

**Sokoine University of Agriculture**



**MSc Dissertation**

**Characteristics of Bee Fodder  
Plants of Mlele Beekeeping Zone,  
Katavi, Tanzania**

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**May 2024**

**CHARACTERISTICS OF BEE FODDER PLANTS OF MLELE  
BEEKEEPING ZONE, KATAVI, TANZANIA**

*Dissertation submitted to Sokoine University of Agriculture in  
Fulfilment of the Requirements for the Degree of Master of  
Science in Ecosystem Science and Management*

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## **EXTENDED ABSTRACT**

Pollination by insects, particularly bees, is essential for biodiversity conservation and plant reproductive success. Tanzania is characterized by a rich diversity of flowering plants estimated to be over 9000 species. A wide variety of flowering plant species serve as bee fodders and are essential to maintaining healthy bee populations. Mlele District in Katavi region of Tanzania is among the highest honey producing area in the region. Several studies on bee fodder plants characteristics, including their composition and nectar quality have been done in temperate and sub temperate regions with few in the tropics. These studies have reported the impact of environmental and human disturbances on bee fodder plants. Despite the potential of Katavi region for beekeeping, few studies have been done in the region, especially on the characteristics of bee fodder plants incorporating environmental, disturbance and the nectar quality. This knowledge gap results into ineffective conservation of food sources for bees, unsustainable beekeeping practices, low production and quality of bee products.

The study overall objective was to determine the characteristics of bee fodder plants of Mlele Beekeeping zone. The study included two objectives, the first objective was to determine the composition of bee fodder plants along environmental and disturbance gradients and the second was to determine the periodicity of floral rewards by the bee fodder plant species. A systematic sampling design was employed to assess how environmental and disturbance gradients impact bee fodder plants composition. A total of 50 rectangular plots of size 50 by 30 m were laid in two transects with 25 plots in each transect. Plant flowers were observed for 10 minutes and were scored as bee fodder plants after at least three bees visited the flower within the observation period. The periodicity of floral rewards objective employed purposive sampling design on the basis of provision of measurable amounts of nectar and enough flowers to conduct the study with repeated measurements. Plants in which the honeybees extended their proboscis into the flowers were

determined as nectar rewarding plants and where bees collected pollen were determined as pollen rewarding plants.

Data collection on bee fodder plants composition was obtained through a summary of species data list and their abundance values. Climatic data was obtained from the current climate data set downloaded from world climate site with a 30 arc seconds resolution and four subsets of biophysical data were used. Disturbance data was recorded for presence or absence and the disturbance type. 550 hours of observation were made for recording of flower visitors on ten bee fodder plant species from 0700 hours to 1800 hours. Nectar was extracted by micro capillary tubes and quality was measured in form of total sugar concentration by the use of a digital handheld refractometer.

In the data analysis section, data skewness was addressed by standardization of the data. Detrended Correspondence Analysis (DCA) was applied to assess the ecological gradient's magnitude within the species composition matrix and to determine the appropriate constrained ordination method. The results gave the option for Canonical Correspondence Analysis (CCA) due to the data's heterogeneity. Log-transformations were applied to species abundance data to meet multivariate normality assumptions. Rare species occurring in fewer than five plots were excluded from the analysis. Stepwise automatic forward selection identified significant explanatory variables for CCA. The chosen variables were then constrained against tree species and community composition. Permutational Multivariate Analysis of Variance Using Distance Matrices (Adonis) was employed for variance partitioning. The community composition was identified by the use of Bray-Curtis's dissimilarity and Silhouette validation. Generalized linear models were created to examine visitations and effect of nectar concentration and temperature on bee visitation rate.

Overall, 71 bee fodder plants belonging to 25 families were recorded. The results revealed that 23% of the variation in the

composition of dominant tree species within the study area could be attributed to the interplay of environmental and disturbance factors. Elevation emerged as the most influential predictor, accounting for approximately 11.6% of the total variation. Annual mean temperature contributed around 3.5% to the observed variation and annual precipitation about 3.6%. Four bee fodder plant communities were identified in the area with first cluster being dominated by *Erythrophleum africanum*, second with *Brachystegia glaucescens*, third with *Diplorhynchus condylocarpon* and fourth *Bobgunnia madagascariensis*. Nectar concentration was identified as a central driver of bee visitation patterns. The bee fodder plants including *Antidesma membranaceum* and *Friesodielsia obovata*, showcased nectar concentration percentages that significantly enhanced their attractiveness to bees.

The results of this research study have the potential in providing valuable insights to beekeepers and conservationists for improving beekeeping practices in Mlele Beekeeping zone. It provides understanding into factors influencing bee visitation rates to different bee fodder plant species. It also highlights the significance of nectar sugar concentration and temperature in shaping bee foraging behavior. Environmental factors particularly elevation, annual mean temperature and annual precipitation are seen to be important in shaping the composition of bee fodder plants. The findings recommend prioritizing and promoting planting and conserving bee plant species with high visitation rates such as *Antidesma membranaceum*, *Psorospermum febrifugum* and *Securidaca longepedunculata* to support bee populations and enhance pollination services.

Further research is needed into other bee fodder plants traits that attract bee to deepen our understanding of bee interactions. Understanding the relationship between environmental factors and bee plant communities in other locations and other factors such as soil type and land use should be considered. As ecosystems face

ongoing challenges from climate change and human activities, such research becomes increasingly valuable in ensuring the health of bee populations and the preservation of biodiversity. Further research in other regions and at different scales is needed to expand our knowledge of these vital relationships and their implications for beekeeping and conservation efforts globally.

**Key words:** Pollination, bees, floral resources, nectar quality, composition, beekeeping

## IKISIRI KUU

Uchavushaji unaofanywa na Nyuki ni muhimu sana kwa uhifadhi wa bioanuai na mafanikio ya uzazi wa mimea. Tanzania ina sifa ya kuwa na aina nyingi za mimea yenye maua inakadiriwa kuwa zaidi ya spishi 9000. Aina mbalimbali za mimea yenye maua hutumika kama chakula cha nyuki na ni muhimu katika kudumisha afya ya makundi ya nyuki. Wilaya ya Mlele katika mkoa wa Katavi ni miongoni mwa maeneo yanayoongoza kwa uzalishaji wa asali katika mkoa huo. Tafiti kadhaa kuhusu sifa za mimea inayolisha nyuki, ikiwemo muundo wake na ubora wa nekta, zimefanyika katika maeneo yenye joto la wastani na baridi, huku chache zikifanyika katika maeneo ya tropiki. Tafiti hizi zimeripoti athari za mabadiliko ya mazingira na uharibifu unaosababishwa na binadamu kwenye mimea inayolisha nyuki. Licha ya uwezo wa mkoa wa Katavi katika ufugaji nyuki, tafiti chache zimefanyika katika mkoa huo, hasa kuhusu sifa za mimea inayolisha nyuki zikihusisha mazingira, uharibifu na ubora wa nekta. Upungufu huu wa maarifa unasababisha uhifadhi usiofaa wa vyanzo vya chakula cha nyuki, ufugaji nyuki usio endelevu, uzalishaji mdogo na ubora duni wa bidhaa za nyuki.

Lengo kuu la utafiti lilikuwa kubaini sifa za mimea inayolisha nyuki katika eneo la ufugaji nyuki la Mlele. Utafiti ulijumuisha malengo mawili, lengo la kwanza lilikuwa kubaini muundo wa mimea inayolisha nyuki kulingana na mabadiliko ya mazingira na uharibifu, na lengo la pili lilikuwa kubaini mzunguko wa zawadi za maua zinazotolewa na aina za mimea inayolisha nyuki. Mbinu ya sampuli ya utaratibu ilitumika kutathmini jinsi mabadiliko ya mazingira na uharibifu yanavyoathiri muundo wa mimea inayolisha nyuki. Jumla ya viwanja 50 vya mstatili vyenye ukubwa wa mita 50 kwa 30 viliwekwa katika mistari miwili, kila mstari ukiwa na viwanja 25. Maua

ya mimea yalionekana kwa dakika 10 na kuainishwa kama mimea inayolisha nyuki ikiwa angalau nyuki watatu walitembelea ua ndani ya muda wa uchunguzi. Lengo la mzunguko wa zawadi za maua lilitumia mbinu ya sampuli ya makusudi kwa kuzingatia utoaji wa kiasi kinachopimika cha nekta na maua ya kutosha kufanya utafiti kwa vipimo vinavyorudiwa. Mimea ambayo nyuki walinyoosha mirija yao ya kunyonya kwenye maua ilibainishwa kama mimea inayotoa nekta na ambapo nyuki walikusanya chavua ilibainishwa kama mimea inayotoa chavua.

Ukusanyaji wa data kuhusu muundo wa mimea inayolisha nyuki ulipatikana kwa muhtasari wa orodha ya data ya spishi na thamani za wingi wao. Data ya hali ya hewa ilipatikana kutoka kwa seti ya data ya hali ya hewa ya sasa iliyopakuliwa kutoka kwa tovuti ya hali ya hewa ya dunia yenye azimio la sekunde 30 za arc na vikundi vidogo vinne vya data ya kibayolojia vilitumika. Data ya uharibifu ilirekodiwa kwa uwepo au kutokuwepo na aina ya uharibifu. Masaa 550 ya uchunguzi yalifanywa kwa kurekodi wageni wa maua kwenye spishi kumi za mimea inayolisha nyuki kuanzia saa 0700 hadi saa 1800. Nekta ilitolewa kwa kutumia mirija midogo ya kapilari na ubora wake ulipimwa kwa namna ya mkusanyiko wa jumla wa sukari kwa kutumia kipima joto cha dijitali kinachoshikiliwa kwa mkono.

Katika sehemu ya uchambuzi wa data, upotoshaji wa data ulishughulikiwa kwa kuweka viwango vya data. Uchambuzi wa Detrended Correspondence Analysis (DCA) ilitumika kutathmini ukubwa wa mteremko wa ikolojia ndani ya matrix ya muundo wa spishi na kubaini njia inayofaa ya upangaji uliopunguzwa. Matokeo yalipa chaguo la Uchambuzi kupitia Canonical Correspondence Analysis (CCA) kutokana na utofauti wa data. Mabadiliko ya logi

yalitumiwa kwa data ya wingi wa spishi ili kukidhi mawazo ya kawaida ya multivariate. Aina adimu zinazotokea katika viwanja vichache kuliko vitano zilitengwa kwenye uchambuzi. Uchaguzi wa hatua kwa hatua wa kiotomatiki uliobainisha vigeu muhimu vya maelezo kwa CCA. Vigezo vilivyochaguliwa vilipunguzwa dhidi ya spishi za miti na muundo wa jamii. Uchambuzi wa Tofauti wa Multivariate wa Permutational Kutumia Matrices za Umbali (Adonis) ulitumika kwa kugawanya tofauti. Muundo wa jamii ulibainishwa kwa kutumia kutofanana kwa Bray-Curtis na uthibitishaji wa Silhouette. Mifano ya mstari wa jumla iliundwa ili kuchunguza ziara na athari ya mkusanyiko wa nekta na halijoto kwenye kiwango cha ziara za nyuki.

Kwa jumla, mimea 71 inayolisha nyuki inayomilikiwa na familia 25 ilirekodiwa. Matokeo yalionyesha kuwa 23% ya mabadiliko katika muundo wa spishi za miti kubwa ndani ya eneo la utafiti yanaweza kuhusishwa na mwingiliano wa mambo ya mazingira na uharibifu. Urefu ulionekana kuwa kigezo chenye ushawishi mkubwa zaidi, kikichangia takriban 11.6% ya mabadiliko ya jumla. Wastani wa halijoto ya kila mwaka ulichangia karibu 3.5% kwa tofauti iliyoonekana na mvua ya kila mwaka karibu 3.6%. Jamii nne za mimea inayolisha nyuki zilibainishwa katika eneo hilo, kundi la kwanza likitawaliwa na *Erythrophleum africanum*, la pili na *Brachystegia glaucescens*, la tatu na *Diplorhynchus condylocarpon* na la nne *Bobgunnia madagascariensis*. Mkusanyiko wa nekta ulibainishwa kuwa kichocheo kikuu cha mitindo ya ziara za nyuki. Mimea inayolisha nyuki ikiwemo *Antidesma membranaceum* na *Friesodielsia obovata*, ilionyesha asilimia ya mkusanyiko wa nekta ambayo kwa kiasi kikubwa iliongeza mvuto wao kwa nyuki.

Matokeo ya utafiti huu yana uwezo wa kutoa maarifa muhimu kwa wafugaji nyuki na wahifadhi kwa ajili ya kuboresha mbinu za ufugaji

nyuki katika eneo la ufugaji nyuki la Mlele. Inatoa uelewa kuhusu mambo yanayoathiri viwango vya ziara za nyuki kwa spishi tofauti za mimea inayolisha nyuki. Pia inasisitiza umuhimu wa mkusanyiko wa sukari ya nekta na halijoto katika kuunda tabia ya kutafuta chakula kwa nyuki. Mambo ya mazingira, hasa urefu, wastani wa halijoto ya mwaka na mvua ya kila mwaka yanaonekana kuwa muhimu katika kuunda muundo wa mimea inayolisha nyuki. Matokeo yanapendekeza kuweka kipaumbele na kukuza upandaji na uhifadhi wa spishi za mimea ya nyuki zilizo na viwango vya juu vya ziara kama vile *Antidesma membranaceum*, *Psorospermum febrifugum* na *Securidaca longepedunculata* ili kusaidia makundi ya nyuki na kuimarisha huduma za uchavushaji.

Utafiti zaidi unahitajika katika sifa zingine za mimea inayolisha nyuki zinazovutia nyuki ili kuongeza uelewa wetu wa mwingiliano wa nyuki. Kuelewa uhusiano kati ya mambo ya mazingira na jamii za mimea ya nyuki katika maeneo mengine na mambo mengine kama vile aina ya udongo na matumizi ya ardhi yanapaswa kuzingatiwa. Wakati mifumo ikolojia inakabiliwa na changamoto zinazoendelea kutokana na mabadiliko ya hali ya hewa na shughuli za binadamu, utafiti kama huo unamaanika muhimu: Uchavushaji, nyuki, rasilimali za maua, ubora wa mbochi, muundo, ufugaji nyuki

## DECLARATION

I, **DOROTHEA CLEMENCE KIPANGULA**, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution.

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Dorothea Clemence Kipangula  
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Date

The above is confirmed by:

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**Dr. Paulo J. Lyimo**  
(Supervisor)

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Date

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**Prof. Ruwa-Aichi P. C. Temu**  
(Supervisor)

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Date

## LIST OF MANUSCRIPTS

**Manuscript 1:** Bee fodder plants composition along environmental and disturbance gradients in Mlele Beekeeping zone, Tanzania

**Manuscript 2:** The periodicity of reward release by Bee fodder plants of Mlele Beekeeping zone, Tanzania

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## **DEDICATION**

I would like to dedicate this work to my Husband, parents, Clemence and Frida and my siblings, Emmanuel, Harieth and Jonathan.

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**LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS**

AMT	Annual Mean Temperature
ANOVA	Analysis of Variance
AP	Annual Precipitation
CCA	Canonical Correspondence Analysis
DCA	Detrended Correspondence Analysis
EU	European Union
FAO	Food and Agriculture Organization
GLMs	Generalized Linear Models
HEET	Higher Education for Economic Transformation
HSD	Honestly significant difference
RH	Relative humidity
S.D	Standard Deviation
TaFF	Tanzania Forest Fund
	United States Agency for International
USAID	Development
UTM	Universal Transverse Mercator
VIF	Variance Inflation Factor

## CHAPTER ONE

### 1.0 General Introduction

#### 1.1 Background Information

Bee fodder plants includes plant species that provide bees with food sources in form of nectar or pollen or both (Bhalchandra, 2014; Kumar *et al.*, 2015). Not all bee plants are equally important to bees and honey production(Nuru *et al.*, 2015). Bee fodder plants vary widely with latitude, region, season and type of vegetation they associate with (Latham, 2007).Identifying bee floral sources specific to a region is essential in honey production and selection of suitable apiary sites (Ausseil *et al.*, 2018; Hosamani *et al.*, 2020; Mensah *et al.*, 2017) as beekeepers can use this information to selectively grow plants that are important to bees(Otim *et al.*, 2019).

Ninety-three bee plant species belonging to 43 families were identified in Ethiopia, of which the family Asteraceae was the most abundant followed by Lamiaceae, Fabaceae, Acanthaceae and Rubiaceae (Bareke *et al.*, 2017).In Tanzania, several studies have shown that honeybee plant species differ with agroecological zones. For example, *Commiphora africana*, *Acacia mellifera*, *Albizia anthelmintica*, *Aspilia mossambicensis*, *Justicia debile* and *Acacia tortilis* were shown to be important fodder plants in Northern Tanzania(Mpondo *et al.*, 2021).In Western Tanzania, according to Kayombo *et al.* (2013) bee forage plants in the area include *Pterocarpus angolensis*, *Brachystegia* spp , *Anisophylla pomifera*, *Combretum* spp and *Terminalia* spp.

The composition of bee fodder plants varies along environmental gradients (Panlong Wu *et al.*, 2018).Elevation serves as a significant gradient leading to shifts in both temperature and precipitation(Ghafari *et al.*, 2020; Lasway *et al.*, 2023) affecting the floral composition of bee fodder plants. Differences in temperature, precipitation and seasonal patterns can affect the timing and duration of flowering in bee fodder plant species (Creux *et al.*, 2021;

Descamps *et al.*, 2018; Descamps, Jambrek, *et al.*, 2021; Gu *et al.*, 2020). Disturbance gradients that includes anthropogenic activities can impact the floral composition of an area (Cruz *et al.*, 2022; Winfree *et al.*, 2009). Understanding these gradients is important as they provide insights into the dynamic nature of bee foraging habitats (Ghafari *et al.*, 2020; Giovanetti *et al.*, 2022; Jaboor *et al.*, 2022; Tingfeng Wu, 2019).

Pollen and nectar are the primary rewards offered by flowers to bees in order to buy their services as pollinating agents (Ghramh and Khan, 2023; Mahalkar and Dhore, 2022; Richardson *et al.*, 2021; Sajwani *et al.*, 2014). Variation in floral traits, both within (Rosas-Guerrero *et al.*, 2014) and across (Chauhan *et al.*, 2017; Erickson *et al.*, 2022) plant species, can influence pollinator foraging behavior and plant pollination success. These traits include visual cues, such as flower shape and color, olfactory cues like floral volatiles, quantity and chemical composition of nectar and pollen rewards (Galetto and Bernardello, 2004).

Nectar concentration plays a significant role in attracting bees (Knopper *et al.*, 2016; Mallinger and Prasifka, 2017; Pamminger *et al.*, 2019). Nectar sugar concentration is directly linked to the amount of sugar bees can extract from flowers and has traditionally served as a proxy for nectar quality (Russo, 2019; Vaudo *et al.*, 2015). Bees prefer higher nectar concentrations as they provide more energy for them (Silva and Dean, 2000). Temperature affects bee foraging behavior by influencing the metabolic rates of bees (Creux *et al.*, 2021; Descamps *et al.*, 2021). Understanding the effect of nectar concentration and temperature on bee visitation rates is essential for optimizing bee pollination services (Cavalcante *et al.*, 2018; Liporoni *et al.*, 2020; Plos *et al.*, 2023; Uthoff and Ruxton, 2022).

Tanzania is endowed with favourable environment for beekeeping. It has an area of 945,000 km<sup>2</sup>, with high diversity of flowering plants, estimated to be over 9,000 species (Ruffo *et al.*, 2002). In addition,

Tanzania is recognized to hold large honeybee populations in Africa being the 14th largest producer of honey in the world, and biggest African supplier of honey to the European Union (FAO, 2019). Beekeeping contributes up to 33% of the household income in the Miombo woodlands of Tanzania according to Monela *et al.* (2000) and it is one of the options that help to promote forest conservation.

Katavi Region is one of the potential areas for beekeeping in Tanzania, with Mlele District being the highest honey producing area in the Region (Mwakatobe *et al.*, 2011). There is a scarce documentation on the characteristics of the bee fodder plants of Tanzania, in terms of their composition, floral rewards, and the quantity and quality of the floral rewards. Extensive understanding of the characteristics, value and the management of bee flora are significant factors for effective beekeeping of an area (Fitchl *et al.*, 1994).

## **1.2 Problem Statement and Study Justification**

The success of beekeeping depends on composition, availability and quality of bee floral plants (Guajardo-Rojas *et al.*, 2022). The interactions between bees and plants play a crucial role in maintaining biodiversity and support to plant reproductive productivity (Papa Nikolaou *et al.*, 2017). Understanding the factors that shape these interactions is essential for ecosystem conservation (Hoffmann, 2022). Bees, as key pollinators, play a fundamental role in ecosystems and agriculture, making it essential to understand the drivers of their foraging behaviour (Anne and Socolar, 2018). Floral rewards, particularly nectar, are critical ecological resources (Vaudo *et al.*, 2015). The dynamics of nectar sugar concentration during the day and between plant species can provide the sustainability of bee populations (Galetto and Bernardello, 2004), integral to pollination services (Rosas-Guerrero *et al.*, 2014).

Studies have been done in different parts of the world including Europe and Australia (Leech, 2012) where top producers plants for nectar and pollen were documented. The guidelines showed bee fodder plants, with their features including composition and honey yielding capacity. In America, a documentation of honey bee plants bloom calendar, showing their habitat, flower colour and pollinator value was produced (Mary *et al.*, 2018). In Asia, a study done in India by Bhalchandra *et al.* (2014) revealed Mid-December to February and mid-July to September to be honey flow periods, while mid-April to mid-June were the critical dearth periods. In Africa, a study in Ethiopia revealed 93 species of bee plants, belonging to 43 families (Bareke *et al.*, 2020). The family Asteraceae was the most abundant, followed by Lamiaceae, Fabaceae, Acanthaceae and Rubiaceae. Numerous investigations have also documented how both environmental changes and human disruptions can influence availability of food sources for bees (Cruz *et al.*, 2022; Jaboor *et al.*, 2022; Jacobs *et al.*, 2023; Pardee *et al.*, 2023; Patel, 2023; Vander Planck *et al.*, 2019).

Several studies on nectar secretion by honeybee fodder plants have been done in the temperate and sub-temperate regions (Petanidou *et al.*, 1996; Castellanos *et al.*, 2002; Galetto *et al.*, 2004; Kim *et al.*, 2011). In Saudi Arabia, a study conducted by Adgaba *et al.* (2012) on nectar of *Ziziphus spina-christi* (L) willd (Rhamnaceae) showed the overall average mass of nectar sugar per flower to be  $0.55 \pm 0.23$  mg (range 0.06 - 1.29 mg). Many important honey source plants of the tropics, subtropics and arid climatic zones, their nectar secretion potentials and their significance for honey production have not yet been well studied and documented.

In Tanzania, few studies have been conducted on bee fodder plants (Latham, 2007; Ismail *et al.*, 2021), and these studies were mainly carried out in Northern and Southern Tanzania. Studies by Mwangulango (2004) and Bloesch (2018) in Mlele Beekeeping Zone in Katavi Region produced a checklist of trees and shrubs of the

area. Another study by Kayombo *et al.* (2013) came up with a checklist of the bee plants of the area. There is little information on characteristics of bee fodder plants in the region and country at large. This study therefore, aims at characterizing bee fodder plants of the Mlele Beekeeping Zone in Katavi region, Tanzania by investigating their composition and periodicity of floral rewards.

### **1.3 Objectives**

#### **1.3.1 Main objective**

The overall objective of this research was to characterize bee fodder plants of Mlele Beekeeping zone, Katavi

#### **1.3.2 Specific objectives**

The specific objectives during this research were to;

- i. Determine the composition of bee fodder plants along environmental and disturbance gradients
- ii. Determine the periodicity of floral rewards in bee fodder plants

## CHAPTER TWO

### MANUSCRIPT ONE

#### **2.0 Bee Fodder Plants Composition Along Environmental and Disturbance Gradients in Mlele Beekeeping Zone, Katavi, Tanzania**

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#### **2.1 Abstract**

Pollination by bees increases outcrossing and chances of successful fertilization in flowering plants and therefore increases biodiversity. Bee populations, including domesticated and wild species, heavily depend on flowering plants for their survival. Katavi region has diverse of floral resources of which majority are visited by bees. This paper aimed to assess the composition of bee fodder plants along environmental and disturbance gradients in Mlele beekeeping zone, Katavi. The study had three specific objectives including the composition of bee fodder plants along environmental gradient, composition along disturbance gradient and the community composition. Data for bee fodder plants, environmental and disturbance were obtained from 50 plots by systematic sampling design with rectangular plots of size 50 ×30 m. Canonical Correlation Analysis (CCA) was used to analyze the composition along the gradients. The results showed that 23% of variation of

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dominant tree species composition was explained by the environmental and disturbance factors. The variables elevation and annual mean temperature were seen to be important predictors of bee fodder plants composition. Elevation explained about 11.6% and annual mean temperature about 3.5% of the total variation in community. The results highlight the importance of elevation, annual mean temperature, and annual precipitation as crucial indicators for explaining the variability of bee fodder plants composition. Further research is needed to understand the relationship between environmental factors and bee plant communities in other locations and other factors such as soil type and land use should be considered to understand. These findings can be used to inform best practices for beekeeping in the region, such as timing of hive management and selection of suitable sites for apiaries.

**Keywords:** Bee fodder plants, Floral resources, environmental gradients, composition, sustainable apiculture

## 2.2 Introduction

Majority of flowering plants rely on pollination by animals (Ollerton *et al.*, 2011) especially insect pollinators (Khalifa *et al.*, 2021; Rader *et al.*, 2019) that contribute to maintenance of natural biodiversity (Glenny *et al.*, 2022; Majewski, 2018; Misganaw *et al.*, 2020) and increase of flowering plant reproductive production (Ollerton, 2017). Bees, both domesticated and wild, are the most important group of pollinators, visiting more than 90% of the 107 most important crops in the world (Usaid and Bridge, 2020) and entirely depend on flowering plants for food (Vaudo *et al.*, 2015b). Higher bee abundance are typically correlated with higher plant diversity and thus food source diversity (Kennedy *et al.*, 2013). Bee fodder plants composition play a vital role in supporting the health and survival of honeybee populations (Rahimi *et al.*, 2022). Diverse range of bee fodder plant species are necessary for sustaining healthy bee populations (Durazzo *et al.*, 2021) as they provide a variety of nutrients, vitamins, and minerals that are essential for bee growth

and reproduction (Ghramh and Khan, 2023). Moreover, bee plants also provide important ecosystem services (Lasway *et al.*, 2022) which contributes to the maintenance of biodiversity and food security (Ulian *et al.*, 2020). Understanding factors influencing bee plant communities and promoting their growth is crucial for supporting healthy bee populations and maintaining the broader ecological balance (Fedoriak *et al.*, 2021) Beekeeping is more successful in areas where there is high diversity and composition of flowering plants (Bojago, 2022). The potential for improving woodland floral resources with pollinator-friendly management is considered to be large (Cole *et al.*, 2020).

Several studies have reported the impact of environmental and human disturbances on bee forage plants (Cruz *et al.*, 2022; Jaboor *et al.*, 2022; Jacobs *et al.*, 2023; Pardee *et al.*, 2023; Patel, 2023; Prendergast *et al.*, 2022; Vanderplanck *et al.*, 2019). Precipitation was found to be the key predictor variable for 23 out of 30 studied bee forage species including *Eucalyptus annulata* and *Eucalyptus redunca* (Patel, 2023). A study by (Kerr *et al.*, 2015) showed a mismatch between flowering plants and bees as an impact of climate change and made a list of tolerant bee fodder plants including *Symphytichum novaeangliae*. Warming associated with climate change potentially induced shifts in the nectar bee fodder plants by changing nectar characteristics (McCombs *et al.*, 2022). Moreover, human influence may cause detrimental effects on bees and floral visitors by diminishing floral resources and nesting sites (Cruz *et al.*, 2022).

Katavi Region is one of the potential areas for beekeeping in Tanzania (Mwakatobe *et al.*, 2021; Ngassapa *et al.*, 2022), with Mlele District being the highest honey producing area in the Region. Studies have been done in the area providing a checklist of bee plants in the area (Kayombo *et al.*, 2013). On the other hand, few have been conducted on how the bee plants composition is affected by environmental and disturbance factors.. For every geographical

region there are important honey source plants and characterizing and mapping them is important for their utilization (Al-Ghamdi *et al.*, 2020). Despite the importance of bees and their relationship with vegetation, knowledge gaps persist in relation to bees and composition and diversity of their vegetation (Panlong Wu *et al.*, 2018).

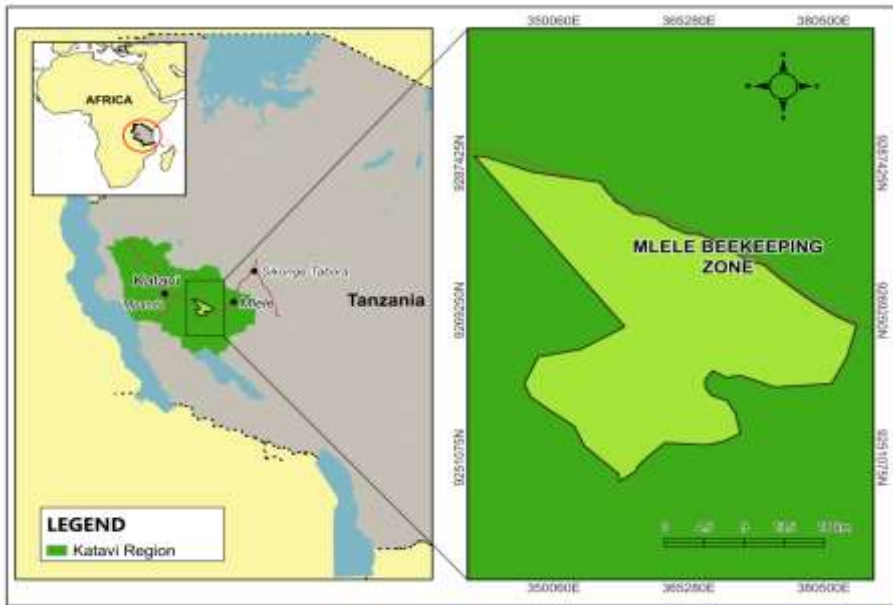
The knowledge gaps hinder effective conservation of bee food sources, sectors contribution to the economy by scaling down bee product production and sustainable beekeeping practices. Acquiring data in these areas is important for addressing these challenges and laying the groundwork for supporting efforts of protecting, restoring plant-pollinator community structure and function (Tonietto and Larkin, 2018). This will increase survival, abundance of bees (Bird shire *et al.*, 2020; Donkersley, 2019; Tarakini *et al.*, 2021; Tingfeg Wu, 2019) and scale up bee products production (Harianja *et al.*, 2023). The data can also inform management decisions for sustainable apiculture (Patel, 2023). Changes in land use, climate and environmental management decisions can affect the availability of quality bee fodder plants accessed by beekeepers by changing mobility patterns (Ausseil *et al.*, 2018).

## **2.3 Materials and Methods**

### **2.3.1 Study area**

This study was conducted at Mlele Beekeeping Zone in Mlele District, Katavi region. Mlele lies at 36UTM 351963 and 9248114 in the Southern side of the beekeeping reserve and 36UTM 353524 and 9284884 Northern side, with an altitude range of 900 to 1600m a.s.l. It is located North West of Inyonga Township, along main road to Mpanda and road to Rukwa Game Reserve headquarters. The area covers a total of 850,000 hectares. The climate is Tropical wet and dry or savanna climate. The topography is characterized by the presence of two plateaus divided by a steep escarpment (Hausser *et al.*, 2017). Several intermittent and a few permanent streams run down the escarpment. The zone is dominated by Miombo

woodlands covering an area of more than 90%. The miombo type is transitional between drier and wetter miombo. The genera dominating include *Brachystegia* and *Julbernardia* with *Brachystegia spiciformis* and *Julbernardia globiflora* being the most common tree species (Kayombo *et al.*, 2013).



**Figure 2.1: A map showing the study area**

### 2.3.2 An overview of the study design

The study employed systematic sampling design on basis of altitudinal gradients. A total of 50 plots were laid in two transects with 25 plots in each transect. Rectangular plots of size 50 by 30 m were established with 100m apart (Gbesso *et al.*, 2014). Plants flowers were observed for 10 minutes and was scored as bee forage species after at least three (3) bees foraged the flower within the observation period (10 minutes) (Bhalchandra, 2014). Data collection was conducted during multiple sampling periods throughout the wet and dry season. Samples of plants that could not be identified in the field were collected and saved in herbarium

sheets in specimen box for further identification or confirmation at the Tanzania National Herbarium. The name of taxon author was verified using The Plant Name Index (2023) and The Plant List (2023).

### **2.3.3 Data collection**

#### **2.3.3.1 Bee fodder plants composition**

Observation and identification of bee fodder plants within rectangular and sub plots was done on each plot for their local and scientific names. For observing an individual species, systematic sampling method was used. Plant characteristics, including leaf morphology and flower color were recorded along with spatial coordinates (latitude, longitude and elevation) using a global positioning system sample difficult to identify were carefully labeled, including information about the plot location and stored in herbarium sheets. To determine species composition of the area, the species data sets were summarized into a list of all species recorded and their abundance values. Data on each plants flowering period, type of reward offered were also recorded.

#### **2.3.3.2 Environmental and disturbance data**

Climatic data used in this study includes 19 bioclimatic variables prepared using the Tanzania current climate data set downloaded from World Climate site ([worldclim.com](http://worldclim.com)) with a 30 arc seconds resolution. For more accurate results, four subsets (annual mean temperature, precipitation seasonality, annual precipitation and temperature seasonality) of biophysical variables were used (Low *et al.*, 2021). Disturbance data was assessed in the field on each plot through direct observation. A point scale was used to assess the degree of disturbance in each plot as proposed by Anderson and Currier (1973) where six-point scale of 0-5 was used in which 0 stands for no disturbance, 1 for 0-20% off the plot disturbed, 2 for 21-40% disturbed plot, 3 if 41-60% of the plot is disdturbed, 4 if 61-80% of the plot is disturbed and 5 if 81-100% of the plot is disturbed (Podani *et al.*, 2018).

### **2.3.4 Data analysis**

#### **2.3.4.1 Bee Fodder plants composition**

The data was first standardized to avoid data skewness. The next step involved application of Detrended correspondence analysis (DCA) to assess the extent of ecological gradient present in the species composition matrix. This information was then used to determine the appropriate constrained ordination method to be employed (Hejcmanova-Nežerková & Hejcman, 2006). The length result of the first DCA axis was 4.25 S.D. (i.e. > 4 S.D.), suggesting that the data is heterogenous thus suitable for unimodal methods including CCA. Before conducting Canonical Correlation Analysis, we assessed the presence of collinearity across variables by examining the Variance Inflation Factor (VIF). Predictor variables exhibiting a Variance Inflation Factor value exceeding ten (10) and correlation coefficient larger than 0.7 were deemed to process a high degree of collinearity and were excluded from the list of predictors. The log-transformed of species abundance data was performed in order to satisfy the requirements of multivariate normality (Andrew *et al.*, 2012). Species that were present in fewer than five plots were considered to lack significant ecological importance, hence excluded from the matrix. (Kyaw Myo *et al.*, 2016). To determine the significant explanatory factors that should be included in the matrix, a stepwise automatic forward selection method was employed (Andrew *et al.*, 2012).

The explanatory variables that were chosen were further subjected to constraints based on bee fodder plants and community composition using CCA. The study employed Permutational Multivariate Analysis of Variance technique, specifically utilizing the Adonis algorithm to assess variance partitioning through analysis of distance matrices. The analysis was conducted under a simplified model.

### 2.3.4.2 Bee fodder plants community composition

Similar communities were identified using cluster analysis. We employed the Bray-Curtis distance matrix to quantify dissimilarity, which takes into account species presence, absence, and abundance, effectively capturing the divergence in species composition and abundance across sites. The decision on number of clusters was based on Silhouette validation technique using *Nbclust* package. For clustering, we utilized Ward's method, designed to minimize total within-cluster variance by iteratively merging clusters that result in the least increase in the sum of squares within each cluster. To accentuate the four distinct clusters formed by cutting the dendrogram at a predetermined height, colored rectangles were incorporated using the *rect.hclust* function. The indicator species analysis was performed for identification of significant dominant species of communities using *labdsv*.

## 2.4 Results

### 2.4.1 Bee fodder plants composition

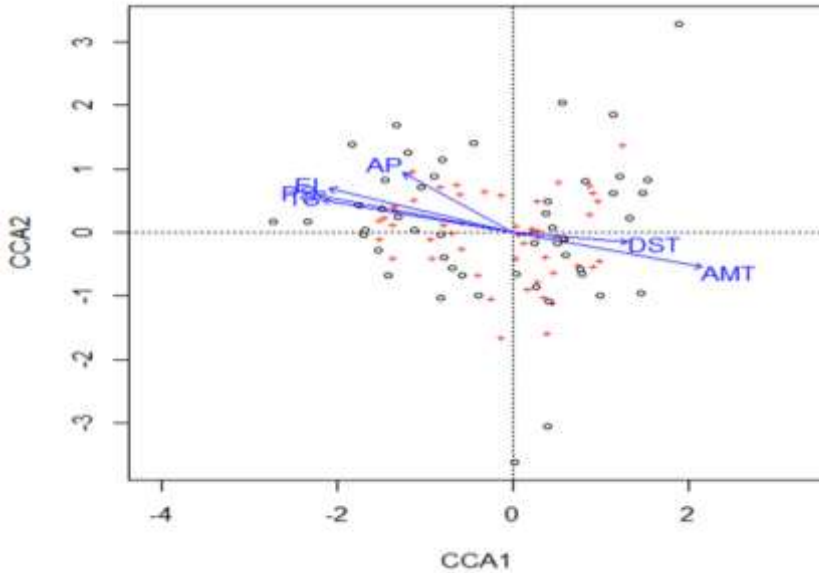
Overall, 71 bee plant species belonging to 25 families were recorded in both plots and transects. The highest species richness was observed in for the families Fabaceae (20 species), Euphorbiaceae (7 species) and Combretaceae (6 species). Our results showed that, 23% of variation of dominant tree species composition was explained by the environmental and disturbance factors after R-squared adjustment (Table 2.1). The overall CCA model ( $\chi^2 = 0.97$ ,  $P = 0$ ), as well as the first constrained axis (CCA1) explained 6% of the variation with eigen value of 0.3767, while the second (CCA2) explained 3.4% of the variation with eigen value 0.2139 as shown on Table 2.1.

The first ordination axis was significantly correlated with disturbance and annual mean temperature while the second canonical axis showed strong significant correlations with annual precipitation, elevation, precipitation seasonality and temperature seasonality (Figure 2.2). The biplots indicated that he most positively correlated

with CCA1 is *Ximenia americana* and *Strychnos innocua*. The most negatively correlated was *Combretum fragrans* highly influenced by elevation and annual mean temperature. The CCA 2 was positively correlated with species *Ximenia americana* and most negatively correlated with *Burkea africana* and *Cassipourea mollis*. Environmental factors (22%) explained variability in tree species composition seventeen times more than the disturbance factors (1.3%). Elevation explained about 11.6% of the total variation in community (Figure 2.3), annual mean temperature about 3.5% of the total variation in community and annual precipitation explained about 3.6% of the total variation in community (Table 2.1).

#### **2.4.2 Bee fodder plants Community composition**

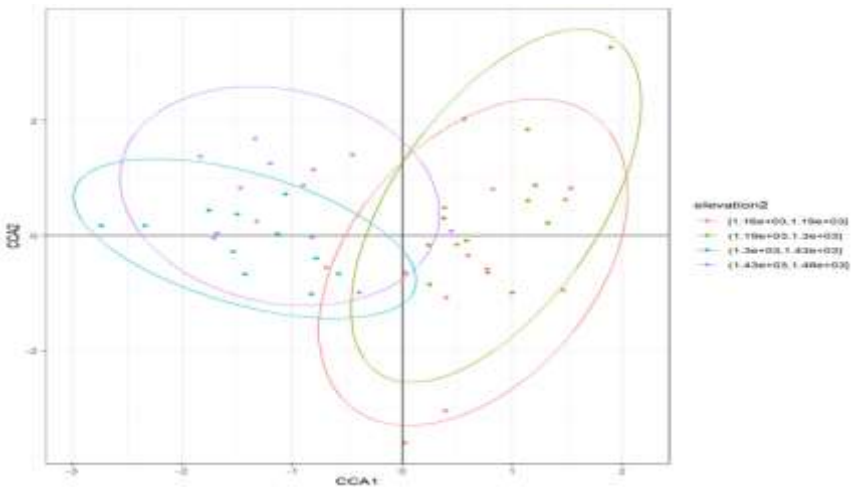
We identified four bee fodder plants species communities in the study area (Figure 2.4). Most of the bee fodder plants species were shared across communities however each community was characterized by a distinct dominant species. The community composition structure in the area was influenced by all the variable (Figure 2.5). The first cluster had *Erythrophleum africanum* as the dominant bee fodder plant and was significantly influenced by annual mean temperature and disturbances, the second was dominated by *Brachystegia glaucescens*, influenced by annual mean temperature, the third was a *Diplorhynchus condylocarpon* dominated community influenced by precipitation seasonality and temperature seasonality. The fourth had *Bobgunnia madagascariensis* as a dominant bee fodder plant species influenced by precipitation seasonality and temperature seasonality. The bee fodder plant communities occupied different elevation gradients.



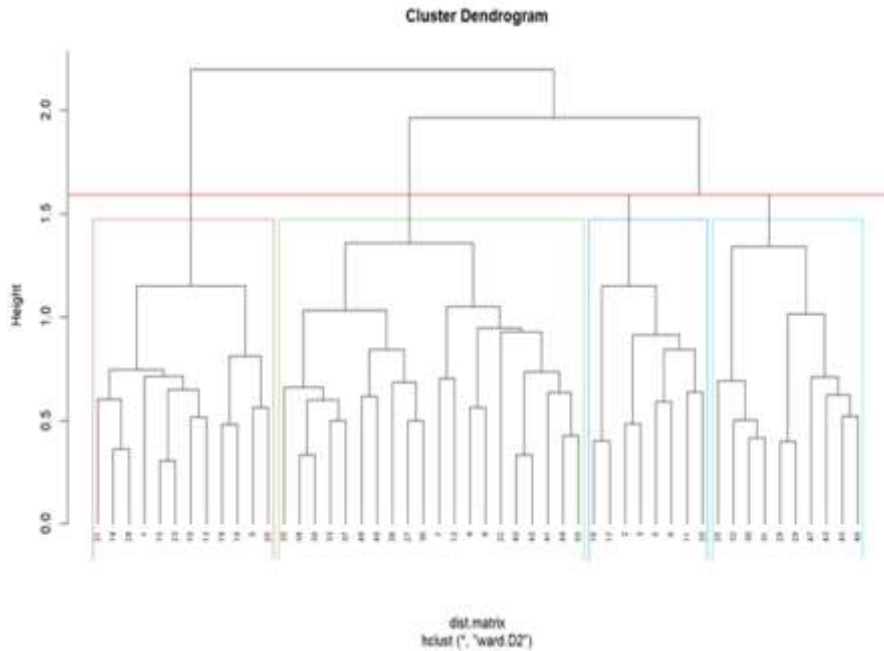
**Figure 2.2:** Canonical correspondence analysis diagram showing ordination of bee fodder plants species composition and their correlation with environmental and disturbance variables in Mlele Beekeeping Zone. The arrows are the environmental variables, the red crosses are the species and the open circles are the sites. The axes vectors indicate the significant explanatory variables in their abbreviated form: EL=Elevation, TS=Temperature Seasonality, MT=Annual Mean Temperature, PS=Precipitation Seasonality, DST=Disturbance and AP=Annual Precipitation.

**Figure 2.3: The environmental and disturbance factors and their variation explained, F and P values**

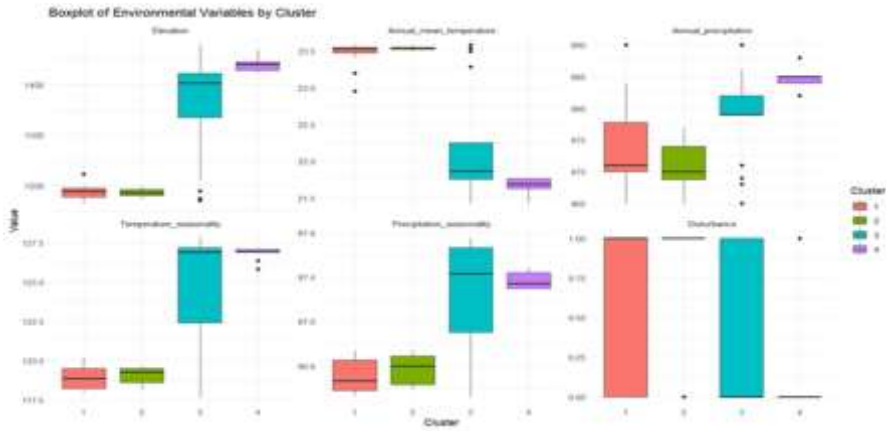
Variable	Variation explained (%)	F-value	P-value
Elevation	11.6	6.4991	0.001
Annualmean temperature	3.5	1.9695	0.030
Annual precipitation	3.6	1.9920	0.020
Temperature seasonality	1.7	0.9761	0.474
Precipitation seasonality	1.4	0.7904	0.662
Disturbance	1.3	0.7543	0.709



**Figure 2.4: Canonical correspondence analysis diagram showing ordination of bee fodder plants species composition and their correlation with elevation**



**Figure 2.5: Dendrogram of hierarchical clustering using similarity ratio showing four clusters of community (1 to 50) of the study area (Wards method, Bray Curtis distance).**



**Figure 2.6: Box plot showing difference among individual communities with respect to environmental and disturbance factors**

## 2.5 Discussion

### 2.5.1 Bee fodder plants composition

Similar to many other dry tropical forests in the world, the woodlands in the Katavi region of Tanzania have a lot of plant species from the Fabaceae family. This dominance of the family Fabaceae, Euphorbiaceae and Combretaceae has also been observed across the entire miombo region of Africa. The findings of the study highlight the significance of certain environmental variables in explaining the variation in bee fodder plants. Elevation, annual mean temperature, and annual precipitation emerge as the most influential predictors, while temperature seasonality, precipitation seasonality, and disturbance do not demonstrate a significant impact in this particular analysis (Table 2.1). These findings align with studies done in other areas (Gu Yue *et al.*, 2020; Zheng *et al.*, 2021). The influence of elevation in bee fodder plants composition is particularly noteworthy because the analysis reveals a strong and highly significant relationship (Steinbauer *et al.*, 2022). This implies that as elevation increases or decreases, there are corresponding changes in composition. This finding suggests that elevation plays a crucial

role in shaping the observed patterns and dynamics of the system under investigation. Researchers and stakeholders should consider the effect of elevation when studying or managing the response variable. Consequently, temperature should be carefully monitored and considered in the context of the response variable to gain a comprehensive understanding of the system and its dynamics.

In contrast, the results did not indicate a significant impact of temperature seasonality, precipitation seasonality, and disturbance on the response variable as shown on Table 2.1. It is important to note that the lack of significance does not necessarily imply the absence of an effect. Other studies have reported contrasting findings, emphasizing the context-dependent nature of these variables and the complex interactions they may have with other ecological drivers. Further investigations considering different spatial and temporal scales, as well as specific ecological contexts, are warranted to gain a comprehensive understanding of their contributions.

### **2.5.2 Bee fodder plants community composition**

The observed results regarding bee fodder plant community composition in the study area yield important insights into the relationships between plant species, environmental factors, and community dynamics. The findings reveal the presence of four distinct bee fodder plant communities, each characterized by a dominant species that defines its unique composition. These outcomes underscore the ecological complexity within the studied ecosystem and emphasize the need for a comprehensive understanding of the factors driving such community structures as shown on Figure 2.4.

The co-occurrence of bee fodder plant species across multiple communities suggests a degree of functional redundancy, where various species contribute to similar ecological roles. However, the presence of distinct dominant species within each community

highlights the role of niche specialization and competition in shaping the observed patterns. This scenario aligns with the theory that in diverse ecosystems, species interactions and environmental conditions combine to structure communities in complex ways.

The results further demonstrate the substantial influence of environmental variables on the composition of bee fodder plant communities. Notably, the first community, dominated by *Erythrophleum africanum*, exhibited sensitivity to both annual mean temperature and disturbances. This underscores the importance of climatic and disturbance-related factors in governing the prevalence of specific plant species. The prominence of *Brachystegia glaucescens* in the second community, mainly influenced by annual mean temperature, echoes the role of temperature in mediating species dominance.

*Diplorhynchus condylocarpon* dominance in the third community, with precipitation seasonality and temperature seasonality as influential factors, showcases the joint impact of climatic variables on shaping species distribution. Similarly, the fourth community, led by *Bobgunnia madagascariensis*, demonstrates the significance of precipitation seasonality and temperature seasonality in influencing plant species dominance (Table 2.1). These findings resonate with the concept of climate-driven species-environment relationships and highlight the need for comprehensive studies encompassing temporal and spatial climatic dynamics.

## **2.6. Conclusion**

Identification of dominant bee fodder plant species, their correlations with environmental variables, and their distribution patterns across elevation gradients contribute significantly to our understanding of ecosystem functioning. This study contributes to a broader understanding of plant community dynamics in the context of bee forage availability. The identified dominant species provide insights into potential forage preferences for local bee populations, thus

contributing to pollinator conservation efforts. The results of this study highlight the significance of species-environment interactions in shaping bee fodder plant communities. The observed dominance of specific species in relation to various environmental variables provides a foundation for further investigations into the underlying mechanisms governing such patterns.

These findings contribute to the growing body of knowledge concerning plant-pollinator interactions and ecosystem dynamics, underscoring the need for approaches to conservation and management strategies in changing environments. The significance of elevation, annual mean temperature, and annual precipitation as key predictors in explaining the variation in bee fodder plants composition is seen from the study findings. Emphasizing the importance of considering these variables in studies aiming to understand and predict ecological patterns and processes is important. Future research should continue exploring the complex interplay between these variables and other ecological drivers to improve our understanding of ecosystem dynamics in the face of ongoing global environmental changes.


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### **Conflict of Interest**

The authors declare no conflict of interest.

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## CHAPTER THREE

### MANUSCRIPT TWO

#### **3.0 Periodicity of Reward Release by Bee Fodder Plants of Mlele Bekeeping Zone, in Katavi Region, Tanzania**

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#### **3.1 Abstract**

Tanzania is endowed with favorable environment for beekeeping activities, with Katavi region being one of the potential regions. Katavi region has high diversity of floral resources of which the majority are visited by bees. This study aimed at investigating the bee visitation rates, nectar quality, and the effects of temperature and nectar concentration on bee visitation rates for ten selected flowering plant species. The selected plants in Mlele Beekeeping zone were: *Antidesma membranaceum*, *Psorospermum febrifugum*, *Senegalia polyacantha*, *Securidaca longepedunculata*, *Dichrostachys cinerea*, *Uapaca nitida*, *Bauhinia thonningii*, *Phyllanthus engleri*, *Pseudolachnostylis maprounefolia* and *Friesodielsia obovata*. The study employed purposive sampling design on the basis of bee fodder plants, provision of measurable amounts of nectar and enough flowers to conduct the study with repeated nectar measurements overlapping flowering periods. The study area is characterized by a tropical wet and dry climate. Data on bee visitations were collected through observation, while nectar quality was measured in terms of total nectar sugar concentration. Statistical tests, including ANOVA, Tukey HSD, and generalized

linear models, were employed to analyze the data. The study found that *Antidesma membranaceum* and *Friesodielsia obovata* were the most visited plant species by bees, while *Pseudolachnostylis maprouneifolia* was less visited. Visitation rates were significantly higher when there was an increase in nectar concentration, with *Friesodielsia obovata*, *Psorospermum febrifugum*, and *Securidaca longepedunculata* showing a strong correlation in this regard. Temperature was also found to impact visitation rates, with *Bauhinia thonningii* visitation rates increasing as temperature increased. These findings contribute to our understanding of the plant-pollinator interactions in the study area. Continued research should be done to provide deeper insights into the dynamics of bee-plant interactions that can help inform more targeted conservation efforts

**Keywords:** Periodicity, visitation rates, nectar quality, temperature,

### 3.2 Introduction

Most flowering plants depend on animals for their pollination(Ollerton *et al.*, 2011), particularly insects(Khalifa *et al.*, 2021; Rader *et al.*, 2019)to maintain natural biodiversity (Glenny *et al.*, 2022; Majewski, 2018; Misganaw *et al.*, 2020) and enhance their reproductive production(Ollerton, 2017). Bees are the most significant group of plant pollinators because they visit over 90% of the 107 most crucial global crops (Usaid and Bridge, 2020) and rely entirely on flowering plants for food(Herrmann *et al.*, 2023; Vaudo *et al.*, 2015).Higher abundance of bees is typically associated with greater plant diversity (Panlong Wu *et al.*, 2018), which leads to a more diverse food source(Gerner and Sargent, 2022).The rate and composition of flower visitors in a given community depend on the characteristics of the plant species(Brzosko *et al.*, 2023; Hernández-Villa *et al.*, 2020). Different plant species have distinct floral traits associated with their pollination syndrome, including corolla size, shape, color, scent, and nectar composition (Erickson *et al.*, 2022). These traits can vary significantly even among closely related plants(Macukanovic-Jocic *et al.*, 2011; Xiang *et al.*, 2023). For example, *Salvia officinalis* L. and *Lamium album* L. are both plant species in the family Lamiaceae that attract bees because of their bilabiate corollas and nectar rewards. However, only bees with a long proboscis are able to reach the nectar of *Lamium album* (Lye *et al.*, 2009), whereas the nectar of *Salvia officinalis* is accessible to both long-tongued and short-tongued bees (Macukanovic-Jocic *et al.*, 2011).

The rate of flower visitation is often influenced by the rewards provided by plants (Creux *et al.*, 2021; Latty and True blood, 2020; Zariman *et al.*, 2022), which can also be affected by abiotic factors (Jambrek, *et al.*, 2021; Liporoni *et al.*, 2020; Plos *et al.*, 2023). Abiotic factors, such as temperature, directly impact the production of floral resources like nectar (Plos *et al.*, 2023). Nectar production has been observed to be low at both low and high temperatures (Takkis *et al.*, 2018), peaking at intermediate temperatures in a unimodal relationship (Corbet, 1990). The sugar concentration of nectar increases with temperature due to higher evapotranspiration

(Borghi *et al.*, 2019). However, high temperatures can lead to rapid evaporation and higher nectar concentrations than preferred by pollinators (Corbet, 1990), increasing the risk of plant-pollinator mismatches (Bagangao and Manila-Fajardo, 2022). Animal pollinators adapt their foraging behavior based on the quantity and quality of floral rewards (Brunet *et al.*, 2023), establishing associations between nectar and flower visitation (Nicolson, 2022). Thus, abiotic factors can indirectly impact flower visitation rates (Plos *et al.*, 2023).

Several studies have reported on how visitation rate is affected by nectar concentration (Cavalcante *et al.*, 2018; Finkelstein *et al.*, 2022; Mallinger and Prasifka, 2017), type of plant species (Daniels *et al.*, 2020; Dellinger *et al.*, 2021; Russo *et al.*, 2019) and temperature (Boubnan *et al.*, 2021; Descamps *et al.*, 2020; Giovanetti *et al.*, 2022; Hennessy *et al.*, 2021; Kudo *et al.*, 2023; Mallinger *et al.*, 2019; Ploset *et al.*, 2023; Uthoff and Ruxton, 2022). A study in Germany showed that flower visitation rates in four plant species (*Dictamnus albus*, *Lamium album*, *Salvia officinalis*, *Vincetoxicum hirundinaria*) were affected by nectar concentration and temperature. A study of the nectar concentration of the plant species *Senegalia polyacantha* resulted for mean concentration to be 29.82% while the plant species *Terminalia schimperiana* was seen to be more visited by bees (Wekere *et al.*, 2018).

Tanzania is endowed with favorable environment for beekeeping (Ngassapa *et al.*, 2022) and several studies have been done in the Northern (Arnold *et al.*, 2021; Sawe *et al.*, 2020), Southern (Latham, 2007) with few on the Western parts of Tanzania. Katavi Region is one of the potential areas for beekeeping in Tanzania (Mwakatobe *et al.*, 2021), with Mlele District being the highest honey producing area in the Region. Despite of this potential, there is limited information on the characteristics of the bee fodder plants of the District.

For every geographical region there are important honey source plants, and characterizing and mapping them is important for their

utilization (Al-Ghamdi *et al.*, 2020). The information may be useful in the efforts of protecting, restoring plant-pollinator community structure and function (Tonietto and Larkin, 2018) through enrichment planting, increase survival and abundance of bees (Birdshire *et al.*, 2020; Donkersley, 2019; Tarakini *et al.*, 2021; Tingfeng Wu, 2019), scale up bee products production (Gajardo-Rojas *et al.*, 2022; Harianja *et al.*, 2023) and inform management decisions for sustainable apiculture (Patel, 2023).

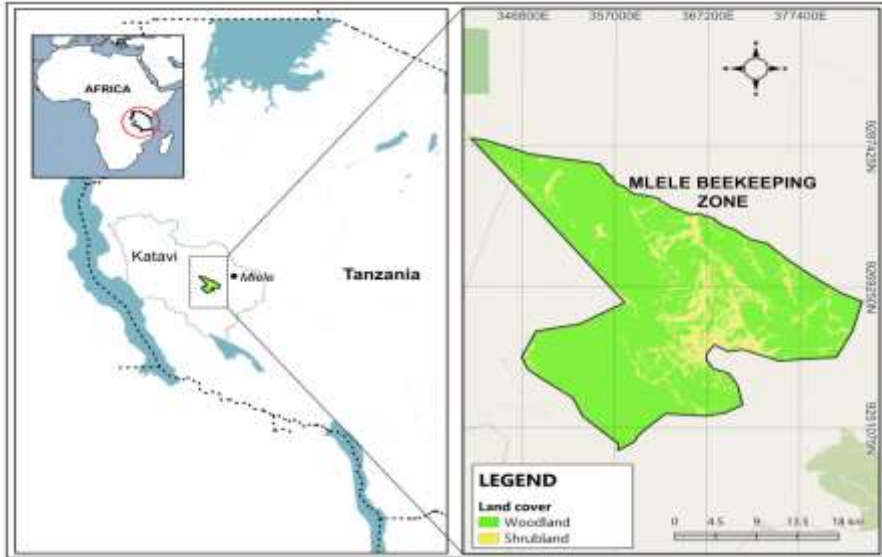
In this study, we aimed at filling this knowledge gap, by collecting a comprehensive dataset on bee visitation rates and how they are affected by periodicity of nectar release, nectar quality and temperature for ten plant species. The selected plant species were: *Senegalia polyacantha*, *Pseudolachnostylis maprounefolia*, *Dichrostachys cinerea*, *Uapaca nitida*, *Bauhinia thonningii*, *Antidesma membranaceum*, *Fresodielsia obovata*, *Securidaca longepedunculata*, *Psorospermum febrifugum* and *Phyllanthus engleri* in the Mlele Beekeeping zone of Katavi region.

### 3.3 Materials and Methods

#### 3.3.1 Study area

This study was conducted at Mlele Beekeeping Zone in Mlele District, Katavi region (Figure 3.1). Mlele lies at 36UTM 351963 and 9248114 in the Southern side of the beekeeping reserve and 36UTM 353524 and 9284884 Northern side, with an altitude range of 900 to 1600m a.s.l. (Fig. 2). The area covers a total of 850,000 hectares. The climate is Tropical wet and dry or savanna climate. The topography is characterized by presence of two plateaus divided by a steep escarpment (Hausser *et al.*, 2017). The zone is dominated by Miombo woodlands covering an area of more than 90%. The miombo type is transitional between drier and wetter miombo. The seasonally waterlogged mbugas are mainly covered with grasslands and occasionally with few trees and shrubs (wooded grasslands). Miombo are dominated by the genera *Brachystegia* and *Julbernardia*

with *Brachystegia spiciformis* and *Julbernardia globiflora* being the most common tree species.



**Figure 3.1: Location map of study area**

### 3.3.2 Sampling design

The study employed purposive sampling design on the basis of bee fodder plants, provision of measurable amounts of nectar and enough flowers to conduct the study with repeated nectar measurements overlapping flowering periods. Flowers were observed for 10 minutes and were scored as bee forage species after at least three (3) bees visited the flower within the observation period (10 minutes) (Bhalchandra, 2014). Plants in which honeybees extended their proboscis into the flowers and collected pollen on their hind legs were determined as nectar and pollen bee fodder plants respectively. Data collection was conducted during multiple sampling periods. Samples of plants that could not be identified in the field were collected and saved in herbarium sheets in specimen box for further identification or confirmation at the Tanzania National

Herbarium. The name of taxon author was verified using The Plant Name Index (2023) and The Plant List (2023).

### **3.3.3 Data collection**

#### **3.2.3.1 Bee visitations**

550 hours of observation were made in total for the whole study period. All flower bee visitors of the ten plant species were observed on 5 days each, covering the main flowering period of the investigated species. Observations were conducted throughout the day from 7:00 hours to 18:00 hours. Flower visits of every insect were counted for 30 min per plant species per flower. The number of flower visits in the 30-minute observation interval was considered as the visitation rate in this study. A stop watch was used for observation of number of bee visitors per flower.

#### **3.3.3.2 Nectar concentration**

Nectar quality was measured in form of total nectar sugar concentration in five flowers per plant species (Galetto and Bernardello, 2004). Nectar was extracted by the use of micro capillary tubes and micropipettes (Tew *et al.*, 2023). Nectar was expelled from the micro capillary tubes and micro pipettes for analysis of sugar concentration. Sugar concentration in the field was measured using a digital handheld refractometer (Tew *et al.*, 2023). The refractometer measure via the related property of refractive index giving a reading in percent (this is % w/w, or percent of sucrose equivalents or how many grams of sucrose are present per 100g of solution) (Mahalkar and Dhore, 2022; Tew *et al.*, 2022).

#### **3.3.3.3 *Effect of temperature on nectar concentration***

Data loggers were used to record temperature and relative humidity in real time at three-time interval morning (0700 to 0900 hours), afternoon (1200 to 1300) and noon (1600 to 1800) hours (Nielsen and Morelli, 2017). The data loggers were elevated 2.5 meters above the ground. Loggers were equipped with sun shields and were placed directly next to the plants during flower visitor

observations to measure the local microclimate experienced by the plant (Plos *et al.*, 2023).

### **3.3.4 Data analysis**

#### **3.2.4.1 Effect of nectar on bee visitation rates**

A generalized linear model (GLM) was created to examine the correlation between nectar concentration and temperature. The GLM utilized a Poisson distribution with a logarithmic link function. The summary of the GLM presented estimations for the coefficients and their standard errors. To visually represent the association between visitation and nectar concentration for individual species, distinct scatter plots were generated for each species, with data points overlaid and a smooth line fitted. Additionally, a collective scatter plot was generated, illustrating all species together.

#### **3.3.4.2 Effect of temperature on bee visitation rates**

A generalized linear model (GLM) was developed to analyze the relationship between visitation and temperature. The GLM used a Poisson distribution with a log link function and the summary provided estimates for the coefficient values and their standard errors. To visualize the relationship between visitation, nectar concentration and temperature for each species, separate scatter plots for each species were created, overlaying the data points and fitting a smooth line. Furthermore, we created a combined scatter plot that displayed all species together.

#### **3.3.4.3 Visitation across ten bee fodder plants**

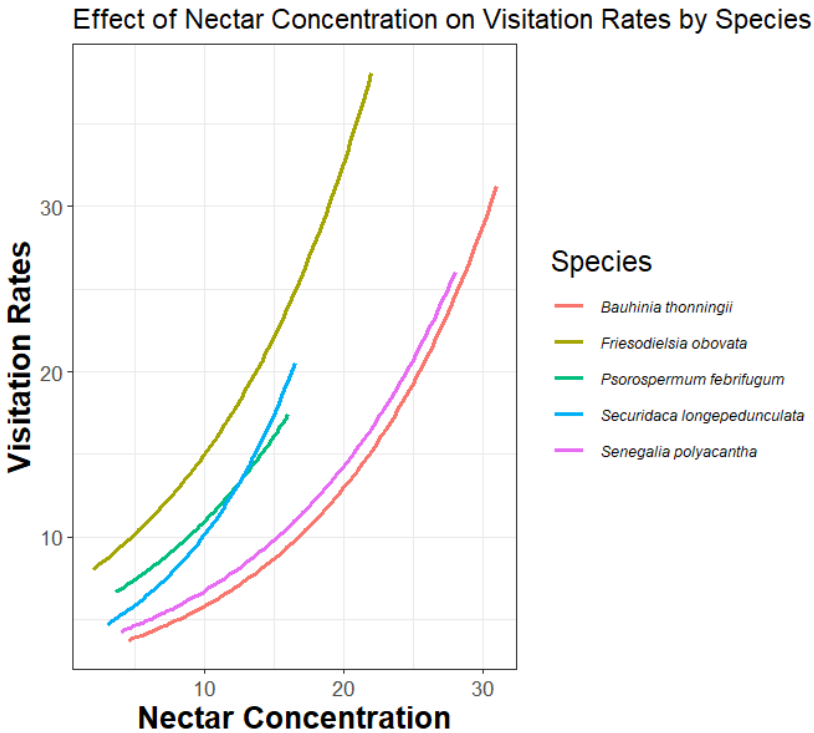
Analysis was done in R software version 4.3.0. Shapiro-Wilk test was performed for each subset to assess the normality of the visitation data. The results of the Shapiro-Wilk test were summarized for further analysis using ANOVA (analysis of variance) to determine any significant differences in visitation among the ten species. To further investigate the significant differences, we conducted the Tukey HSD (honestly significant difference) test. This test allowed us to identify pairs of species with significantly different visitation

patterns. The significant differences were filtered based on an adjusted p-value threshold of 0.05.

### **3.4 Results**

#### **3.4.1 Effect of nectar concentration on visitation rates**

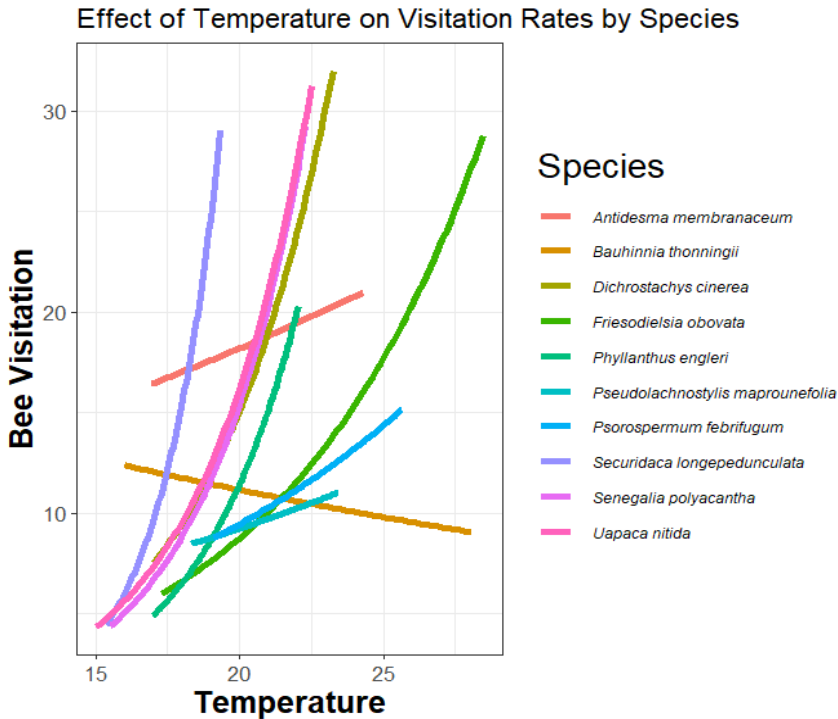
The results revealed significant effects of both nectar concentration (Estimate = 0.0802,  $p < 0$ ) and plant species ( $p < 0$ ) on visitation rates. Nectar concentration exhibited a positive and statistically significant relationship with visitation rates (Fig 3). Specifically, a one-unit increase in nectar concentration was associated with an increase of 0.0802 units in the log-count of visitation rates, all else being equal. The plant species showed significant effects on visitation rates. Notably, the species *Friesodielsia obovata* (Estimate = 0.9403,  $p < 0$ ) demonstrated the highest positive impact on visitation rates among the species considered, followed by *Psorospermum febrifugum* (Estimate = 0.6276,  $p < 0$ ) and *Securidaca longepedunculata* (Estimate = 0.5964,  $p < 0$ ). However, *Senegalia polyacantha* did not exhibit a statistically significant effect on visitation rates (Estimate = 0.0864,  $p = 1$ )



**Figure 3.2: Effect of nectar concentration on visitation rates for five bee fodder plants species**

### 3.4.2 Effect of temperature on visitation rates

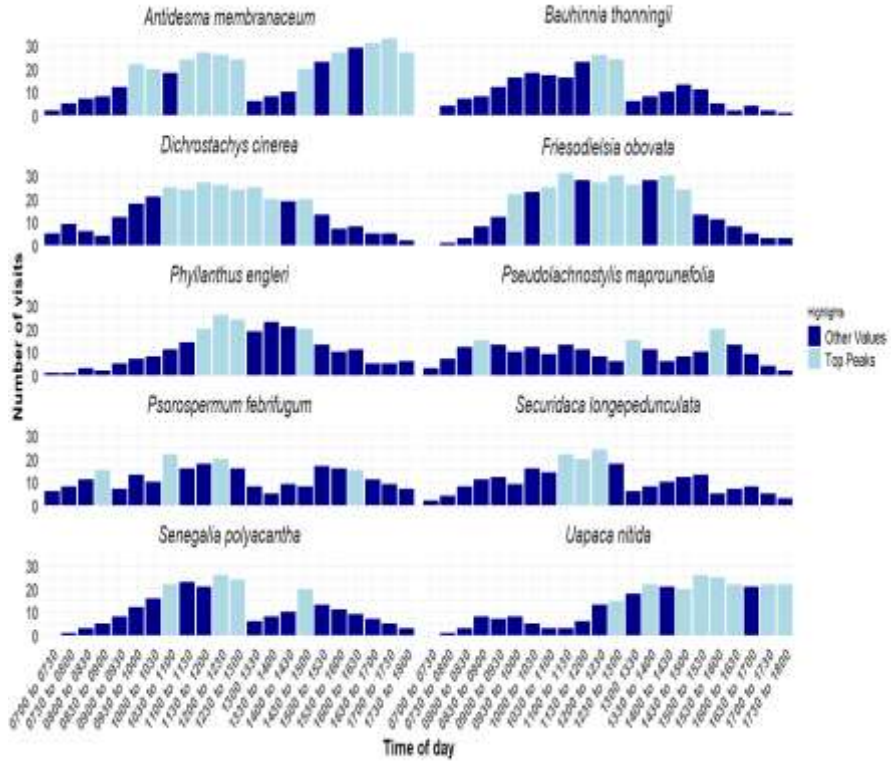
The results indicated that temperature was highly statistically significant at  $p < 0.05$ . All species variables were statistically significant except species *Dichrostachys cinerea* and *Securidaca longepedunculata*. The species *Bauhinia thonningii* was shown to be highly significant with temperature. The coefficient for temperature in relation to the species *Bauhinia thonningii* was 0.114635. This positive coefficient suggests that there is a positive trend between temperature and visitation for the bee fodder plant when holding other variables constant. Hence, for every one-unit increase in temperature, visitation increases by 0.114635.



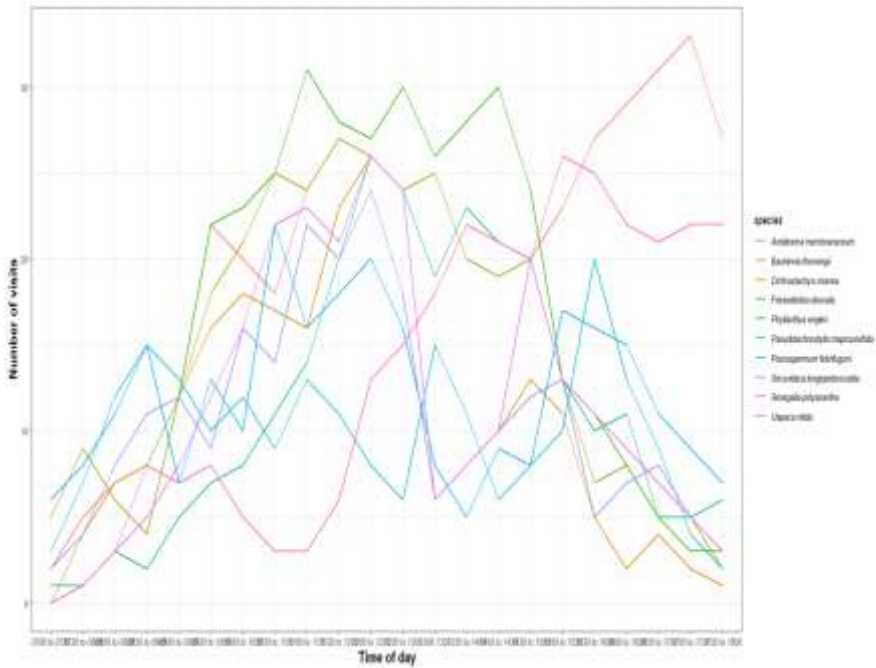
**Figure 3.3: The effect of temperature on bee visitation rates for ten bee fodder plant species**

### 3.4.3 Visitation per plant species

The bee fodder plants, *Antidesma membranaceum* and *Friesodielsia obovata* were seen to be more visited by bees. *Antidesma membranaceum* had a major peak at noon and minor in the morning while *Friesodielsia obovata* had one major peak from 11:00 hours to 15:30 hours. *Pseudolachnostylis maprounefolia* had one major peak from 15:00 hours and was seen to be less visited by bees. The Anova results were shown to be highly significant at  $p < 0.001$ . Results from a Tukey test, to compare pairwise differences between species visitation rates showed that there was a significance difference with the species *Uapaca nitida*, *Bauhinia thonningii*, *Securidaca longepedunculata* from *Antidesma membranaceum*.



**Figure 3.4: Bar graph of visitation trends for ten bee fodder study plants**



**Figure 3.5: Combined visitation trends for the ten bee fodder plant species**

### 3.5 Discussion

#### 3.5.1 Effect of nectar concentration on bee visitation rates

The results suggested that the amount or quality of nectar plays a crucial role in attracting bees to the flowers. The findings highlight the importance of nectar as a key factor in determining the visitation rates of bee species. Among the species tested, *Friesodielsia obovata*, *Psorospermum febrifugum*, and *Securidaca longepedunculata* were found to have a significant impact on visitation rates. This implies that these plant species produce nectar that is highly attractive to bees, leading to increased visitation. The specific characteristics of their nectar, such as its volume, sugar concentration, or composition, may contribute to their attractiveness to bees. On the other hand, *Senegalia polyacantha* did not show a significant association with visitation rates, suggesting that its nectar

may be less appealing to bees or that other factors outweigh the nectar's attractiveness.

These results have important implications for understanding the ecological interactions between plants and bees. By identifying the plant species that have a significant impact on visitation rates, beekeepers and conservationists can focus on promoting these specific plants to support bee populations and enhance pollination services. Additionally, the significance of nectar concentration emphasizes the importance of maintaining healthy nectar resources in natural and agricultural landscapes to sustain bee populations.

### **3.5.2 Effect of temperature on visitation rates**

The results suggested that temperature played a crucial role in influencing the visitation behavior of bees. The findings highlight the importance of considering temperature when studying bee-plant interactions and understanding the factors that affect bee foraging patterns. Among the species variables analyzed, *Dichrostachys cinerea* and *Securidaca longepedunculata* did not show a statistically significant association with visitation rates. This implies that these species may be less influenced by temperature variations compared to the other species studied. Other factors, such as nectar availability or floral traits, may have a stronger influence on the visitation rates. This suggests that there was a positive trend between temperature and visitation rates for this particular bee fodder plant, when holding other variables constant. Hence, as temperature increased, the visitation rates for *Bauhinia thoningii* were expected to increase as well.

### **3.5.3 Visitation per plant species**

The plant species *Antidesma membranaceum* and *Friesoldielsia obovata* were seen to be more visited by bees. This suggests that these species may possess characteristics that attract bees, such as abundant nectar or attractive floral traits (Chuttong *et al.*, 2022). The differing visitation patterns observed for the species further suggest

that these plants may have distinct strategies to attract bees. *Antidesma membranaceum* exhibited a major peak at noon and a minor peak in the morning, indicating that it is highly attractive to bees during midday hours. On the other hand, *Friesodielsia obovata* had a single major peak between 11:00 a.m. and 15:30 p.m, suggesting that it is most visited by bees during this time period.

These findings highlight the importance of considering time factor of plant-flower interaction when studying bee visitation rates. In contrast, *Pseudolachnostylis maprounefolia* showed a single major peak in bee visitation occurring from 15:00 hours onwards suggesting that it may have specific traits that attract bees during the late afternoon hours. The low visitation rates of *Pseudolachnostylis maprounefolia* may be due to various factors, such as competition from other floral resources, differences in the quality or quantity of nectar production, or variations in the floral traits that appeal to bees. The highly significant ANOVA results ( $p < 0.001$ ) indicate that there are significant differences in bee visitation rates among the different plant species. This suggests that the plant species themselves play a crucial role in attracting bees and influencing their foraging preferences. These species produce nectar and the high foraging to these species might be due to the quantities of nectar they produce.

### **3.6 Conclusion**

The study provides valuable insights into the factors influencing bee visitation rates to different bee plant species. We observed that *Antidesma membranaceum* and *Friesodielsia obovata* were the most visited by bees, suggesting their potential as crucial bee forage plants due to their attractive floral traits. Furthermore, the timing of floral interactions when studying bee visitation patterns should be considered. Nectar concentration emerged as a significant factor influencing bee visitation rates, with certain plant species, such as *Friesodielsia obovata*, *Psorospermum febrifugum*, and *Securidaca longepedunculata*, exhibiting nectar characteristics that were particularly appealing to bees.

These findings emphasize the importance of maintaining healthy nectar resources to support bee populations and enhance pollination services. Temperature was also a significant driver of bee visitation behavior, with *Bauhinia thonningii* showing a strong positive association with temperature. This highlights the need to consider temperature fluctuations when studying bee-plant interactions and underscores the potential impact of climate change on bee foraging patterns.

Conservation efforts should prioritize and promote the cultivation of highly visited plant species like *Antidesma membranaceum*, *Psorospermum febrifugum*, and *Securidaca longepedunculata* to support bee populations and enhance pollination services. Ensuring an adequate and healthy supply of nectar resources is essential for sustaining bee populations. Conservationists and land managers should consider planting and conserving nectar-rich plants and wildflowers to provide bees with the resources they need. Given the influence of temperature on bee visitation rates, climate change adaptation strategies should be developed to address potential shifts in bee foraging patterns. Monitoring temperature variations and their impact on bee-plant interactions is crucial for effective conservation and pollinator management. Continued research into the specific nectar traits that attract bees, as well as the factors influencing bee foraging behaviors, can provide deeper insights into the dynamics of bee-plant interactions. This knowledge can inform more targeted conservation efforts.

### **Acknowledgements**

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### **Conflict of Interest**

The authors declare no conflicts of interest.

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## CHAPTER FOUR

### 4.0 General Discussion

Tanzania's natural environment presents ideal conditions for beekeeping activities, and Katavi region stands out as one of its most promising areas (Mwakatobe *et al.*, 2021). Katavi boasts a rich diversity of floral resources, with many of them attracting bees (Kayombo *et al.*, 2013). This study provides valuable insights into the factors influencing bee visitation rates to different bee plant species. It highlights the significance of nectar sugar concentration and temperature in shaping bee foraging behaviour. It is important for conservation efforts to prioritize and promote conservation of bee-attractive plant species to support bee populations and enhance pollination services.

The results of this research have the potential to provide valuable insights for improving beekeeping practices in the Mlele Beekeeping Zone. This includes optimizing the timing of hive management and making informed choices about the location of apiaries. This newfound knowledge has the potential to play a pivotal role in ensuring the long-term viability and success of beekeeping endeavours in the area. Recognizing the influence of climate-related factors on composition of bee fodder plants holds significant importance, especially in light of climate change (Borghetti *et al.*, 2019; Gajardo-Rojas *et al.*, 2022; Marshman *et al.*, 2019). Alterations in temperature and precipitation patterns may have consequences for the availability of suitable forage resources for bees (Descamps *et al.*, 2021; McCombs *et al.*, 2022). These changes could, in turn, have repercussions on bee populations and, consequently, their vital role in pollination services.

One of the central findings of this study is the significant impact of nectar quality on bee visitation rates. Plant species with high-quality nectar, characterized by factors like sugar concentration and composition, attracted more bees. *Friesodielsia obovata*, *Psorospermum febrifugum*, and *Securidaca longepedunculata* stood

out as particularly attractive to bees. This underscores the pivotal role of nectar as a primary determinant of bee foraging behaviour. Ensuring the availability of nectar-rich plants in ecosystems is crucial for supporting bee populations and enhancing pollination services, which contribute to biodiversity conservation and agricultural productivity (Bhalchandra, 2014; Knopper *et al.*, 2016).

The research underscores the importance of environmental factors, particularly elevation, annual mean temperature, and annual precipitation, in shaping the composition of bee fodder plants. Elevation, in particular, plays a pivotal role in determining the plant species found in the area. This knowledge is critical for beekeepers and conservationists, as it highlights the need to consider these factors when planning for beekeeping and pollinator-friendly habitat restoration (Rosas-Guerrero *et al.*, 2014)

The study's findings hold practical implications for beekeepers in Mlele Beekeeping Zone and similar regions. By recognizing the importance of specific environmental factors and their influence on bee fodder plant composition, beekeepers can make informed decisions about hive management and apiary site selection (Ghramh and Khan, 2023). Moreover, conservation efforts can be tailored to protect and restore the preferred bee forage plants, thereby supporting healthy bee populations and maintaining biodiversity (Hoffmann, 2022)

## CHAPTER FIVE

### 5.0 General Conclusions and Recommendations

#### 5.1 Conclusion

This study explains relationships between environmental factors, disturbance indicators, and composition of bee fodder plants and floral rewards periodicity. These findings have important implications for sustaining bee populations, promoting beekeeping practices, and conserving biodiversity. To ensure the availability of diverse bee fodder plants and support the apiculture industry, it is imperative to consider these environmental variables in ecological research and conservation efforts.

The study helps us understand and recommends prioritizing and promoting planting and conserving bee-attractive plant species, such as *Antidesma membranaceum*, *Psorospermum febrifugum*, and *Securidaca longepedunculata*, to support bee populations and enhance pollination services. The study also encourages further research into the specific nectar traits that attract bees to deepen our understanding of bee-plant interactions. This research study enriches our understanding of the intricate connections between environmental factors, disturbances, and bee fodder plant communities.

The knowledge gained has practical applications for beekeeping practices, pollinator conservation, and land management. As ecosystems face ongoing challenges from climate change and human activities, such research becomes increasingly valuable in ensuring the health of bee populations and the preservation of biodiversity. Further research in other regions and at different scales is needed to expand our knowledge of these vital relationships and their implications for beekeeping and conservation efforts globally.

## 5.2 Recommendations

Based on the results and conclusions of this study, it is recommended that:

- a) Future research should explore the relationships between environmental factors and bee plant communities in different locations within the Katavi region and consider additional variables such as soil type and land use to gain a more comprehensive understanding of these dynamics.
- b) Conducting longitudinal studies spanning multiple seasons or years can capture temporal variations in bee-plant interactions and provide a more complete picture of their dynamics.
- c) Researchers should conduct comparative studies in different regions to assess the generalizability of their findings and determine whether similar factors influence bee fodder plant communities elsewhere.
- d) Conservation initiatives should prioritize the protection and preservation of diverse bee fodder plants and their associated ecosystems to support healthy bee populations and maintain ecological balance.

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## APPENDICES

Appendix 1: The bee fodder plants of Mlele Beekeeping Zone,  
Katavi Region

Species name	Family	Floral rewards	Flowering period
<i>Erythrophleum africanum</i>	Fabaceae	N	JAN
<i>Pterocarpus angolensis</i>	Fabaceae	N	OCT
<i>Strychnos innocua</i>	Loganiaceae	N	OCT
<i>Combretum molle</i>	Combretaceae	N	DEC
<i>Psorospermum febrifugum</i>	Clusiaceae	N	NOV
<i>Antidesma membranaceum</i>	Euphorbiaceae	NP	JAN
<i>Bobgunnia madagascariensis</i>	Fabaceae	P	FEB
<i>Brachystegia utilis</i>	Fabaceae	P	NOV-DEC
<i>Terminalia kaiseriana</i>	Combretaceae	NP	NOV-DEC
<i>Combretum fragrans</i>	Combretaceae	NP	SEPT-NOV
<i>Pseudolachnostylis maprouneifolia</i>	Euphorbiaceae	N	OCT
<i>Senegalia polyacantha</i>	Fabaceae	NP	NOV-DEC
<i>Julbernardia globiflora</i>	Fabaceae	P	MAY, JUNE- JULY
<i>Lonchocarpus capassa</i>	Fabaceae	N	NOV-DEC
<i>Diplorhynchus condylocarpon</i>	Apocynaceae	N	JAN-FEB
<i>Bauhinia thonningii</i>	Fabaceae	NP	JAN
<i>Hymenocardia acida</i>	Euphorbiaceae	N	DEC
<i>Isoberlinia angolensis</i>	Fabaceae	NP	FEB-MAR
<i>Brachystegia spiciformis</i>	Fabaceae	P	SEPT, OCT- NOV
<i>Friesodielsia obovata</i>	Annonaceae	NP	FEB
<i>Memecylon flavovirens</i>	Melastomataceae	N	NOV-DEC
<i>Burkea africana</i>	Fabaceae	N	NOV

<i>Pericopsis angolensis</i>	Fabaceae	N	NOV
<i>Crossopteryx febrifuga</i>	Rubiaceae	N	FEB
<i>Uapaca nitida</i>	Euphorbiaceae	N	NOV
<i>Brachystegia manga</i>	Leguminosae	P	SEPT,OCT-NOV
<i>Afzelia quanzensis</i>	Fabaceae	P	NOV
<i>Ziziphus</i> sp	Rhamnaceae	NP	JAN,FEB
<i>Lannea schimperi</i>	Anacardiaceae	N	NOV-DEC
<i>Euphorbia matabelensis</i>	Euphorbiaceae	N	DEC-JAN
<i>Flacourtia indica</i>	Flacourtiaceae	P	JAN-FEB
<i>Monanthotaxis discolor</i>	Annonaceae	N	FEB
<i>Oldfieldiadactylophylla</i>	Euphorbiaceae	NP	NOV
<i>Brachystegia glaucescens</i>	Fabaceae	P	OCT-NOV
<i>Combretum fragrans</i>	Combretaceae	NP	SEPT-NOV
<i>Pterocarpus tinctorius</i>	Fabaceae	NP	FEB
<i>Dalbergia nitidula</i>	Fabaceae	N	JAN-FEB
<i>Annona senegalensis</i>	Annonaceae	NP	NOV
<i>Acacia gerrardii</i>	Fabaceae	NP	OCT
<i>Sterculia quinqueloba</i>	Sterculiaceae	N	OCT
<i>Dichrostachys cinerea</i>	Fabaceae	N	JAN
<i>Ozoroa insignis</i>	Anacardiaceae	P	FEB
<i>Sterculia africana</i>	Sterculiaceae	N	OCT
<i>Combretum collinum</i>	Combretaceae	P	OCT-NOV
<i>Strychnospotatorum</i>	Loganiaceae	N	OCT
<i>Senna singueana</i>	Fabaceae	N	JAN-FEB
<i>Phyllocosmus lemareanus</i>	Ixonanthaceae	N	DEC-JAN
<i>Monotes africana</i>	Dipterocarpaceae	N	DEC
<i>Ximenia caffra</i>	Olcaceae	N	NOV-DEC
<i>Kigelia africana</i>	Bignoniaceae	N	NOV
<i>Brachystegia microphylla</i>	Fabaceae	P	FEB
<i>Vitex payos</i>	Verbenaceae	N	NOV
<i>Parinari curatellifolia</i>	Chrysobalanaceae	NP	FEB
<i>Uapaca kirkiana</i>	Euphorbiaceae	N	DEC

<i>Hexalobusmonopetalus</i>	Annonaceae	N	FEB
<i>Vitex doniana</i>	Verbenaceae	P	OCT
<i>Monotes katangensis</i>	Dipterocarpaceae	N	DEC
<i>Erythrina abyssinica</i>	Fabaceae	N	DEC
<i>Ziziphus mucronata</i>	Rhamnaceae	NP	JAN-FEB
<i>Phyllanthus engleri</i>	Euphorbiaceae	N	FEB
<i>Markhamia obtusifolia</i>	Bignoniaceae	NP	FEB
<i>Maranthes floribunda</i>	Chrysobalanaceae	N	OCT
<i>Olax obtusifolia</i>	Olacaceae	N	DEC
<i>Anisophyllea pomifera</i>	Anisophylleaceae	P	NOV
<i>Multidentia crassa</i>	Rubiaceae	N	NOV-DEC
<i>Ximenia americana</i>	Olacaceae	N	DEC
<i>Garcinia huillensis</i>	Clusiaceae	N	NOV
<i>Maytenus senegalensis</i>	Celastraceae	S	FEB
<i>Isoberlinia angolensis</i>	Fabaceae	NP	FEB-MAR
<i>Cassipourea mollis</i>	Rhizophoraceae	N	NOV
<i>Combretum zeyheri</i>	Combretaceae	N	NOV
<i>Securidaca longependunculata</i>	Polygalaceae	NP	OCT
<i>Bauhinia petersiana</i>	Leguminosae	P	FEB
<i>Ekebergia capensis</i>	Meliaceae	NP	FEB

**N- Nectar**

**P- Pollen**