figure 4.5).

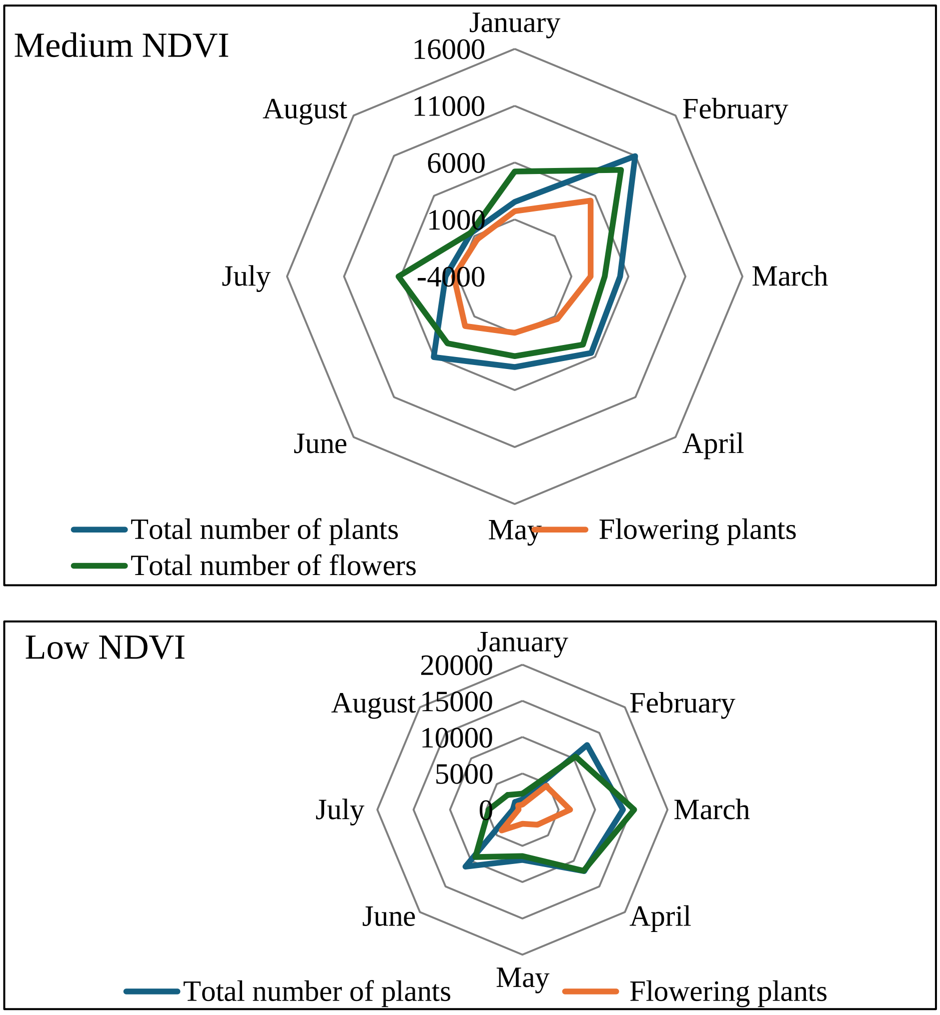

Figure 4.5: Total number of plants, plant-producing flowers, and total number of flowers in low and medium NDVI across the months

In the low NDVI class, three plant genera (*Bidens spp., Vernonia spp.,* and *Argeratum spp.)* provided pollens to honeybees for 11th, 10th and 8th months of the year, respectively. In the medium NDVI class, there was one family (Poaceae), four genera (*Vernonia spp., Syzigium spp., Terminalia spp* and *Bidens spp*., that provided pollens for 12th ,10th, 8th and 7th 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 (Figure 4.6).

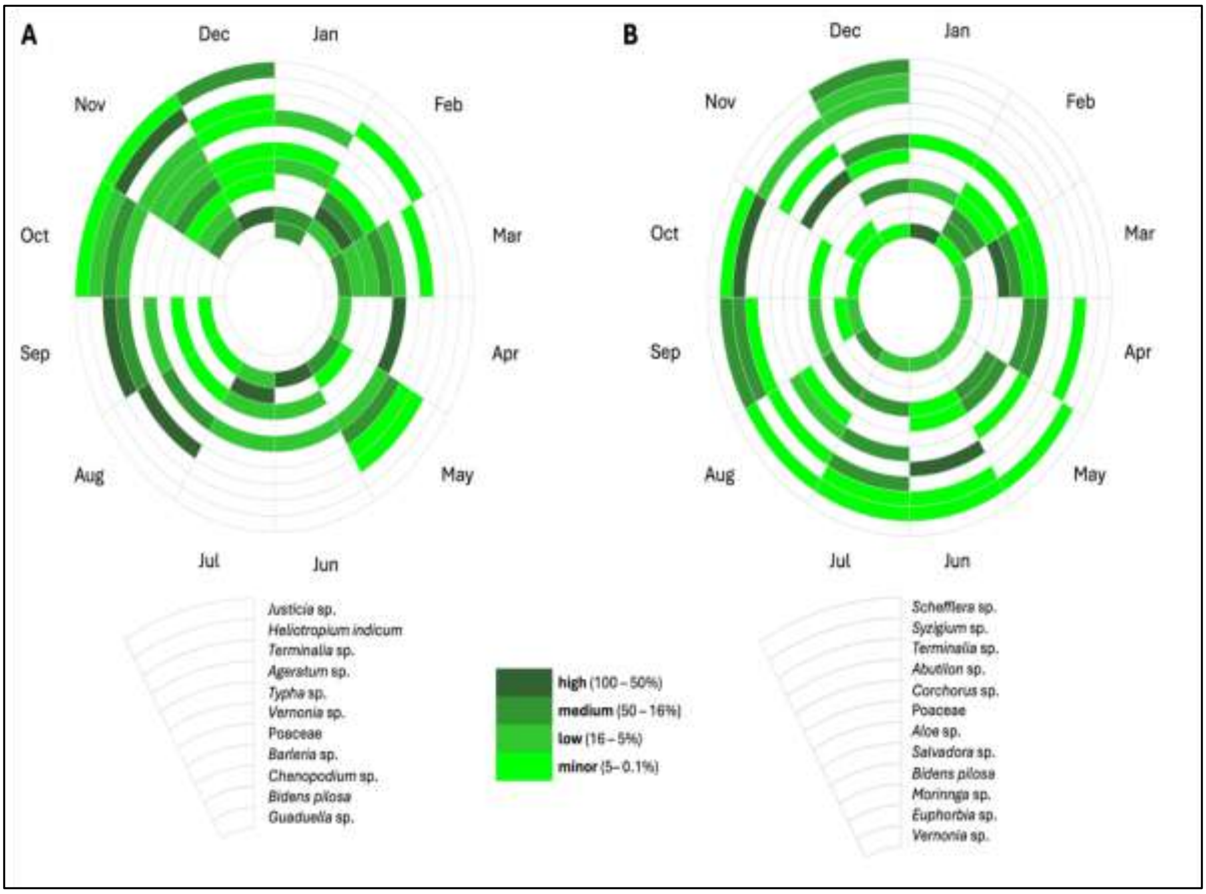

Figure 4.6*:* Floral calendar of plant taxa used for pollen collection by honey bees in the low (A) and medium (B) in Machakos county.

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.

4.4 Diversity and abundance of pollen grains across months

The diversity of pollen grains sources varied across the months and NDVI classes. In medium NDVI the diversity was high in the months of July, August, Septembers, October, February, March and June. In low NDVI the diversity was high in the months of November, December and April as illustrated in Figure 4.7.

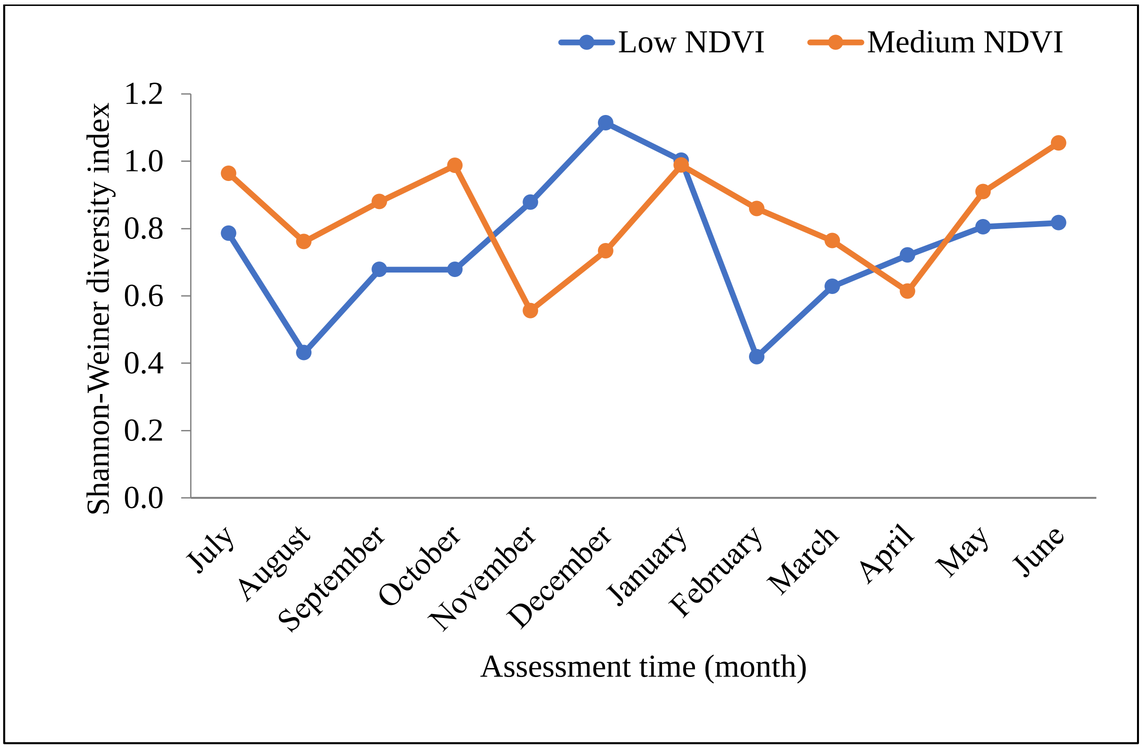

Figure 4.7: Diversity of pollen grains across months in low and medium NDVI

Abundance of pollen varied significantly across the NDVI classes (χ^2 = 2500, df = 1, p< 0.001), month (χ^2 = 9551, df = 11, p < 0.001), and flowering plants families (χ^2 = 114506, df = 69, Pp< 0.001).

4.4.1 Pollen grain sources collected by honeybees

Pollen analyses on 133 pollen samples carried from honeybee pollen basket/corbicular identified the sources of honeybee pollen. The amount of pollen from these sources varied across months and between the two NDVI classes. The plants that were a source of pollen were identified to the family level; these included: Poaceae, Asteraceae, Solanaceae, Typhaceae, Malvaceae, Salvadoraceae, Commelinaceae and Fabaceae. Some of the most common pollen types are illustrated in Figure 4.8.

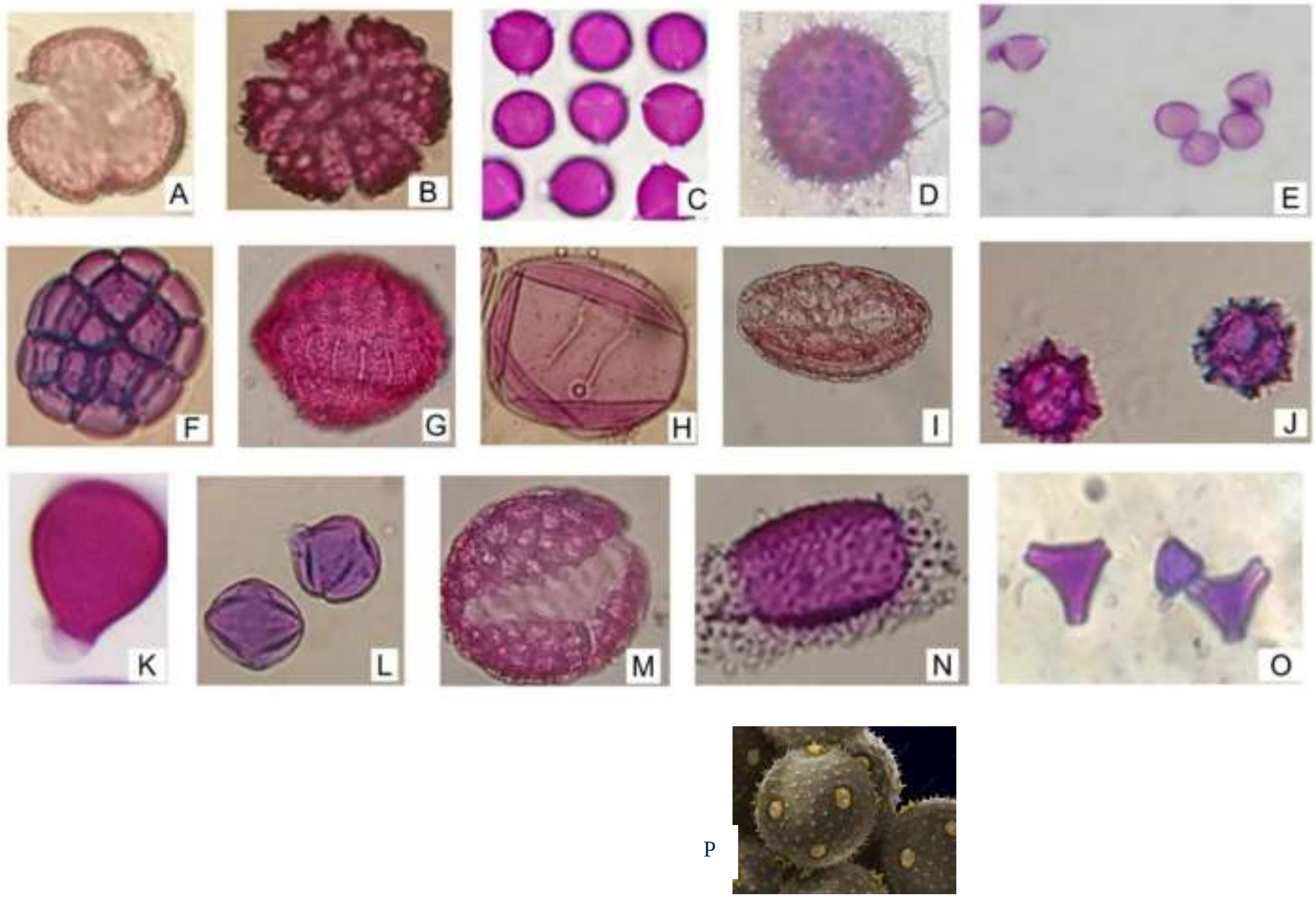

Figure 4.8:Photomicrographs of some pollen types collected by *Apis mellifera*. A:Euphorbiaceae: *Euphobia spp.* B:Lamiaceae: *Ocimum spp.* C:Fabaceae: *Phaseolus spp*. D:Asteraceae: *Bidens pilosa* E:Urtricaceae: *Utrica dioica*. F: Fabaceae

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 March (H' = 2.2) 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 (Figure 4.9).

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 (March, June and October) and low diversity of pollen sources (April, July and October) (Figure 4.9).

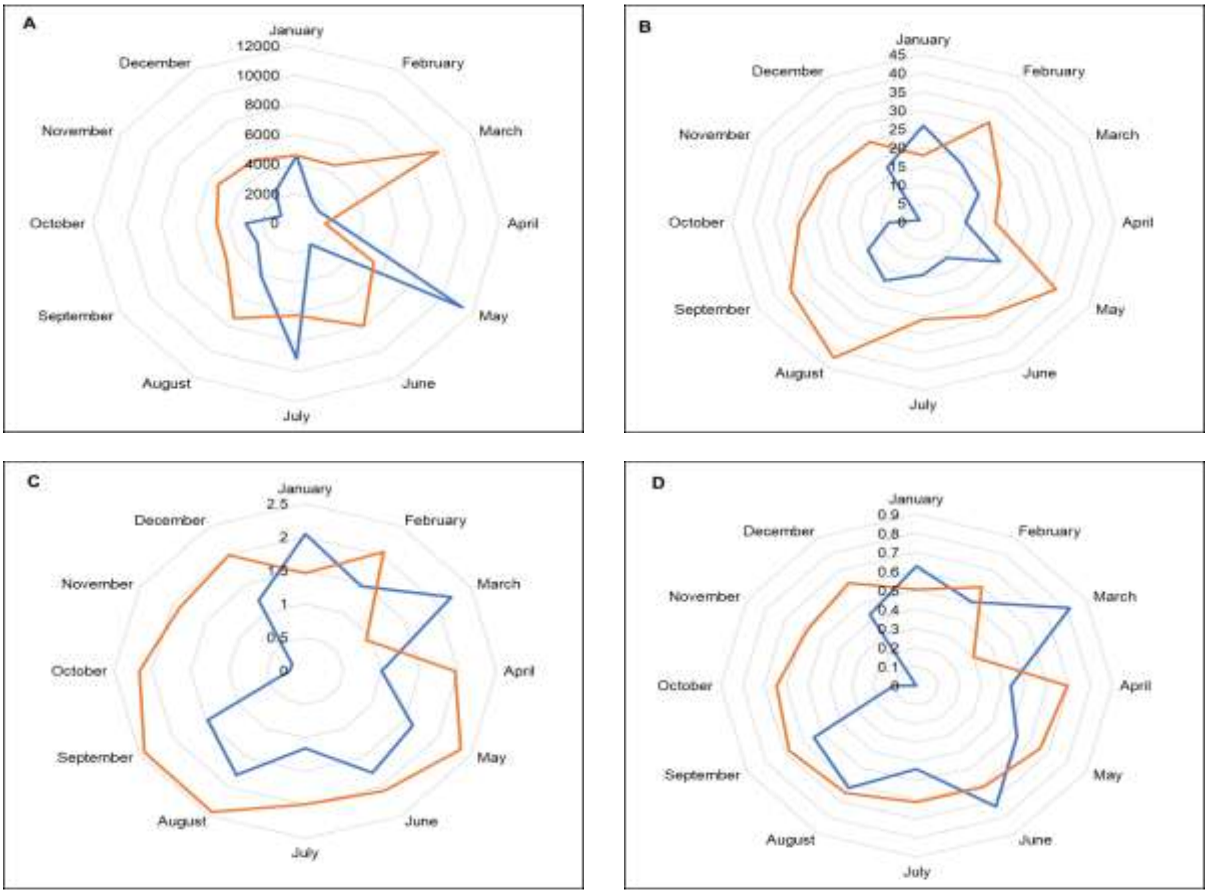

Figure 4.9: Abundance and diversity indices for the pollen samples collected by honey bees in the low and medium NDVI landscapes throughout the year. Indices include abundance (A), species richness (B), Shannon diversity index. (blue - low NDVI; orange - medium NDVI).

Honeybees foraged sixty-one plant genera in low NDVI and 103 genera in Medium NDVI in Yatta and Masinga sub-counties (Appendix 11; Appendix 111). The research was conducted from May 2020 to May 2021. In low NDVI, the most predominant and frequently visited plant families by honeybees throughout the year were: Asteraceae (Bidens pilosa), Fabaceae (Acacia), Poaceae (Zea), and the least visited families were Anacardiaceae (Rhus, Mangifera indicum), Agavaceae, Burseraceae (*Commiphora*), Commelinaceae (*Commelina difusa*), Sapindaceae, Zygophyllaceae (*Balanites*), Podocaceae, Urticaceae (*Urtica*), Asclepicidaceae (*Launaea hafunensis*) (Figure 4.10 and Appendix IV).

In medium NDVI, the most predominant and frequent plant family and genera that acted as pollen sources for honeybees across all months were: Asteraceae (*Ageratum*, *Bidens*, *Stoebe*, *Vernonia*), Fabaceae (*Acacia*, *Delonix*, *Indigofera*, *Phaseolus*) and Poaceae (*Zea*). Honeybees visited the flowers of the following families less often: Bombaceae (*Bombax*), Oleaceae, Caryophyllaceae, Cupressaceae (*Cupressus*), Lentibulariaceae (*Urtricularia*), Onagraceae (*Ludwiga*), Polygonaceae (*Oxygonum sinuatum*) and Sapindaceae (*Allophylus, Cardiospermum*) (Figure 4.11 and Appendix V)

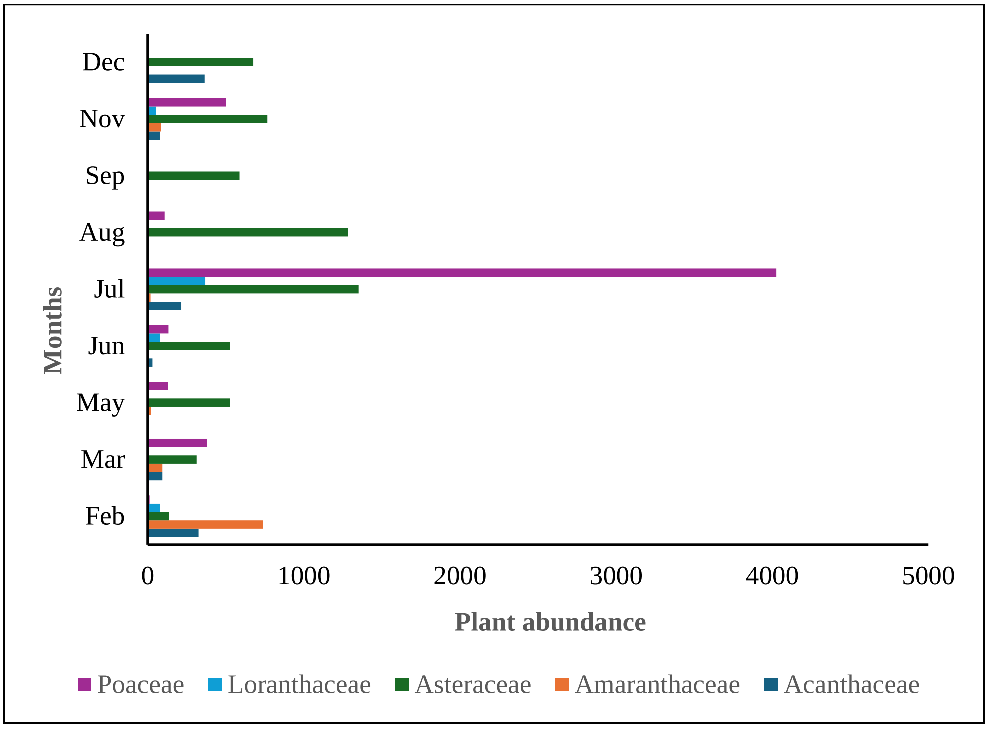

Figure 4.10: Plant families and abundance of pollen grains collected by honeybees in medium NDVI

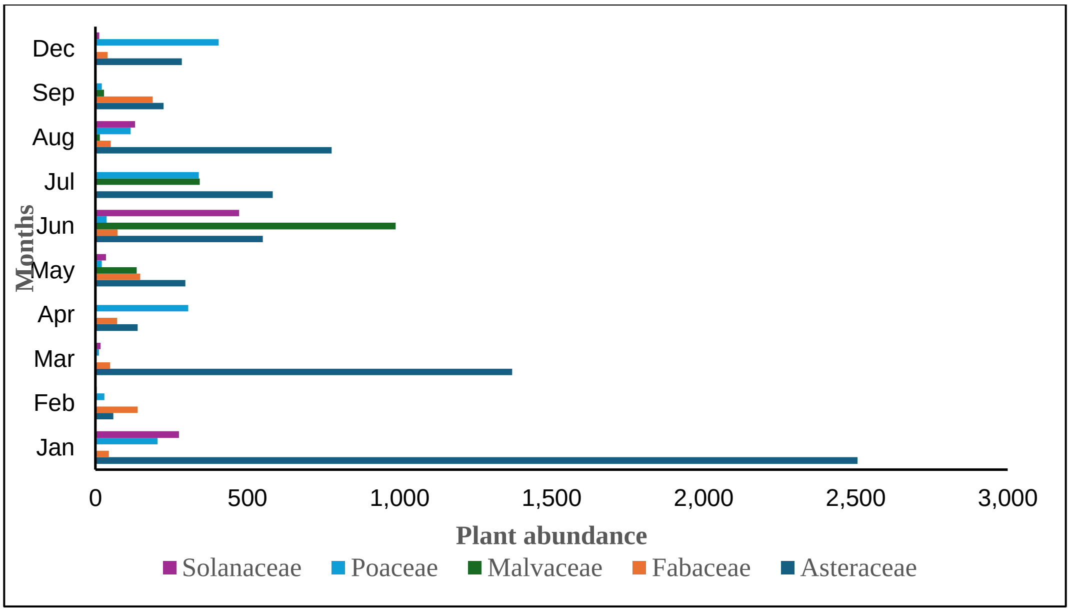

Figure 4.11: Families and abundance of pollen grains collected by honeybees in medium NDVI in Yatta and Masinga sub-counties

In low NDVI, predominant pollen (45%) flora varied across the months as follows: February (*Chenopodium spp*.), June (*Bidens pilosa*), July (Grass), September (*Terminalia spp*.), August (*Ageratum spp*.), October (*Heliotropium indicum*), December (*Bidens pilosa*) while most secondary pollen (16-45%) occurred as follows: January (*Guaduella spp*., *Bidens pilosa*), February (*Barleria spp*.), March (Grass, *Bidens pilosa*), May (*Typha spp*., *Bidens pilosa*), August (*Vernonia spp*.), September (*Ageratum spp*.), October (*Terminalia spp*.), November (Grass, *Bidens pilosa*, *Vernonia spp*.), and December (*Justicia spp*.) (Appendix VI).

In medium NDVI, the predominant pollen (45%) sources were recorded in January (*Vernonia spp*.), March (*Bidens pilosa*), June (*Corchorus spp*.), October (*Terminalia* spp.), and November (*Aloe spp*.) while the secondary pollen (16%-45%) was recorded in February (*Euphorbia spp*., *Moringa spp*.), March (*Salvadora spp*.), April (*Aloe spp*., Grass), May (*Salvadora spp*., *Bidens pilosa*), July (*Bidens pilosa*, *Abutilon spp.* Grass), August (*Vernonia spp*., *Bidens Pilosa*), September (*Terminalia spp*., *Syzigium spp*.), December (*Schefflera spp*., *Bidens pilosa*, Grass) (Appendix VII).

Most pollen was collected in July (6,054 pollen loads) in low NDVI, while March and June had the least pollen pockets, 961 and 877. The highest diversity (H' = 2.3) of pollen from 35 plant genera was observed in November. Pollen diversity of H'= 1.1 to 1.8 from different plant genera was observed between January and December. The lowest diversity (H' =0.4 and H' = 0.8) was recorded in April and November, where the pollen was collected from 3 and 8 plant genera, respectively as illustrated in appendix VI.

In medium NDVI, the highest amount of pollen collected was in January (3,222 pollen pockets), followed by March (2,066 pollen pockets), while October had the least amount of pollen pockets (976) in low NDVI. In medium NDVI, the highest diversity (H' = 2.4 and H' = 2.3) of pollen sources from 40 and 34 plant genera were recorded in August and September, respectively. Honeybees collected relatively high pollen diversity (H' =1.8, 2.1, 1.9, 2.0, 2.0, 2.0) sourced from 27, 31, 23, and 29 different plant genera in February, May and October. Lowest diversity (H' =1.1 and 1.2collected from 16 and 19 plant genera in January and March, respectively (Appendix VII).

4.4.2 Abundance of flower visitors within and around pumpkin farms

The asymmetric abundance of flower visitors directly dictated their interactions with flowering plant species based on corresponding abundances. Approximately eight pollinator guilds were observed on the flowers in both low and medium NDVI. Numerically, honeybees followed by butterflies were the most abundant and interacted with most plant species observed in both low and medium NDVI.

In low NDVI, honeybees, and butterflies visited 47 and 46 plant species, respectively, stingless bees visited 15 plant species while hoverflies were observed on two plant species, houseflies and carpenter bees each were observed on one plant species. In medium NDVI, honeybees and butterflies each visited 50 plant species, while stingless bees visited 10 plant species. Carpenter bees visited three plant species, hoverflies and wasps each visited two plant species while sweat bees, and beetles each visited one plant species (Figure 4.13).

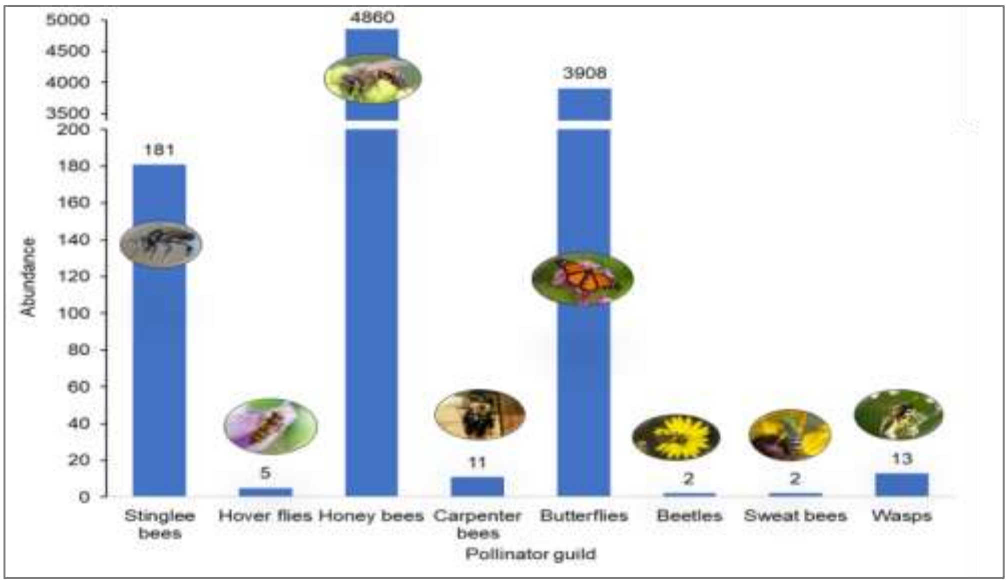

Figure 4.12: Abundance of flower visitors

Poisson regression indicated that the number of pollinators recorded varied significantly between low and medium NDVI (χ^2 = 29.50, df = 1, P < 0.001) across the data collection months (χ^2 = 822.67, df = 7, P < 0.001) and pollinator groups (χ^2 = 239.85, df = 5, P < 0.001). The most common flower visitor was the honeybee (52.98%), followed by butterflies (37.01%), stingless bees (9.33%), carpenter bees (0.38%), wasps (0.13%), beetles (0.10%), and hoverflies (0.07%). The number of flower visitors varied across NDVI classes.

More honeybees were recorded in the months of March, April, May, and June compared to January, February and August in low NDVI. In Medium NDVI, the number of honeybees was higher in January, February, March, April and June but fewer in July and August. Butterflies were observed in March, April, May, and June with the lowest numbers recorded in January and August in both low and medium NDVI. Likewise, in medium NDVI.

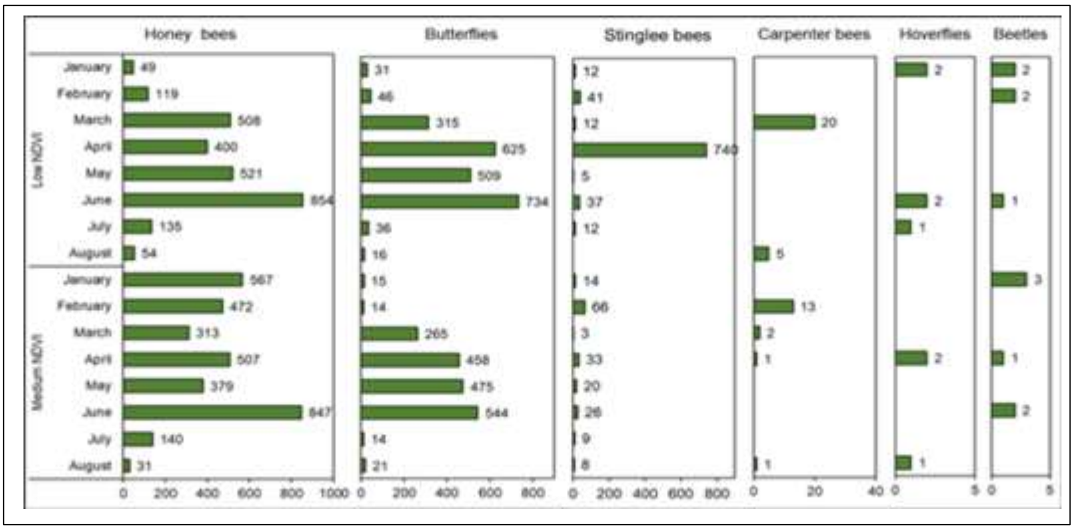

Figure 4.13: Abundance of pollinators across the months in low and medium NDVI

More butterflies were observed in March, April, May, and June, with the lowest numbers recorded in January, February. The highest number of stingless bees was recorded in April. Carpenter bees were only observed in March and August in low NDVI, while in medium NDVI, they were observed in February, while hoverflies were observed in February in low NDVI. (Figure 4.14).

4.5 Pollination inhibition on pumpkin flowers in the farms

Pollen grains collected from other flowering plants were observed on the stigma of pumpkin flowers, indicating the potential for pollen contamination and inhibition. Poisson regression model was used to analysis pollen inhibition dataset. The number of pollens deposited on the stigma of cucurbits differed significantly among the major group of plants ($\chi2$ = 8938.30, df = 9, p < 0.0001). The number of pollen grains deposited was also varied significantly between low and high NDVI class ($\chi2$ = 78.30, df = 1, p< 0.0001). Both in the low and medium NDVI, pollen deposited on cucurbit stigmas were predominantly of cucurbit origin.

About 83±17 and 64±13 pollens/stigma (means±standard error) of cucurbit origin were recorded on stigma of cucurbits in the low and medium NDVI respectively. Although, pollens from other plants including Rubaceae, Combretum, Nicotiana, Ocimum, Tagetes, Acacia, Tapinathus, Delonix and Cereals were recorded and occurred in low numbers (< 4 pollens/stigma) as illustrated in Figure 4.15.

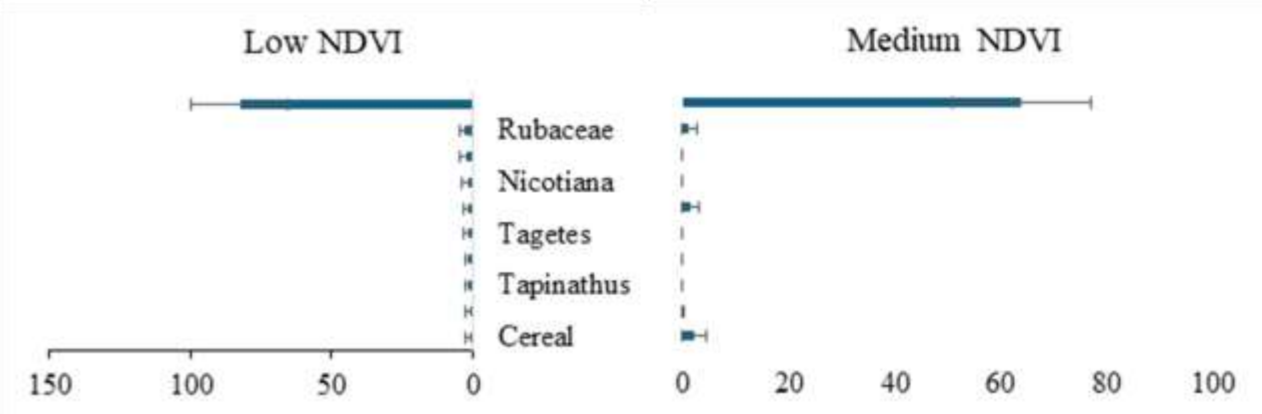

Figure 4.14: Pollen loads on the stigma of pumpkin flower

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1: Determination of the abundance and diversity of flowering plants in pumpkin farms at Masinga and Yatta sub-counties.

The study revealed 42 plant families out of a total of 90 flowering plants collected; among these families, the following families were particularly predominant: Fabaceae, Asteraceae, Lamiaceae, Solanaceae, and Malvaceae. They exhibited the highest number of species and are likely to contribute more significantly to the available floral biomass. Studies by Saikia *et al*. (2020) established that the Fabaceae (Legume family) is recognized as the source of pollinator diets, providing abundant nectar and often protein-rich pollen. Many species within Fabaceae such as soyabean, peas, acacia, wild bean and alfalfa are known to be major bee forage plants in African savanna and agro-ecosystems. Their prevalence ensures a continuous or pulsed supply of critical resources for honeybees.

The Asteraceae (Daisy/Sunflower family) is an important family for generalist pollinators due to its composite flower structure, which presents numerous small florets in an easily accessible inflorescence, yielding large quantities of both nectar and pollen. Species like *Tagetes* (also noted previously) are highly attractive to bees and represent a substantial food source (Wróblewska *et al*., 2016). Lamiaceae (Mint/Basil family): This family is renowned for its excellent nectar-producing flowers, often with specialized structures that guide pollinators. The dominance including *Ocimum suave* (Wild Basil), signifies a consistent source of carbohydrate-rich rewards for foraging bees (Guantai *et al*, 2019).

Solanaceae (Nightshade family) contribute to the overall floral diversity, often providing pollen resources and the Malvaceae (Mallow family) are also known to offer both pollen and nectar, further diversifying the array of resources available to pollinators (Onyango, 2020). These extensive diversity of plant families form the backbone of the floral calendar in Yatta and Masinga sub-counties, ensuring a continuous supply of nectar and pollen throughout the year. This is important for supporting a healthy colony of honeybee and population dynamics. This finding collaborates with Da Silva Mouga *et al*. (2015) who found that families with more species that are mostly foraged by bees include Fabaceae (22 species), Asteraceae (20 species), Solanaceae (11 species), Rosaceae (10 species) and Lamiaceae (8 species). This study also recorded a high diversity of flowering plants as well as a high abundance of pollinators in medium NDVI compared to the low NDVI. This may explain why pumpkins perform well in medium NDVI due to the increased availability of pollinators. This agrees with the study done by Hoehn *et al.,* 2008, reporting that species-rich bee communities promote efficiency pollination due to their spatial and temporal complementarity in pollination behavior. This indicates that a single or a few plant species may not provide the benefits equating a rich community of functionally distinct species.

The quadrat analysis revealed that the frequency of plants observed differed significantly among plant species ($\chi 2=451.72$, df = 141, $p < 0.001$), indicating that not all plant species are equally distributed or abundant within the smaller sampling areas. Furthermore, there was significant difference in frequency between NDVI classes ($\chi 2=44.79$, df = 1, $p < 0.001$) and across months ($\chi 2=353.06$, df = 7, $p < 0.001$) in the quadrat data reinforces the strong influence of vegetation density and seasonality on plant presence. These findings from the quadrat method provide a detailed snapshot of plant occurrence, confirming heterogeneity of the landscape at a micro-scale. The 4m x 50m belt transect data also showed highly significant variations in the frequency of observed plants among species ($\chi2=439.98$, df = 131, $p < 0.001$), between NDVI classes ($\chi2=4.87$, df = 1, $p = 0.027$), and across months ($\chi2=321.45$, df = 7, $p < 0.001$).

The consistency of these significant results across both sampling methods, despite the belt transect capturing a broader spatial extent, strengthens the conclusion that plant frequency is profoundly influenced by species-specific distributions, underlying vegetation density, and seasonal climatic shifts. The slightly lower Chi-square value for NDVI in the belt transect compared to the quadrat might suggest that while NDVI is a significant factor, its influence on frequency might be slightly more pronounced at a very localized scale (quadrat) than across a longer linear stretch (transect).

In Masinga sub-county, the frequency of flowering plants was notably high in January, February, May, and June within medium NDVI areas. These months largely correspond to periods immediately following the short rains (January/February) and the main long rains (May/June) in the Machakos region, when moisture availability promotes robust flowering (GOK, 2008). Medium NDVI zones, characterized by more vegetation, are evidently vital for providing a sustained supply of floral resources to the honeybees during these periods. This study is consistent with a case study at Mwingi in Kenya by Ochunga (2020) revealed that an extended flowering season is highly beneficial for honeybee colonies, ensuring a consistent forage base for nectar and pollen collection, which is vital for colony maintenance, growth, and honey production.

In contrast, in low NDVI areas of Masinga sub-county, the frequency of flowering plants was high only in July. This suggests that low NDVI environments, often drier or more degraded, support a much shorter and more concentrated flowering period. The July peak might correspond to the flowering of highly drought-tolerant or opportunistic species that can bloom with minimal moisture. This limited flowering window highlights their reduced capacity to provide continuous floral support for pollinators, potentially leading to resource scarcity during other times of the year (Philips *et al*., 2018).

The analysis also revealed a notably high species evenness (J = 0.92) in medium NDVI within Yatta sub-county during the month of January. This indicates that in these moderately vegetated areas, the plant species present were distributed almost equally in terms of abundance, with no particular plant species overwhelmingly dominating the community. January in Yatta is typically a dry month following the short rains (Oct-Dec) hence high species evenness often signifies a more stable and resilient ecosystem. In environments where resources are not monopolized by a few dominant species, the plant communities develop adaptations to withstand disturbances such as drought and maintain ecosystem functions such as soil stability (Chauhan and Singh, 2018).

Popcorn Cassia (*Senna didymobotrya*) emerged as the most abundant plant species, comprising a substantial 55.8% of the observed flora. It is known for its bright, yellow-colored flowers. Its dominance suggests its ecological resilience and ability to thrive in conditions that might be less favorable for a wider array of plants, such as disturbed sites or areas with lower soil fertility or moisture. It significantly contributes to the floral landscape as a primary resource for generalist foragers like honeybees. Wild Basil (*Ocimum suave*) was the second most abundant species in low NDVI areas, accounting for 20.2% of the plants. *Ocimum suave* is a widespread herbaceous plant known for its adaptability and aromatic qualities providing a consistent source of nectar.

The dominance of these two plant species indicates that low NDVI areas, despite less biodiverse in terms of richness, it is significantly shaped by a few hardy and abundant plant types (Sajjanar *et al*., 2002). In the medium NDVI areas, passion fruit (*Passiflora edulis*) was the most abundant plant, making up 33.6% of the flora. Passion fruit flowers are known to be highly attractive to bees and other pollinators, necessitating effective pollination for fruit set (Yamamoto *et al*., 2012)). The presence of a cultivated plant species as a dominant element points out the integration of agricultural production with natural floral resources in these landscapes.

5.2 Phenology of honeybee plants within and around pumpkin farms in Masinga and Yatta sub-counties.

Monthly variations in the abundance of flowering plants and total flowers provide a critical framework for constructing the floral calendar of Yatta and Masinga sub-counties, a vital tool for understanding pollinator resource availability and informing agricultural practices. The distinct patterns observed across medium and low NDVI classes reveal a dynamic and heterogeneous temporal landscape for foraging honeybees. In medium NDVI, the floral calendar is characterized by multiple significant pulses of flowering activity, reflecting a relatively sustained supply of resources.

The primary "flow" period was evident in February, which recorded 11,000 flowering plants and 6,000 flowers. This period represents a critical time for honeybee colonies to build up their populations and resources. While March showed a comparatively lower abundance of flowering plants (2,000) and flowers (3,000), this might indicate a brief change in the dominant flowering species. Importantly, medium NDVI areas also sustained a notable mid-year flowering pulse in July (4,000 flowering plants, 4,000 flowers)**.** This suggests the presence of resilient plant species that can bloom during the drier periods following the long rains, thereby extending the floral calendar and mitigating potential periods of resource dearth for pollinators throughout the year.

Conversely, the low NDVI, a significant "flow" period was observed in February (5,000 flowering plants, 10,000 flowers)**,** with a remarkably high ratio of flowers to flowering plants. This trend became even more pronounced in March (6,000 flowering plants, 15,000 flowers)**,** indicating that while these less vegetated areas might host fewer individual plants, the species that flower are highly floriferous, producing many blooms per plant. This strategy is critical for maximizing reproductive success in resource-limited environments and provides concentrated pockets of high-reward forage for bees. Subsequent peaks in low NDVI occurred in April (14,000 flowers) and June (3,000 flowering plants, 4,000 flowers)**.** These distinct monthly peaks demonstrate that low NDVI areas, despite their overall sparser vegetation, contribute significantly to the floral calendar during specific temporal windows, often by supporting opportunistic plant species that quickly respond to environmental cues. These findings agree with a study by Medina-Serrano (2024), reporting that most plant species are biyearly and recurrent while some are annual plant species, they provide pollen and nectar for a relatively short time each year. Additionally, foraging economies are enhanced when floral resources are next to nesting sites and pollination reservoir directly affects crop production in the farmlands of blooming crops (Ventrurini *et al*., 2017). Also, Carvalheiro *et al.* (2012), reported that pollination reservoirs in mango orchards in South Africa improved flower visitors and yields substantially in the bordering mango farms.

This study also observed that in the low NDVI class, three specific plant genera demonstrated remarkable persistence in providing pollen to honeybees. *Bidens spp*., a genus within the highly attractive Asteraceae family, supplied pollen for an impressive 11 months of the year. Similarly, *Vernonia spp*. (Asteraceae) provided pollen for 10 months, and *Ageratum spp*. (Asteraceae) for 8 months. The extended availability of pollen from these weedy genera in less vegetated areas is ecologically significant. It indicates that even in environments characterized by lower overall plant density, specific resilient species play a crucial role in buffering periods of potential pollen scarcity, offering a continuous dietary component for honeybee colonies (Vaudo *et al*., 2015). In the medium NDVI class, which generally exhibited higher overall plant abundance and diversity, an even broader range of consistent pollen sources was identified. The Poaceae family (grasses) remarkably provided pollen for the entire 12 months of the year. While grasses are predominantly wind-pollinated, their presenc and consistent pollen production in medium NDVI zones mean that honeybees, either incidentally or for specific nutritional requirements, collect their pollen year-round, suggesting a continuous, albeit potentially less targeted, resource.

These results are inconsistent with studies by Pound *et al*., (2022) where both families, Poaceae and Plantaginaceae pollen were foraged on by *A. mellifera.* The pollen is utilized by honeybees during the challenging summer period (also referred to as the 'hungry gap'). Honeybees may also collect pollen from grasses to supplement pollen sources to ensure a diverse and balanced diet for the honeybee colony. Beyond grasses, several key genera also exhibited long-term pollen availability: *Vernonia spp*. (10 months), *Syzygium spp*. (8 months), *Terminalia* spp. (7 months), and *Bidens spp*. (7 months).

5.3 Diversity of pollen sources for honeybees in pumpkin farms in Masinga and Yatta sub-counties

The identification of pollen sources to the genus level revealed a variety of plant families contributing to the honeybee diet. These included: Asteraceae, Acanthaceae, Amaranthaceae, Combretacea, Commelinaceae, Fabaceae, Myrtaceae, Malvaceae, Poaceae, Salvadoraceae, Solanaceae and Typhaceae. The presence of these families in the corbicula of honeybees confirms that these forage plants have an ecological importance within the study sites; Yatta and Masinga sub-counties. This also shows that honeybees have a generalist foraging behavior and they rely on a wide range of floral resources available across the heterogeneous agricultural and natural landscapes of Yatta and Masinga. This study confirms with Burger *et al*. (2013), the generalist behavior of bees and they also correspond with Ochungo *et al*. (2021) in a study in the semi-arid and arid areas in Kenya which showed that the Capparaceae, Combretaceae, and Asteraceae were among the plant families largely foraged by the honeybee. These plant families were the most preferred because of the abundance of pollen and nectar reward, ease of accessibility of the pollinator to the flower, they are attractive and visible from a far distance by pollinators.

Also, Asteraceae is one of the largest and most widespread plant families found in diverse habitats from arid regions to temperate grasslands. This ubiquity means that honeybees frequently encounter Asteraceae plant species across various landscapes, including agricultural and disturbed areas where many Asteraceae are common weeds.

These findings are similar to a study by Muller and Kuhlmann (2008) whereby Asteraceae family are the most important pollen source contributing to 23.6 % of pollen-plant spectrum of bees. Interestingly, the pollen from cucurbits (pumpkin) where bees were expected to have collected occurred as minor pollen (less than 3%) in pollen samples. This may indicate that either the bees had less preference for the pollen of pumpkin flower, the short blooming period of pumpkin affected pollen collection, or there were several other pollen sources near the nest sites.

The findings of this study also revealed that honeybees collected a significantly greater total number of pollen grains in medium NDVI areas (67,125 pollen grains) compared to low NDVI areas (45,758 pollen grains). This indicates that areas with higher vegetation density and health (medium NDVI) offer more abundant and accessible pollen resources, making them primary foraging grounds for honeybee colonies. This spatial difference in resource provisioning profoundly impacts honeybee nutrition and, by extension, their capacity to provide effective pollination services. In the medium NDVI class**,** the highest amount of pollen grains was collected in March (9,689 pollen grains)**.** This peak aligns with the onset of the long rains in the study area which triggers a flush of flowering in various plant species, thus providing abundant pollen. The least amounts of pollen grains were collected in February (4,527 pollen grains)**,** the low collection might represent a transitional period after the short rains. According to Boulter *et al*. 2006, a study done in Northern Australia, there is a close relationship in the flowering pattern of plants and the weather.

Regarding pollen source diversity, high level of diversity was observed in medium NDVI supporting the richness of flora. The highest diversity (H' = 2.4) of pollen sources was recorded in August and September**.** These months reflect a period when an array of plant species is in bloom, providing a varied diet for honeybees. Correspondingly, the highest numbers of plant families foraged by honey bees were observed in August (42 families), May (37 families), and September (36 families)**,** further confirming the broad spectrum of plant utilization. However, low diversity was recorded in January (H' = 1.5**)** and in March (H' = 0.9) exhibiting a narrower range of pollen sources. This fluctuation suggests that even within generally rich medium NDVI areas, resource availability can be dynamic, with certain months or specific floral flushes being dominated by a few key pollen sources. This study is in contrast with the studies by Danner *et al*. (2017) in Germany who established out that the amount and diversity of pollen input were influenced by season but not by landscape diversity.

5.3.1 Abundance of flower visitors within and around pumpkin farms

Several insects such as honeybees, hoverflies, wasps, ants, Halictus bees, stingless bees, beetles, and butterflies were documented visiting flowering plants within and around the pumpkin farms in this study sites. Key to note is that most flower visitors were honeybees, an indicator that honeybees are key insect pollinators in Machakos county. This finding agrees with Hung *et al.* (2018) research on worldwide importance of honeybees as pollinators reported that *A. mellifera* contributes ≥50% of all floral visits to flowering plants. These findings directly reflect the functional diversity of pollinators present in the agro-ecosystem and their adaptation to varying vegetation densities.

In low NDVI areas where there is sparse vegetation, a diverse guild of pollinators was observed utilizing a range of plant species. Honeybees **(***Apis mellifera***)** demonstrated their characteristic generalist foraging behavior by visiting 47 plant species. Similarly, butterflies exhibited a broad foraging scope, being observed on 46 plant species**.** These numbers underscore the critical role of honeybees and butterflies in pollinating a wide array of plants, even in environments with comparatively lower overall floral abundance. In medium NDVI areas**,** the pattern of pollinator visitation is reinforced by greater floral resource availability. Both honeybees and butterflies continued to act as highly effective generalists, each visiting 50 plant species**.** This slightly higher number of visited species compared to low NDVI areas confirms that medium NDVI landscapes offer a richer and more diverse array of floral resources, which can support a broader foraging range for these key pollinator groups.

Interestingly**,** stingless bees were observed on fewer plant species in medium NDVI, visiting ten plant species compared to fifteen in low NDVI. This intriguing difference might suggest that stingless bees, due to their smaller size or specific foraging preferences, might face increased competition from more dominant generalists like honeybees or they might specialize in specific floral types that are more prevalent or accessible in low NDVI areas. Other pollinator groups in both low and medium NDVI areas also contributed to the overall pollination service: Other pollinator groups showed more specialized or limited visitation**:** stingless bees were found on fifteen plant species, hoverflies and carpenter bees each utilized one plant species**,** and wasps each visited two plant species, while sweat bees and beetles each visited one plant species. The presence of these diverse pollinator groups across both NDVI classes, even with varying degrees of foraging breadth, shows the importance of a resilient pollinator guild in the agro-ecosystem.

5.4 Pollination inhibition in pumpkin flowers

The study reveals that the number of pollen grains deposited on the stigma of pumpkin flowers by honeybees differed significantly among the main groups of plants like Rubaceae, Combretum, Nicotiana, Ocimum, Tagetes, Acacia, Tapinathus, Delonix and Cereals.It also established that honeybees forage across a varied floral landscape, they inevitably carry mixed loads of pollen from multiple plant species on their bodies as shown in these study results. The non-pumpkin pollen can prevent germination of pollen tube on the stigma due to stigma clogging.

The study by Dickinson *et al*., (2018) investigated the effects of foreign pollen on pollen germination and pollen tube growth in *Solanum peruvianum.* Their research found that pollen from different plant species can influence the recipient plant's ability to successfully pollinate and develop pollen tubes. They found that pollen from closely related species within the same genus could negatively impact pollen tube growth and reduce the recipient plant's post-pollination success. While pollinators are crucial for transferring pumpkin pollen, their generalist foraging behavior traversing varied floral resources, can inadvertently lead to reduced efficiency in targeted pollen transfer to crops like pumpkins. This could be due to chemical incompatibility or presence of strong structural or temporal barriers against pollination by non-self-pollen. Such mechanisms have been previously observed in other plant species (Hiscock, 2002; Borba and Semir, 1999).

For the smallholder farmers in Masinga and Yatta sub-counties, the abundance of other flowering plants in farms and surrounding areas, while they are beneficial for overall pollinator sustenance, they might introduce elements of pollination inefficiency for pumpkins. Reduced effective pollen deposition can translate to suboptimal fruit set, malformed fruits, and lower yields (Garibaldi *et al.*, 2013), impacting the livelihood of the farmers and food security.

5.5 Conclusions

This research reveals that flowering plants like weeds other than crops are crucial in providing floral resources (pollen, nectar) to the flower-visiting insects when crops like pumpkins are not flowering. The bees can forage on at least 30% of plant species in and around pumpkin farms that remain actively flowering during the January to August sampling period, indicating year-round availability of pollinators' forage rewards.

The honeybee collected pollen was delivered from multiple plants, including natural vegetation, croplands, grasses, and hedges. Pollen from multiflora sources in different months indicates that multiple flowering plants can act as refugia for honeybees when main crops, such as cucurbits, are not blooming or out of season. The findings of this study give insights that farmers in Yatta and Masinga sub-county should maintain year-round flowering plants in and around the nearby farmlands to boost population of pollinators and their pollination services hence increasing crop production.

5.6 Recommendations

(i) Farmers in Masinga and Yatta sub-counties should be advised to plant and maintain strips of diverse, native flowering plants from Fabaceae, Asteraceae, Lamiaceae families around farm borders, along access roads, or within unproductive areas of the farm. These can act as continuous nectar and pollen sources, especially in medium NDVI areas which consistently support higher diversity.

(ii) Conservation and management of plant genera/families identified as main pollen sources such as Fabaceae and Asteraceae across months in each landscape to retain honeybees at a particular locale enhancing pollination services for flowering crops such as pumpkin. These plants are vital for providing continuous and varied pollen throughout the year.

(iii) Further studies determine the nectar volume, sugar concentration, and pollen nutritional quality of the most abundant and frequently visited plant species in both NDVI classes. This will provide a deeper understanding of their energetic and protein contribution to honeybee diets.

(iv) Further research on the correlation of the difference in non-pumpkin pollen grain deposition on the stigma with subsequent fruit set rates, fruit quality parameters, and seed viability. This can be done by application of pollen grains from various plant families or genera directly onto the stigma.

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APPENDICES

Appendix I: Flowering plant species in Yatta and Masinga sub-counties

Family	Common name	Scientific name	Low	Medium
Acanthaceae	Black eye Susan	*Thunbergia alata*	✓	✓
Amaranthacease	Devil's horsewhip	*Achyranthes aspera*	✓	✓
Amaranthacease	Pigweed	*Amaranthus retroflexus*	✓	✓
Anacardiaceae	Mango	*Citrus sinensis*	✓	✓
Anacardiaceae	Mango	*Mangifera indicum*	✓	✓
Apocynaceae	Yellow oleander	*Cascabel therein*	✓	✓
Apocynaceae	Oleander	*Nerium oleander*		✓
Apocynaceae	Yellow Oliendar	*Verbena officinalis*		✓
Asclepiadaceae	Bitter lettuce	*Launaea cornuta*	✓	✓
Asclepiadaceae	Milkweed	*Launaea hafunensis*	✓	✓
Asteraceae	Bristly starbur	*Acanthospermum hispidum*	✓	✓
Asteraceae	Billy goat weed	*Ageratum conyzoides*	✓	
Asteraceae	Wild sunflower	*Aspillia mossambiensis*	✓	✓
Asteraceae	Blackjack	*Bidens pilosa*	✓	✓
Asteraceae	Bristly Hawks' beard	*Crepis setosa*	✓	✓
Asteraceae	Speedy weed	*Flaveria bidentis*	✓	✓
Asteraceae	Gallant soldier	*Galinsoga parviflora*	✓	✓
Asteraceae	Carrot grass	*Pathernium hysterophorus*	✓	
Asteraceae	Mexican marigold	*Tagetes minuta*	✓	✓
Asteraceae	Coat buttons	*Tridax procumbens*	✓	✓
Asteraceae	Ironweed	*Vernonia noveboracensis*	✓	✓
Bignoniaceae	Nandi flame	*Spathodea campanulata*	✓	
Bignoniaceae	Yellow trumpet	*Tecoma stans*	✓	✓
Boraginaceae	string of stars	*Heliotropium steudneri*	✓	✓
Boraginaceae	Camel bush	*Trichodesma zeylanicum*	✓	✓
Brassicaceae	Sweet Alice	*Lobularia maritima*		✓
Caricaceae	Paw Paw	*Carica papaya*	✓	✓
Cleomaceae	African spider flower	*Cleome gynandra*	✓	✓
Commelinaceae	Spreading dayflower	*Commelina diffusa*	✓	✓
Convolvulaceae	Ipomea	*Ipomea convolvulaceae*	✓	✓
Convolvulaceae	Sweet potato	*Ipomea batatas*	✓	✓
Convolvulaceae	Morning glory	*Ipomea convolvulaceae*	✓	✓
Convolvulaceae	Ipomea	*Ipomea spp.*	✓	✓
Cucurbitaceae	Hedgehog cucumber	*Cucumis dipsaceus*	✓	✓
Cucurbitaceae	Bottle guard	*Lagenaria siceraria*	✓	✓
Cucurbitaceae	Bad smell melon	*Momordica foetida*	✓	✓
Euphorbiaceae	Castor	*Ricinus communis*	✓	✓
Fabaceae	Acacia	*Acacia nilotica*	✓	✓
Fabaceae	Acacia albida	*Acacia xanthophloe*	✓	✓
Fabaceae	Pigeon peas	*Cajanus cajan*	✓	✓
Fabaceae	Locust bean	*Ceratonia siliqua L.*	✓	✓

Fabaceae	Rattle pod	*Crotalaria marginella*	✓	✓
Fabaceae		*Dolichos luticola*	✓	✓
Fabaceae	Black beans	*Lablab purpureus*	✓	✓
Fabaceae	Common laburnum	*Laburnum anagyroides*	✓	
Fabaceae	Alfalfa	*Medicago arborea L.*	✓	✓
Fabaceae	Common bean	*Phaseolus vulgaris*	✓	✓
Fabaceae	Popcorn Cassai	*Senna didymobotria*	✓	✓
Fabaceae	Coffee Senna	*Senna occidentalis*	✓	✓
Fabaceae	Tamarind	*Tamarindus indica*	✓	✓
Fabaceae	Green grams	*Vigna radiata*	✓	✓
Fabaceae	Cow peas	*Vigna unguiculata*	✓	✓
Lamiaceae	Lion's ear	*Leonotis nepetifolia*	✓	✓
Lamiaceae	Thumbai	*Leucas aspera*	✓	✓
Lamiaceae	White wort	*Leucas martinicensis*	✓	✓
Lamiaceae	Thumbai	*Leucas neuflizeana*	✓	✓
Lamiaceae	wild basil	*Ocimum basilicum*	✓	✓
Lamiaceae	Wild basil	*Ocimum gratisenum*	✓	✓
Lamiaceae	Wild basil	*Ocimum suave*	✓	✓
Lamiaceae	White thyme	*Satureja montana*	✓	✓
Malvaceae	Indian mallow	*Abutilon hirtum*	✓	✓
Malvaceae	Prickly hibiscus creeper	*Hibiscus surrattensis*	✓	✓
Malvaceae	Flower of an hour	*Hibiscus trionum*	✓	✓
Malvaceae	Rose Mallow	*Hibiscus vitifolius*	✓	✓
Malvaceae	Southern Sida	*Sida acuta*	✓	✓
Moringaceae	Drumstick tree	*Moringa oleifera*	✓	✓
Musaceae	Banana	*Musa acuminate*	✓	✓
Nyctaginaceae	Bougainvillea	*Bougainvillea spectabilis*	✓	✓
Orobanchaceae	Rattle pod	*Parentucellia viscosa*	✓	✓
Papaveraceae	Mexican pricky poppy	*Argemone mexicana*	✓	✓
Passifloraceae	Passion fruit	*Passioflora edulis*	✓	✓
Pedaliaceae	Luta	*Sesamum calycinum*	✓	✓
Pedaliaceae	Sesame	*Sesamum indicum*	✓	✓
Plantaginaceae	pale toad flower	*Linaria nepens*	✓	✓
Poaceae	Maize	*Zea mays*	✓	✓
Polygonaceae	Double thorn	*Oxygonum sinuatum*	✓	✓
Rubiaceae	Blue woodruff	*Asperula arvensis* L.	✓	✓
Rubiaceae	White eye	*Richardia brasiliensis*	✓	✓
Rubiaceae	Dyer's madder	*Rubia tinctarum*	✓	✓
Rutaceae	Lemon	*Citrus limon*	✓	✓
Solanaceae	Pepper	*Capsicum annuum*	✓	✓
Solanaceae	Thorn apple	*Datura stramonium*	✓	✓
Solanaceae	Tomato	*Salonum lycopersicum*	✓	✓
Solanaceae	Sodom apple	*Solanum incanum*	✓	✓
Solanaceae	Tomatoes	*Solanum lycopersicum*	✓	✓
Solanaceae	Eggplant	*Solanum melongena*	✓	✓
Solanaceae	Black nightshade	*Solanum nigrum*	✓	✓

Solanaceae	Red-fruited nightshade	*Solanum villosum*	✓	
Verbanaceae	Wild sage	*Lantana camara*	✓	✓

Appendix II: Families, genera, and abundance of pollen grains identified in low NDVI

Family	Plant genera	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acanthaceae	*Barleria*	-	323	95	-	-	30	216	2	4	-	42	1
Acanthaceae	*Justicia*	-	3	-	-	-	-	-	-	-	3	37	365
Agavaceae	*Agave*	2	-	-	-	-	-	-	-	-	-	-	-
Amaranthaceae	*Amaranthus*	-	-	-	-	21	-	18	-	-	-	4	-
Amaranthaceae	*Chenopodium*	-	740	94	-	-	-	-	-	-	-	81	-
Anacardiaceae	*Bosquia*	-	1	-	-	-	-	-	-	-	-	-	-
Arecaceae	*Hyphaene*	-	-	-	-	-	-	-	-	-	-	1	8
Asclepiadaceae	*Asclepias*	-	-	-	-	-	-	1	-	-	-	-	-
Asteraceae	*Ageratum*	159	-	28	-	39	-	-	918	544	8	115	1
Asteraceae	*Aspilia*	78	3	33	-	-	-	-	-	-	-	11	-
Asteraceae	*Bidens*	386	132	191	181	433	469	776	15	31	-	352	676
Asteraceae	*Stoebe*	-	3	-	-	-	-	-	-	-	-	-	-
Asteraceae	*Tagetes*	-	-	-	-	1	10	1	-	-	-	-	-
Asteraceae	*Tarchonathus*	-	-	-	-	-	-	1	-	-	-	-	-
Asteraceae	*Vernonia*	6	-	62	1778	56	47	573	351	14	-	287	1
Boraginaceae	*Cynoglossum*	15	-	-	-	-	-	-	-	-	-	2	-
Boraginaceae	*Heliotropium*	-	-	-	-	-	-	-	-	1	934	-	-
Burseraceae	*Commiphora*	-	-	-	-	-	105	-	-	-	-	11	-
Cactaceae	*Epiphyllum*	87	-	-	-	-	-	-	-	-	-	9	-
Capparaceae	*Cleome*	-	-	-	-	-	-	-	56	-	-	6	-
Clusiaceae	*Garcinia*	-	-	-	-	-	-	-	-	-	-	-	1
Combretaceae	*Combretum*	-	-	-	-	-	-	-	5	43	3	1	-
Combretaceae	*Terminalia*	-	1	-	-	1	-	-	-	750	523	-	1
Commelinaceae	*Commelina*	-	1	-	-	-	-	-	-	-	-	-	-
Convolvulaceae	*Ipomea*	-	-	58	-	-	-	60	19	-	-	14	-
Cucurbitaceae	*Cucumis*	-	-	18	-	-	-	-	-	-	-	2	-
Cucurbitacea	*Cucurbit*	-	43	-	15	-	-	-	38	-	-	-	-
Euphorbiaceae	*Acalypha*	-	-	-	-	-	-	1	-	-	-	-	3
Euphorbiaceae	*Croton*	-	-	-	-	-	-	-	2	-	-	-	-
Euphorbiaceae	*Euphorbia*	-	-	-	-	-	-	-	-	1	-	-	-
Euphorbiaceae	*Manihot*	-	-	-	-	-	-	-	-	-	-	9	92
Euphorbiaceae	*Tragia*	-	-	-	-	-	-	1	-	-	-	-	-
Fabaceae	*Acacia*	1	9	1	-	-	-	1	-	1	-	1	2
Fabaceae	*Albizia*	-	-	-	-	-	-	-	-	1	-	-	-
Fabaceae	*Crotalaria*	-	-	-	-	1	-	-	-	-	-	-	-
Fabaceae	*Delonix*	-	-	-	-	27	-	-	-	-	-	-	19
Fabaceae	*Glycine*	-	-	-	-	31	-	-	-	-	-	3	-
Fabaceae	*Indigofera*	-	-	-	-	1	-	-	-	7	-	-	-
Fabaceae	Legume	-	-	-	-	-	-	-	-	-	-	-	1
Fabaceae	*Phaseolus*	-	-	-	-	7	-	-	16	-	-	2	-
Guaduellaceae	*Guaduella*	735	-	-	-	-	-	-	-	-	-	74	-
Lamiaceae	*Leonitis*	14	-	-	-	-	1	-	-	-	-	2	1
Lamiaceae	*Leucas*	-	-	1	-	-	-	-	1	-	-	-	-
Lamiaceae	*Ocimum*	-	1	-	-	-	-	-	128	-	-	13	4
Loranthaceae	*Loranthus*	-	77	-	-	-	-	-	-	-	-	8	-
Loranthaceae	*Plicosephalus*	-	-	-	-	-	79	370	7	-	-	46	2
Malvaceae	*Grewia*	-	-	-	-	8	-	-	-	-	-	1	-

Molluginaceae	*Mollugo*	-	-	-	-	134	-	-	-	-	-	13	-
Myrtaceae	*Syzigium*	-	-	-	-	158	1	8	14	53	-	13	-
Oleaceae	*Olea*	-	-	-	-	-	-	-	-	19	-	-	-
Poaceae	Grass	175	11	382	-	43	-	427	83	-	-	472	4
Poaceae	*Zea mays*	50	2	-	-	86	133	-	27	-	3	30	-
Salvadoraceae	*Salvadora*	-	-	-	-	-	-	-	2	-	6	1	-
Sapindaceae	*Allophylus*	-	-	-	-	-	1	-	-	-	-	-	-
Solanaceae	*Solanum*	-	2	-	-	-	-	-	-	2	13	1	-
Typhaceae	*Typha*	-	-	-	-	88	-	-	-	-	-	81	-
Urticaceae	*Urtica*	-	-	-	-	-	1	-	-	-	-	-	-
Zygophyllaceae	*Balanites*	6	-	-	-	-	-	-	-	-	-	1	-

Appendix III: Families, genera, and abundance of pollen grains identified in medium NDVI

Family	Genera	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Acanthaceae	*Barleria*	12	52	-	-	33	19	-	4	-	-	-	-
Acanthaceae	*Cathaceae*	-	-	-	-	-	-	-	-	-	-	-	1
Acanthaceae	*Ecbolium*	-	-	-	-	-	-	17	-	-	-	-	-
Acanthaceae	*Hygrophilla*	-	-	-	-	-	1	-	-	-	-	-	-
Acanthaceae	*Justicia*	21	-	-	-	-	-	-	1	1	1	1	2
Agavaceae	*Agave*	-	-	-	105	15	-	-	-	-	-	48	-
Aizoaceae	*Zaleya*	-	-	-	38	-	-	-	-	-	-	-	-
Amaranthaceae	*Acrynthes*	-	-	-	-	-	-	-	-	1	-	-	-
Amaranthaceae	*Celosia*	-	-	-	-	10	-	-	-	-	-	-	-
Amaranthaceae	*Cheno*	-	-	3	-	-	-	-	-	-	-	-	-
Anacardiaceae	*Rhus*	-	158	-	-	-	-	-	-	19	77	-	-
Apocynaceae	*Carissa*	-	-	-	-	1	-	-	-	-	-	-	-
Apocynaceae	*Tapirathuo*	-	-	-	-	-	-	-	15	-	-	-	-
Arecaceae	*Hyphaene*	1	1	-	-	-	-	-	-	110	1	68	-
Asphodelaceae	*Aloe*	-	-	1	319	-	-	-	1	-	-	563	1
Asteraceae	*Ageratum*	1	2	4	-	9	-	1	1	1	1	2	7
Asteraceae	*Aspilia*	-	-	-	-	-	-	-	-	1	1	-	-
Asteraceae	*Bidens*	206	5	1265	-	223	15	505	273	127	10	-	276
Asteraceae	*Carthium*	-	1	-	-	-	-	-	-	-	-	-	-
Asteraceae	*Stoebe*	-	-	-	-	-	206	1	-	-	-	-	-
Asteraceae	*Tagetes*	-	-	-	-	-	59	-	1	-	-	-	-
Asteraceae	*Tarchonathus*	-	16	-	-	8	3	-	-	-	1	-	-
Asteraceae	*Vernonia*	2299	35	102	139	57	268	77	502	95	2	1	1
Bombacaceae	*Bombax*	-	-	-	-	-	-	-	-	1	-	-	-
Boraginaceae	*Heliotropium*	-	-	-	-	-	-	1	-	23	21	3	-
Brassicaceae	*Brassica*	-	-	-	-	4	-	5	-	-	-	-	-
Burseraceae	*Commiphora*	-	-	19	-	1	-	-	-	-	129	-	55
Cannabaceae	*Celtis*	-	-	-	-	-	-	-	1	1	-	-	-
Capparaceae	*Boscia*	-	-	-	-	2	-	-	121	-	1	-	-
Capparaceae	*Cleome*	-	-	-	23	-	1	-	-	1	-	-	-
Casuarinaceae	*Cassuarina*	-	-	-	-	-	-	-	-	-	-	-	28
Combretaceae	*Combretum*	-	-	3	-	-	-	-	-	-	42	114	1
Combretaceae	*Terminalia*	-	-	-	7	-	1	8	165	481	441	97	108
Commelinaceae	*Commelina*	-	1	1	2	-	-	-	1	-	-	-	-
Convolvulaceae	*Ipomea*	-	2	-	-	10	-	25	70	2	-	-	5
Convolvulaceae	*Seddera*	-	-	-	-	-	-	4	-	-	-	-	-
Cucumbitaceae	*Cucumis*	1	15	-	-	1	-	20	-	-	1	-	1-
Cucurbitacea	*Cucurbit*	-	-	87	-	1	-	-	-	-	-	1	-
Cupressaceae	*Cupressus*	-	-	-	-	-	-	-	-	-	-	-	2
Ebenaceae	*Diospyros*	-	-	-	-	-	-	-	-	252	-	-	-
Ebenaceae	*Dyspiros*	-	-	-	-	-	-	-	-	-	-	33	-
Euphorbiaceae	*Acalypha*	-	-	-	-	2	-	-	1	-	-	-	-
Euphorbiaceae	*Croton*	-	15	-	-	-	-	-	-	-	89	1	10
Euphorbiaceae	*Euphorbia*	-	549	-	-	-	-	-	-	1	-	11	-
Euphorbiaceae	*Manihot*	-	-	-	-	1	-	-	-	-	1	-	-
Euphorbiaceae	*Ricinus*	-	1	-	-	-	-	-	-	-	-	4	-
Fabaceae	*Acacia*	27	137	13	-	-	-	-	1	1	1	1	-
Fabaceae	*Cajanus*	-	-	-	-	-	-	-	1	-	-	-	-

Fabaceae	*Crotalaria*	-	-	11	-	-	-	-	-	-	-	-	-
Fabaceae	*Delonix*	1	1	-	71	146	12	-	8	121	16	-	-
Fabaceae	*Desmodium*	-	-	-	-	-	-	-	-	1	-	-	-
Fabaceae	*Indigofera*	-	-	12	-	1	-	-	-	1	4	31	4
Fabaceae	Legume	1	1	5	-	-	-	-	37	36	1	-	36
Fabaceae	*Phaseolus*	15	-	7	-	-	45	-	2	-	2	-	-
Fabaceae	*Rhynochosia*	-	-	-	-	-	-	1	-	-	-	-	-
Fabaceae	*Tamarindus*	-	-	-	-	-	-	-	-	27	-	-	-
Fabaceae	*Vicia*	-	-	-	-	-	-	-	-	-	26	-	-
Fabaceae	*Vigna*	-	-	-	-	-	-	-	1	-	-	-	-
Lamiaceae	*Basilicum*	-	-	-	-	-	-	-	-	-	-	8	-
Lamiaceae	*Leonitis*	-	4	-	-	5	-	-	-	-	-	-	-
Lamiaceae	*Leucas*	-	-	-	-	12	-	-	-	-	-	-	-
Lamiaceae	*Ocimum*	5	1	7	-	-	-	-	-	-	-	-	1
Lentibulariaceae	*Urtricularia*	-	-	-	-	-	-	-	1	-	-	-	-
Liliaceae	*Lilium*	-	-	-	-	-	-	-	-	3	-	-	-
Loranthaceae	*Plicosephalus*	-	-	-	-	-	-	-	-	-	-	41	-
Loranthaceae	*Tapinanthus*	-	-	-	-	-	-	-	37	-	-	-	-
Malvaceae	*Abutilon*	-	-	-	-	-	-	316	12	27	-	-	-
Malvaceae	*Corchorus*	-	-	-	-	29	987	-	-	-	-	24	-
Malvaceae	*Ficus*	-	-	-	-	-	-	-	1	-	-	-	1
Malvaceae	*Grewia*	-	-	-	-	106	-	26	-	-	-	39	-
Malvaceae	*Hibiscus*	-	1	-	-	-	-	1	1	-	1	-	-
Malvaceae	*Pavonic*	-	-	-	-	-	-	-	-	1	-	-	-
Moraceae	*Trilepsium*	-	-	-	-	-	-	3	-	-	-	-	-
Moringaceae	*Moringa*	-	201	-	-	-	-	-	-	-	-	-	-
Myrtaceae	*Eucalyptus*	-	-	-	-	-	-	1	1	32	-	3	65
Myrtaceae	*Syzigium*	-	-	-	-	20	48	8	4	297	10	-	58
Nyctaginaceae	*Boerhavia*	-	-	-	-	-	-	-	-	-	3	-	-
Nyctaginaceae	*Bougainvillea*	-	-	-	-	-	-	-	-	4	-	-	-
Nyctaginaceae	*Commicarpus*	-	-	-	-	26	-	-	-	-	-	-	-
Oleaceae	*Olea*	-	-	-	-	-	-	-	-	-	-	-	1
Onagraceae	*Ludwiga*	-	-	-	-	2	-	-	1	-	-	-	-
Phyllanthaceae	*Phyllathus*	-	-	-	-	-	14	1	1	1	28	-	-
Plantaginaceae	*Stemodia*	-	-	-	-	-	-	172	100	-	-	-	-
Poaceae	Grass	55	4	11	305	11	-	306	65	11	-	-	405
Poaceae	*Zea mays*	149	26	-	-	10	37	35	51	11	1	49	-
Polygalaceae	*Polygala*	-	-	-	-	-	38	-	1	-	-	-	-
Polygonaceae	*Rumex*	-	-	-	-	-	-	-	-	1	-	-	-
Primulaceae	*Maesa*	-	-	-	-	-	-	-	4	-	-	-	-
Rubiaceae	*Coffee*	-	-	-	-	-	31	-	-	-	-	-	-
Rubiaceae	*Spermococe*	-	-	-	-	-	-	-	4	-	-	-	-
Rutaceae	*Teclea*	-	-	-	-	-	-	-	-	114	-	-	-
Salvadoraceae	*Salvadora*	-	4	496	50	502	5	-	-	-	-	-	-
Salvadoraceae	*Schefflera*	-	-	-	-	-	-	-	-	-	-	-	347
Sapindaceae	*Allophylus*	-	-	-	-	-	-	-	1	-	-	-	-
Sapindaceae	*Cardiospermum*	-	2	-	-	-	-	-	-	-	-	-	-
Solanaceae	*Lycium*	-	-	-	-	-	1	-	-	-	-	-	-
Solanaceae	*Solanum*	428	6	19	-	34	3	-	129	1	63	1	12
Typhaceae	*Typha*	-	-	-	-	-	-	-	-	-	-	-	-
Urticaceae	*Urtica*	-	-	-	-	7	-	-	-	-	-	-	-
Zygophyllaceae	*Tribulus*	-	-	-	-	-	2	1	1	-	-	-	-
Zygophyllaceae	*Balanites*	-	-	-	-	6	-	-	-	-	-	12	-

Appendix IV: Plant families and abundance of pollen grains in low NDVI in Yatta and Masinga sub-county

Plant Families	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acanthaceae	0	326	95	0	0	30	216	2	4	3	79	365
Agavaceae	2	0	0	0	0	0	0	0	0	0	0	0
Amaranthaceae	0	741	94	0	21	0	18	0	0	0	87	0
Anacardiaceae	0	1	0	0	0	0	0	0	0	0	0	0
Arecaceae	0	0	0	0	0	0	0	0	0	0	1	8
Asclepiadaceae	0	0	0	0	0	0	1	0	0	0	0	0
Asteraceae	629	137	314	1,959	529	526	1,351	1,284	589	8	767	677
Boraginaceae	15	0	0	0	0	0	0	0	1	934	2	0
Burseraceae	0	0	0	0	0	105	0	0	0	0	11	0
Cactaceae	87	0	0	0	0	0	0	0	0	0	9	0
Capparaceae	0	0	0	0	0	0	0	56	1	0	6	0
Clusiaceae	0	0	0	0	0	0	0	0	0	0	0	1
Combretaceae	0	1	0	0	1	0	0	5	794	526	1	1
Commelinaceae	0	1	0	0	0	0	0	0	0	0	0	0
Convolvulaceae	0	0	58	0	0	0	60	19	0	0	14	0
Cucurbitacea	0	43	18	15	0	0	0	38	0	0	2	0
Euphorbiaceae	0	0	0	0	0	0	2	2	1	0	10	95
Fabaceae	1	9	1	0	67	0	1	16	9	0	7	22
Guaduelleae	735	0	0	0	0	0	0	0	0	0	74	0
Lamiaceae	14	1	1	0	0	1	0	129	0	0	15	5
Loranthaceae	0	77	0	0	0	79	370	7	0	0	53	2
Malvaceae	0	0	0	0	8	0	0	0	0	0	1	0
Molluginaceae	0	0	0	0	134	0	0	0	0	0	13	0
Myrtaceae	0	0	0	0	159	1	8	14	53	0	13	0
Oleaceae	0	0	0	0	0	0	0	0	19	0	0	0
Plantaginaceae	0	0	0	0	125	0	0	0	0	0	0	0
Poaceae	225	13	382	0	129	133	4,027	109	0	3	502	4
Podocarpaceae	0	0	0	0	1	0	0	0	0	0	0	0
Salvadoraceae	0	0	0	0	0	0	0	2	0	6	1	0
Sapindaceae	0	0	0	0	0	1	0	0	0	0	0	0
Solanaceae	0	2	0	0	0	0	0	0	2	13	1	0
Typhaceae	0	0	0	0	808	0	0	0	0	0	81	0
Urticaceae	0	0	0	0	0	1	0	0	0	0	0	0
Zygophyllaceae	6	0	0	0	0	0	0	0	0	0	1	0

Appendix V: Families and abundance of pollen grains in medium NDVI in Yatta and Masinga sub-counties

Plant Families	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acanthaceae	33	52	0	0	33	20	17	5	1	1	1	3
Agavaceae	0	0	0	105	15	0	0	0	0	0	48	0
Aizoaceae	0	0	0	38	0	0	0	0	0	0	0	0
Amaranthaceae	0	0	3	0	10	0	0	0	1	0	0	0
Anacardiaceae	0	158	0	0	0	0	0	0	19	77	0	0
Apocynaceae	0	0	0	0	1	0	0	15	0	0	0	0
Arecaceae	1	1	0	0	0	0	0	0	110	1	68	0
Asparagaceae	0	0	0	0	0	0	0	1	0	0	0	0
Asphodelaceae	0	0	1	319	0	0	0	1	0	0	563	1
Asteraceae	2,506	59	1,371	139	296	550	583	777	224	15	3	284
Bombacaceae	0	0	0	0	0	0	0	0	1	0	0	0
Boraginaceae	0	0	0	0	0	0	1	0	23	21	3	0
Burseraceae	0	0	19	0	5	0	5	0	0	129	0	55
Capparaceae	0	0	0	23	2	1	0	122	2	1	0	0
Caryophyllaceae	1	0	0	0	0	0	0	0	0	0	0	0
Casuarinaceae	0	0	0	0	0	0	0	0	0	0	0	28
Combretaceae	0	0	3	7	0	1	8	165	481	483	211	109
Commelinaceae	0	1	1	2	0	0	0	1	0	0	0	0
Convolvulaceae	0	2	0	0	10	0	30	70	2	0	0	5
Cucurbitacea	1	15	87	0	2	0	20	0	0	1	1	10
Cupressaceae	0	0	0	0	0	0	0	0	0	0	0	2
Ebenaceae	0	0	0	0	0	0	0	0	252	0	33	0
Euphorbiaceae	0	565	0	0	3	0	0	1	1	90	16	10
Fabaceae	44	139	48	71	147	72	1	50	188	49	32	40
Lamiaceae	5	5	7	0	17	0	0	0	0	0	8	1
Lentibulariaceae	0	0	0	0	0	0	0	1	0	0	0	0
Liliaceae	0	0	0	0	0	0	0	0	3	0	0	0
Loranthaceae	0	0	0	0	0	0	0	37	0	0	41	0
Malvaceae	0	1	0	0	135	987	343	14	28	1	62	1
Moraceae	0	0	0	0	0	0	3	0	0	0	0	0
Moringaceae	0	201	0	0	0	0	0	0	0	0	0	0
Myrtaceae	0	0	0	0	20	48	9	5	329	10	3	123
Nyctaginaceae	0	0	0	0	26	0	0	0	4	3	0	0
Oleaceae	0	0	0	0	0	0	0	0	0	0	0	1
Onagraceae	0	0	0	0	2	0	0	1	0	0	0	0
Phyllanthaceae	0	0	0	0	0	14	1	1	1	28	0	0

Plantaginaceae	0	0	0	0	0	0	172	100	0	0	0	0
Poaceae	204	29	11	305	21	37	340	116	21	1	49	405
Polygalaceae	0	0	0	0	0	38	0	1	0	0	0	0
Polygonaceae	0	0	0	0	0	0	0	0	1	0	0	0
Primulaceae	0	0	0	0	0	0	0	4	0	0	0	0
Rubiaceae	0	0	0	0	0	31	0	4	0	0	0	0
Rutaceae	0	0	0	0	0	0	0	0	114	0	0	0
Salvadoraceae	0	4	496	0	502	5	0	0	0	0	0	347
Sapindaceae	0	2	0	0	0	0	0	1	0	0	0	0
Solanaceae	274	4	17	0	34	472	0	130	1	67	1	12
Urticaceae	0	0	0	0	7	0	0	0	0	0	0	0
Zygophyllaceae	0	0	0	0	6	2	1	1	0	0	12	0

Appendix VI: Quantitative analysis of pollen samples from plants collected by *A. mellifera* L. in low NDVI

Months	**Pollen category**				**Shanonn-Weinner Parameters**		
	Predominant pollen (>45%)	Secondary pollen (16-45%)	Important minor pollen (3-15%)	Minor pollen (<3%)	N	Richness	Diversity index (H')
January		*Guaduella* spp., *Bidens pilosa*	Grass, *Ageratum* spp., *Epiphyllum* spp., *Aspilia* spp., *Zea mays*	*Cynoglossum* spp., *Leonitis* spp., *Vernonia* spp., *Balanites* spp., *Agave* spp., *Acacia* spp.,	1,713	13	1.7
February	*Chenopodium* spp.	*Barleria* spp.	*Bidens pilosa*, *Loranthus* spp., Cucurbitaceae	Grass, *Acacia* spp., *Justicia* spp., *Aspilia* spp., *Solanum* spp., *Stoebe* spp., *Zea mays*, *Chenopodium* spp., *Ocimum* spp., *Bosquia* spp., *Terminalia* spp., *Commelina* spp.	1,348	17	1.3
March		Grass, *Bidens pilosa*	*Barleria* spp., *Aspilia* spp., *Chenopodium* spp., *Vernonia* spp., *Ipomea* spp.,	*Ageratum* spp., *Cucumis* spp., *Leucas* spp., *Acacia* spp.	961	11	1.8
April	*Vernonia* spp.		*Bidens pilosa*	*Cucurbita spp.*	1,974	3	0.4
May		*Typha* spp., *Bidens pilosa*	*Mollugo* spp., *Syzigium* spp., *Zea mays*,*Vernonia* spp.	Grass, *Ageratum* spp., *Glycine* spp., *Tagetes* spp., *Syzigium jambolanum*, *Delonix* spp., *Amaranthus*, *Grewia* spp., *Phaseolus* spp., *Terminalia* spp., *Crotalaria* spp., *Indigofera* spp.	1,856	18	1.8
June	*Bidens pilosa*		*Zea mays*, *Commiphora* spp., *Plicosephalus* spp., *Vernonia* spp., *Barleria* spp.	*Tagetes* spp., *Leonitis* spp., *Syzigium* spp., *Allophylus* spp., *Urtica* spp.	877	11	1.4
July	Grass		*Bidens pilosa*, *Vernonia* spp., *Plicosephalus* spp., *Barleria* spp.	*Asclepias* spp., *Tagetes* spp., *Tarchonathus* spp., *Acalypha* spp., *Tragia* spp., *Acacia* spp., *Ipomea* spp.	6,054	14	1.1
August	*Ageratum* spp.	*Vernonia* spp.	*Ocimum* spp., Grass, *Cleome* spp.	*Cucurbita* spp., *Zea mays*, *Ipomea* spp., *Phaseolus* spp., *Bidens pilosa* spp., *Syzigium jambolanum*, *Plicosephalus* spp., *Combretum* spp., *Barleria* spp., *Salvadora* spp., *Croton* spp., *Syzigium* spp., *Leucas* spp.	1,680	18	1.5

September	*Terminalia* sp	*Ageratum* spp.		*Combretum* spp., *Bidens pilosa* spp., *Olea* spp., *Syzigium jambolanum* spp., *Syzigium* spp., *Vernonia* spp., *Indigofera* spp., *Barleria* spp., *Euphorbia* spp., *Solanum* spp., *Heliotropium indicum* spp., *Acacia* spp., *Albizia* spp.	1,472	15	1.2
October	*Heliotropium indicum* spp.	*Terminalia* spp.		*Solanum* spp., *Ageratum* spp., *Salvadora* spp., *Justicia* spp., *Combretum* spp., *Zea mays*	1,491	8	0.8
November		Grass, *Bidens pilosa*, *Vernonia* spp.	*Ageratum* spp., *Typha* spp., *Chenopodium* spp., *Guaduella* spp.	*Plicosephalus* spp., *Barleria* spp., *Justicia* spp., *Zea mays*, *Ipomea* spp., *Mollugo* spp., *Syzigium* spp., *Ocimum* spp., *Aspilia* spp., *Commiphora* spp., *Chenopodium* spp., *Manihot* spp., *Epiphyllum* spp., *Loranthus* spp., *Cleome* spp., *Amaranthus* spp., *Glycine* spp., *Phaseolus* spp., *Cucumis* spp., *Leonitis* spp., *Cynoglossum* spp., *Acacia* spp., *Solanum* spp., *Grewia* spp., *Hyphaene* spp., *Combretum* spp., *Salvadora* spp., *Balanites* spp.	1,747	35	2.3
December	*Bidens pilosa*	*Justicia* spp.	*Manihot* spp.	*Delonix* spp., *Hyphaene* spp., *Ocimum* spp., Grass, *Acalypha* spp., *Plicosephalus* spp., *Acacia* spp., *Barleria* spp., *Ageratum* spp., *Garcinia* spp., *Terminalia* spp., *Legume* spp., *Vernonia* spp., *Leonitis* spp.	1,181	17	1.1

Appendix VII: Quantitative analysis of pollen samples from plants collected by *Apis mellifera* L. in medium

Months	Pollen category				Shanonn-Weinner Parameters		
	Predominant pollen (>45%)	Secondary pollen (16-45%)	Important minor pollen (3-15%)	Minor pollen (<3%)	N	Richness	Diversity index (H')
January	*Vernonia* spp.		*Solanum* spp., *Bidens pilosa*, *Zea mays*	Grass, *Acacia* spp., *Justicia* spp., *Phaseolus vulgaris* spp., *Barleria* spp., *Ocimum* spp., *Hyphaene* spp., *Cucumis* spp., *Delonix* spp., *Legume* spp., *Ageratum* spp.	3,222	16	1.1
February		*Euphorbia* spp., *Moringa* spp.	*Rhus* spp., *Acacia* spp., *Barleria* spp.	*Vernonia* spp., *Zea mays*, *Tarchonathus* spp.,*Croton* spp., *Cucumis* spp., *Bidens pilosa*,*Salvadora* spp., *Solanum* spp.,*Leonitis* spp., Grass, *Cardiospermum* spp., *Ageratum* spp., *Ipomea* spp., *Solanum* spp., *Hyphaene* spp., *Carthium* spp., *Delonix* spp., *Legume* spp., *Ocimum* spp., *Hibiscus* spp., *Commelina* spp., *Ricinus* spp.	1,240	27	1.8
March	*Bidens pilosa*	*Salvadora* spp.	*Vernonia* spp., *Cucurbita* spp.	*Commiphora* spp., *Solanum* spp., *Acacia* spp., *Indigofera* spp., Legume, *Crotalaria* spp., Grass, *Phaseolus vulgaris*, *Ocimum* spp., *Aloe* spp., *Ageratum* spp., *Combretum* spp., *Chenopodium* spp., *Solanum* spp.	2,066	19	1.2
April		*Aloe* spp., Grass	*Vernonia* spp., *Zaleya*., *Agave* spp., *Delonix* spp.	*Cleome* spp., *Terminalia* spp., *Commelina* spp.	1,007	9	1.7
May		*Salvadora* spp., *Bidens pilosa*	*Delonix* spp., *Grewia* spp., *Vernonia* spp.	*Solanum* spp., *Barleria* spp., *Corchorus* spp., *Commicarpus* spp., *Syzigium* spp., *Agave* spp., *Leucas* spp., Grass, *Ipomea* spp., *Zea mays*, *Celosia* spp., *Ageratum* spp., *Tarchonathus* spp., *Urtica* spp., *Balanites* spp., *Leonitis* spp., *Brassica* spp., *Boscia* spp., *Ludwiga* spp., *Acalypha* spp., *Carissa* spp., *Commiphora* spp., *Cucurbita* spp., *Manihot* spp., *Indigofera* spp.,	1,292	31	2.1

				Cucumis spp.			
June	*Corchorus* spp.		*Vernonia* spp., *Stoebe* spp., *Tagetes* spp.	*Syzigium* spp., *Phaseolus vulgaris*, *Polygala* spp., *Zea may*, *Coffea* spp., *Barleria* spp., *Phaseolus* spp., *Bidens pilosa*, *Phyllathus* spp., *Delonix* spp., *Salvadora* spp., *Tarchonathus* spp., *Solanum* spp., *Tribulus* spp., *Hygrophilla* spp., *Cleome* spp., *Terminalia* spp., *Lycium* spp.	1,810	22	1.7
July		*Bidens pilosa*, *Abutilon* spp. Grass,	*Stemodia* spp., *Vernonia* spp.	*Zea mays*, *Grewia* spp., *Ipomea* spp., *Cucumis* spp., *Ecbolium* spp., *Stoebe* spp., *Terminalia* spp., *Syzigium* spp., *Brassica* spp., *Seddera* spp., *Trilepsium* spp., *Heliotropium indicum* spp., *Rhynochosia* spp., *Tribulus* spp., *Hibiscus* spp., *Eucalyptus* spp., *Phyllathus* spp., *Ageratum* spp.	1,534	23	1.9
August		*Vernonia* spp., *Bidens pilosa*	*Terminalia* spp., *Solanum* spp., *Boscia* spp., *Stemodia* spp., *Ipomea* spp., Grass, *Zea mays*	*Tapinanthus* spp., *Legume* spp., *Tapirathuo* spp., *Abutilon* spp., *Delonix* spp., *Spermococe* spp., *Barleria* spp., *Syzigium* spp., *Maesa* spp., *Vigna* spp.,*Aloe* spp., *Phaseolus vulgaris* spp., *Allophylus* spp., *Justicia* spp., *Ageratum* spp., *Commelina* spp.,*Acalypha* spp., *Cajanus* spp., *Acacia* spp., *Phaseolus* spp., spp., *Ficus* spp., *Hibiscus* spp., *Eucalyptus* spp., *Ludwiga* spp., *Phyllathus* spp., *Polygala* spp., *Tribulus* spp., *Tagetes* spp., *Celtis* spp.	1,750	40	2.4
September		*Terminalia* spp., *Syzigium* spp.	*Diospyros* spp., *Bidens pilosa*, *Delonix* spp., *Teclea* spp., *Hyphaene* spp., *Vernonia* spp.	Legumes, *Eucalyptus* spp., *Tamarindus indica*, *Abutilon* spp., *Heliotropium indicum*, *Rhus* spp., *Zea mays*, Grass, *Bougainvillea* spp., *Lilium* spp., *Ipomea* spp., *Justicia* spp., *Acrynthes* spp., *Ageratum* spp., *Bombax* spp., *Celtis* spp., *Cleome* spp., *Acacia* spp., *Desmodium* spp., *Indigofera* spp., *Pavonic* spp., *Phyllathus* spp., *Rumex* spp., *Solanum* spp., *Aspilia* spp., *Euphorbia* spp.	1,804	34	2.3
October	*Terminalia* spp.		*Commiphora* spp., *Croton* spp., *Rhus* spp., *Solanum* spp.,	*Phyllathus* spp., *Vicia* spp., *Heliotropium indicum*, *Delonix* spp., *Bidens pilosa*, *Syzigium* spp., *Solanum* spp., *Indigofera* spp., *Boerhavia*	976	29	2

			Combretum spp.	spp., *Phaseolus vulgaris*, *Vernonia* spp., *Cucumis* spp., *Justicia* spp., *Aspilia* spp., *Hyphaene* spp., *Tarchonathus* spp., *Boscia* spp., *Manihot* spp., *Acacia* spp., *Legume* spp., *Hibiscus* spp., *Zea mays*, *Ageratum* spp., *Terminalia* spp.			
November	*Aloe* spp.		*Combretum* spp., *Terminalia* spp., *Hyphaene* spp., *Zea mays*, *Agave* spp., *Plicosephalus* spp., *Grewia* spp.	*Dyspiros* spp., *Indigofera* spp., *Corchorus* spp., *Balanites* spp., *Euphorbia* spp., *Basilicum* spp., *Ricinus* spp., *Heliotropium indicum* spp., *Eucalyptus* spp., *Ageratum* spp., *Acacia* spp., *Croton* spp., *Solanum* spp., *Justicia* spp., *Vernonia* spp., Cucurbita spp.	1,155	24	2
December		*Schefflera* spp., *Bidens pilosa*, Grass	*Terminalia* spp., *Eucalyptus* spp., *Syzigium* spp., *Commiphora* spp.	Legumes., *Cassuarina* spp., *Solanum* spp., *Croton* spp., *Cucumis* spp., *Olea* spp., *Ageratum* spp., *Ipomea* spp., *Indigofera* spp., *Cupressus* spp., *Justicia* spp., *Vernonia* spp., *Cathaceae* spp., *Aloe* spp., *Combretum* spp., *Ficus* spp., *Ocimum* spp.	1,435	24	2

Appendix VIII: Data sheet for collection of data on flowering plants

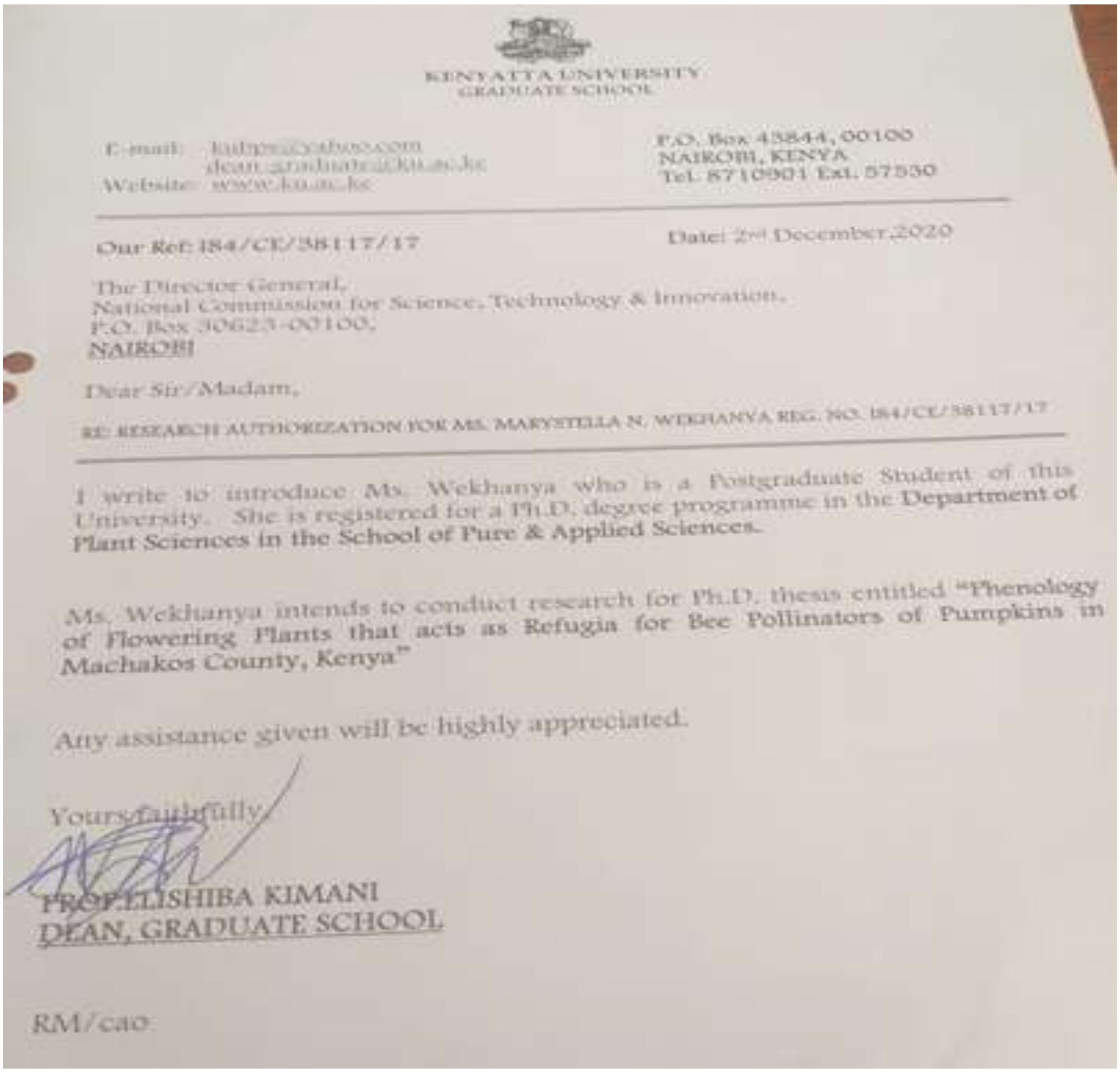
DATA SHEET FOR COLLECTION OF DATA ON POLLEN AND FL0WERING PLANTS AROUND THE BEE HIVE SITE		
Date		
Start time		
Farmer's Name		
Farmer's Phone No.		
Sub-County		
Village Name		
NDVI		
GPS Coordinates :Latitude	Longitude	Elevation
Soil Type		
Name of Data Collector		
Weather	Humidity	
	Temperature	
	Wind speed	
	General Weather	
End Time		

PART 1 A FLORAL DATA FROM HONEY BEES HIVE 1KM X 50 M TRASECT WALK TOWARDS EXIT OF FARM

Scientific Name	No. of flowering plants	Status of flowering plants		Colour of petals	No. of flowers	Type of flower solitary/ Inflorescence	Name of	No. of visitors	Time taken by visitor in flower	Honey Bee Hive Status	
		No. flowering	No. not flowering				Visitor			No. of Bees IN	No. of bees OUT

REMOVAL OF POLLEN TRAP	
DATE OF POLLEN TRAP REMOVAL	
TIME	
BEE HIVE NUMBER	
TRAP REMOVED BY	
NO. OF POLLEN POCKETS COLLECTED	

Appendix IX: Data sheet for collection of pollen Graduate School Research Authorization Letter



KENYATTA UNIVERSITY
GRADUATE SCHOOL

E-mail: [illegible]
dean-graduate@ku.ac.ke
Website: www.ku.ac.ke

P.O. Box 43844, 00100
NAIROBI, KENYA
Tel. 8710901 Ext. 57530

Our Ref: I84/CE/38117/17

Date: 2nd December,2020

The Director General,
National Commission for Science, Technology & Innovation,
P.O. Box 30623-00100,
NAIROBI

Dear Sir/Madam,

RE: RESEARCH AUTHORIZATION FOR MS. MARYSTELLA N. WEKHANYA REG. NO. I84/CE/38117/17

I write to introduce Ms. Wekhanya who is a Postgraduate Student of this University. She is registered for a Ph.D. degree programme in the Department of Plant Sciences in the School of Pure & Applied Sciences.

Ms. Wekhanya intends to conduct research for Ph.D. thesis entitled "Phenology of Flowering Plants that acts as Refugia for Bee Pollinators of Pumpkins in Machakos County, Kenya"

Any assistance given will be highly appreciated.

Yours faithfully,

PROF.ELISHIBA KIMANI
DEAN, GRADUATE SCHOOL

RM/cao

Appendix X: Research permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 988582

Date of Issue: 25/May/2021

RESEARCH LICENSE

This is to Certify that Ms.. Marystella Nangoni Wekhanya of Kenyatta University, has been licensed to conduct research in Machakos on the topic: Phenology of Flowering Plants that acts as refugia for Bee Pollinators of Pumpkins in Machakos County, Kenya for the period ending : 25/May/2022.

License No: NACOSTI/P/21/10770

988582

Applicant Identification Number

Director General
NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

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APPENDIX XI: Evidence of dissemination

Article

JPE

Annual diversity of honey bee pollen sources in two pumpkin growing landscapes, Machakos County, Kenya

Marystella W Nang'oni[1,2], Muo Kasina[2,*], Rebecca Karanja[1], Mary M Guantai[3], Rahab N. Kinyanjui[4,5], Evanson R. Omuse[6], H. Michael G. Lattorff[7], Elfatih M. Abdel-Rahman[6], Marian Adan[6], Samira A Mohamed[6] and Thomas Dubois[6]

[1]*Department of Plant Sciences Kenyatta University, Nairobi, Kenya*
[2]*Food Crop Research Center, Kenya Agricultural and Livestock Research Organization (KALRO), Kabete, (NARL), Nairobi, Kenya*
[3]*Kenya Plant Health Inspectorate Service (KEPHIS), Nairobi, Kenya*
[4]*Department of Earth Sciences, Nationals Museums of Kenya, Nairobi, Kenya*
[5]*Department of Coevolution of Land Use and Urbanization, Max Planck Institute of Geo-anthropology, Kahlaische Straße 10 07745 Jena, Germany*
[6]*International Centre of Insect Physiology and Ecology (ICIPE), Nairobi, Kenya*
[7]*School of Life Sciences, University of KwaZulu Natal, Westville Campus. Private Bag X54001.Durban 4000, South Africa*

NATIONAL MUSEUMS OF KENYA

May 14, 2024

Dear Marystella Wekhanya,

Subject: Acceptance of Abstract and Next Steps for National Museums of Kenya - Association of Kenya Entomologist 1st Joint International Scientific Conference.

We are delighted to inform you that your abstract submission for the National Museums of Kenya (NMK) - Association of Kenya Entomologist (AKE) 1st Joint International Scientific Conference, scheduled from 3rd to 5th June 2024, at the NMK headquarters in Nairobi, has been accepted. Your abstract **"Floral Calendar of Flowering Plants and Honey Bees' Resources in Machakos County, Kenya"** has been chosen for an Oral presentation, following independent reviews by experts in the field. Your abstract ID is **NMK_AKE182**. Kindly reference this ID in all future communications with the Conference organizers.

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Research Article — Open Access

Pollinator Diversity and Floral Calendar of Forage Resources for Pumpkin, Machakos County, Kenya

Marystella W Nang'oni[1,2], Karanja Rebecca[1], Thomas Dubois[4] Mary M Guantai[3], Evanson R Omuse[4], H Michael G Lattorff[4], Samira A Mohamed[4] Muo Kasina[2].

[1]Department of Plant Sciences Kenyatta University, P. O. BOX 43844-00100 Nairobi, Kenya.
[2]Apiculture and Beneficial Insects Research Institute (ABIRI), Kenya Agricultural and Livestock Research Organization (KALRO), P.O. Box 32-30403 Marigat, Kenya.
[3]Kenya Plant Health Inspectorate Service (KEPHIS), P. O BOX 19164-00501 Nairobi, Kenya.
[4]International Centre of Insect Physiology and Ecology (*icipe*), P. O. Box 30772-00100 Nairobi, Kenya

Corresponding author: nangoniwck@gmail.com

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