# ABUNDANCE AND DIVERSITY OF BEE POLLINATORS IN COMMON BEAN (*Phaseolus vulgaris* L.) AGROECOSYSTEMS ALONG A FOREST-AGRICULTURE GRADIENT IN BORABU, KENYA

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# Abundance and Diversity of Bee Pollinators in Common Bean (*Phaseolus Vulgaris* L.) Agroecosystems along A Forest-Agriculture Gradient in Borabu, Kenya

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## DECLARATION

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

Signature……………………………………….. Date……...................……………

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This thesis has been submitted for examination with our approval as University Supervisors:

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## DEDICATION

I dedicate this work to my caring brothers and my beloved children; Brian, Alvin and Paul for their untiring support and encouragement in writing this thesis.

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# TABLE OF CONTENTS

# LIST OF TABLES

## LIST OF FIGURES

# LIST OF PLATES

## LIST OF APPENDICES

## ABBREVIATIONS AND ACRONYMS

| | |
|---|---|
| **CCD** | Colony Collapse Disorder |
| **FAO** | Food and Agriculture Organisation |
| **GPS** | Geographical Positioning Satellite |
| **JKUAT** | Jomo Kenyatta University of Agriculture and Technology |
| **KNBS** | Kenya National Bureau of Statistics |
| **MEA** | Millennium Ecosystem Assessment |
| **NRC** | National Research Council |
| **SPSS** | Statistical package for social science |
| **UNEP** | United Nations Environment Programme |
| **USA** | United States of America |

**ABSTRACT**

Declining bee colonies have led to reductions in food production worldwide. Nevertheless, little is known about crop pollination in African countries, especially in Kenya, where pollination studies lack harmonization and only a few crops have been studied. This study sought to determine the abundance and diversity of bee pollinators visiting common bean (*Phaseolus vulgaris*) flowers along a forest-agriculture gradient, evaluate the effect of caged and uncaged pollination treatments on pod and seed set of common beans, and assess the level of farmers' indigenous knowledge of bee pollinators of common beans in Borabu Sub-County, Kenya. Nyansiongo Administrative Sub-location was purposively selected. A survey was conducted along three plots, extending from the forest edge of the natural habitat into the surrounding farmlands. Sampling points were established at 0.3 km intervals along each plot. Pollinator sampling was undertaken within 100 $m^2$ bean plots located at the designated sampling points. Sampling was conducted three times a week between 0730 hrs and 1200 hrs during the flowering period. Bee sampling was carried out for three months from January to March 2018 using sweep nets and pan traps. The pan traps consisted of three conspicuous colours; blue, white, and yellow which were randomly positioned at ground level within each 100 $m^2$ bean plot. Questionnaires were administered to bean farmers and bean farm managers to obtain information on bean crop pollination. Beans from each treatment were weighed, recorded, and their data analysed using a t-test. Diversity was computed using Shannon's diversity index, while abundance was determined using abundance curves. A total of 992 bee visitors belonging to two families and eight species were collected from the three study farms. The bee species diversity index ($H'$) yielded a value of $H' = 0.55$. There was an increase in crop quality and yields due to bee pollination. There was no significant difference between the number of pods in closed and open bean flowers ($p > 0.05$). There was a significant difference in seed weight between caged and uncaged bean plants ($p < 0.05$). There was also a significant difference in seed number between caged and uncaged bean plants ($p < 0.05$), as well as seed weight ($p < 0.05$). This confirms that bees enhance bean yields by improving both quality and quantity. *Apis mellifera* was the most commonly recognized bee species, as indicated by 42.7% of male respondents and 75.0% of female respondents, followed by *Xylocopa calens*, identified by 28.6% of male and 18.8% of female respondents, while *Meliponula* sp. and *Megachilidae* sp. were identified only by 7.1% of male respondents. There was no significant difference ($p > 0.05$) between male and female respondents regarding the methods or inputs used to enhance pollination. This indicates that awareness on pollination issues should target both male and female farmers. Therefore, farmers and other stakeholders should be sensitized and trained on the importance of bee pollination, its contribution to their welfare, and the utilisation of cost-effective strategies for bee conservation.

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background Information

Pollination is the process of sexual reproduction in plants, in which the male sexual cell, the pollen grain (a group of cells called gametophyte) is transferred to a female flower of the same species (Britannica, 2026). Fertilisation occurs when the pollen grains germinate on receptive stigma and subsequently fertilizes the female gametophyte (ovule) (Keystone Foundation, 2025; Britannica, 2026). Flowering plants require pollination to produce seed or fruit. Some plants are wind pollinated and others are self-pollinated, but many plant species require animal mediated cross pollination (Ritchie, 2024; Ghazoul, 2025). Those species capable of self-pollination or animal pollination can increase the quantity and quality of production (Sun *et al.*, 2024). Various plants have varied adaptations for different pollinators. The structure of the flower determines the extent to which a plant depends on an insect pollinator besides flower arrangement on a plant and flower self-sterility (Sagwe *et al*., 2023; Ghazoul, 2025).

Studies have shown that plant community composition, pollination syndromes, and pollinator types have historically been under-documented in Africa compared to other regions. While foundational work laid the groundwork, recent data suggests that the pollination gap in Kenyan crop productivity remains a significant challenge for most high-value crops (Sagwe *et al*., 2021). The lack of baseline data on specific wild pollinator species continues to hinder the development of targeted conservation strategies tailored to the East African context.

Pollination biology is of great ecological and conservation relevance, as changes in plant growth rates, population size, and community composition are intrinsically linked to reproductive success. Population size and diversity are markedly affected by the efficiency of the pollination process (Rodger *et al*., 2021). Pollinators are considered a "limiting factor" in agricultural productivity; even when water, fertilizer, and pest control are optimized, yields cannot reach their genetic potential without adequate pollen transfer. Pollinator abundance, diversity, and effectiveness are now used as primary bioindicators to assess the overall health of agricultural ecosystems (Garibaldi *et al*., 2020).

In agricultural systems, the "pollinator force" is essential for successful crop yields. This efficacy is determined by specific behavioral and physical characteristics, including high abundance, significant pollen-carrying capacity, high visitation frequency, and floral constancy (Rader *et al*., 2020). Furthermore, pollination is critical for genetic health; and there is prediction that limited dispersal of both seeds and pollen results in high relatedness among neighbors, making the mating of close relatives and subsequent genetic bottle-necking highly probable (Sagwe *et al*., 2023).

In small and isolated habitat fragments, a limited number of mating partners and reduced genetic variation increase the likelihood of inbreeding depression, which directly compromises crop vigor and yield (Ågren & Sletvold, 2025). Despite their importance, knowledge gaps persist regarding the resilience of feral pollination services provided by wild bees and their susceptibility to anthropogenic environmental changes, such as land-use intensification and climate change (Khalifa *et al*., 2021). Therefore, there is an urgent need in Kenya to document wild pollinators of economically vital crops to inform future food security strategies (Sagwe *et al*., 2021; Soli *et al*., 2024).

Pollination does more than just increase quantity; it significantly enhances the quality of harvests, such as the bean size (Rodger *et al*., 2021). Similarly, intercropping systems such as soya beans and maize offer stability and risk mitigation. These systems provide biological insurance, improve soil physico-chemical properties, and enhance the natural suppression of weeds and pests (Cheruiyot *et al*., 2022). When coupled with robust pollination services, these diversified systems maximize both food security and income for smallholder farmers.

Pollination is an essential agricultural input, comparable to labor, seed quality, or fertilizer (Dainese *et al*., 2019). Comprehensive studies on biotic pollination are vital for guiding policy formulation and management decisions, which remain underdeveloped in the Kenyan agricultural sector (Soli *et al*., 2024). Even where pollination increases yields, there is a lack of localized longitudinal studies linking these ecological services directly to long-term economic gains for rural farmers (Porto *et al*., 2020). Inadequate pollination remains a primary constraint for fabaceous crops; for example, faba bean (*Vicia faba*) yields significantly increase when nearby natural habitats support a diverse community of wild pollinators (Seddik & Ali, 2025).

**1.2 Pollinator Diversity**

The ecological interactions between plants and pollinators make important contributions to the global diversity of both plant and animal species. This is normally by facilitating sexual reproduction in flowering plants, maintaining genetic variation, structuring ecological communities, and supporting ecosystem stability and resilience (Porto *et al*., 2020). Recent research confirms that the nested architecture of plant-pollinator networks is a fundamental structural property that minimizes competition and increases biodiversity by promoting species coexistence (Song *et al*., 2017).

Diverse pollinator assemblages lead to enhanced pollination services, improved plant reproduction, and long-term ecosystem persistence (Allebone-Webb *et al*., 2025). This diversity and the accompanying community-level maintenance of pollination services are currently challenged by rapid environmental change and significant population declines of both plants and pollinators (Katumo *et al*., 2022). Pollinators provide extremely valuable services and benefits to society. By fortifying food security, pollinators play a foundational role in the cultivation of high-value cash crops, horticultural products, and non-timber forest products (NTFPs). These outputs ranging from essential nuts to bioactive medicinal plants constitute a vital pillar of African agrarian economies and rural livelihoods (Allebone-Webb et al., 2025).

The majority of African countries depend mainly on subsistence agriculture as their primary occupation. Most people depend on the vital pollination services delivered by a wide variety of different pollinator types (Braman & Griffin, 2022). Pollinators increase food security and contribute to the improvement of livelihoods and the increase of income for some of the world’s poorest populations, in Sub-Saharan

Africa (Otieno *et al*., 2025). While bees are recognized for pollinating the majority of the world's wild plant species and providing economically valuable services to crops, knowledge of specific strategies for bee conservation biology still frequently lags behind other beneficial taxa, such as parasitoids and predators (Braman & Griffin, 2022).

However, pollinators are among the biota most sensitive to disturbance, particularly from anthropogenic activities such as inappropriate pesticide use, habitat destruction, and grazing intensity and the intensification of land-use systems and changing farming practices (Souza *et al*., 2025). Bees are the most critical plant pollinators, and any decline in their numbers or species richness due to these human-driven disturbances constitutes a significant threat to biological diversity, ecosystem services, and entire agricultural economies (Montag, 2024).

Pollinator diversity is also important because different bee species complement each other in their pollination activities. A more diverse bee community provides superior pollination services, especially in mixed cropping systems, as different pollinators target different floral structures (Nyanumba *et al*., 2021). Diversity helps reduce the risk of service failure if a specific pollinator is absent during critical crop flowering periods. For example, honeybees (*Apis mellifera*) may abandon certain flower patches for more suitable ones; in such cases, having a variety of other bee species helps counteract the loss of honeybee function, ensuring stability through niche complementarity (MacInnis *et al*., 2023).

There is significant variation in the social behavior of bees, ranging from solitary to highly eusocial forms (Forster *et al*., 2023). In solitary types, the construction of the nest and the collection of food for offspring are carried out entirely at the individual level. On the other hand, in eusocial bees, there is clear specialization within the colony such as foragers and egg layers and cooperative care of the hive, as typically seen in *A. mellifera* (Forster *et al*., 2023).

Humans have a long history of rearing the eusocial honeybee (*A. mellifera*) for honey production. In the tropics, stingless bees (*Meliponula* spp.) also occur; these species are utilized for honey production and serve as essential pollinators (Rai *et al*., 2025).

While there are seven recognized bee families, only a few are intensively utilized for managed pollination. Pollen and nectar form the primary diet for bees, and many pollinators and plants have co-evolved such that specific plants require specific bee pollinators for effective reproduction (Forster *et al*., 2023).

Solitary bees have also been documented to visit crops frequently. These bees are often localized in open habitats, nesting in soils, pithy stems, or among herbs and shrubs (Braman & Griffin, 2022). Despite their solitary nature, they are often documented to pollinate plants more efficiently than honeybees in specific contexts (Rai *et al*., 2025). They provide an essential service by pollinating crops and ensuring that plant communities remain healthy and productive (Allebone-Webb *et al*., 2025).

### 1.3 Bean Pollination

Globally, dry bean production reached approximately 30.5 million metric tons in 2023, with top producers including Myanmar, India, and Brazil (ReportLinker, 2023). Smallholder farms in Mexico, Brazil, and across Africa continue to account for a significant portion of the world’s annual production, reflecting the crop's socio-economic importance in these regions (Chirwa & Mankhwala, 2021).

In Kenya, particularly in the Western region, recent studies have reaffirmed that bee pollination is a critical driver of yield, with insect-visited plants showing significantly higher pod and seed sets compared to those where pollinators were excluded (Elisante *et al.*, 2020). Thus, although some varieties are capable of self-fertilization, the presence of bees is essential to maximize agricultural productivity, improve food security, and bolster household income (Wekhanya *et al*., 2025). The pollination requirements for legumes are specific to their reproductive biology; while common beans (*Phaseolus vulgaris*) are often considered autogamous, they exhibit a strong positive response to insect visitation (Elisante *et al*., 2020). Conversely, other species like the lima bean (*P. lanatus*) are predominantly self-pollinated, with yield and quality showing less dependence on additional pollinator services (Komo *et al*., 2022).

Beans remain a vital source of protein, iron, and zinc globally, particularly for populations relying on plant-based diets (Jepleting, 2025). They possess a relatively short growing cycle and are highly versatile in various cropping systems, often serving as a cornerstone for crop rotation and intercropping due to their biological nitrogen fixation (BNF) capabilities (Chirwa & Mankhwala, 2021). In Kenya, *P. vulgaris* is the second most important staple food crop after maize, yet yields often fall below their potential due to environmental stressors and pollination deficits (Wekhanya *et al*., 2025). The growing demand for beans has intensified the need to study pollination ecology and the diversity of bee species, such as *Apis mellifera* and various solitary bees like *Xylocopa* species, which are frequent visitors in Kenyan bean fields (Elisante *et al.,* 2020; Wekhanya *et al*., 2025). Current research emphasizes that maintaining natural habitats near farmlands is vital for conserving these feral and solitary bee populations, which are the primary providers of pollination services in smallholder systems (Elisante *et al.*, 2020).

### 1.4 Statement of the Problem

Declines in pollinator abundance and diversity caused by anthropogenic disturbances such as habitat modification, fragmentation, intensive agriculture, and pesticide use negatively impact pollination services for agriculture worldwide (Feuerbacher *et al.*, 2025). Pollination services are increasingly recognised as critical ecosystem services that underpin both agricultural productivity and rural livelihoods, yet pollinator populations, particularly bees, are declining sharply due to multiple interacting threats such as climate change, habitat loss and fragmentation, pesticide exposure, and intensive agricultural practices (Olhnuud, 2025; FAO, 2025; Singh *et al*., 2025). Agricultural intensification often results in habitat destruction, agrochemical pollution, and simplified landscapes that reduce floral resources and disrupt pollinator movements, leading to decreased pollinator abundance and diversity (Jing *et al*., 2025). Evidence from Kenya indicates that common beans (*Phaseolus vulgaris* L.), a vital food and income crop for smallholder farmers, benefit from bee pollination in terms of pod set and quality, yet these benefits are under threat due to declining pollinator populations and ecosystem degradation (Masiga *et al*., 2014; Ojwang, 2017). Despite the importance of pollinator services, research in Kenya remains limited, with most interventions focusing on agronomic inputs rather than on understanding pollinator ecology, abundance, and their effects on bean yields in fragmented agricultural landscapes (Aika *et al*., 2024). Areas such as Borabu Sub-County, characterised by high human population pressure, deforestation and land fragmentation, typify landscapes where pollinator decline could reduce bean yield and household food security. This study therefore sought to assess the abundance and diversity of bee pollinators in common bean (*P. vulgaris*) agroecosystems along a forest-agriculture gradient, bridging this knowledge gap and informing effective policies and farmer sensitisation on pollinator conservation and sustainable pollination management.

### 1.5 Justification of the Study

Globally, food security has been a main concern to many countries. In Kenya common bean is the most important source of protein for many households (FAO, 2025). Consumption and contribution of common bean to human nutrition in Kenya is high. The common bean is grown for its green leaves, green pods and immature and or dry seeds. The dry seeds are the ultimate economic part of the bean plant. High in nutrients and commercial potential, common bean holds great promise for fighting hunger, increasing income and improving soil fertility in sub-Saharan in Africa. The trends in production show that the acreage of crops requiring pollination is increasing (Sagwe *et al.,* 2023).

Therefore, the current food security is supported by pollinators, which make a contribution estimated at hundreds of billions of US dollars each year, representing a substantial portion of global agricultural food production (Elisante *et al*., 2020). In Kenya, few studies have been carried out on crop pollination requirements and most have focused on abundance and diversity of bee species on varied habitats only; for example, research on assessment of abundance and diversity of bee species in various agroecological zones in the Loitokitok area of Kenya identified honey bees (*Apis mellifera* L.) and wild bee species as the primary pollinators of the crop (Aika *et al*., 2024).

The government, farmers, and other stakeholders need to understand the need for optimal bean crop production since there is evidence that when pollination is inadequate, yields are significantly reduced (Elisante *et al*., 2020). There are no widely reported managed pollination services in Kenya and therefore farmers depend largely on feral pollination agents, yet bees are among the main agents of pollination for most agricultural crops. Pollinators can enhance the quantity and quality of seeds and fruits even of self-fertile crops by facilitating cross-pollination and improving reproductive success (Gazzea *et al*., 2023). Therefore, this study sought to provide missing information on abundance and diversity of bee pollinators in common bean (*Phaseolus vulgaris*) agroecosystems along a forest-agriculture gradient in Borabu, Kenya.

## 1.6 Hypotheses

**$H_{01}$** There is no significant difference in the abundance and diversity of bee pollinators in common bean (*Phaseolus vulgaris*) farms along a forest-agriculture gradient in Borabu Sub-County, Kenya.

**$H_{02}$** There is no significant difference in pod and seed set of common beans (*Phaseolus vulgaris*) between caged (pollinator-excluded) and uncaged (open-pollinated) treatments across agroecosystems along the forest-agriculture gradient in Borabu, Kenya.

**$H_{03}$** There is no statistically significant level of farmers' indigenous knowledge of bee pollinators of common beans in Borabu Sub-County, Western Kenya.

## 1.7 Objectives

### 1.7.1 General Objective

To assess the abundance and diversity of bee pollinators in common bean (*Phaseolus vulgaris*) agroecosystems along a forest-agriculture gradient in Borabu, Kenya.

### 1.7.2 Specific Objectives

1. To determine the abundance and diversity of bee pollinators visiting common bean (*Phaseolus vulgaris*) flowers along a forest-agriculture gradient in Borabu Sub-County, Western Kenya.

2. To evaluate the effect of caged and uncaged pollination treatments on pod and seed set of common beans in Borabu Sub-County, Western Kenya.

3. To assess the level of farmers' indigenous knowledge of bee pollinators of common beans in Borabu Sub-County, Western Kenya.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Diversity of Bees

Bees constitute one of the most important and diverse groups of pollinating insects globally, with approximately 20,000 described species, although this figure is widely regarded as an underestimate due to ongoing taxonomic discoveries and unresolved species complexes (Orr *et al.*, 2023). The majority of bee species are solitary, nesting independently rather than forming social colonies, and exhibit diverse life-history strategies and foraging behaviors that contribute significantly to ecosystem functioning (Michener, 2007). Solitary bees often display strong associations with particular plant taxa and are recognized as efficient pollinators due to their high pollen fidelity and lack of nectar or pollen robbing behavior (Brittain *et al*., 2013).

In the America, extensive research has documented exceptionally high bee diversity, particularly in tropical and subtropical regions where habitat heterogeneity supports rich assemblages of solitary and social bees. Studies in North and South America demonstrate that wild bee communities contribute substantially to crop pollination, often exceeding the pollination services provided by managed honey bees, especially in diversified agroecosystems (Klein *et al*., 2007; Winfree *et al*., 2018). Functional complementarity among bee species arising from differences in body size, tongue length, activity periods, and floral preferences has been shown to enhance pollination stability and crop yield under variable environmental conditions (Gagic *et al*., 2015).

In Britain and across Europe more broadly, bee diversity is comparatively lower in species richness than in tropical regions but remains ecologically significant (Dicks *et al*., 2021). Long-term monitoring studies have revealed pronounced declines in both bee abundance and distribution, particularly among specialist solitary bees, largely attributed to agricultural intensification, habitat fragmentation, and pesticide use (Potts *et al*., 2016). Nevertheless, evidence from the United Kingdom indicates that diverse wild bee communities continue to play a critical role in pollinating both wild flora and crops such as oilseed rape, apples, and field beans, especially where agri-environment schemes promote floral resource availability (Dicks *et al*., 2021).

Across Asia, bee diversity spans a wide ecological gradient, from temperate regions to tropical forests, supporting both wild and managed pollination systems (IPBES, 2016). Studies in South and Southeast Asia have emphasized the importance of native bee species, including stingless bees and solitary bees, in pollinating crops such as coffee, cucurbits, and legumes, often under smallholder farming systems (Garibaldi et al., 2016). Rapid land-use change, monoculture expansion, and pesticide exposure, however, pose increasing threats to native bee populations, with implications for food security in the region (IPBES, 2016).

In West Africa, bee fauna is characterized by moderate species richness but high ecological importance, particularly within forest-savanna mosaics and traditional agroforestry systems. Studies have pointed out that indigenous bee species contribute significantly to the pollination of both wild plants and cultivated crops, although regional knowledge remains fragmented due to limited taxonomic and ecological surveys (IPBES, 2016). The reliance on natural habitats for nesting and forage underscores the vulnerability of West African bee communities to deforestation and land conversion.

Sub-Saharan Africa as a whole hosts six of the seven globally recognized bee families, with approximately 2,600 described species recorded to date, reflecting moderate diversity relative to global totals but considerable generic richness (Orr *et al*., 2023). Most genera are either cosmopolitan, suggesting long evolutionary histories within the region. Despite this, comprehensive taxonomic and ecological assessments remain incomplete, particularly for solitary bees, limiting accurate estimates of species richness and distribution (Michener, 2007).

In East Africa, and Kenya in particular, research on bee diversity has focused primarily on natural forests and adjacent agricultural landscapes. Early surveys around Mount Kenya documented diverse bee assemblages associated with both indigenous vegetation and cultivated crops, highlighting the importance of habitat mosaics for sustaining pollinator populations (Gikungu, 2002). More recent studies in western Kenya and coastal forest ecosystems, including Kakamega Forest and Kaya landscapes, have demonstrated that bee diversity and abundance decline along disturbance gradients, closely tracking changes in floral resource availability and habitat structure (Chiawo *et al*., 2017; Tsingalia & Mandela, 2023).

Kenya hosts both managed and wild pollinators, notably the western honey bee (*A. mellifera* L.) and several species of stingless bees (*Meliponula* spp.), which are valued not only for pollination services but also for hive products such as honey, propolis, and beeswax (FAO, 2023). Stingless bees are particularly efficient pollinators of certain crops due to their ability to forage within complex floral morphologies and under low-light conditions (Chiawo *et al*., 2017). Despite their importance, empirical studies linking native bee diversity to crop yield and quality especially in legumes such as common beans remain limited, affirming the need for further research in Kenyan agro-ecosystems.

### 2.2 Bee Habitats and Floral Resources

Flowers are the mainstay of bees' life: they provide nectar (carbohydrates) and pollen (proteins and lipids) that sustain foraging and brood development. Studies have demonstrated that bees depend on a spatially and temporally continuous supply of floral resources throughout their activity period to support both individual nutrition and colony health (Eckerter *et al*., 2022). In agricultural habitats, crops often provide abundant floral resources only briefly during bloom, forcing pollinators to seek additional floral sources in adjacent semi-natural or wild habitats (Eckerter *et al*., 2022; Hyjazie & Sargent, 2022).

In North America, studies have shown that forests and deciduous woodlands with diverse understory flora support rich bee communities, highlighting that not only open fields but diverse natural habitats contribute key floral resources across seasons (Hyjazie & Sargent, 2022; Ulyshen *et al*., 2023). For example, honeybees and wild bees utilize canopy tree flowers, shrubs, and herbaceous layers for pollen and nectar, with temporal complementarity of resources supporting bee diversity (Hyjazie & Sargent, 2022; Ulyshen *et al*., 2023).

In Britain, long-term assessments of floral resources have demonstrated that overall nectar availability declined with agricultural intensification, though targeted management (e.g., permitting clover and other grassland flowers) can increase nectar provision for pollinators (Baude *et al*., 2016). Nectar resource trends mirror long-term changes in pollinator diversity, indicating that flower loss is linked with bee declines across temperate landscapes (Baude *et al*., 2016; British Ecological Society, 2019).

Across Asia, ecological studies reveal that semi-natural and disturbed habitats differ substantially in bee and floral resource dynamics: semi-natural habitats sustain higher bee abundance, species richness, and floral visitation compared to disturbed habitats, underscoring the importance of maintaining flower-rich, minimally disturbed landscapes for pollinator survival (Gerner & Sargent, 2021; Sydenham *et al*., 2025). Certain bee species such as the large carpenter bees in Asia forage on diverse floral resources and nest in woody substrates, illustrating how habitat complexity influences both nesting and floral resource use (Raju & Purnachandra, 2006).

Floral resource diversity not only supports bees' nutritional needs, but it also enhances pollination services and biodiversity resilience: landscapes that maintain hedgerows, forest edges, and flower strips show increased bee abundance and species richness (Hyjazie & Sargent, 2022). Conservation strategies thus emphasize protecting and restoring species-rich floral habitats rather than relying solely on planting flowers, because high plant diversity ensures continuous and varied pollen and nectar sources across seasons (Eckerter *et al*., 2022; Subramanian, 2025).

In West Africa, native and wild pollinators heavily depend on regionally adapted flowering plants that supply nectar and pollen through dry and wet seasons. Though detailed floral resource documentation is still developing for this region, African ecological analyses highlight that forage continuity and diversity are critical for pollination services in many cropping systems, and shifts in land use reduce available forage (Katumo *et al*., 2022; Subramanian, 2025).

In Kenya, honeybees (*A. mellifera* L.) occupy a range of grasslands, forests, marshlands, rangelands, and farmlands, using both cultivated and wild flowering plants for nectar and pollen (Eardley *et al*., 2009). Habitat heterogeneity including native wildflowers and flowering trees enhances landscape-scale floral resource availability and supports both managed and wild bees (Eardley *et al*., 2009). Different pollinator groups also have distinct habitat structures and resource needs. Moths and butterflies require larval host plants in addition to adult nectar sources (Karanja *et al*., 2013).

## 2.3 Bee Pollination of Crops

Pollinators are key components of global biodiversity and essential for maintaining ecological processes, including pollination, which is largely responsible for the reproductive success of most native and cultivated plants (Gleiciani *et al*., 2014; FAO, 2025). Agricultural crops that are animal-pollinated depend heavily on bees for successful pollination: bees visit flowers, transfer pollen, and improve fruit set and seed quality. Globally, bees alone contribute to approximately 30% of total human dietary supply through pollination services, underscoring their central role in food systems (FAO, 2025).

In America, pollination services provided by bees are critical to both smallholder and large-scale agriculture. In the United States, insect pollinators including managed honey bees (*A. mellifera* L.) and native wild bees provide roughly US$34 billion in agricultural value annually (Live Science, 2025). However, declines in bee populations due to habitat loss, pesticides, diseases, and climate change have contributed to pollinator shortages on many farms, limiting yields of crops such as almonds, berries, and legumes (Live Science, 2025). In Latin America's Amazon region, indigenous stingless bee species now receive legal recognition due to their unique pollination role for cacao, coffee, and avocado, highlighting cultural and ecological priorities in crop and forest systems (The Guardian, 2025).

In Britain and Europe, bee pollination remains fundamental to crop yields, but wild pollinator species are increasingly threatened. Studies have shown that the number of wild bee species at risk of extinction in Europe has more than doubled, with bumblebees and specialist solitary bees particularly affected by intensive agriculture and habitat loss (Zattara & Aizen, 2020). European honey bees and bumble bees (*Bombus* spp.) are widely used in greenhouse crop systems such as tomatoes and berries, where their foraging behavior significantly enhances fruit set (Huang *et al*., 2025). However, reliance on managed honey bees alone can mask declines in wild pollinators, which often contribute disproportionately to pollination resilience under environmental stress (Magrach *et al*., 2017).

In Asia, diverse bee taxa play vital roles in crop pollination. Research in India has identified native stingless bees such as *Tetragonula iridipennis* and *Lepidotrigona arcifera* as effective pollinators, significantly increasing crop yields and seed quality in chilli and other horticultural crops (Times of India, 2025).

In Japan, the solitary horned-face bee (*Osmia cornifrons*) has been successfully integrated into apple orchard pollination, demonstrating the value of region-specific bee species for crop productivity beyond the managed honey bee (Wikipedia, 2025). Despite these successes, many Asian farmers still under-value pollination services, reflecting a worldwide need for greater awareness of pollinator benefits (FAO, 2025).

Across West Africa, bee pollination supports both subsistence farming and cash crops. Bees enhance yields in important crops such as cotton, sunflower, and various legumes, with research in Sub-Saharan Africa demonstrating that pollination can increase cotton output by up to 62% compared to un-pollinated controls (Khalifa *et al*., 2021). West African beekeepers also leverage honey bees for pollination and livelihood diversification, though robust data on wild pollinators remains limited. Conserving agricultural landscapes that support diverse bee communities is essential to sustaining crop yields and economic income in these regions (FAO, 2025).

In East Africa, particularly in Kenya, Ethiopia, and surrounding highland regions, both managed and wild bees contribute significantly to the production of vegetables, legumes, and oilseed crops. Studies have indicated that pollination services dramatically improve yields of cowpea, beans, sunflower, and passion fruit, with bee pollination responsible for a large portion of annual crop production in smallholder systems (Khalifa *et al*., 2021). Despite this, farmers in many areas still view bees primarily as pests, resulting in under-investment in pollinator management and monitoring. Greater research and extension efforts are needed to identify effective wild pollinators and integrate them into strategies for sustainable crop production and food security (FAO, 2025).

Bee pollination success depends on characteristics such as pollinator abundance, flower-visiting frequency, pollen load, and pollinator diversity (Karanja *et al*., 2013; Khalifa *et al*., 2021). A species-rich bee community offers better pollination services, particularly in mixed cropping systems where different pollinators may preferentially visit different crops (IPBES, 2017). Managed honey bees (*A. mellifera* L.) are widely used due to their large colony sizes and ease of management, but wild bees including bumble bees and solitary bees often contribute more fruit set per visit and improve resilience against environmental fluctuations (IPBES, 2017; Katumo, 2022).

In Kenya, Chiawo *et al*., (2017) and Aika *et al*., (2024) have observed that enhancing and conserving pollinator diversity is critical to reinforcing agricultural productivity, ecosystem health, and food security globally). Thus, this study sought to assess the abundance and diversity of bee pollinators in common bean (*P. vulgaris* L.) agroecosystems along a forest-agriculture gradient in Borabu, Kenya.

**2.4 Threats to Bees**

Human-driven alterations of habitats remain a principal threat to bee populations globally (FAO, 2025). Intensive agricultural expansion, urbanization, and large-scale livestock rearing reduce floral diversity, nesting sites, and mating habitats, ultimately diminishing bee abundance and effective pollinator services.

Reduced pollinator abundance and species extinctions have profound ecological and evolutionary consequences for plant communities, food webs, and ecosystem function. These impacts are especially acute in the tropics, where biodiversity is high and reliance on animal pollination is greatest (Cornelisse *et al*., 2025; UNESCO, 2025). Without urgent, coordinated conservation and habitat restoration efforts, declines in bee populations will continue to jeopardize both natural ecosystems and global food systems.

In the United States, wild and managed bee declines have been linked to habitat loss, pesticide use, climate change, parasites, and pathogens, with direct impacts on crop pollination services and economic value of pollinators in agricultural systems (Guzmán *et al*., 2024; Cornelisse *et al*., 2025). Wild bee species in some North American regions now face elevated extinction risk, with habitat fragmentation and agrochemical exposure as key drivers (Cornelisse *et al.*, 2025). Moreover, extreme weather events related to climate change have contributed to significant honey bee colony losses, such as reported dramatic declines in Texas linked to heat, drought, and erratic flowering patterns that reduce forage availability (Houston Chronicle, 2025).

Across Britain and Europe, long-term monitoring reveals pervasive declines in insect pollinators, indicating habitat destruction, agricultural intensification, and pervasive pesticide use as core drivers. Citizen science data show a 63 % drop in flying insect populations (including bees and butterflies) between 2021 and 2024, reflecting systemic pressures from habitat loss and chemical exposure (Foucart, 2025). An updated IUCN assessment found nearly 9 % of Europe's wild bee species as threatened with extinction, with agriculture-related habitat degradation and nitrogen pollution exacerbating declines (Mouterde, 2025). Emerging environmental threats such as artificial lighting, microplastics, and air pollution have also been identified as additional stressors weakening pollinator health and foraging behaviour (Potts *et al*., 2025).

In Asia, recent research affirms the complex influence of climate change on plant-pollinator synchrony. Climate-driven mismatches between temperature, plant phenology, and pollinator activity can disrupt bee foraging and reproduction, compounding habitat loss and agrochemical impacts on pollinator populations (Rahimi & Jung, 2025). Studies in South Asia have also directly linked widespread pesticide exposure to significant reductions in pollinator populations and potential losses in global crop yields, highlighting the urgent need to reassess pesticide use policies (Times of India, 2025).

In West Africa, although detailed population trends are less extensively documented than in temperate regions, pollinator decline is a growing concern. Habitat fragmentation from expanding agriculture and elevated pesticide application contribute to diminishing bee diversity, reducing pollination services critical to food security in smallholder systems (Subramanian *et al*., 2025). African apiculture surveys reveal variable honeybee colony loss rates across countries, with land-use change and pesticide exposure consistently implicated as major stressors for both managed and wild bees (Nganso *et al*., 2025).

In East Africa, habitat fragmentation and climate variability negatively affect plant-bee interaction networks. Research shows that fragmentation and reduced floral diversity disrupt mutualistic links, lowering network resilience and increasing vulnerability to local extinction cascades (Foryuy *et al*., 2024). Conservation efforts emphasize maintaining continuous natural habitats to support stable pollination services in montane ecosystems.

In Kenya, empirical evidence confirms ongoing pollinator declines linked to agricultural intensification, deforestation, and pesticide use. Kenyan farmers have reported significant losses in bees, wasps, and butterflies pollinators that underlie approximately 75 % of crop pollination threatening food production and livelihoods (Business Daily Africa, 2025). Beekeeping surveys indicate a notable decrease in swarm availability over recent years, with pesticide exposure, land-use change, and climate pressures reducing colony sources essential for sustainable apiculture (Nganso *et al*., 2025). The integration of pollinator conservation into national agricultural policy and community practices is increasingly advocated to safeguard Kenya's pollination services and food security.

### 2.5 Economic Importance of Pollination in Crops

The importance of pollination in agriculture has been recognized for millennia, yet it is only in recent decades that pollination ecology has been integrated into mainstream agricultural and biodiversity research (FAO, 2025). Pollination services are crucial for the reproductive success of many flowering plants and underpin global food production. Between 35% of global crop production (by volume) and over US$235 billion-US$577 billion in annual agricultural output rely on animal pollinators, primarily insects, highlighting their immense economic value to agriculture worldwide (FAO, 2025).

According to FAO (2025), pollination services not only support food production and nutrition but also contribute to ecosystem resilience, agricultural diversity, and rural economies across the world. Protecting pollinator diversity both managed and wild is increasingly recognized as an urgent requirement for sustaining agricultural productivity in the face of climate change, habitat loss, and biodiversity declines.

Globally, honey bees (*Apis mellifera* L.) are the most widely managed pollinators, significantly enhancing the yield and quality of many crops; however, wild pollinators (native bees, hoverflies, beetles, and butterflies) contribute substantially and, in many cases, are more effective in boosting crop yields across diverse environments (Khalifa *et al*., 2021). Animal pollinators enhance production of over 87 major global food crops, including fruits, vegetables, nuts, and oilseeds, which are critical for both food security and nutrition (FAO, 2025).

In the United States of America, pollination services are vital to crop productivity and the agricultural economy. Recent research shows that crops such as apples, cherries, blueberries, watermelon, and pumpkins exhibit pollination limitation yield losses due to insufficient pollination which can be directly tied to reductions in pollinator abundance (Porto *et al*., 2020). Wild pollinators and managed honey bees together contribute similar pollination services for many crops, with the estimated annual value of wild pollinators alone exceeding US$1.5 billion for a subset of key pollinator-dependent crops. Furthermore, production of pollinator-dependent crops in the U.S. generates more than US$50 billion in annual agricultural value, affirming the economic weight of these ecosystem services (Porto *et al*., 2020).

In Britain, pollination services significantly enhance agricultural output, especially for high-value fruit and vegetable crops (Elliot *et al*., 2020). Bees and other pollinators add over £600 million yearly to crop production in the UK, increasing both yield and quality in commodities like apples, strawberries, field beans, and oilseed rape (Murphy *et al*., 2022). These pollination services extend economic benefits beyond farms to processors, retailers, and consumers and are integral to resilient food systems amidst pollinator declines.

In Asia, recent entomological research continues to reveal the economic and agronomic benefits of pollinators beyond *A. mellifera* L. (Kalita, 2025). For example, stingless bees such as *Tetragonula iridipennis* and *Lepidotrigona arcifera* have been shown to significantly increase yields and seed quality in chilli crops, offering new avenues for sustainable pollination management and added income opportunities for farmers while emphasising the need to conserve native pollinator diversity (Kalita, 2025).

In West Africa, pollination services are critical for staple and cash crops such as cocoa (*Theobroma cacao*), where pollination limitation is a key factor in yield stagnation (Wanger *et al.*, 2021). Enhancing pollination through biodiversity-friendly agroforestry or manual pollination can substantially increase yields and farmers' profits, with modelling studies showing potential increases in cocoa production and profitability under improved pollination or ecosystem management strategies (Wanger *et al*., 2021).

In East Africa, and particularly in Ethiopia, recent empirical studies quantify the rising economic contribution of insect pollination to national crop production (Gebremedhn *et al*., 2025). Between 1993 and 2023, the economic value of insect pollination in Ethiopia increased more than fivefold, with pollinator-dependent crops contributing nearly US$2.3 billion of crop value in 2023. These data demonstrate the growing economic and nutritional importance of pollinators for food security in agriculture-dependent regions (Gebremedhn *et al*., 2025).

In Kenya, pollination services are essential for smallholder agriculture, where unmanaged bee pollination enhances crop yields and improves quality across diverse vegetables, legumes, and fruits (Kasina *et al*., 2009; Chiawo *et al*., 2017). Historical research in Kakamega District showed that bee pollination could account for nearly

40% of annual crop value in smallholder systems, emphasising the substantial on-farm economic returns of pollination for rural livelihoods and food security (Kasina *et al*., 2009).

## 2.6 Threats to Pollinators

Bees remain the predominant and most economically important pollinators in most geographical regions, and pollination by bees and other animals enhances the size, quality, and stability of harvests for a large proportion of the world's crops. Approximately 85% of flowering plant species and 87 of the world's leading crops depend on animal pollinators for successful reproduction and seed set (Brunet & Fragoso, 2024). However, managed honeybee colonies have experienced persistent and substantial annual losses globally, often exceeding sustainable thresholds, which places increasing emphasis on the contributions of wild pollinators to crop pollination services (US Pollinator Conservation, 2025). Recent assessments show that both managed and wild bees are facing multiple, interacting pressures that drive declines in abundance, diversity, and ecosystem function (Cornell CALS, 2025; Knauer *et al*., 2026).

Habitat loss and fragmentation primarily driven by agricultural expansion, urbanization, and land-use change remain among the largest threats to pollinator populations worldwide. The reduction of diverse floral resources, nesting sites, and semi-natural habitats limits the availability of essential forage and breeding environments for pollinators, and can isolate populations, reducing genetic diversity and increasing local extinction risk (Cornell CALS, 2025; Knauer *et al*., 2026). At the same time, pesticide exposure, particularly to systemic insecticides like neonicotinoids and complex mixtures of agrochemicals, negatively affects survival, navigation, immune function, and reproductive success of both honeybees (*A. mellifera* L.) and wild bees in agricultural landscapes (Cornell CALS, 2025; Knauer *et al*., 2026).

Pollinators are also threatened by parasites, pathogens, and disease, which are major drivers of honeybee colony losses and can spill over into wild pollinator populations. Parasites such as *Varroa destructor* mites and fungal pathogens weaken immune responses and interact synergistically with other stressors such as poor nutrition and pesticide exposure to exacerbate declines (Brunet & Fragoso, 2024; US Pollinator Conservation, 2025). Moreover, climate change is increasingly recognized as a principal threat by altering temperature and precipitation regimes, phenological synchrony between plants and their pollinators, and the spatial distribution of suitable habitats. These climatic shifts can reduce floral resource availability, increase desiccation and heat stress, and lead to mismatches between pollinator emergence and peak flowering periods, ultimately undermining pollination services (Kazenel *et al.*, 2024; Pollinator.org, 2025; Oliveira *et al*., 2025).

### 2.6.1 Agricultural Intensification

In North America, agricultural intensification particularly heavy pesticide application has been identified as a major driver of wild bee declines and altered pollinator health (NSF, 2024). Large-scale analyses across the contiguous United States show that increasing pesticide use correlates with substantial decreases in occupancy for multiple wild bee families, including Apidae (e.g., bumble bees) as pesticide intensity rises, indicating that intensive pesticide regimes in agroecosystems pose a significant risk to both wild and managed pollinators (Guzman *et al*., 2024). Pesticides such as neonicotinoids and pyrethroids have been specifically implicated in driving changes in wild bee species occupancy and abundance, and reducing foraging effectiveness and reproductive success (Guzman *et al*., 2024; NSF, 2024).

In Britain, nationwide monitoring has revealed dramatic declines in insect populations including pollinators linked to habitat loss and pervasive pesticide exposure. Large participatory studies demonstrate steep declines in flying insects across the UK, with pesticides identified alongside habitat loss and climate change as a key contributor to these losses, highlighting inadequacies in current environmental risk assessments for agricultural chemicals and their chronic, landscape-wide effects (Foucart, 2025).

Across Asia, research specifically in China, comprehensive risk assessments indicated that current pesticide regulatory frameworks largely focus on the western honey bee and fail to capture the diverse vulnerabilities of soil-nesting and wild bee species, with most wild pollinators exposed to lethal and sub-lethal risks via soil pesticide residues that are overlooked in standard assessments (Shagun, 2026).

In West African countries, while detailed empirical data remain limited, available literature and regional reports caution that intensive pesticide use under agricultural intensification may threaten pollinators. Traditional beekeepers near cotton and other pesticide-treated fields report lower bee abundance and hive productivity, suggesting that pesticide exposure in agroecosystems could negatively affect pollinator populations in the region (CBD, 2022).

In the broader East African context, pesticide applications have been implicated in dramatic, acute pollinator losses during pest crises, such as locust control campaigns. Chemical sprayers deployed during the 2019-2021 desert locust outbreaks in Kenya and Ethiopia were associated with massive honeybee die-offs, indicating how broad-spectrum pesticide use in response to agricultural pests can devastate essential pollinators (Vyawahare, 2023).

In Kenya specifically the agricultural policy landscape, the government has implemented input subsidy programmes, such as subsidized fertilizer schemes and other input support measures, intended to lower production costs and boost productivity among smallholder farmers. These subsidies often target essential inputs like fertilizers and seeds, with the aim of improving food security and farmer incomes, although coverage and targeting have been critiqued for lacking clear coordination and focus on sustainable practices (MoALD, 2025).

Additionally, research and national data reveal a significant correlation between pesticide usage and declining bee populations (Business Daily Africa, 2021). Studies indicate that commonly used insecticides, including neonicotinoids and pyrethroids, are negatively associated with bee health, foraging behavior, and reproduction, raising concerns for both pollination services and agricultural productivity. Moreover, most pesticides classified as toxic or highly toxic to bees remain approved for Kenyan use without the stringent restrictions seen in some other regions, exacerbating pollinator risk under current agricultural intensification practices (Business Daily Africa, 2021; Mwangi, 2024).

### 2.6.2 Parasites and Pathogens

In America, *Varroa destructor* mites are among the most significant biological drivers of honeybee (*A. mellifera* L.) colony loss, not only through direct parasitism but also by vectoring a suite of viral pathogens such as deformed wing virus (DWV) and chronic bee paralysis virus (Bartlett *et al*., 2024). These parasites weaken bees by feeding on fat bodies, compromising immunity, and facilitating viral replication, which synergistically increases mortality and contributes to widespread colony declines observed year-on-year (Hristov *et al*., 2020). Moreover, controlled field studies demonstrated that exposure to systemic neonicotinoid insecticides (e.g., clothianidin and thiamethoxam) can increase the severity of *Varroa* infestation and reduce colony survivorship, likely via sublethal immunosuppression that exacerbates parasite impacts (Bartlett *et al*., 2024).

In the United Kingdom, parasite-pathogen interactions are also central to bee health concerns. The ectoparasitic *Varroa destructor* continues to be a leading cause of winter and overwintering losses in managed colonies, prompting widespread treatment practices among beekeepers. Surveys indicate that most beekeepers in the UK routinely treat hives chemically to control *Varroa*, reflecting the ongoing threat posed by mite-associated pathogens and their contribution to colony weakness and collapse, particularly when integrated with environmental stressors such as pesticides and management practices (Martín-Hernández, 2018).

In Asia, according to Blot *et al*. (2023), honey bee health is also influenced by a complex of parasites and pathogens. Parasitic mites such as *Varroa destructor* and *Varroa underwoodi* infest both Western and Asian honey bee species, facilitating the spread of multiple viruses and microsporidian pathogens like *Nosema ceranae*. These pathogens reduce bee immunity and lifespan, and interactions between neonicotinoid pesticides and *Nosema* infections have been shown to amplify toxicity and mortality in *Apis* species across several Asian contexts, affirming how combined biological and chemical stressors compromise bee colony health (*Nosema ceranae* synergistic effects with insecticides; *Tropilaelaps clareae* parasitism in Southeast Asia).

In West African countries, though comprehensive toxico-ecological studies are fewer, emerging evidence from the broader African continent suggests that honeybee populations can host *Varroa* mites and *Nosema microsporidia*. However, regional apiculture dynamics including differing environmental conditions and beekeeping practices influence the impact of these parasites on colony health (Willis *et al.*, 2022; Schüler *et al.*, 2023).

In East African countries, parasitic mites and microsporidian pathogens are present but may not yet have the same level of detrimental impact seen in temperate regions for bees (Pirk *et al.*, 2015). Surveys across Tanzania found that *Varroa* mites and *Nosema apis* occur in honeybee colonies, but colony size and survival did not yet show strong negative correlations with parasite levels. Only a few viral pathogens common in Western hives were detected at low frequencies, and pesticide residues in hives were generally at low concentrations (Pirk *et al.*, 2015).

In Kenya specifically, baseline data indicate that *Varroa destructor, Nosema* microsporidia, and a subset of common bee viruses have established in apiaries across various ecological zones (Dida *et al.*, 2021). While these biological stressors are present, there is not yet conclusive evidence linking them to widespread colony collapse; Kenyan bees have, to date, shown resilience in colony size despite parasite presence (Muli *et al.*, 2014). Low pesticide levels detected within Kenyan hives suggest that agrochemical-mediated immunosuppression which exacerbates susceptibility to parasites and pathogens elsewhere may currently be a less dominant factor, though shifts in agricultural chemical use could change this trajectory. Long-term surveillance is needed to assess dynamic interactions between parasite loads, pathogen prevalence, pesticide exposure, and bee immune responses in Kenya (Irungu *et al.*, 2016).

### 2.6.3 Monocultures

Across the United States, conversion of heterogeneous landscapes into large fields of single crops has contributed to habitat loss and fragmentation for both managed and wild pollinators, which is recognized as a major driver of pollinator declines (National Research Council, 2007 as cited in CEC, 2024). Monocultures such as expansive row crops provide abundant nectar only during brief flowering periods, limiting continuous food resources, and thereby weakening pollinator nutrition and immune systems (St. Clair *et al*., 2020). Furthermore, heightened prevalence of crop pests and pollinator parasites has been observed in sunflower monocultures in California's Central Valley, indicating that simplified landscapes promote disease spread among bees by concentrating pollinator hosts in limited floral resources (Cohen, 2021).

In Britain, long-term ecological research reveals that agricultural intensification and reduced plant diversity associated with monocultures and improved grasslands drastically diminish wildflower abundance and pollinator numbers (Balfour *et al*., 2025). The Park Grass experiment in Hertfordshire documented that high fertilizer inputs which often accompany monoculture pasture and crop systems cut flower numbers fivefold and reduced pollinator populations by as much as half, demonstrating the direct biodiversity costs of simplified agricultural land use (Balfour *et al*., 2025). Evidence from temperate agroforestry systems further shows that wild pollinator species richness and abundance are substantially higher in diverse landscapes compared with monocultures, reinforcing that landscape complexity supports pollinator biodiversity better than uniform cropping systems (ScienceDirect, 2025).

In Southeast Asia, conversion of forests to oil palm plantations reached hundreds of thousands of hectares annually in the early 21st century, intensifying ecological simplification and negatively impacting multiple species groups, including pollinators indirectly through habitat loss and altered landscape structure (Shah *et al.,* 2019). These monoculture plantations often lack understorey flowering plants and structural diversity, further reducing available resources for insects and other pollinators that depend on diverse plant communities for sustenance and nesting habitats.

In East African countries, Grass *et al*., (2018) established that habitat degradation and land-use change associated with agriculture have been linked to declining pollinator populations. Broad regional surveys across Sub-Saharan Africa report average managed honeybee colony losses of over 20 percent, with land use change including expansion of simplified agricultural landscapes among the key pressures reducing pollinator resilience (Cumming *et al*., 2017).

In Kenya, a study by Njue *et al*., (2023) which focused on insect flower visitors on macadamia monoculture orchards in Murang'a County recorded diverse pollinator taxa including bees, butterflies, and flies indicating that even monoculture crops can support some pollinator activity; however, the overall diversity and temporal distribution of these species varied with seasonal flowering patterns and landscape context, suggesting that uniform cropping systems alone are insufficient to sustain pollinator communities year-round without diverse surrounding habitats. This affirmed the importance of maintaining surrounding floral diversity and mosaic landscapes to support pollinator biodiversity in Kenya's agricultural zones.

### 2.6.4 Industrial Practices

In America, intensive agricultural practices such as widespread tillage, irrigation infrastructure expansion, and removal of semi-natural vegetation have been shown to disrupt pollinator habitat and nesting sites, contributing to declines in both abundance and diversity of wild pollinators (Potts *et al*., 2016; Millard *et al*., 2021). Increased use of synthetic pesticides under conventional intensive agriculture increases exposure of pollinators to lethal and sub-lethal toxicants, which disrupt foraging, reproduction, and colony health, and in turn can directly reduce pollination services for crops like almonds, berries, and apples (Shi *et al*., 2024; U.S. Fish & Wildlife Service, 2026). Moreover, unmanaged landscape simplification through extensive monoculture reduces floral resource diversity and nesting opportunities, exacerbating the vulnerability of native bees and other pollinators (Potts *et al*., 2016).

In Britain, agricultural intensification and land use change characterized by removal of semi-natural habitats, increased pesticide use, and simplified landscape mosaics have been linked with widespread declines in pollinating insects, particularly bees and hoverflies (Powney *et al*., 2019). These shifts reduce habitat heterogeneity and floral resources critical for pollinator life cycles, weakening ecosystem pollination services for crops and wild plant communities (Eckerter *et al*., 2022). Although targeted agri-environment schemes can locally improve pollinator visitation, the overall trend of intensification continues to challenge pollinator conservation without broader landscape habitat retention and restoration (Image *et al.*, 2022).

In Asia, agricultural intensification influences pollinator populations through both land cover transformation and climatic effects that alter plant-pollinator synchrony. In Lao PDR, conventional agriculture was associated with significantly lower native honey bee (*Apis cerana*) abundance compared to agroecological systems that maintain floral diversity and less habitat disturbance (Rahimi & Jung, 2025). Additionally, broader continental analyses indicate that climate-driven spatial mismatches between pollinators and pollinator-dependent crops are projected to intensify under future warming scenarios, undermining pollination services essential to rice, fruits, and legumes across Asia (Rahimi & Jung, 2025).

In Nigeria, studies have established that the increasing reliance on fertilizers and pesticides threatens already rich pollinator diversity, potentially undermining yields of pollinator-dependent crops such as cocoa, coffee, and vegetables (Kumsa & Ballantyne, 2021). Wild pollinators are integral to crop production systems in much of sub-Saharan Africa; however, intensification-related habitat loss and agrochemical exposure are emerging as significant stressors on pollinator communities (Kumsa & Ballantyne, 2021).

In Tanzania, land use intensification through conversion of natural vegetation to agricultural fields and urban areas correlates with reductions in pollinator species richness and alterations in pollination networks (Kingazi *et al.,* 2024). Traditional agroforestry practices, which retain woody plant species and diverse flower resources, support higher pollinator forage diversity relative to simplified agricultural systems, suggesting that local farming practices influence pollinator abundance and function (Kingazi *et al.*, 2024). Loss of natural habitat adjacent to farms has been linked with lowered pollination services, affirming the sensitivity of pollinators to industrial scale landscape change (Cirimwami *et al*., 2019).

In Kenya, agricultural intensification and associated practices such as pesticide application and habitat clearance pose significant threats to pollinators in smallholder systems where wild pollinators perform most pollination services. Studies demonstrate that the presence of natural habitats enhances yields of crops through improved bee pollination, while fragmentation and intensified management reduce these benefits (Kasina *et al*., 2009). Integrated pest and pollinator management approaches in crops such as avocado have shown promise in mitigating pesticide impacts and enhancing pollinator health and farmer livelihoods, underscoring the need for strategies that balance agricultural productivity with pollinator conservation (Muriithi *et al*., 2024). Additionally, awareness of pollination services remains low among farmers in some regions, though agroforestry and traditional landscape heterogeneity provide key forage resources for pollinators (Chege *et al*., 2025).

### 2.6.5 Climate Change

Climate change manifested through rising temperatures, altered rainfall patterns, droughts, and more frequent extreme weather events poses significant threats to pollinator populations and pollination services worldwide (Pollinator Research Centre, 2023). These ecological variations can affect pollinator physiology, phenology, habitat suitability, and the synchrony between pollinators and flowering plants, ultimately reducing pollinator abundance and diversity (Pollinator Research Centre, 2023).

In North America, climate change has contributed to significant declines in key pollinators. Studies across the contiguous United States show a 22% decline in butterfly populations since 2000, attributed in part to climate change interacting with habitat loss and agrochemical exposure (Associated Press, 2025). There is also evidence that wild bee abundance and diversity are particularly sensitive to variations in temperature and precipitation, with extreme warm events shortening bee life spans and altering seasonal emergence, which threatens pollination dynamics (LaJeunesse, 2021).

In Britain, long-term monitoring and citizen science efforts have documented dramatic declines in flying insect abundance, which include many pollinators. A national “Bugs Matter” experiment found an 80% decline in flying insects over two decades, strongly linked to climate change interacting with land-use change and pesticide pressures (Foucart, 2025). Additionally, intensive fertiliser use in agricultural landscapes has significantly reduced wild flower abundance, halving pollinator numbers, especially bees, further compounding climate change impacts on pollinator habitats (The Guardian, 2025).

In tropical regions of Asia, combined effects of climate change and land-use transformation are projected to severely affect pollinator-dependent crops and their pollinators. Modeling studies indicate that most pollinator-dependent crops such as cocoa, mango, and watermelon are at heightened risk due to pollinator loss under warming scenarios, especially across South and Southeast Asia (UCL, 2023). Furthermore, studies have emphasised that Asia's pollinator diversity remains poorly known, with urgent need for targeted studies to understand species distributions, climate vulnerabilities, and conservation needs (Warrit *et al*., 2023).

Although fewer formal studies focus exclusively on West African pollinators, global data and modeling underscore that tropical regions including West Africa are highly vulnerable. Climate change is projected to drive significant declines in habitat suitability for pollinators, contributing to reduced pollination services for key crops important to West African agriculture (Rahimi & Jung, 2025). Additionally, global assessments of pollinator-dependent crops indicate that West Africa faces high risk from climate-induced pollinator losses because warming trends exceed historical norms, threatening food security and ecosystem stability (Millard *et al*., 2023).

In East Africa, climate change has already been associated with shifting ecological conditions affecting pollinator populations. Studies on East African bee taxa such as *Ceratina moerenhouti* shows that ongoing climatic alterations have reduced suitable habitat distributions over recent decades and are expected to continue driving declines in solitary bee populations critical for wild and crop plant pollination (Mukundamago *et al.*, 2023). Climate variability has also been linked to bee health challenges that affect beekeeping and pollination services broadly across landscapes, with droughts and altered rain patterns cited as stressors to bee colonies (Rahimi & Jung, 2025).

In Kenya, climate change directly affects pollinators, especially honey bees, which are crucial for both agricultural productivity and rural livelihoods (Mukundamago *et al.*, 2023). A related study documented that Kenyan beekeepers experienced an average 36.6% loss of honey bee colonies in 2021-2022, with colony declines strongly associated with higher temperatures and reduced precipitation during dry seasons (Leyton *et al*., 2025). These findings noted that temperature and water availability are key determinants of bee survival in the face of climate variations, and adaptive strategies such as water supplementation can partially mitigate these losses.

**2.7 Declines of Pollinators**

At the global scale, declines in pollinator populations and species diversity have raised significant concern because of their widespread implications for food security, ecosystem services, and economic development (Potts *et al.,* 2016). Over 75 % of the world's leading food crops and nearly one-third of overall global crop production rely at least partly on animal pollination to maintain yield and quality (Dicks *et al*., 2021; Cooley *et al*., 2021). Habitat loss, intensive agricultural practices, pesticide use, climate change, disease, and invasive species are among the primary drivers of pollinator declines worldwide (Potts *et al*., 2016; Dicks *et al*., 2021).

In North America, extensive studies have documented alarming decreases in both managed and wild pollinator taxa. Wild bee abundance and richness in major U.S. crop regions, including studies published in *Proceedings of the Royal Society B*, show that declines in wild bee species directly limit pollination services for crops such as apples, pumpkins, cherries, blueberries, and watermelon (Rondeau *et al.*, 2022). These losses are linked to habitat fragmentation and pesticide exposure, resulting in measurable pollination deficits that reduce crop yield and threaten economic output of key agricultural sectors (Reilly *et al*., 2020). Modeling of global pollinator distributions also indicates that warming and climate change are altering suitable climates for many North American pollinators, posing further risk to their persistence (Rahimi & Jung, 2024).

In Britain, long-term monitoring has revealed substantial declines in flying insects including pollinators over recent decades. Data from citizen science programs show up to a 63 % drop in flying insect biomass over three years, contributing to a broader, multi-decadal collapse of pollinating insects, particularly bees and butterflies (Buglife & Kent Wildlife Trust, 2025). These trends contribute to pollination shortfalls with cascading effects on wild plant reproduction and agricultural productivity in temperate ecosystems.

In the tropical South and Southeast Asia, evidence also points to pronounced declines in insect pollinator abundance and diversity (Datta *et al.,* 2025). Studies have established that combined pressures of climate change and land-use change especially habitat conversion and intensive farming have reduced pollinator populations at many sites, threatening the reproduction of tropical crops like coffee, mango, watermelon, and cocoa (Millard *et al*., 2023). These declines are expected to be especially severe where ecosystems already lie near climate thresholds, illustrating how climate warming disproportionately impacts tropical pollinator networks compared to temperate systems (Datta *et al.,* 2025).

In parts of West Africa, pollinator declines have similarly been correlated with intensified land use and deforestation (FAO, 2023). Related studies have affirmed the lack of long-term monitoring but highlight widespread threats from habitat loss and agrochemical exposure that compromise pollinator diversity and ecosystem resilience. Several West African staple and export crops including cashew, cocoa, and Shea are highly sensitive to pollination deficits, exacerbating food insecurity and income instability for smallholder farmers (Dicks *et al.,* 2021).

In East Africa, including countries such as Uganda and Tanzania, studies have documented declines in key pollinator taxa associated with agricultural intensification and climate variability (Sagwe *et al*., 2020). Land conversion to monocultures and increasing pesticide use reduce floral resources and nesting habitats for indigenous pollinators, contributing to lower pollination service levels and crop yields in both smallholder and commercial farming systems (Tommasi *et al.,* 2021).

In Kenya, evidence of declining pollinator populations is growing rapidly. Research on avocado orchards in Kenya has documented substantial pollination deficits with insect pollinators strongly limiting fruit set highlighting the reliance on both managed honey bees and wild pollinator communities to sustain production (Sagwe *et al*., 2021). Findings from related studies have indicated a significant decrease in honey bee colony numbers in recent years, with losses exceeding one-third of colonies in some regions due to combined pressures from pesticides, habitat degradation, and climatic stressors (Sibaja *et al*., 2025). Conservation initiatives in Kenya are now focusing on monitoring pollinator health, improving habitat quality, and encouraging sustainable agricultural practices to mitigate further decline (Sagwe *et al*., 2025). Given pollinators' critical role in supporting fruit, vegetable, and seed production an important component of nutrition and farmer income these declines constitute a substantial threat to both rural livelihoods and national food systems.

### 2.8 Knowledge Gap

Bee and pollination studies have been widely conducted across different regions and cropping systems globally. For instance, extensive work on bee diversity, functional complementarity, and pollination services has been documented in America (Klein *et al*., 2007; Winfree *et al.*, 2018), Europe and Britain (Potts *et al*., 2016; Dicks *et al*., 2021), and Asia (Garibaldi *et al*., 2016), with strong emphasis on pollinator diversity, habitat requirements, threats, and economic importance of pollination in crops. In sub-Saharan Africa, studies have focused on pollinator diversity, habitat use, and contributions to crop yields, particularly in West and East Africa (IPBES, 2016; Khalifa *et al*., 2021). In Kenya specifically, research has concentrated on bee diversity in natural and semi-natural ecosystems such as Mount Kenya, Kakamega Forest, and coastal Kaya forests (Gikungu, 2002; Chiawo *et al*., 2017; Tsingalia & Mandela, 2023), as well as on the economic value of pollinators and pollination of selected crops including coffee, watermelon, avocado, and other horticultural crops (Kasina *et al*., 2009; Karanja *et al*., 2013; Muriithi *et al*., 2024).

However, despite the acknowledged importance of bees in crop production, there is limited empirical evidence linking bee abundance and diversity to yield and quality outcomes in common bean (*P. vulgaris* L.) agro-ecosystems in Kenya, particularly within forest-agriculture gradients. Moreover, no documented studies have been conducted in Borabu Sub-County to assess bee pollinator diversity, abundance, and their contribution to common bean production. Therefore, this study was undertaken to address this gap by evaluating the abundance and diversity of bee pollinators in common bean agro-ecosystems along a forest-agriculture gradient in Borabu, Kenya, and to determine their significance in supporting sustainable bean production.

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Description of the Study Area

Nyansiongo Sub-location is part of Borabu Sub County in the larger Nyamira County. It is one of the 14 sub-locations found in Borabu. It is situated at the border of Kisii-Sotik, about 40km south east from Kisii town. According to the KNBS (2019), this region is less populated compared to other sub-locations and covers an area of 3000ha with the population of 35,413. The area has rich agricultural soils and receives plenty of rain which is well distributed throughout the year. In the months of January-February dry periods are experienced. More rain is experienced in the month of April with more than 1500mm. The soil types in this area are reddish brown and silt clay. The area consists of a rolling landscape with an altitude of 1850-1950m above sea-level but with some steep conical hills whose tops can have an altitude of 2060m above sea level. Nyansiongo is known for its richness of flora. It consists of both tea as the main cash crop and indigenous trees like acacia and food crops such as bananas, maize, beans and sweet potatoes.

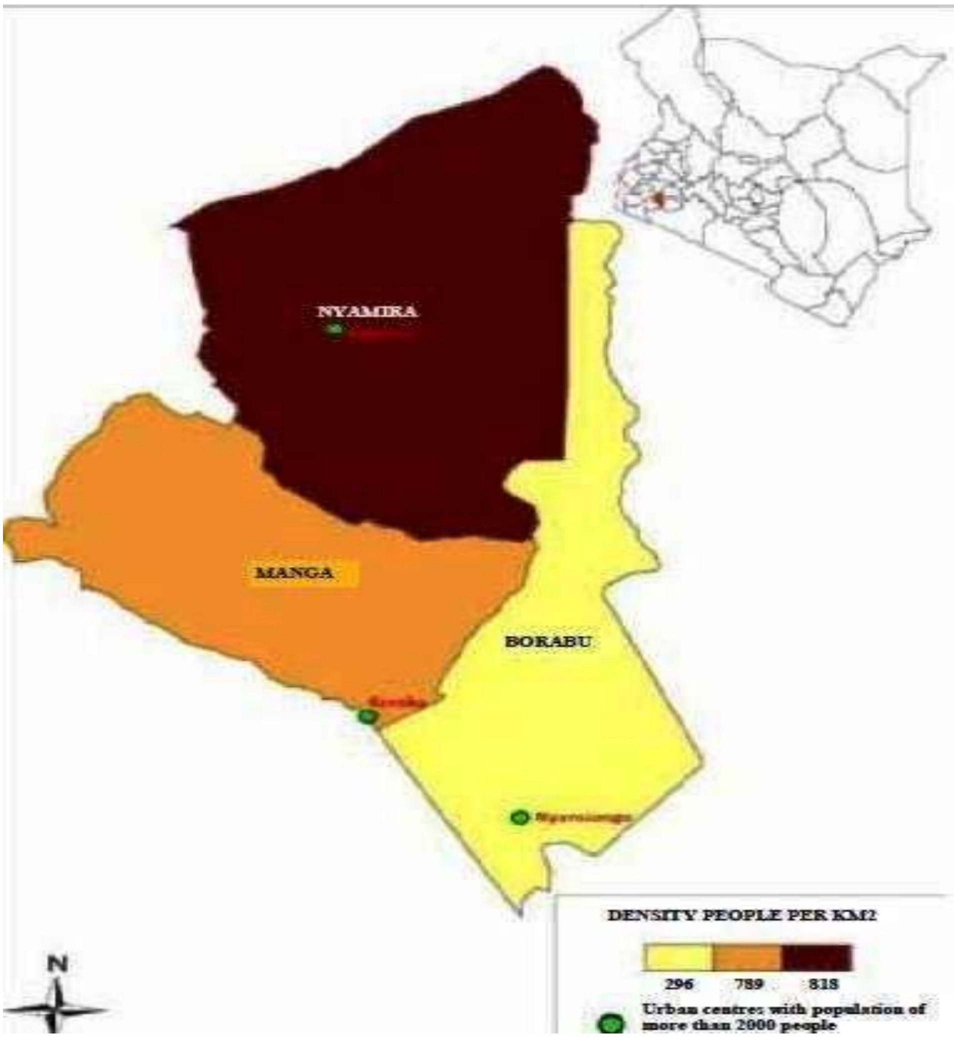


**Figure 3.1: Map of Borabu Sub County (showing Nyansiongo sub-location)**

**Source:** Nyamira County Development Plan, (2017).

## 3.2 Sample Size and Sampling Procedures

The sample size was determined from four locations and fourteen sub-locations of Borabu Sub County as illustrated in Table 3.1.

**Table 3.1: Administrative units of Borabu Sub County**

| Location | Sub locations |
|---|---|
| **Mekenene** | Mwongori, Mogusii, Kitaru and Nyankono |
| **Kiabonyoru** | Omonono, Mokomoni, Nyangoge and Nyaramba |
| **Nyansiongo** | Nyansiongo and Matutu |
| **Esise** | Manga, Ekerubo, Isoge and Kineni |

**Source;** County Commissioner office, Nyamira County.

Purposive sampling was first used to identify the study area within Borabu Sub-County, Nyamira County. Among the fourteen sub-locations in the Sub-County, Nyansiongo Sub-location was purposively selected because the area is characterized by highly fertile soils and intensive bean production compared to the other sub-locations. Nyansiongo Sub-location lies within Nyansiongo Ward and comprises Nyansiongo and Matutu villages/sub-areas. According to records for Nyansiongo Ward, the area has an approximate population of 27,495 people and covers about 74.5 km², while the larger Nyansiongo urban centre (Kijauri) has an estimated population of 5,993 people (KNBS, 2019).

After purposively selecting Nyansiongo Sub-location, simple random sampling was used to identify the specific study village/sub-area. Each village was assigned a unique identification number, and two villages namely Nyansiongo and Matutu were randomly selected using a computer-generated randomization process. This approach ensured impartiality and equal selection probability for all villages. Further on Nyansiongo village/sub-area was selected to represent the entire sub-location due to its suitability for bean farming.

The study plots were distributed across the study area in Nyansiongo Sub-location. Within the selected area, a 3km transect was systematically established, along which three bean plots measuring 100 m² each were demarcated at 1 km equidistant intervals. The plots were located on three different farms practicing bean cultivation and constituted the sampling units for the study, as presented in Table 3.2. This approach ensured adequate spatial representation of bean farms within the selected sub-location while maintaining uniformity in sampling procedures.

The total land area under bean (*Phaseolus vulgaris* L.) cultivation within the selected farms was estimated to determine the extent of production and to contextualize sampling intensity.

Data collection was undertaken at the phenological stage when at least 50% of the bean plants across the farms had attained flowering. This growth stage was considered appropriate to ensure uniformity in developmental status and enhanced the comparability of observations across all sampling sites. The month of March coincided with the long rains season characterized by moderate to high rainfall, warm temperatures, and relatively high soil moisture content, while the months of May to September occurred during short rains season, which experienced comparatively lower rainfall amounts and intermittent dry spells. Average temperatures during the study period ranged between approximately 18°C and 27°C, conditions considered favorable for bean growth and development. The study area generally exhibited well-drained fertile soils with moderate humidity levels suitable for intensified bean production.

Geographic positioning system (GPS) coordinates was used to mark the study sites. Purposive sampling was also done on 25 farmers who engaged in bean crop farming and 5 farm managers from the study area. The sampled farmers needed to plant their beans at the same time and the same variety of beans was used on the sample farms. Prior consent from farmers to use their farms was sought before data collection.

**Table 3.2: Altitude of the studied farms in Nyansiongo Sub-location**

| Plot Number | South (Degrees) | East (Degrees) | Altitude (Meters) |
|---|---|---|---|
| **1.3km furthest** | 00.46188 | 00.34581 | 1902 |
| **2. 2km away** | 00.46288 | 00.34586 | 1959 |
| **3. near forest** | 00.46232 | 00.34586 | 1762 |

### 3.3 Data Collection Procedure

At the onset of bean flowering, the numbers of bees visiting flowers were observed at each site in the bean farm. The common bean variety in the area was Mwezi moja, which takes 90 days to mature and is planted at a spacing of 50 cm × 100 cm. The behaviour of bees in relation to the time of visiting the flowers was noted and recorded in order to distinguish between mere floral visitors and effective pollinators. Effective pollinators were defined as flower visitors that made contact with the reproductive structures of the flower, particularly the anthers and stigma, thereby facilitating the transfer of pollen and increasing the likelihood of fertilisation. In contrast, mere floral visitors were insects that visited flowers to obtain nectar or other floral resources without contacting the reproductive parts of the flower or contributing to pollen transfer.

Foraging bee species were captured from each plot using a sweep net for 20 minutes. Each plot was monitored three times a week for three months for the purpose of replication. The bees were placed in vials with ethyl acetate-soaked in cotton wool to kill the bees (Chiawo *et al.*, 2017). Some 10 minutes were taken after each collection to observe and record the bee species. Each plot had a different observer and each day the observers were rotated to avoid bias (Ricketts, 2004).

Bee species that may not have been collected directly from flowers using sweep nets were sampled using nine pan traps per plot. The traps consisted of three conspicuous colours (blue, white, and yellow) and were randomly positioned at ground level within each 100 m² bean plot. Three pan trap colours were used to capture a range of flower visitors since different taxa are attracted to different colours (Moreira *et al.*, 2016). Every pan trap contained 200 ml of water mixed with 4 ml of odorless liquid detergent (equivalent to a 2% v/v detergent solution). Each set of pan traps was filled with 200 ml of water containing 4 ml of odorless liquid detergent (2% v/v concentration) and left in the field for 24 hours during each sampling event. The traps were deployed in the morning (between 0800 and 0900 hours) and retrieved the following day at the same time. Monitoring was conducted during peak flowering, and the contents of each trap were carefully collected, filtered, and preserved for subsequent identification. This approach was intended to capture pollinators that might not be effectively sampled using sweep nets (Morandin *et al*., 2007). All the bees trapped were counted and transferred to transparent containers using a pair of forceps for later identification and determination of diversity.

Preserved insects were transported to the laboratory at the Zoology Department, National Museums of Kenya, Nairobi, for identification. During the identification exercise, bees were differentiated using standard identification keys.

**Plate 3.1: Pan Trap Laid in the Farm 1**

Observation of bees was done from 0730 hrs to 1230 hrs, the period known to coincide with peak foraging activity of most bee species, thereby maximizing the likelihood of capturing representative visitation data. This was simultaneously conducted in the three study farms at intervals of 20 minutes in each sampling round. The selection of three farms was intended to provide spatial replication. Using three independent farms reduced site-specific bias and strengthened the reliability and generalization of the pollination and yield comparisons.

The visitation rate of bees was determined by recording individual flower visitors and the number of flowers in the sampled bean plots. A twenty-minute observation period was set to record the number of flower visitors per plot (100 m × 100 m) during the flowering period of beans, a duration considered sufficient to obtain consistent and comparable visitation frequencies across sites without causing observer fatigue or temporal overlap in counts.

In each of the three sample farms, bean plants were labeled and thirty plants were selected randomly. The selection of thirty plants per farm was based on the need to achieve adequate within-site replication for statistical analysis while maintaining logistical feasibility in flower marking, caging, and yield monitoring. To achieve randomization in farm selection, a list of all bean-growing farms within the selected study area was first compiled with the assistance of local agricultural officers and village leaders. Each farm was assigned a number, and simple random sampling was then applied using a lottery method whereby the required farms were selected without bias, ensuring that every eligible farm had an equal chance of being included in the study. A sample size of thirty is widely regarded as sufficient to approximate normal distribution assumptions in biological field studies and to provide reliable estimates of treatment effects.

Selected flowers were numbered and marked using masking tape following established pollination study protocols (Roubik, 2002a). For each selected bean plant, thirty flowers were enclosed individually using 1 $mm^2$ nylon mesh cages (fine insect-proof netting with approximately 1 mm × 1 mm apertures) before anthesis to exclude insect pollinators while allowing adequate air circulation, light penetration, and prevention of heat accumulation around the floral structures. Another thirty flowers were marked and left open to allow natural pollination. This balanced design enabled a controlled comparison between self-pollination (caged) and open pollination treatments within the same plant, thereby minimizing genetic and micro-environmental variation.

Installation, inspection, and adjustment of the nylon mesh cages required approximately 10 hours per farm, distributed across flower selection, cage mounting, securing to prevent insect entry, and routine monitoring to ensure structural integrity throughout the flowering period. The use of 1 $mm^2$ nylon mesh cages ensured effective exclusion of bee and other insect pollinators without mechanically damaging flowers, thereby providing a robust and reliable experimental framework for assessing the direct effects of insect pollination on bean yield.

Later, the plants were carefully uncaged to record fruit (pod) set and then re-caged where necessary to prevent further insect interference during early pod development. Once pods matured and dried completely, they were harvested for yield assessment. The size and weight of pods and the number of seeds per pod were recorded across the different pollination treatments (caged and uncaged) to assess yield quality and quantity. The uncaged pods were left to mature naturally and harvested for overall yield comparison.

**Plate 3.2: Closed Flowers in Farm 2**

**Plate 3.3: Uncaged Plants in Farm 3**

### 3.3.1 Study Design

The study aimed to assess the abundance and diversity of bees in Borabu and their floral resources. A survey along three plots from the forest edge of the natural habitat and traversed through the farmlands was conducted. Sampling plots were located at an interval of 1km along 3km transect in the forest edge and farmlands (Plate 3.1 and plate 3.2).

The points in dots indicate the sampling plots in replication (Figure 3.3). Individual bees were labelled according to the sampled plot, date of collection, location and colour of pan traps. Bees collected each day were inactivated and killed using ethyl acetate and kept in vials. Later bees were transferred to the laboratory of the National Museum of Kenya for identification. In the laboratory, they were relaxed, pinned and set in the insect boxes and placed in the oven for 72 hours to ensure complete dry.

**Plate 3.4: Pinned Bees on Insect Box**

### 3.3.2 Establishment of Sampling Points and Transects

Observation plots were established along the forest-farmland gradient. Three plots were selected (1km apart), and within each plot, three sampling points were established giving a total of nine sampling points. Observations were made at each sampling point, as illustrated in Figure 3.2.

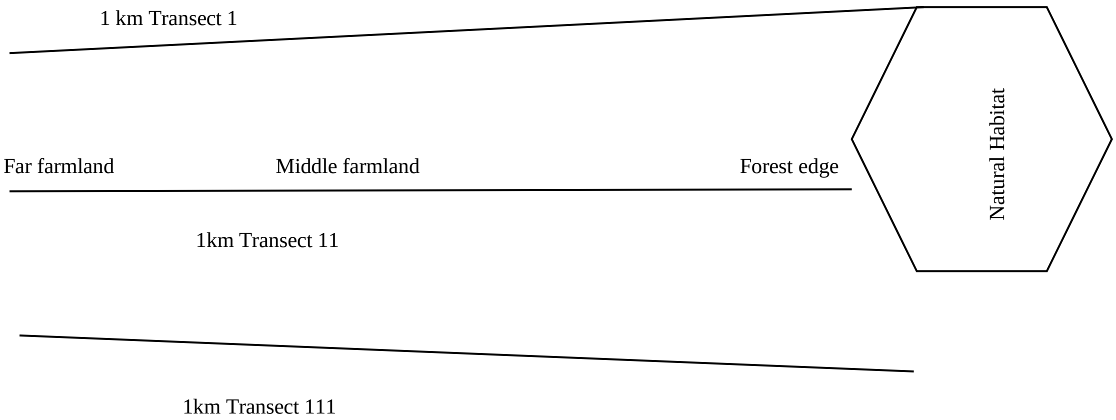


**Figure 3.2: Location of the Sampled Plots**

The sampling points were taken in the same order in the three months collection period. For each collection day, establishment of sampling points was randomized among the three plots as illustrated by Winfree *et al.,* (2018) to minimize temporal impacts. To sufficiently test species with different day-to-day pattern, sampling was conducted between 0730hrs to 1200hrs.

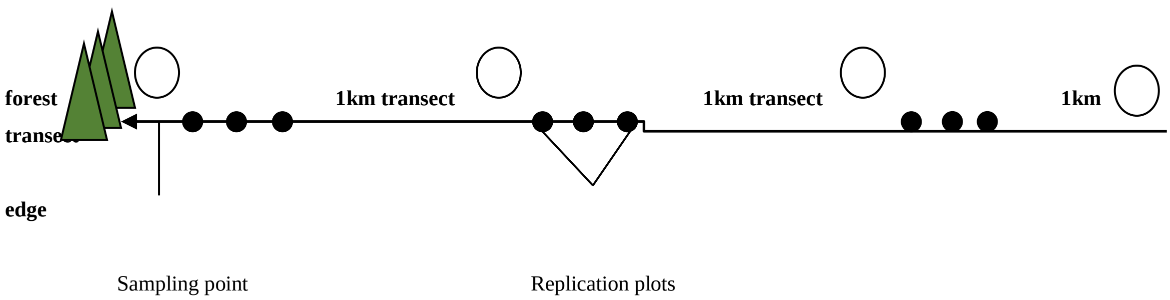


**Figure 3.3: Schematic Demonstration of Sampling Points and Transects**

Questionnaire administration was conducted to obtain socio-demographic information and farmer perceptions regarding bee pollinators and bean production practices within the selected study area. The target respondents comprised bean farmers and bean farm managers involved in bean cultivation in Nyansiongo Sub-location, Borabu Sub-County, Nyamira County. The questionnaires were designed to complement field observations and insect sampling data by providing information on local farming practices, pollinator occurrence, and farmers' knowledge regarding pollination in bean production systems.

Purposive sampling was initially used to identify respondents actively engaged in bean farming within the selected study area. Assistance from local agricultural extension officers, village elders, and community leaders was sought to compile a list of farmers practicing bean cultivation during the study period. From this list, twenty-five (25) bean farmers and five (5) bean farm managers were selected, giving a total of thirty (30) respondents. The selected respondents were drawn from the two villages/sub-areas within Nyansiongo Sub-location, namely Nyansiongo village and Matutu village, with priority given to farmers who had active bean plots during the sampling seasons and who cultivated the commonly grown bean variety locally known as Mwezi moja.

Simple random sampling was then applied among the eligible farmers to ensure that every farmer had an equal chance of participating in the study. The names of all eligible farmers from the two villages were written down and assigned numbers, after which the required respondents were randomly selected using a lottery method. Farm managers were purposively selected because of their direct involvement in managing bean farms and their familiarity with farming operations, pesticide application, and pollination-related activities within the study area.

Prior to questionnaire administration, the purpose of the study was clearly explained to all respondents and prior informed consent was obtained. Respondents were assured that the information collected would be treated confidentially and used strictly for academic research purposes. The questionnaires were administered through face-to-face interviews conducted by the researcher in order to improve response accuracy and to assist respondents who experienced difficulties in reading or interpreting some questions.

The questionnaires contained both closed-ended and open-ended questions structured into different sections. Information collected included respondents' age, gender, educational level, farming experience, bean varieties grown, farm size, use of agrochemicals, methods used to enhance pollination, knowledge of pollinators, and the time of day when most pollinators were observed visiting bean flowers. Additional questions focused on farmers' perceptions regarding the importance of bees in bean production and the challenges affecting pollinator abundance within the farms.

Questionnaire administration was conducted during the flowering period of beans concurrently with field sampling activities. This timing enabled respondents to provide current and reliable information based on ongoing farming activities and pollinator observations. Each interview lasted approximately 20-30 minutes depending on the respondent's availability and the level of detail provided.

Completed questionnaires were checked immediately after each interview to ensure completeness and consistency of responses before data entry and analysis.

### 3.4 Data Analysis

Bee diversity was computed using Shannon diversity index. Species abundance accumulation curves were used to compute abundance. The diversity was determined based on the species richness.

Beans from each experimental plot were harvested at physiological maturity, weighed using a calibrated digital balance, and the corresponding weights systematically recorded to document the yields of the beans. The recorded yield data were subjected to statistical analysis using one-way Analysis of Variance (ANOVA) to determine whether there were statistically significant differences among treatment means by the help of the statistical package of social sciences (SPSS) version 25.

The data on yield were compared using the Analysis of variance (ANOVA) at 95% level of accuracy. Data on gender and pollination knowledge were analysed using the paired t-test.

# CHAPTER FOUR

# RESULTS

## 4.1 Diversity and Abundance of Bee Pollinators Visiting Common Bean (*Phaseolus vulgaris*) Flowers Along a Forest-agriculture Gradient

### 4.1.1 Abundance of Bee Pollinators Visiting Common Bean (*Phaseolus vulgaris*) Flowers Along a Forest-agriculture Gradient

A total of 992 bee specimens from 2 families and 8 species were collected from the three study farms (Table 4.1). *Apidae* was the most abundant family with six bee species. There were five un- identified bee species; three from *Apidae* family and two from *Megachilidae* family. The distribution of total bee specimens collected included; 850 from *Apis mellifera*, 77 *Meliponula sp.*, 52 *Xylocopa calens*, 2 *Xylocopa flavorufa*, 2 *Xylocopa sp*.1, 7 *Xylocopa sp.*2, 1 *Xylocopa sp.* 3 and *Megachilidae sp.*1. (Table 4.1).

**Table 4.1: Bee Family, Genera and Species Names**

| | Family | Genus | Species | No. of individuals | Abundance (%) |
|---|---|---|---|---|---|
| **1** | *Apidae* | *Apis* | *mellifera* | 850 | 85.7 |
| | | *Xylocopa* | *calens* | 52 | 5.2 |
| | | *Xylocopa* | *flavorufa* | 2 | 0.2 |
| | | *Xylocopa* | *Sp.1* | 2 | 0.2 |
| | | *Xylocopa* | *Sp. 2* | 7 | 0.7 |
| | | *Xylocopa* | *Sp. 3* | 1 | 0.1 |
| | | *Meliponula* | *Sp. 1* | 77 | 7.8 |
| **2** | *Megachilidae* | *Megachilida* | *Sp. 1* | 1 | 0.1 |
| **TOTAL** | | | | **992** | **100** |

In terms of percentage abundance, out of the total bee specimens collected, 85.7% were *A. mellifera,* 7.8% were *Meliponula sp.*1and 5.2% represented *X. calens. X. flavorufa* was 0.2% and *Xylocopa. sp*. 2 had 0.7% of the total bee specimens collected. *Xylocopa sp.*1 had 0.2% while *Xylocopa. sp.* 3 and *Megachilidae sp.*1 had 0.1% of the total bee species collected respectively (Figure 4.1).

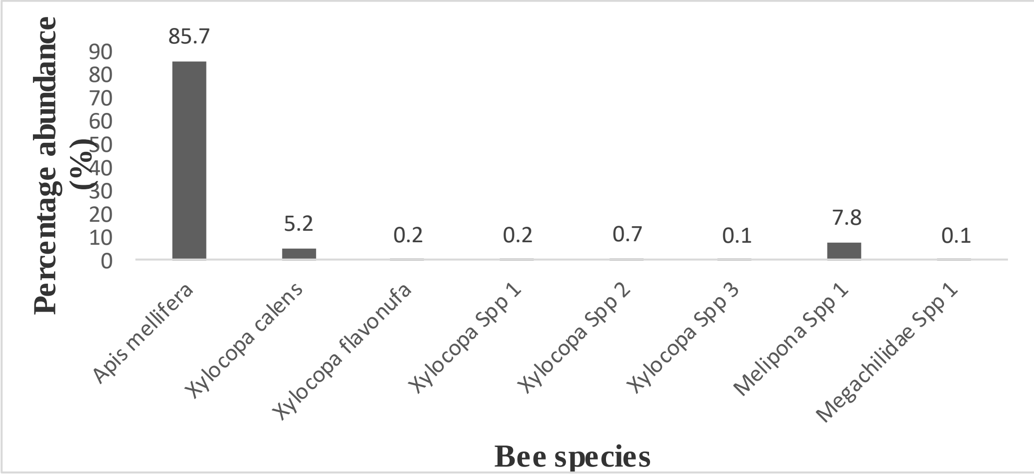


**Figure 4.1: Percentage Abundance of Bee Species Collected**

Among the identified species include *Xylocopa calens* and *Apis mellifera* as shown in Plates 4.1 and 4.2 respectively.

**Plate 4.1: *Xylocapa calens***

**Plate 4.2: Apis mellifera**

### 4.1.2 Diversity of Bee Pollinators Visiting Common Bean (*Phaseolus vulgaris*) Flowers Along a Forest-agriculture Gradient

Bee species diversity index was computed using Shannon index;

$H' = -\sum p_i(\ln p_i)$

Where, $H'$= diversity, $\sum$= Summation, $p_i = N_i/T_{otal}$, ln = natural logarithim,

$N_i$=number of individuals of species *i*

$T_{otal}$ = Total number of individuals in all species

The data on the bee diversity at different times of day was used to compute the Shannon-Wiener Diversity Index (Table 4.2).

**Table 4.2: Diversity Index of Bee Species Visiting the Bean Flowers at Different Times of the Day**

| | | Time in the day | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 7.00-8.00 | | 8.00-9.00 | | 9.00-10.00 | | 10.00-11.00 | | 11.00-12.00 | |
| Pollinator bee | | Ni | - (pi * ln pi) | Ni | - (pi * ln pi) | Ni | - (pi * lnpi) | Ni | - (pi * lnpi) | Ni | - (pi * lnpi) |
| **1** | *Apis mellifera* | 77 | -0.130 | 264 | -0.125 | 203 | -0.153 | 81 | -0.201 | 225 | -0.089 |
| **2** | *Xylocopa calens* | 2 | -0.078 | 27 | -0.215 | 14 | -0.163 | - | - | 9 | -0.120 |
| **3** | *Xylocopa flavorufa* | - | - | - | - | 2 | -0.039 | - | - | - | - |
| **4** | *Xylocopa Sp.1* | - | - | - | - | 1 | -0.023 | - | - | - | - |
| **5** | *Xylocopa Sp. 2* | - | - | - | - | 2 | -0.039 | 1 | -0.066 | 4 | -0.066 |
| **6** | *Xylocopa Sp. 3* | 1 | -0.050 | - | - | 1 | -0.023 | - | - | - | - |
| **7** | *Meliponula Sp. 1* | 10 | -0.050 | 14 | -0.140 | 21 | -0.021 | 23 | -0.333 | 9 | 0.120 |
| **8** | *Megachilidae Sp. 1* | - | - | - | - | - | - | - | - | 1 | -0.022 |
| **TOTAL** | | **90** | ***H'***=0.31 | **305** | ***H'***=0.35 | **244** | ***H'***=0.46 | **105** | ***H'***=0.60 | **248** | ***H'***=0.42 |

The pollinator diversity was low during early morning hours, 0700hrs to 0800hrs (*H* = 0.31), 0800hrs- 0900hrs recorded *H* of 0.35 and 0900h to 1000hrs had diversity index of 0.46 respectively. The peak activity was recorded at 1000h-1100h with diversity index of 0.60 and decreased consecutively in the day, 1100hrs- 1200hrs (H = 0.42). However, the peak abundance of flower pollinators was 10.00 to 11.00. The variations in H values in the overall diversity of both farms were not statistically significant. This implies that there were no significant differences in the total diversity depending on the time of the day of bees visiting flowers. The findings of the analysis are illustrated in Figure 4.2.

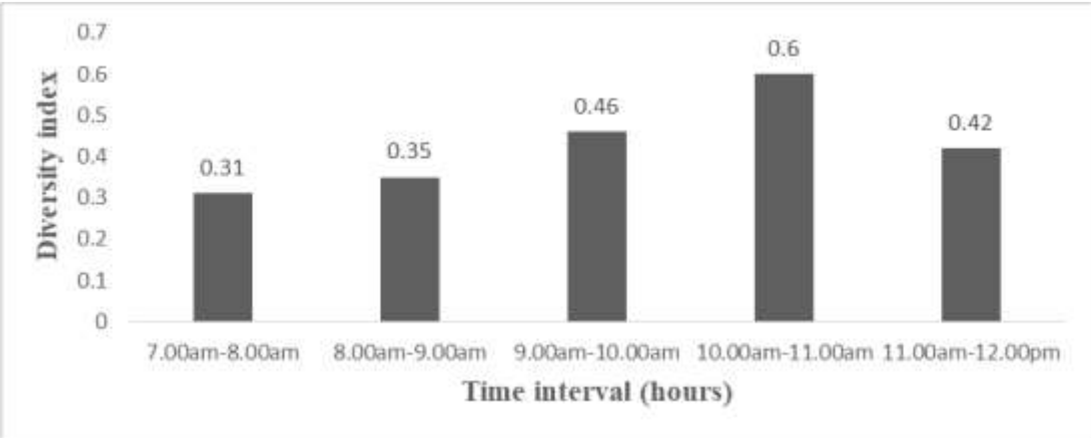


**Figure 4.2: Diversity Index of Individual Bee Species**

The overall diversity index of bee species collected from all the farms were not statistically significant (Table 4.3).

**Table 4.3: Overall Diversity Index of Bee Species Collected From the Study Farms**

| | Bee species | No. of Individuals | p*i*= Sample/sum | ln(p*i*) | P*i* *ln(p*i*) |
|---|---|---|---|---|---|
| **1** | *Apis mellifera* | 850 | 0.857 | -0.154 | -0.132 |
| **2** | *Xylocopa calens* | 52 | 0.052 | -2.957 | -0.154 |
| **3** | *Xylocopa flavorufa* | 2 | 0.002 | -6.215 | -0.012 |
| **4** | *Xylocopa Sp.1* | 2 | 0.002 | -6.215 | -0.012 |
| **5** | *Xylocopa Sp. 2* | 7 | 0.007 | -4.962 | -0.035 |
| **6** | *Xylocopa Sp. 3* | 1 | 0.001 | -6.908 | -0.007 |
| **7** | *Meliponula Sp. 1* | 77 | 0.078 | -2.551 | -0.199 |
| **8** | *Megachilida Sp. 1* | 1 | 0.001 | -6.908 | -0.007 |
| SUM= 992 | | | | TOTAL= -0.553 | |

Diversity index $H^{/}$; summation of p*i**ln (p*i*) of each bee species and therefore;

$H^{/}$= 0.553

### 4.1.3 Bee Pollinators Visiting Common Bean (*Phaseolus vulgaris*) Flowers Along a Forest-agriculture Gradient

Bees visiting flowers of the beans in each plot were observed, noted and recorded. A total of 992 bee visitors from 8 species were collected from the three study farms. *Apis mellifera* represented the highest percentage of 85.7% of the total bee specimens collected. Individuals of nine bee species were recorded visiting flowers of the bean crop (Table 4.4). A zero distance of 1km from forest edge to the first farm was considered. The same 1km distance was maintained between the three successive study plots. Bee populations decreased from the forest edge towards the farmland. The plot adjacent to the forest recorded the highest number of bees (462), plot two had 314 and plot three which was furthest from forest edge had 211 bees.

**Table 4.4: Number of Bee Visitors per Farm**

| **Plot Number** | **No. of bees** | **Replication** | |
|---|---|---|---|
| | | **Plot Number** | **No. of Bees** |
| **1). Near the forest** | 462 | 1 | 452 |
| **2). 2 km from forest** | 314 | 2 | 319 |
| **3). 3 km furthest** | 211 | 3 | 221 |
| **TOTAL** | 987 | TOTAL | 992 |

#### 4.1.3.1 Number of Bee Specimens Distributed in a transect of ≤3 km from the Forest Edge into the Nyansiongo Farmland

Distance from the forest edge into the farms had significant effects ($p<0.05$) on the abundance of individuals of the bee species visiting the bean flowers. The number of *A. mellifera* bees decreased as the distance from the forest edge into the farmland increased (Table 4.5).

**Table 4.5: Number of Bee Species Distributed in a Transect Of ≤3km From the Forest Edge into Nyansiongo Farmland**

| Transect | Kilometres from the forest edge | Plot Number 1 far from forest edge | Plot Number 2 middle | Plot Number 3 near the forest edge |
|---|---|---|---|---|
| 1 | 1 | 110 | 120 | 203 |
| 2 | 2 | 72 | 7 | 132 |
| 3 | 3 | 39 | 92 | 117 |
| Total | | 221 | 319 | 452 |

**4.1.3.2 Diversity of Bee Specimens Distributed in a transect of ≤3 km from the Forest Edge into the Nyansiongo Farmland**

The farm near the forest edge recorded higher diversity index $H'$=0.198 followed by the farm 2km away from the forest edge at $H'$= 0.184 while the farm furthest from the forest edge (3km) recorded the lowest diversity index of $H'$= 0.171**.** The overall Diversity index**;** $H'$= 0.553 as illustrated in Figure 4.3.

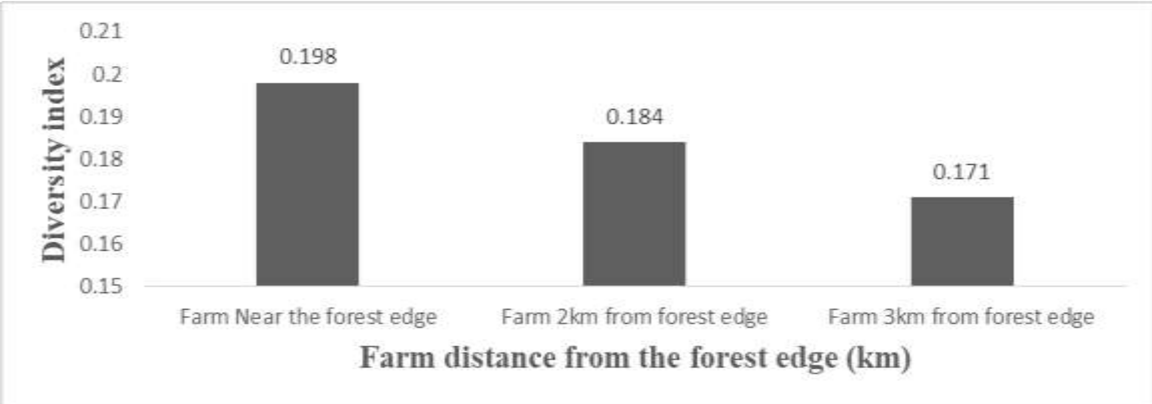


**Figure 4.3: Diversity Of Bee Specimens Distributed in a Transect Of ≤3 Km from the Forest Edge into the Nyansiongo Farmland**

## 4.2 Effect of caged and uncaged pollination treatments on pod and seed set of common beans in Borabu Sub-County, Western Kenya

The study sought to evaluate the effect of caged and uncaged pollination treatments on pod and seed set of common beans in Borabu Sub-County, Western Kenya.

### 4.2.1 Bee visitation rates

The number of bees visiting the uncaged flowers were observed, counted and recorded within an interval of one hour from 7.00am and 12.00 pm. The highest number of flower visitors were *A. mellifera* at 87% followed by *Meliponula Sp.* 1at 7.8%, *Xylocopa calens* at 5.2% while *Xylocopa Sp.* 2 had 0.7%. *X. flavorufa* and *Xylocopa Sp.* 3 each had 0.2% while *Xylocopa Sp.*1 and *Megachilidae Sp.* 1 had 0.1% respectively as illustrated in Table 4.6.

**Table 4.6: Bee Visitation Rate**

| **Name of bee** | | **Time in the day** | | | | | | **Percentage (%)** |
|---|---|---|---|---|---|---|---|---|
| | | **7.00-8.00** | **8.00-9.00** | **9.00-10.00** | **10.00-11.00** | **11.00-12.00** | **TOTAL** | |
| **1** | *Apis mellifera* | 77 | 81 | 203 | 264 | 225 | 850 | 87.0 |
| **2** | *Xylocopa calens* | 2 | - | 14 | 27 | 9 | 52 | 5.2 |
| **3** | *Xylocopa flavorufa* | - | - | 2 | - | - | 2 | 0.2 |
| **4** | *Xylocopa Sp.1* | - | - | 1 | - | - | 1 | 0.1 |
| **5** | *Xylocopa Sp. 2* | - | 1 | 2 | - | 4 | 7 | 0.7 |
| **6** | *Xylocopa Sp. 3* | 1 | - | 1 | - | - | 2 | 0.2 |
| **7** | *Meliponula Sp. 1* | 10 | 23 | 21 | 14 | 9 | 77 | 7.8 |
| **8** | *Megachilidae Sp. 1* | - | - | - | - | 1 | 1 | 0.1 |
| TOTAL | | 90 | 105 | 244 | 305 | 248 | 992 | 100 |

### 4.2.2 Bee Visitation Rates on Influence of Pod and Seed Set

There was a difference between plants that were open pollinated (uncaged) and those that were not visited by bees (caged). Differences were found in the number of pods set per plant, pod weight, seed weight and number of seeds per pod.

### 4.2.3 Mean Number of Pods per Plant

The mean number of pods per plant obtained from open access to bee pollinated flowers was higher than that obtained from close pollinated flowers in the treatments (Table 4.7), which could be attributed to frequent bee pollination. Since the *p*-value was more than 0.05, it can be concluded that there was no statistically significant difference between number of pods in closed and open bean plants [Appendix 3(i)].

**Table 4.7: Mean Number of Pods per Plant**

| Treatment 1 | Mean Value | Treatment 2(Replication) | Mean Value |
|---|---|---|---|
| **Closed flowers** | 8 (30) | Closed flowers | 7.71 (30) |
| **Open flowers** | 13 (30) | Open flowers | 13.94(30) |

Number in parentheses represents N value.

### 4.2.4 Average Pod Weight

There was a significant difference ($p<0.05$) in the mean pod weight obtained from closed and open pollinated flowers of the beans. Higher weights were recorded for pods obtained from open pollinated flowers in all replicates in the treatments (Table 4.8) and [Appendix 3(ii)]. Therefore, the hypothesis that bees' visitation rates do not influence pod set of beans in farms in Borabu Sub County, Western Kenya was rejected.

**Table 4.8: Mean Pod Weight (G) Per Plant**

| Treatment 1 | Mean weight | Treatment 2 (Replication) | Mean weight |
|---|---|---|---|
| Closed flowers | 3.84 (30) | Closed flowers | 3.81(30) |
| Open flowers | 6.87 (30) | Open flowers | 6.88(30) |

Number in parentheses represents N value.

### 4.2.5 Average Seed Number in Pods per Plant

The average number of seeds per pod of the beans obtained from open pollinated flowers (Table 4.9) was significantly more than self-pollinated flowers after carrying out replication ($p<0.05$) [Appendix 3(iii)]. Therefore, the hypothesis that bees' visitation rates do not influence seed set of beans in farms in Borabu Sub County, Western Kenya was rejected.

**Table 4.9: Average Seed Number of Pods per Plant**

| Treatment 1 | Mean Value | Treatment 2 (Replication) | Mean Value |
|---|---|---|---|
| Closed pollinated flowers | 3.76 (30) | Closed flowers | 3.71 (30) |
| Open pollinated flowers | 5.38 (30) | Open flowers | 5.44(30) |

Number in parentheses represents N value

### 4.2.6 Average Seed Weight per Pod

The higher weight was recorded for seeds obtained from open pollinated flowers (Table 4.10). Since $p < 0.05$, then it can also be concluded that there is a significant difference in seed weight of closed and open pollinated flowers [Appendix III (iv)]. Therefore, the hypothesis that bees' visitation rates do not influence seed weight of beans in farms in Borabu Sub County, Western Kenya was rejected.

**Table 4.10: Mean Seed Weight (G) Per Pod per Plant**

| **Treatment 1** | **Mean weight** | **Treatment 2(Replication)** | **Mean weight** |
|---|---|---|---|
| Closed flowers | 0.72 (30) | Closed flowers | 0.69(30) |
| Open flowers | 1.32 (30) | Open flowers | 1.35(30) |

Number in parentheses represents N value.

### 4.2.7 The Dependence of the Bean Crop on Bee Pollination

The dependence of the bean crop on bee pollination was determined (Table 4.11). This was done by comparing the yield from bee pollinated flowers (open flowers) with those which had been denied bee visits (closed flowers). Dependence can be expressed as:

$$Pdr = \frac{Y_{ub} - Y_b}{Y_{ub}} + qcv$$

where *pdr* is the pollination dependence ratio of a crop; *ub Y* is the yield (6,875kg) from closed flowers (with unlimited access by bees or from hand-pollinated flowers, whichever is higher); *b Y* is the yield (3,825kg) from closed flowers (not accessed by bees); *qcv* is a quality coefficient value that represents the value addition due to a better quality after bee pollination. The *qcv* equals 0.1 in case there is quality improvement or 0.0 if there is no quality enhancement.

**Table 4.11: Dependence of Bean Crop on Bee Production**

| **Pda** | **Qcv** | **Pdr** |
|---|---|---|
| **0.44** | 0.1 | 0.44 |

*Pda*-pollination dependence amount; *qcv*-quality coefficient value; *pdr*-pollination dependence ratio

### 4.3 Level of farmers' Indigenous Knowledge of Bee Pollinators of Common Beans in Borabu Sub-County, Western Kenya

The study sought to assess the level of farmers' indigenous knowledge of bee pollinators of common beans in Borabu Sub-County, Western Kenya.

#### 4.3.1 Demographic Characteristics of the Respondents

The respondents for the study were 25 farmers and 5 farm managers. The categories were characterized by gender, age, years in practice and experience.

#### 4.3.2 Distribution of Respondents by Gender

Most respondents were female 16(53.3%) while male respondents were 14(46.7%) (Figure 4).

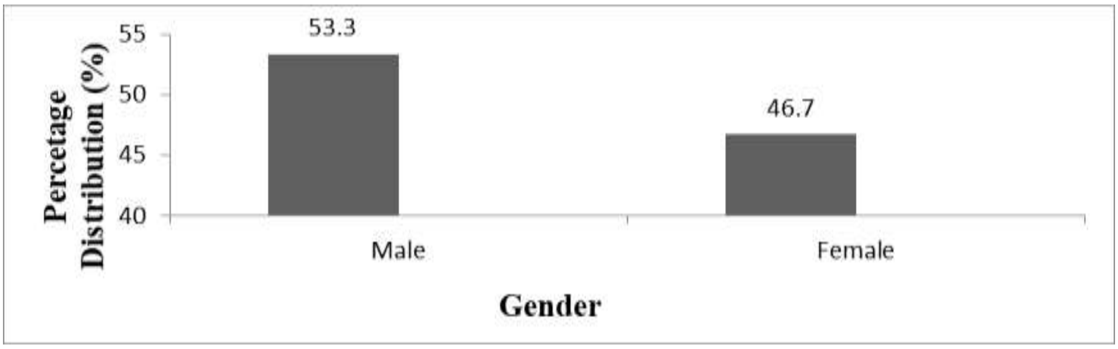


**Figure 4.4: Distribution of Respondents on Gender**

#### 4.3.3 Distribution of Respondents by Age

Table 4.12 reveals that majority of the respondents 12 (40%) were aged 36-53 years, 9(31%) were aged 18-35 years, 5(17%) were aged 54-71 years. The table further reveals that 2 respondents fell under the age bracket of 0-17 years. There were also 2 respondents past the age of 72 (Table 4.12).

**Table 4.12: Distribution of Respondents by Age**

| Age | Frequency (f) | Percentage (%) |
|---|---|---|
| 0 -17 | 2 | 6 |
| 18 -35 | 9 | 31 |
| 36 - 53 | 12 | 40 |
| 54 -71 | 5 | 17 |
| 72- above | 2 | 6 |
| Total | 30 | 100 |

### 4.3.4 Distribution of Respondents by Income (Shillings)

The findings reveal that majority of the respondents 11(37%) had their income between 0-23670, 9(30%) had income between 47371-71010 while 5(17%) respondents had their income between 71011-4680. The data further reveals that 3(10%) respondents had their income between 0-23670, 2(6%) had income of 94681-118350 while there no respondent had income above 118351 as illustrated in Figure 4.5. However, there was as a significant difference ($p<0.05$) in income levels among the different ages brackets of the respondents [appendix 3(vi)].

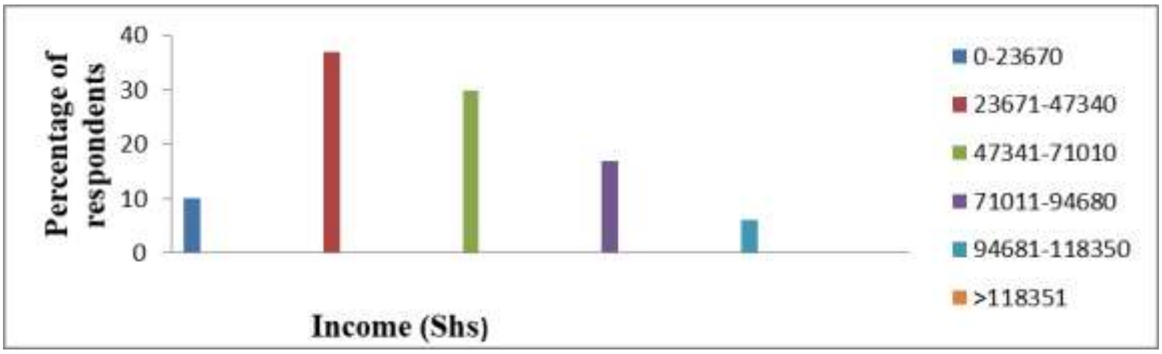


**Figure 4.5: Distribution of Respondents Based on Income**

### 4.3.5 Distribution of Respondents by Farm Size

Most of the respondents 14(47%) had 1/4 acre of land followed by a half an acre 7(23%) and 4(13%) had 1 acre while 5(17%) had 1 acre and above (Table 4.13).

**Table 4.13: Distribution of Respondents by Farm Size**

| Gender | Frequency (f) | Percentage (%) |
|---|---|---|
| ¼ Acre | 14 | 47 |
| 1/2 Acre | 7 | 23 |
| Acre | 4 | 13 |
| 1 Acre and above | 5 | 17 |
| Total | 30 | 100 |

### 4.3.6 Distribution of Respondents by Year of Practise

It's evident that most respondents 10(33.3%) had worked for over 3 years. Only 5(16.6%) respondents had been in the farming practice for one year and below. Nine (30%) of them had been in farming for one to two years while 6(20%) said they have been practicing agriculture in the study area for between 2 to 3 years (Figure 4.6). However, there was no significant difference (p>0.05) on farm size and duration of practicing bean production [Appendix 3(viii)].

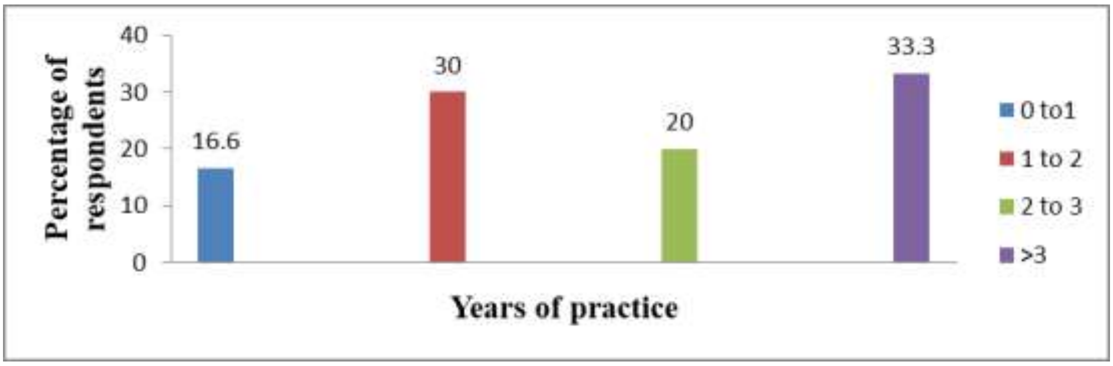


**Figure 4.6: Distribution of respondents based on duration of practice**

#### 4.3.7 Distribution of Respondents by Level of Training

Majority of the respondents 13 (43.3%) had certificate level of training. Respondents with Diploma training were 9 (30%), Bachelors 4(3.3%) while respondents with Masters and PhD level of training were 3(10%) and 1(3.3%) respectively (Table 4.14).

**Table 4.14: Distribution of Respondents by Level of Training**

| Gender | Frequency (f) | Percentage (%) |
|---|---|---|
| Diploma | 9 | 30 |
| Bachelors | 4 | 13.3 |
| Masters | 3 | 10 |
| PhD | 1 | 3.3 |
| Others | 13 | 43.3 |
| Total | 30 | 100 |

#### 4.3.8 Farmer's Knowledge on Pollinators

The questionnaires administered to the respondents had questions on pollination aspects such as pollinators identity and their presence in farms, time when most pollinators visit been flowers and inputs used in bean farms which boost bee pollination in bean farms.

#### 4.3.9 Frequency and Percentage Number of Respondents who were Familiar with Different Bees that Visit Bean Flowers in Nyansiongo Farmland

Six (42.7%) male respondents and 12(75%) female respondents were able to identify *Apis mellifera* bees. *Xylocopa calens* were also identified by a few male respondents 4(28.6%) and 3(18.8%) female respondents as a bee. However, *Meloponula sp.* and *Megachilidae sp*. were identified only by males 1(7.1%) while none of the females was able to identify them. Most respondents said there is presence of bee pollinators in their farms with female respondents being more affirmative (85%) than male respondents (70%) (Table 4.15). The differences were significant ($p<0.05$) between the male and females based on pollination knowledge on bee visitors [Appendix 3(x)]. Therefore, the hypothesis that there is no significant difference in the level of indigenous knowledge on bean pollinators of beans in farms in Borabu Sub-County Western Kenya was rejected.

**Table 4.15: Pollination Knowledge on Bee Visitors**

| | **Male** | | **Female** | |
|---|---|---|---|---|
| **Bee pollinators** | **Frequency** | **Percentages (%)** | **Frequency** | **Percentages (%)** |
| *A. mellifera* | 6 | 42.7 | 12 | 75 |
| *X. calens* | 4 | 28.6 | 3 | 18.8 |
| *X. flavorufa* | 2 | 14.3 | 1 | 6.3 |
| *Meliponula Sp.* | 1 | 7.1 | 0 | 0 |
| *Megachilidae Spp.* | 1 | 7.1 | 0 | 0 |
| Totals | 14 | 100 | 16 | 100 |

#### 4.3.9.1 Level of Knowledge on Time of the Day when Most Pollinators Visit Bean Flowers

Majority of the respondents 10 (33.3%) had knowledge that pollinators visit bean flowers at 10.00am-11.00am followed by 8 (26.7%) at 7.00am-8.00am while 5(16.7%) and 5(16.7%) respondents had knowledge that pollinators visit bean flower sat 9.00am-10.00am and 11.00am-12.00pm respectively. Time interval at 8.00am-9.00am had 2(6.7%) respondents respectively (Figure….). However, the differences were significant ($p<0.05$) between the male and females based on pollination knowledge on time of the day pollinators visit bean flowers [Appendix 3(x)]. Therefore, the hypothesis that there is no significant difference in the level of indigenous knowledge on bean pollinators of beans in farms in Borabu Sub-County Western Kenya was rejected.

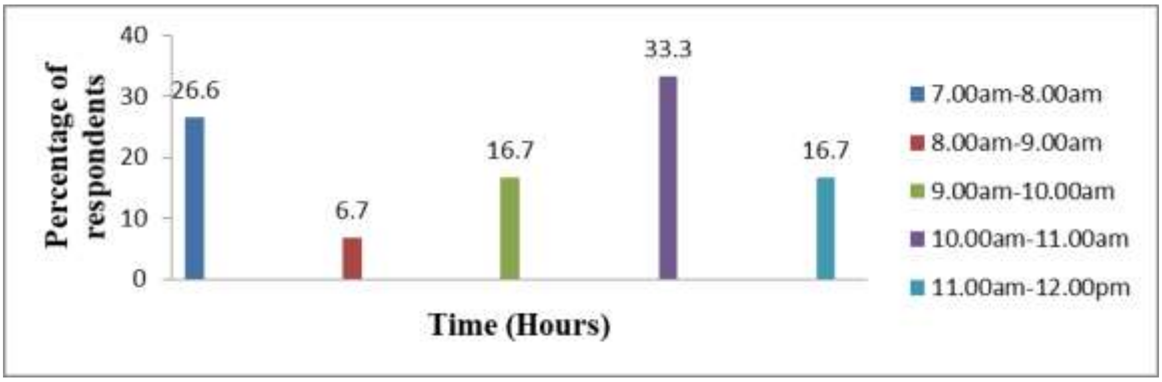


**Figure 4.7: Distribution of Respondents Based On Knowledge on Time Pollinators Visit Bean Flowers**

#### 4.3.9.2 Methods Used to Enhance Pollination Levels

Nine (64.3%) male respondents indicated that they used intercropping as a method of increasing pollination in bean flowers while 3(21.4%), 2(14.3%) indicated setting of bee hives and spreading bee wax respectively. Eleven (68.7%) of female respondents employed intercropping with flowering plants, 5(31.3%) setting of bee hives on farms and none of the females used live fences (Figure 4.8). The differences were not significant ($p>0.05$) between the male and females based on methods/ inputs used to increase pollination [Appendix 3(xi)]. Therefore, the hypothesis that there is no significant difference in the level of indigenous knowledge on bean pollinators of beans in farms in Borabu Sub-County Western Kenya was rejected.

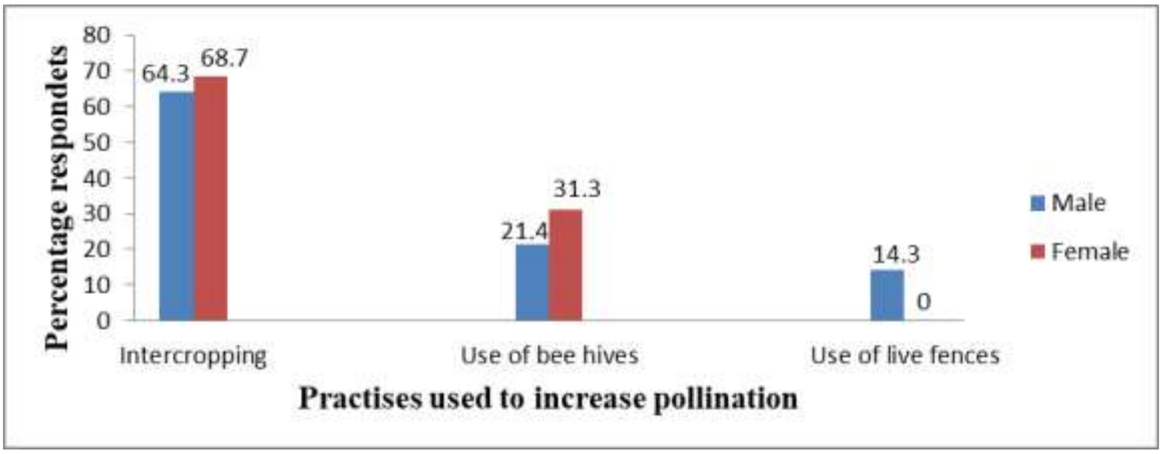


**Figure 4.8: Distribution of Respondents Based on Practise Used to Increase Pollination**

#### 4.3.9.3 Respondents' Knowledge on Chemicals used in Farms during Production of Beans in Nyansiongo Farmland

Only 12(75%) and 4(25%) of female respondents used insecticides and fungicides respectively. Utilization of herbicides, insecticides and fungicides was embraced by 2(14.3%), 7(50%) and 5(35.7%) male respondents respectively (Table 4.16). The differences were not significant ($p>0.05$) between the male and females based on chemicals used during bean production [Appendix 3(xi)]. Therefore, the hypothesis that there is no significant difference in the level of indigenous knowledge on bean pollinators of beans in farms in Borabu Sub-County Western Kenya was accepted.

**Table 4.16: Knowledge on Chemicals Used During Bean Production**

| Chemical type | Male | | Female | |
|---|---|---|---|---|
| | Frequency | Percentages (%) | Frequency | Percentages (%) |
| Herbicides | 2 | 14.3 | 0 | 0 |
| Insecticides | 7 | 50 | 12 | 75 |
| Fungicides | 5 | 35.7 | 4 | 25 |

# CHAPTER FIVE

# DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 5.1 Introduction

Pollination is an important input in crop production comparable to other inputs such as fertilizer, labour, or pesticides. Globally, pollinators contribute significantly to agricultural productivity, with many crops depending on animal-mediated pollination for improved yields and quality (Seddik *et al.,* 2025). Even where increases in yield are achieved through effective pollination, limited empirical studies have linked these gains directly to farmers' economic benefits, particularly in developing countries. Inadequate pollination remains a major constraint to achieving the potential yields of faba bean (*Vicia faba*) crops. Recent studies confirm that insect pollinators substantially enhance faba bean productivity, increasing seed weight, pod formation, and overall yield (Dirkson *et al*., 2025; Seddik *et al*., 2025). Furthermore, pollinators from nearby natural habitats significantly improve both yield and crop quality, thereby increasing market value and farmer income (Silva *et al.*, 2023). Comprehensive studies on biotic pollination are therefore essential to inform policy formulation and decision-making regarding pollination management for agricultural productivity, an area that remains insufficiently addressed in Kenya.

## 5.2 Abundance and Diversity of Bee Pollinators Visiting Common Bean (*Phaseolus Vulgaris*) Flowers along A Forest-Agriculture Gradient in Borabu Sub-County, Western Kenya

### 5.2.1 Abundance of Bee Pollinators

Eight bee species from four genera belonging to two families were collected from the farms studied. Bees remain among the relatively understudied insect groups in East Africa, with limited taxonomic capacity and collections (Tarakini *et al*., 2021). The dominance of *Apis mellifera* can be attributed to its social organization, large colony sizes, efficient recruitment communication (waggle dance) and high ecological adaptability, which enable it to exploit floral resources more effectively than most solitary bees. *Apis* followed by *Xylocopa* recorded the highest bee abundance. The individuals of *Apis mellifera* were more compared to other bee species. However, *A. mellifera* is not always the most efficient bean pollinator compared to other bees. A decline in *Xylocopa* populations may lead to reduced bean yields due to their superior pollination efficiency, particularly through effective tripping of flowers. These findings are consistent with studies indicating that honey bees are often the most abundant visitors in crop systems, including common beans (*P. vulgaris*), despite variability in pollination efficiency (Mallinger *et al*., 2017; Hung *et al*., 2018). The high abundance of this bee species is of great significance in enhancing the pollinator force of more efficient pollinators through sheer numbers (Garibaldi *et al*., 2016).

The collective role of a species-rich bee community is very important for pollination success (Dainese *et al*., 2019). The number of individuals of *A. mellifera* was higher than those of other bee species and consistently dominated in each sampled farm compared to other bee species. This numerical dominance is particularly important in improving overall pollination services, even where individual efficiency is lower (Garibaldi *et al*., 2016).

*Apis mellifera* was observed in all sampled farms because it is a highly adaptable and dominant bee species in most agroecosystems. Social bees tend to be more abundant though less diverse than solitary bees. Sociality plays a central role in pollination since social bees can communicate the presence of floral resources and recruit nestmates in large numbers to mass flowering crops (Klein *et al*., 2007; Hung *et al*., 2018). *A. mellifera* is also highly adaptable, capable of exploiting diverse habitats, nesting under varied conditions, and foraging on a wide range of plant species (Potts *et al*., 2016; Requier *et al*., 2019). These findings agree with studies showing that honey bees and solitary bees are key pollinators of crops such as *Coffea arabica* (Classen *et al*., 2015). Similarly, studies in Latin America have shown that *A. mellifera* often dominates pollinator assemblages, sometimes contributing over 80% of flower visits (Roubik, 2009; Hung *et al*., 2018).

### 5.2.2 Diversity of Bee Pollinators

This study realized that there is a low diversity of bees that visit bean flowers. The foraging activity of bee visitors was highest between 1000h and 1100h with a diversity index of 0.60. Similar observations have been reported in other studies, where peak activity of carpenter bees such as *Xylocopa* species on legume crops occurs during late morning to early afternoon hours, coinciding with optimal nectar secretion periods (Classen *et al.,* 2015; Reilly *et al*., 2020). These studies affirm that peak activity is strongly correlated with periods of maximum nectar availability in flowers. In broad beans, it has been observed that bees visiting extra-floral nectaries are most numerous around midday, while those collecting pollen from flowers tend to increase later in the day (Czechofsky *et al.*, 2025). These findings are also consistent with those obtained by recent studies which indicate that bee foraging activity increases progressively from morning to afternoon due to improving environmental conditions such as temperature and light intensity (Rader *et al*., 2016; Klein *et al*., 2018). Variations in diversity indices across time periods can be attributed to fluctuations in temperature, dew presence, light intensity, and floral resource availability. This concurs with broader ecological findings that weather conditions during crop blooming significantly influence the abundance and activity of insect pollinators (Potts *et al*., 2016).

Individuals belonging to eight bee species were observed visiting bean flowers in the Nyansiongo farmland. Comparable studies have documented higher bee diversity in both natural and agricultural ecosystems, with significantly greater species richness recorded in heterogeneous landscapes (Classen *et al*., 2015; Winfree *et al.,* 2018). It has been established that while abundance is important, the diversity of wild bee populations plays a more critical role in enhancing pollination success and crop yields (Garibaldi *et al*., 2016). These results are also consistent with findings from studies on French beans in East Africa, which reported multiple bee families and species contributing to pollination services in agricultural landscapes (Kiatoko *et al*., 2017). Similarly, studies conducted in tropical regions have recorded substantial variation in bee species visiting *Phaseolus vulgaris*, depending on habitat type, floral diversity, and landscape structure (Ratto *et al*., 2018; Bänsch *et al*., 2021).

## 5.3 Effect of Caged and Uncaged Pollination Treatments on Pod and Seed Set of Common Beans in Borabu Sub-County, Western Kenya

### 5.3.1 Bee Visitors in the Study Area

More bees were collected relatively early morning, more especially *A. mellifera*. Studies have revealed that foraging behavior of bees is temperature dependent and that there is a positive relationship between species number and temperature. According to Singh *et al*. (2025), bee foraging activity is strongly correlated with temperature, with higher temperatures enhancing foraging intensity and activity levels. Additionally, honey bee flight and foraging are restricted within specific thermal ranges, with optimal activity occurring under moderate temperatures (Frunze *et al*., 2026). At cold temperatures, bees prefer to visit sunny flowers to raise their body temperature, which enhances their flight capability and foraging efficiency. This may explain why there were few bees during the morning hours.

These findings are in agreement with studies conducted in Kenya and other regions which have reported that *A. mellifera* is abundant and frequent across different habitats due to its highly adaptable foraging behavior and ability to exploit diverse floral resources (Abou-Shaara, 2014; Giannini *et al*., 2017). These scholars further explain that *A. mellifera* bees are long-distance foragers with well-developed foraging strategies, enabling them to explore diverse nectariferous flowers across various habitats. These results are also consistent with findings that identify *A. mellifera* as one of the most dominant and common flower-visiting bee species in agricultural landscapes due to its ecological flexibility and efficiency in resource utilization (Potts *et al*., 2016).

### 5.3.2 Number of Bee Specimens Distributed in a transect of ≤3 km From the Forest Edge into the Nyansiongo Farmland

There was an observed tendency of most bee populations to decrease from the forest edge towards the farmland. This may be attributed to the fact that the forest serves as the main habitat for those bees. The forest could be providing conducive sites for bee nests, resting, hiding, mating and foraging in seasons when crops are not flowering

(Kennedy *et al*., 2013; Dainese *et al*., 2019). This supports the role of the forest as the main habitat of such species. It is agreed that the distance a bee will fly from the nest depends on the expected gain from floral rewards. Bees will only forage over longer distances when the energetic benefits outweigh the costs associated with flight and resource acquisition (Greenleaf *et al*., 2007; Zurbuchen *et al*., 2010). However, the mean number of some bee species kept on decreasing from the edge of the forest towards the farmland. The prevailing sunny and open-air conditions and presence of host plants such as beans on farms far from the forest edge might have attracted these bees. Open and sunny conditions in agricultural landscapes have been shown to enhance bee activity and dispersion in agro-ecosystems, particularly for species adapted to such environments (Steffan-Dewenter & Westphal, 2008; Dainese *et al*., 2019). Additionally, the spatial distribution of host plants strongly influences the dispersion and foraging patterns of bees, especially solitary species in farmlands (Kennedy *et al*., 2013; Garibaldi *et al.*, 2016).

### 5.3.3 Bee Visitation Rates

The results reveal that most bee species like *Apis spp*. and *Xylocopa spp*. did not prefer foraging during the early morning hours (0700h-0900h), with peak foraging occurring at 1000h-1100h, a pattern that may be attributed to fluctuations in temperature, dew presence, light intensity, and the availability of floral resources in bean crops. These results align with findings by Ngwa *et al*. (2025), who reported that honeybee visitation to bean flowers was significantly influenced by time of day and climatic conditions, with activity peaking around mid-day when environmental conditions were most favorable. Similarly, Ruticumugambi *et al*. (2025) showed that honeybee visitation rates on common bean flowers were positively correlated with floral abundance and were influenced by landscape and microclimate factors. In addition, recent research by Kot *et al*. (2023) on runner beans indicated that honeybees exhibited higher foraging activity later in the morning and early afternoon compared to early hours, highlighting the role of ambient temperature and relative humidity in regulating bee foraging behavior. These findings suggest that environmental conditions during bloom influence the foraging activities of insect pollinators, and support the observed visitation trends in this study.

#### 5.3.3.1 Bee Visitation Rates on Influence of Number of Pods

There was a higher number of pods in uncaged beans compared to caged bean plants, indicating that insect visitation significantly enhances pod production in legumes. Open-pollinated plants exposed to bee and other insect visitors consistently produce more pods per plant than those from which pollinators were excluded, demonstrating the positive role of bee visitation in successful fertilization and pod set (Raderschall *et al.,* 2024; Seddik & Ali, 2025). These findings align with recent research showing that insect pollination can lead to substantially higher pod numbers and overall yield components compared with self-pollinated or pollinator-excluded treatments (Raderschall *et al*., 2024; Seddik & Ali, 2025). Therefore, pollination by bees and other flower visitors contributed significantly to the number of developed pods via improved fertilization and resource allocation, further supporting the influence of bee visitation on reproductive success in bean crops.

#### 5.3.3.2 Mean Number of Pods per Plant

The findings of this study indicated that the mean number of pods per plant was higher in open (bee-pollinated) treatments than in closed treatments but without a statistically significant difference ($p > 0.05$). Studies have reported that open pollination enhances pod formation due to effective pollen transfer by insects, particularly bees. For instance, a recent study by Seddik and Ali (2025) found that open-pollinated faba bean plants recorded significantly higher pod numbers per plant compared to pollinator-excluded plants, with nearly a 98% increase attributed to bee activity. Similarly, a related by Elisante *et al*. (2020) demonstrated that insect-pollinated bean plants produced a higher number of pods per plant than self-pollinated plants, confirming the positive contribution of pollinators to bean yield components. These findings support the observed trend in the present study where open pollination resulted in higher pod numbers.

However, the lack of statistically significant differences observed in this study aligns with some earlier findings indicating that pollination effects on pod number may not always reach statistical significance depending on environmental conditions, crop variety, or experimental design. For example, Lundin & Raderschall, (2021) reported that although plants exposed to pollinators often produced more pods initially, the total number of pods harvested did not differ significantly between pollinated and non-pollinated treatments under certain conditions. Likewise, Bishop *et al*. (2020) noted that while pollination significantly influenced several yield parameters such as seed number and mass, its effect on pod number per plant could vary and was sometimes not statistically significant across cultivars. These variations suggest that pod formation in beans is partially self-fertile and may not always be strongly limited by pollinator activity.

Furthermore, broader reviews indicate that while insect pollination generally improves yield components, the magnitude of its effect on pods per plant is variable. Johansson (2020) reported that insect pollination increases pods per plant by an average of about 30-53%, but also emphasized that variability exists across studies due to differences in ecological and experimental conditions. This helps explain why the current study observed numerical differences without statistical significance. Therefore, the present findings are in agreement with existing literature, confirming that although bee pollination tends to increase the number of pods per plant, the effect is not always statistically significant.

#### 5.3.3.3 Bee Visitation Rates on Influence on Pod Weight

The pod weight of beans and their size depend on the number of developed seeds. Seeds usually initiate development of mesoderm, hence the more the seeds, the more ‘flesh’, and thus weight. In this study, the number of developed seeds was found to positively correlate with the pod weight (Appendix 3(ii and iii)). Seed production follows successful pollen deposition on the stigma and subsequent pollen tube germination. Bees were responsible for the pollination, and the more pollen deposited, the higher the likelihood of fertilization of more ovules, resulting in an increased number of seeds; thus, better-pollinated flowers produced a higher fruit weight. These findings are consistent with recent research demonstrating that open-pollinated common bean (*P. vulgaris*) plants visited by insect pollinators, including bees, produce significantly more pods, seeds per pod, and higher seed weight compared to self-pollinated plants from which pollinators were excluded

(Elisante *et al.*, 2020). Further, enhanced pollination has been shown to improve seed weight and other yield components in related legume species, affirming the importance of effective bee visitation for optimal bean yield (Chirilá *et al.*, 2026).

#### 5.3.3.4 Bee Visitation Rates on Influence of Seed Number

Seed production is due to successful pollen deposition on the stigma and subsequent pollen tube germination in a flower (Elisante *et al.*, 2020). Bees (*A. mellifera*) were responsible for the pollination, and the more pollen deposited, the higher the likelihood of fertilization of more ovules, which brings about increased numbers of seeds. The number of seeds per pod of beans obtained from caged and un-caged flowers was found to be significantly different ($p < 0.05$) [Appendix 3(iii)]. The results show that the mean number of seeds was lower than the maximum attainable in the un-caged flowers, which implies that bee pollination of the bean crop in the study area was not sufficient. This aligns with findings by Wolditsadik *et al.,* (2023), who reported that honeybee pollination significantly increased seed yield over excluded treatments in legume crops, indicating the importance of bees in effective seed set. Similarly, Desha *et al.*, (2023) observed significant differences in the number of seeds per pod and overall seed yield among treatments with and without honeybee access. Additionally, Seddik and Ali (2025) showed that honeybee pollination enhanced both seed weight and seed number in *Vicia faba* (broad bean), demonstrating the positive impact of bee visitation on seed development and yield. Pollination by bees thus made a measurable impact on the number of developed seeds.

#### 5.3.3.5 Bee Visitation Rates on Influence on Bean Seed Weight

Seed formation is due to effective pollen deposition on the stigma and subsequent pollen tube germination. Bees (*A. mellifera*) were responsible for much of the pollination, and the greater pollen deposition increases the chances of fertilization of more ovules, which leads to increased number and weight of seeds in uncaged flowers compared to caged flowers. These findings are supported by related studies showing that honeybee visitation enhances seed weight and quality parameters in legume crops, indicating that pollinator activity contributes significantly to seed development and yield quality (Kot *et al*., 2023; Seddik & Ali, 2025).

#### 5.3.3.6 Dependence of Bean Crop on Bee Pollination

Bean crops were found to benefit significantly from pollination when yields between caged (pollinator-excluded) and uncaged (open-pollinated) flowers were compared. Although common bean (*P. vulgaris* L.) is capable of self-pollination, recent experiments have shown that insect pollination, particularly by bees and other flower visitors, substantially increases yield components, including pods per plant, seeds per pod, and seed weight compared with self-pollination alone (Elisante *et al*., 2020). In East African smallholder systems, open-pollinated beans produced nearly double the yield per hectare relative to plants where pollinators were excluded, indicating that the presence of insect pollinators strongly enhances harvestable output and contributes to food security and income (Elisante *et al*., 2020). Similarly, studies in Brazil demonstrated that higher densities of native flower visitors are associated with increased probability of beans being classified as high quality, which has implications for market value and economic return (da Silva *et al*., 2023). While some crops can produce seeds without bees, biotic pollination frequently optimizes reproductive success and yield in legumes such as beans by facilitating cross-pollination, resulting in more and heavier seeds (Elisante *et al.,* 2020; da Silva *et al*., 2023). The use of caged and uncaged flowers enables clear assessment of the effects of insect pollinators on crop yields, with non-bee pollination largely limited to selfing or rare visits by nectar thieves, and the highest attainable yields achieved via effective cross-pollination either by hand or by sufficient bee visitation (Elisante *et al*., 2020). Therefore, the dependence of bean crops on bees for maximal reproductive performance is substantial, reinforcing the need to conserve pollinator communities to sustain yield and strengthen food systems.

## 5.4 Level of Indigenous Knowledge on Bean Pollinators of Beans in Farms in Borabu Sub-County Western Kenya

### 5.4.1 Distribution of Respondents by Gender

Despite traditional cultural norms that assign most farming activities to men, recent studies in African smallholder agriculture show that women frequently represent a large proportion of smallholder farmers and often dominate participation in key crop production activities, including legumes like common beans (*P. vulgaris* L.). For example, analyses in bean seed systems across sub-Saharan Africa report that women contribute significantly to bean production and decision-making, and in some contexts even carry out the majority of labor in bean plots (Ngoh *et al.,* 2020; Nchanji *et al*., 2024). Relatedly, studies on smallholder agroforestry and pollinator knowledge highlights how gender intersects with agricultural knowledge, with men sometimes having greater formal knowledge of pollination services, but women still playing central roles in farm labor and crop cultivation (Kingazi *et al*., 2024; Adebayo & Worth, 2024). Therefore, this study's finding that most respondents were female while male respondents were relatively fewer aligns with current literature on the feminization of smallholder crop production in Africa, contrasting earlier assumptions about male dominance in farming roles.

These findings affirm the need for gender-responsive agricultural extension programs that specifically target and empower women farmers, who constitute the majority of practitioners, while also addressing knowledge gaps among both genders to enhance productivity and adoption of improved farming practices.

### 5.4.2 Distribution of Respondents by Age

Age determines how actively a farmer engages in farming activities, as physical strength and vigor tend to decline with increasing age, which can reduce productivity and efficiency. In this study, it was found that most of the respondents were in their productive age, indicating their capacity and energy to actively participate in farming tasks. This finding aligns with recent empirical evidence showing that a high proportion of farmers fall within the economically active age brackets, which supports sustained agricultural involvement and output among smallholder farming populations (Akukwe *et al*., 2024; Olatoye *et al*., 2026).

### 5.4.3 Distribution of Respondents by Income

The study revealed that income levels varied among the respondents, with the majority of them earning low incomes, suggesting that limited earnings constrain farmers' ability to invest in and sustain productive farming practices. These low-income levels influence decisions about engaging in supplementary farming activities to augment earnings from crop production, as low profitability often limits access to quality inputs, technologies, and market opportunities for smallholders. This finding aligns with more recent evidence from a study on coffee smallholders in central Kenya, which found that farmers earn significantly below living income benchmarks, with many households' earnings constrained by structural and market limitations that contribute to persistently low farm incomes and restricted investment capacity in agriculture (Boukaka & Benfica, 2025).

### 5.4.4 Distribution of Respondents by Farm Size

The increase in population in the study area has led to massive land subdivision, resulting in many people managing smaller pieces of land. This trend toward reduced farm size and fragmented parcels is driven by demographic pressure combined with inheritance and land-use change, which limits the availability of contiguous agricultural plots and alters farming practices (Mayele *et al*., 2024). As a consequence, habitat fragmentation arising from subdivided farms and intensified land use disrupts ecological connectivity and diminishes pollinator abundance, thereby reducing pollen movement between plant populations. This can decrease reproductive success, impede effective gene flow, and contribute to the erosion of genetic diversity and adaptive potential within isolated populations (Montoya et *al.*, 2021; Sevenello *et al*., 2026).

### 5.4.5 Distribution of Respondents by Years of Practise

The years of practice translate into the time one has been involved in agricultural activities, especially crop cultivation in the study area, either as a farmer or agricultural officer, and reflect the depth of respondents' engagement in productive farming. Findings from recent agricultural studies indicate that longer farming experience significantly enhances farmers' production knowledge, decision-making capacity, and adaptability to climate-resilient practices, underscoring that most respondents in the study region actively engage in agricultural production (Tshikororo *et al*., 2024). Moreover, research on women's empowerment in agricultural activities highlights that limited experience and structural barriers continue to constrain many women's active involvement in certain agricultural enterprises, suggesting that experience is a key factor in effective engagement (Beriso, 2023). These findings align with the current study results, affirming that respondents' years of practice are integral to their participation and effectiveness in agricultural production.

### 5.4.6 Distribution of Respondents by Level of Training

From the findings, pollination knowledge among bean farmers of both males and females varied based on education backgrounds. It was noted that farmers in the study area had inadequate know-how on the importance of pollinators to beans, with a majority of smallholder farmers lacking awareness of pollination services and the role of insect pollinators in crop production (Elisante *et al*., 2020). Similar gaps in knowledge have been reported in other contexts, where farmers often cannot differentiate between pollinators and pests or lack training on pollinator conservation despite their critical role in food security (Sindhu & Krishna, 2025). In related studies, the limited understanding of pollinators and their management among smallholder farmers has been linked to a lack of targeted education and extension support, which tends to focus more on conventional inputs like fertilizers and pesticides rather than on ecological services such as pollination (Elisante *et al*., 2020; Sindhu & Krishna, 2025). It is therefore of great importance to offer agricultural extension services to farmers to educate them that pollination services are as significant as other farm practices such as weeding and fertilizer application for crop productivity (Elisante *et al*., 2020). It was also evident that farming of beans tends to be dominated by less educated people, whereas those with higher levels of formal education are more likely to be involved in managerial positions or large-scale farming zones where access to knowledge and resources is greater (Elisante *et al*., 2020).

### 5.4.7 Distribution of Respondents on Knowledge of Different Bees Visiting Bean Flowers

Most respondents knew that different species of bees visit their bean farms. Both genders had an almost equal understanding of the bees visiting bean flowers; however, female respondents had better knowledge of bees than male respondents. In particular, female respondents were relatively more conversant with solitary bees than male respondents since most females recognized bees among other insects displayed for identification. These findings align with current research showing that while many farmers can identify honey bees, knowledge of other pollinating insects (such as wild or solitary bees) is generally lower and varies with gender and education level, with some groups (including women and more educated farmers) showing higher awareness of diverse bee taxa and their roles in crop pollination (Elisante *et al*., 2019; Tarakini *et al*., 2020). Nevertheless, other studies have found that overall awareness of pollination services and the contributions of non-Apis pollinators remains limited among smallholder farmers, affirming the need for enhanced training and awareness on pollinator diversity and ecosystem services (Kingazi *et al*., 2024).

### 5.4.8 Distribution of Respondents based on Level of Knowledge on Time of the Day when Most Pollinators Visit bean Flowers

Majority of the respondents were aware of the time when bees and other pollinators frequent bean flowers, which aligns with scientific observations that pollinator activity is clearly associated with specific hours of the day and can vary in intensity throughout the daylight period. Studies on *Phaseolus* species has documented that honeybees (*A. mellifera*) and other flower visitors tend to be active over the course of the day and often show increased visitation around mid-day and early afternoon, with activity declining toward late afternoon, indicating predictable daily patterns of pollinator frequency that farmers and extension workers can plan around when scheduling field activities and pesticide applications to avoid peak pollinator presence (Kot *et al*., 2023; Li *et al*., 2025). Such knowledge is useful to agricultural extension workers since they can educate farmers on peak pollinator activity periods to minimize harmful pesticide exposure to beneficial insects and to promote targeted rather than blanket spraying of pesticides when necessary to protect pollinator populations and enhance pollination services for bean crops (Kot *et al*., 2023; Li *et al*., 2025).

### 5.4.9 Distribution of Respondents on Methods used to Increase Pollination

Male respondents had lower knowledge on methods used to enhance pollination than females. There is a need for educational campaigns to advise farmers on best farm management options to support the growth of bee populations, especially during flowering periods, because enhancing floral resources and adopting bee-friendly practices improves pollinator abundance and crop yields (Christmann *et al*., 2022; Innovative Agriculture, 2025). Integrated pest and habitat management practices such as reducing pesticide use, timing applications outside of bloom periods, and using non-chemical pest control are widely recommended to protect pollinators and maintain their effectiveness on farms (Xerces Society, 2024). Farmers can also be encouraged to manage bee forage by planting diverse flowering plants and establishing habitats that provide continuous nectar and pollen sources throughout the growing season (Agropec Futuro, 2024). A few respondents, especially male farmers, knew that a live fence is important in their compounds for various reasons, and therefore they can be encouraged to grow fences composed of bee-attractive plants not only to conserve pollinators but also for benefits such as beauty and confining animals (Pollinator Conservation Resource Guide, 2025). Globally, bees and other pollinators are endangered by multiple farming management practices and environmental stressors, and recent study shows that complex interacting factors including pesticide exposure, habitat loss, nutritional stress, and parasites contribute to phenomena similar to the previously termed Colony Collapse Disorder, where colonies collapse or suffer severe worker losses with no single clear causal agent identified (Taylor, 2025).

### 5.4.10 Distribution of Respondents on Knowledge of Chemicals Used in Farms during Production of Beans in Nyansiongo Farmland

Results from this study reveal that most farmers use chemicals in bean production. However, female respondents did not widely embrace the use of herbicides in enhancing bean production. These findings are consistent with recent studies indicating that pesticide use is widespread among smallholder farmers in Africa, often involving chemicals that are harmful to pollinators such as bees (Fikadu, 2020; Lanfranco & Heinrich-Böll-Stiftung, 2022). Furthermore, evidence from Kenya shows that pesticide residues, including insecticides, fungicides, and herbicides, are commonly detected in agricultural environments, suggesting frequent and sometimes excessive use of agrochemicals by farmers (Schut & Giller, 2020). However, these findings contrast with studies conducted in some regions where a significant proportion of farmers rely less on chemical inputs due to limited access, cost constraints, or adoption of alternative pest management strategies (Otieno *et al*., 2020).

## 5.5 Conclusion

Habitat heterogeneity is a significant factor that influences diversity and abundance of bees on farms. Farms with high heterogeneity have the highest potential to meet the various ecological requirements of bee pollinators. In this study, diversity and abundance of bee pollinators decreased from the forest edge to the farmland. *Apis mellifera* (Honey bees) was the most common visitor on flowers of the common beans (*P. vulgaris*).

The findings of this study have revealed that flower pollinators are important in pod set of bean crops and therefore, there is a need to conserve the populations of non-Apis bees, especially, *Xylocopa* and *Megachilidae* in order to enhance bean production. Bean crops depended greatly on bee pollination for their yield in this study. The seed weight per pod obtained from open flowers was higher (64.1%) than that obtained from closed flowers (35.9%), implying that cross pollination is quite important.

Based on these study findings, it is evident that pollination knowledge among bean farmers, both male and females, income levels and different education backgrounds is limited. As observed in related studies, it has been documented that community involvement in pollination initiatives has not been emphasized and most stakeholders may not account for the availability of insects during crop flowering periods.

## 5.6 Recommendations

Promotion and adoption of bee-friendly farming practices within the study area to enhance bee diversity and abundance, particularly in farm locations situated away from forest edges. This may include the preservation of natural habitats, reduced pesticide use, and the incorporation of floral resources to support diverse pollinator communities.

There is a need to prioritize the conservation of diverse bee species rather than focusing solely on the abundance of dominant species such as *A. mellifera*, since pollination efficiency and crop yield improvement in beans are strongly associated with species diversity.

Environmental management practices that enhance pollinator populations such as habitat restoration, maintenance of ecological corridors, and the adoption of sustainable agricultural practices should be strengthened to ensure effective pollination services and improved crop productivity.

Awareness creation initiatives targeting farmers, agricultural extension officers, policymakers, and other stakeholders should be intensified to emphasize the role of natural habitats in sustaining bee pollinators and enhancing agricultural outcomes.

Farmers should be encouraged to actively manage pollination services as an integral component of crop production, comparable to other agronomic practices such as weeding, fertilization, and pest control, through structured training programs and incentive-based approaches.

Government agencies and relevant stakeholders should develop and implement supportive policies that promote pollinator conservation, encourage stakeholder participation, and facilitate behavioral change among farmers toward sustainable farming practices.

Agricultural extension services should be strengthened to provide continuous sensitization and technical support to bean farmers on the importance of pollination services in improving both yield and crop quality.

The integration of hedgerows into Payment for Ecosystem Services (PES) schemes should be promoted as a strategy to enhance habitat connectivity, support pollinator diversity, and incentivize farmers to adopt conservation-oriented land management practices.

Further researchable gaps include;

1. Determination of the pollination requirements of other crops not considered by this study.

2. Determination ways of enhancing crop pollination in the larger Nyamira County and other bean crop production areas.

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## APPENDICES

### Appendix I: Farmers' Questionnaire

Dear Sir/Madam

You have been selected to assist in providing information considered important for the study: Abundance and diversity of bee pollinators a long a disturbance gradient in Borabu Sub County, Nyamira County**.** Kindly fill the questionnaire which will be used for the purpose of this study.

**Section A. Demographic Data**

1. Gender: Male [ ] Female [ ]
2. Age in Years: 0- 17 [ ] 18- 35 [ ] 36- 53 [ ] 54- 71 [ ] 72 and above [ ]
3. Monthly Income (Kshs): 0- 23670 [ ] 23671- 47340 [ ] 47341- 71010 [ ] 71011- 94680 [ ] 94680- 118350 [ ] 118351 and above [ ]
4. Size of field ; ¼ Acre [ ] 1 Acre [ ] 2 Acre [ ] 3 Acre and above
5. Years you have been practicing agriculture; 0-1 years [ ] 1-2 years [ ] 2-3 [ ] 3 years and above [ ]

**Section B: Education level**

To assess the education level of the respondents

6. What is the highest level of training that you have attained?

(Please mark one choice)

□1 Diploma Level□2 Bachelors Degree Level□3 Masters Degree Level

□4 PhD Level□5 Other

7. Are you satisfied with your level of qualification as a farmer?

YES☐ NO☐

**SECTION C: KNOWLEDGE ON POLLINATORS**

To assess farmer pollinator knowledge in Borabu Sub County, Nyamira County, Kenya

8. Are there pollinators in your farm? YES [ ] NO[ ]

9. Do you know the pollinators by name? YES [ ] NO[ ]

10. What are the types of pollinators that visit your farm? ...........................................................................................................................

11. In the pollinator types in (3) above, do you know their specific time they visit your farm?

YES [ ] NO [ ] (please provide the time)

12. What other methods are used in your farm to increase pollination? ………..…

13. Do you add any inputs to increase pollination? YES [ ] NO [ ]

14. If Yes in 6 above, provide the type(s) of inputs added

……………………………………………………………………………………

15. Do you use chemicals in your bean plots? YES [ ] NO [ ]

16. If Yes in 8 above, what type(s)of chemicals do you use in your bean plots? .........................................................................................................

## Appendix II: Farm Managers' Questionnaire

No…………

Dear Sir/Madam

You have been selected to assist in providing information considered important for the study: Abundance and diversity of bee pollinators in a disturbance gradient in Borabu Sub County, Nyamira County**.** Kindly fill the questionnaire which will be used for the purpose of this study.

**Section A. Demographic Data**

1. Gender: Male [ ] Female [ ]

2. Age in Years: 0- 17 [ ] 18 - 35 [ ] 36- 53 [ ] 54- 71 [ ] 72 and above [ ]

3. Where do you work and what is your role?

……………………………………..……………………………………………
……..

4. Years you have been working in agriculture; 0-1 years [ ] 1-2 years [ ] 2-3 [ ] 3 years and above [ ]

**Section B: Education level**

To assess the education level of the respondents

5. What is the highest level of training that you have attained?

(Please mark one choice)

□1 Diploma Level□2 Bachelors Degree Level□3 Masters Degree Level □4 PhD Level□5 Other

6. Are you satisfied with your level of qualification as a farm manager?

YES ☐ NO ☐

7. How long have you been working as a farm manager?

Where possible exclude extended periods of possible breaks.

Less than 1 year ☐1 1-2 years ☐2 3-5 years ☐3 6-10 years ☐4 11-15 years ☐5 16-20 years 6 More than20 years ☐7

**SECTION C: KNOWLEDGE ON POLLINATORS**

To assess pollinator knowledge among farm managers in farms in Borabu Sub County, Nyamira County, Kenya

8. Are there pollinators in farms under your area of jurisdiction? YES [ ] NO[ ]

9. Do you know these pollinators by name? YES [ ] NO[ ]

10. What are the types of pollinators that visit farms under your area of jurisdiction?

..........................................................................................................................

11. In the pollinator types in (3) above, do you know their specific time they visit farms?

YES [ ] NO [ ] (please provide the time)

12. What other methods are used in your farms to increase bean pollination? ………………………………………………………………………………………..…

13. Do you add any inputs to increase pollination? YES [ ] NO [ ]

14. If Yes in 6 above, provide the type(s) of inputs added

…………………………………………………………………………………………..

15. Do you recommend use chemicals in bean plots? YES [ ] NO [ ]

16. If Yes in 8 above, what type(s) of chemicals do you use in your bean plots? ...................................................................................................................................

**END**

**Appendix III: Statistical Analysis Output**

**(i)** Number of pods per plant

Unbagged- Bagged

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .144 | 8 | .018 | .166 | .993 |
| Within Groups | 2.275 | 21 | .108 | | |
| Total | 2.419 | 29 | | | |

**(ii)** Average pod weight per plant

Unbagged-Bagged

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .027 | 9 | .003 | 2.924 | .022 |
| Within Groups | .021 | 20 | .001 | | |
| Total | .048 | 29 | | | |

**(iii)** Average number of seeds per pod

Unbagged-Bagged

| | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .001 | 3 | .000 | 3.758 | .023 |
| Within Groups | .001 | 26 | .000 | | |
| Total | .002 | 29 | | | |

**(iv)** Seed weight per pod

Unbagged-Bagged

| | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Between Groups | .002 | 4 | .000 | 3.551 | .020 |
| Within Groups | .003 | 25 | .000 | | |
| Total | .005 | 29 | | | |

(**v**) Number of bees between plot 1 and 3(from the forest edge into Nyansiongo farmland)

| | | Paired Differences | | | | | T | Df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | P1 – P2 | -77.0000 | 16.52271 | 9.53939 | -118.0469 | -35.95531 | -8.072 | 2 | 0.015 |

**(vi)** Respondents' Age and Income levels

| | | Paired Differences | | | | | T | Df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Age-Income | -14.0000 | 9.38083 | 4.19524 | -25.64784 | -2.35216 | -3.337 | 4 | 0.029 |

**(vii)** Income level and level of training

| | Paired Differences | T | Df | Sig. |
|---|---|---|---|---|

**viii)** Farm size and duration of practice

| | | Paired Differences | | | | | t | df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Male - Female | .0000 | 12.68582 | 7.32416 | -31.51332 | -31.51332 | .000 | 2 | 1.000 |

**(ix)** Pollination knowledge between male and female respondents

| | | Paired Differences | | | | | T | Df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Duration of practise | 0.02500 | 20.71913 | 10.35957 | -32.94377 | 32.99377 | 0.002 | 3 | 0.998 |

| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Lower | Upper | | | |
| Pair 1 | Income level-Training | 0.2000 | 27.11396 | 12.12573 | -33.64643 | 33.68643 | 0.002 | 4 | 0.999 |

**(x)** Respondents' knowledge on method used to increase pollination

| | | Paired Differences | | | | | T | Df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Male-Female | 16.76000 | 10.85210 | 4.85321 | 3.28534 | 30.23466 | 3.453 | 4 | 0.026 |

(xi) Pollination knowledge on chemicals used in bean production

| | | Paired Differences | | | | | T | Df | Sig. (2 tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 1 | Male-Female | 0.000 | 21.72533 | 12.54313 | -53.96871 | 53.96871 | .000 | 2 | 1.000 |