

**ECOLOGY AND BEHAVIOUR OF SELECTED POLLINATING INSECTS IN
CUCURBIT FIELDS IN MOROGORO, EASTERN - CENTRAL TANZANIA**

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**A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE
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EXTENDED ABSTRACT

Cucurbits are fruit vegetables belonging to the family Cucurbitaceae. They supply humans with essential compounds in edible products containing vitamins, minerals and phyto-protective compounds. The importance of cucurbits' essential compounds to human health has raised the demand for its products. However, the production of cucurbit fruits is hampered by insufficient pollination services. Most of the cucurbits are monoecious, having both male and female flowers separately on the same plant. Male flowers have sticky and heavy pollens which for successful transfer to female flowers requires insect pollinators. Honeybees (*Apis mellifera*) are known to be the major pollinators of cucurbits. However, the population of the former is declining, this has negatively impacted cucurbits production. This is due to their territories being threatened by climatic change and agriculture intensification which involves the excessive use of pesticides. There is little hope in the efforts for enhancing the abundance of honeybees for effectiveness and sustainable pollination services in cucurbits. This situation entails the investigation of other insect pollinators who are attracted to cucurbits for supplementary pollination services.

In Literature, the Syrphidae (hoverflies) family members have been reported to have pollination potential. Their bodies are covered with bristles which assist in carrying pollen grains from one flower to another. However, the foraging behaviour of most hoverfly species in cucurbits is not well understood, requiring further investigation. Therefore, this study investigated four dominant hoverflies species attracted to cucurbits namely *Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus* and *Toxomerus floralis* along with *A. mellifera* on: 1) the floral visitation of hoverflies and honeybees on the three cucurbit species; cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*) and Squash (*Cucurbita moschata*) which are commonly grown in Tanzania, 2) how

environmental variables; temperature, relative humidity and rainfall affect their diurnal visitation patterns, and 3) how different management practices in cucurbits production influence their foraging activities.

A Randomized Complete Block Design (RCBD) in a factorial arrangement with four replications was used. The floral visitation was assessed based on pollinator visitation abundance per cucurbit species, visitation frequency (number of visits per pollinating species per cucurbit flower) and visitation rate (number of flowers visited by individual pollinating species). The influence of environmental variables on diurnal visitation patterns of pollinators were assessed based on pollinator visitation abundance on cucurbit flowers per specific time along the day: Five-time slots from 0800 h to 1700 h at the interval of 1 hour were considered. For the effects of cucurbits management practices on pollinator foraging activities; GAMOUR - Agroecology and conventional practices were evaluated and pollinators foraging activities were assessed based on their visitation abundance, visitation frequency, visitation rate and handling time (time spent on cucurbit flowers). The plots where no any management practices except weeding and irrigation during the dry season were used as a negative control. The experiments were conducted at two agroecological zones of Morogoro (plateau and mountainous) for two seasons (rainy and dry season).

Results revealed a significant relationship between visitation abundance with flower density and relative humidity. Agroecological zones, cucurbit species and seasons had significant effects on the number of visits per cucurbit flowers and the number of flowers visited by pollinating species. *Apis mellifera* was the dominant species in cucurbit flowers at both agroecological zones during the two growing seasons and *M. caffer* was the least visitors on flowers of all three cucurbit species. *Toxomerus floralis* and *P. bobornicus* were dominant visitors of *C. sativus* and *C. lanatus* at the plateau zone during the season

of May-June. Environmental variables had negative effects on the diurnal visitation patterns of flower visitors. The highest average visitation abundance for all pollinating species were recorded between 0800 – 1100 h and the least between 1600 – 1700 h. Environmental variables had less impact on hoverflies' diurnal visitation patterns as compared to honeybees because from 1200 – 1700 h the visitation abundance of honeybees was ceasing, whereas no significant difference in visitation abundance was found for hoverflies. Management practices applied during cucurbit production affected the visitation frequencies and handling time of pollinators on cucurbit flowers. The number of visits and the time spent by pollinators on cucurbit flowers in plots receiving GAMOUR - Agroecology practices were significantly higher than that in plots assigned Conventional practices and the control plots.

This study concludes that, all the studied hoverflies can have pollination potentials in cucurbits, however their foraging activities are influenced by Agroecological zone, seasons, cucurbit species and management practices that are employed during cucurbit production. Therefore, cucurbit growers have to consider producing this crop during the season when pollinators are abundantly present and the practices that enhance pollinators' abundance and their foraging activities. Also, this study recommends further investigations on the effect of cucurbits management practices on floral rewards quality and floral receptiveness longevity followed by an investigation of pollination efficiency of the studied hoverflies.

Keywords; Cucurbits, GAMOUR- Agroecology, conventional, honeybees, hoverflies, pollination, *Apis mellifera*, *Paragus borbonicus*, *Toxomerus floralis*.

DECLARATION

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

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LIST OF MANUSCRIPTS

Chapter Two: Presents a manuscript titled “Floral visitation of honeybees and hoverflies on selected cucurbit crops in Morogoro, Eastern-Central Tanzania” which has been submitted to the Journal of Oriental Insects.

Chapter Three: Presents a manuscript on “The influence of abiotic factors on diurnal visitation patterns of honeybees and hoverflies in selected cucurbit crops in Morogoro, Eastern-Central Tanzania” which is under preparation to be submitted in any recognized journal.

Chapter Four: Presents a manuscript on “Effects of management practices in cucurbits on foraging activities of honeybees and hoverflies in Morogoro, Tanzania” which has been submitted to the Journal of Agroecology and Sustainable Food Systems.

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DEDICATION

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| | | |
|--|---|----|
| 1.3 | Objectives..... | 8 |
| 1.3.1 | Overall objective..... | 8 |
| 1.3.2 | Specific objectives..... | 8 |
| CHAPTER TWO..... | | 10 |
| Manuscript one..... | | 10 |
| Floral Visitation of Honeybees and Hoverflies in Selected Cultivated Cucurbitaceous Vegetables in Morogoro, Eastern-Central Tanzania..... | | 10 |
| Abstract..... | | 11 |
| 2.0 | Introduction..... | 12 |
| 2.1 | Materials and Methods..... | 14 |
| 2.1.1 | Description of study area..... | 14 |
| 2.1.2 | Experimental layout and treatment..... | 15 |
| 2.1.3 | Crop establishment and cucurbits flower visitors assessment..... | 15 |
| 2.1.4 | Data collection..... | 15 |
| 2.1.5 | Statistical analysis..... | 17 |
| 2.2 | Results..... | 17 |
| 2.2.1 | Temporal variation on the visitation abundance of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the period of May-June and October-November..... | 17 |
| 2.2.2 | Abundance of honeybees and hoverflies on cucurbit species..... | 19 |
| 2.2.3 | The relationship between cucurbit flowers variables, weather parameters and visitation abundance of honeybees and hoverflies on the three cucurbits species..... | 20 |

| | | |
|-------|---|--------|
| 2.2.4 | Temporal variation on the visitation frequency of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June and October-November..... | 21 |
| 2.2.5 | Effects of agroecological zone, season, cucurbit species and pollinator species on visitation frequency of honeybees and hoverflies on three cucurbit flowers..... | 23 |
| 2.2.6 | Temporal variation on the visitation rate of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June and October-November..... | 26 |
| 2.2.7 | Effects of agroecological zone, season, pollinator species and cucurbit species on visitation rate of honeybees and hoverflies on three cucurbit flowers..... | 28 |
| 2.3 | Discussion..... | 31 |
| 2.4 | Conclusions..... | 33 |
| | Acknowledgement..... | 34 |
| | References..... | 35 |
| | CHAPTER THREE..... | 42 |
| | Manuscript two..... | 42 |
| | Influence of Abiotic Factors on Diurnal Visitation Patterns of Honeybees and Hoverflies in Selected Cucurbit Crops in Morogoro, Eastern-Central Tanzania..... | 42 |
| | Abstract..... | 43 |
| 3.0 | Introduction..... | 44 |
| 3.1 | Materials and Methods..... | 46 |
| 3.1.1 | Description of the study area..... | 46 |
| 3.1.2 | Experimental layout and treatment..... | 46 |

| | | |
|-------|--|----|
| 3.1.3 | Crop establishment..... | 46 |
| 3.1.4 | Assessment of pollinator diurnal visitation patterns..... | 47 |
| 3.1.5 | Data collection..... | 47 |
| 3.1.6 | Statistical analysis..... | 47 |
| 3.2 | Results..... | 48 |
| 3.2.1 | Diurnal visitation patterns of pollinators on cucurbit flowers..... | 48 |
| 3.2.2 | Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>A. mellifera</i> on cucurbits flowers..... | 49 |
| 3.2.3 | Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>P. borbonicus</i> on cucurbits flowers..... | 51 |
| 3.2.4 | Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>T. floralis</i> on cucurbits flowers..... | 54 |
| 3.2.5 | Effect of weather parameters and cucurbit flower densities on visitation patterns of honey bees and hoverflies..... | 55 |
| 3.3 | Discussion..... | 56 |
| 3.4 | Conclusions and Recommendations..... | 58 |
| | References..... | 59 |
| | CHAPTER FOUR..... | 63 |
| | Manuscript three..... | 63 |
| | Effects of Management Practices in Cucurbits on Foraging Activities of Honeybees and Hoverflies in Morogoro, Eastern-Central Tanzania..... | 63 |
| | Abstract..... | 64 |
| 4.0 | Introduction..... | 65 |

| | | |
|-------|---|----|
| 4.1 | Material and Methods..... | 66 |
| 4.1.1 | Description of the study area..... | 66 |
| 4.1.2 | Experimental layout and crop establishment..... | 67 |
| 4.1.3 | Assessment of honeybees' and hoverflies' foraging activities..... | 68 |
| 4.1.4 | Data collection..... | 69 |
| 4.1.5 | Statistical analysis..... | 70 |
| 4.2 | Results..... | 70 |
| 4.2.1 | Abundance of honeybees and hoverflies on cucurbit flowers across the three cucurbits management practices..... | 70 |
| 4.2.2 | Effects of agroecological zones, seasons, cucurbit species and cucurbits management practices on the visitation frequency of honeybees and hoverflies on cucurbits flowers..... | 71 |
| 4.2.3 | Effects of agroecological zones, seasons, cucurbit species and cucurbits management practices on the visitation rate of honeybees and hoverflies on cucurbits flowers..... | 74 |
| 4.2.4 | Effect of agroecological zones, seasons, cucurbit species and cucurbits management practices on time spent on cucurbit flowers (handling time) by honeybees and hoverflies..... | 77 |
| 4.3 | Discussion..... | 81 |
| 4.4 | Conclusions..... | 83 |
| | References..... | 85 |
| | CHAPTER FIVE..... | 92 |
| 5.0 | General Discussion..... | 92 |
| | CHAPTER SIX..... | 94 |
| 6.0 | General Conclusions and Recommendations..... | 94 |

| | | |
|-----|----------------------|----|
| 6.1 | Conclusions..... | 94 |
| 6.2 | Recommendations..... | 95 |
| | Reference..... | 96 |

LIST OF TABLES

| | | |
|------------|--|----|
| Table 2.1: | Abundance honeybees and hoverflies in three cucurbit species..... | 20 |
| Table 2.2: | Flowers parameters of the three cucurbits under the study..... | 21 |
| Table 2.3: | The relationship between cucurbit flowers variables, weather parameters and the visitation abundance of honeybees and hoverflies on the three cucurbits species..... | 21 |
| Table 2.4: | Effects of agroecological zones, seasons and cucurbit species on visitation frequency honeybees and hoverflies on cucurbit flowers..... | 24 |
| Table 2.5: | Effects of agroecological zones, seasons and cucurbit species on visitation rate honeybees and hoverflies on cucurbit flowers..... | 29 |
| Table 3.1: | Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>A. mellifera</i> | 50 |
| Table 3.2: | Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>P. borbonicus</i> | 53 |
| Table 3.3: | Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of <i>T. floralis</i> | 54 |
| Table 3.4: | Spearman's correlation coefficient between environmental variables and diurnal visitation patterns of the studied pollinators..... | 56 |
| Table 4.1: | Characteristics of the study area..... | 67 |

LIST OF FIGURES

LIST OF ABBREVIATIONS, ACRONYMS AND SYMBOLS

| | |
|---------|--|
| AGROVEG | Agroecological Methodology in VEGetable crops |
| ANOVA | Analysis of Variance |
| CA | Central America |
| CAN | Calcium ammonium nitrate |
| DF | Degree of Freedom |
| g | gram |
| GBIF | Global Biodiversity Information Facility |
| GLMMs | Generalized Linear Mixed Models |
| h | Hour |
| HSD | Honestly significant difference |
| IPBES | Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services |
| IPM | Integrated Pest Management |
| l | litre |
| m | Metre |
| m.a.s.l | Meters above sea level |
| min | minute |
| n.s | no significant difference |
| NPK | Nitrogen, Phosphorus and Potassium |
| pH | Hydrogen ion |
| P-value | Observed significance level |
| RCBD | Randomized Complete Block Design |
| S | Second |
| SE | Standard Error |

| | |
|-----|-----------------------------------|
| SUA | Sokoine University of Agriculture |
| TMA | Tanzania Meteorological Authority |
| UK | United Kingdom |
| URT | United Republic of Tanzania |
| USA | United State of America |
| VIF | Variance Inflation Factor |

CHAPTER ONE

1.0 GENERAL INTRODUCTION

1.1 Background Information

Cucurbits are fruit vegetables under the family Cucurbitaceae, consisting of nearly 825 species in about 118 genera (Mondal *et al.*, 2020). Some cucurbit species of economic importance include cucumber, pumpkins, squash and watermelons (Choudhary and Singh, 2019). They are among the most important plant families supplying humans with edible products rich in vitamins A, C and vital minerals such as copper, phosphorus, zinc, iron, and magnesium (Mondal *et al.*, 2020). Furthermore, cucurbits contain phyto-protective compounds that perform various biological activities in the human body. These compounds function as antioxidants, antimicrobial, anti-inflammatory, and anticancer (Rolnik and Olas, 2020) and due to their low carbohydrate contents, it is advisable to be consumed by people with diabetes (McCreight, 2016).

The cucurbits are of remarkable economic importance and have been cultivated for their fleshy fruits, leaves, shoots, seeds and flowers for food and commodity goods throughout the world from arid climates to the humid tropics (Mondal *et al.*, 2020). However, tropical or subtropical climate is preferred for commercial production (Agbagwa *et al.*, 2007; Saroj and Choudhary, 2020). Their seeds germination, plant growth and yield are influenced by both abiotic and biotic factors. Cucurbits grow well in the day temperature at a range of 25⁰C –35⁰C (Wehner *et al.*, 2020). Globally, China, Turkey, India and the United State are leading producers of Cucurbitaceae (Rolnik and Olas, 2020). In Africa, Algeria and Egypt are also considered the larger producer of cucurbits which accounts for 3% of global production (Dhillon *et al.*, 2020).

In Tanzania, cucurbits are produced in many regions although the production records are hardly reported. Morogoro is among the regions with suitable conditions for cucurbits production (De Putter *et al.*, 2007). Due to increasing awareness of the nutrition benefits of consuming cucurbits in the country, there is a growing demand for these products (Nordey *et al.*, 2017; Sawe *et al.*, 2020). To meet the growing demand for cucurbits, their production has to be elevated. However, the production is hindered by both abiotic and biotic factors including climate change, inadequate soil fertility, diseases, pests and insufficient pollination services. Amongst these factors, insufficient pollination service is mostly reported to be the constraint to cucurbits production (Anandhabhairavi *et al.*, 2020; Christmann *et al.*, 2017; Sawe *et al.*, 2020).

1.1.1 Cucurbit physiognomies

Cucurbits are herbaceous annual or perennial crops that grow either horizontally along the ground or climb using tendrils (Mondal *et al.*, 2020). The blooming period in most cucurbit species starts 30–45 days after planting depending on crop species, climatic factors and agronomic practices (Bouzo and Küchen, 2012; Saroj and Choudhary, 2020; Wehner *et al.*, 2020) with male inflorescences emerging first and predominating in number throughout the flowering period, then, female inflorescence appears 10 days later (Knapp & Osborne, 2019). The ratio of male to female flowers usually produced per plant varies from 25–30:1 to 15:1 depending on crop species and environmental conditions (Bomfim *et al.*, 2016; Mondal *et al.*, 2020). Most cucurbit species are monoecious as male and female flowers are born separately on the same plant (Bomfim *et al.*, 2016). The receptacle of individual flowers differentiates a male from a female flower, for that of a female flower is enlarged due to the presence of the ovary (Saroj and Choudhary, 2020). Many cucurbit flowers have five yellow petals which attract diverse insect pollinators (Agbagwa *et al.*, 2007; de Souza *et al.*, 2017), the inflorescence size and corolla depth

depend on cucurbit species (Ishii *et al.*, 2019). Cucurbit flowers open by stretching outward of the corolla early in the morning when both stigma receptivity and pollen viability are at their greatest and rapidly decline within a day (Emuh and Ojeifo, 2011). The duration of flower receptiveness within a day depends on crop species and environmental conditions, and once the flower is closed does not reopen again (Bomfim *et al.*, 2016; Teresinha *et al.*, 2019). Both flowers produce nectar that attracts insect pollinators which are found in a chamber at the base of the stamens in staminate flowers and a lower ring at the base of the pistil in pistillate flowers (Lobo and Bravo-Méndez, 2021). Male flowers produce heavy and sticky pollen grains, hence, their transfer from anthers to stigma is limited in the absence of insect pollinators (Dorjay *et al.*, 2017). Therefore, insect pollinators are very essential in cucurbit crops to achieve fruit setting (Fayeun *et al.*, 2016; Mondal *et al.*, 2020).

1.1.2 Economic importance of insect pollinators

Insect pollinators are invertebrate animals that assist in the transfer of pollen grains from the anthers to the stigma in cross-pollinated crops to ensure fruit setting and seed formation (Dorjay *et al.*, 2017). Pollination is an indispensable ecosystem service for sustaining food security and improving livelihoods (Lever *et al.*, 2014). Globally, about 80% of cultivated flowering crops depend on insect pollinators mainly under the order Hymenoptera and Diptera for yield enhancement (Bashir *et al.*, 2019). The contribution of these insect pollinators to the global agricultural economy has been evaluated to be about USD 200 billion annually as the improvement in crop production accredited to insect pollination (Zameer *et al.*, 2017). Hymenopterans are considered to be the major pollinators in more than 16% of 0.25 million flowering plant species including cucurbits in the world (Sree *et al.*, 2018) which makes less attention to be given to other insect pollinators.

Despite the enormous importance of insect pollinators in agriculture, there is increasing evidence that their populations and diversity are declining worldwide consequently impacting negatively crop productivity (Dan *et al.*, 2019; Reilly *et al.*, 2020). Inadequate pollination service has been estimated to cause up to 90% fruit production loss in cucurbits (Bomfim *et al.*, 2016; Mokam *et al.*, 2014). Poor pollination service can result in low fruit set, small, contorted fruit and in absence of pollination, fruit abortion occurs (Knapp and Osborne, 2019). An investigation from the Global Biodiversity Information Facility (GBIF) conducted over a century discovered that bee species have declined rapidly, with fewer species reported between 2006 and 2015 than before the 1990s (Zattara and Aizen, 2021). The same situation has been reported on hoverflies (Syrphidae) in Mediterranean countries; the Netherlands and the U.K (Sánchez-Bayo and Wyckhuys, 2019). Addition to that, the study by Sawe *et al.* (2020) in northern Tanzania on watermelon discovered the presence of inadequate pollination services to the crop due to the low number of insect pollinators, several fruits had aborted in plots receiving natural insect pollinators as compared to the plots received extra hand pollination.

1.1.3 Ecology and behavior of insect pollinators

Pollinators – plants interaction is linked to floral morphology, quality and quantity of floral rewards and changes in climatic conditions (Cook *et al.*, 2020; Gérard *et al.*, 2020). Each pollinator group has a specific physiological adaptation that assist them for acquisition of pollens and nectars, for example, the presence of hairs or scales on their bodies and proboscis (Gérard *et al.*, 2020). Pollinators get attracted to certain flowers basing on the length of nectar spurs, corolla tubes with respect to their body size and proboscis length (Cook *et al.*, 2020; Gérard *et al.*, 2020; van der Kooi *et al.*, 2021). Pollinators locate floral resources through volatile organic compounds released by a

flower (Gérard *et al.*, 2020) and can avoid harmful reward compounds (van der Kooi *et al.*, 2021).

Furthermore, changes in climatic conditions affect pollinators – plants interaction. Can result to the mismatch between emergence of pollinators and the blooming period (Saroj and Choudhary, 2020). Also, elevated temperatures alter resource nutritional quality like decrease in pollens viability and nectar sugar concentration which become unsuitable for pollinators (Gérard *et al.*, 2020). Bees prefer to collect warm nectar from flowers at low ambient temperatures and from cooler flowers at ambient temperatures above about 30° C (Gérard *et al.*, 2020; Shrestha *et al.*, 2018).

1.1.4 Drivers for the decline of insect pollinators

Several studies have documented the decline of insect pollinators world wide (Rafferty, 2017; van der Sluijs, 2020). This decline is attributed to several factors including farming intensification, agrochemical pollutants, urbanization, climate change and socio-cultural perceptions (Grubisic *et al.*, 2018; van der Sluijs, 2020).

1.1.4.1 Farming Intensification on insect pollinators

Land fragmentation and farming intensification resulted from the industrialization of agriculture which involved the extensive use of pesticides and fertilizers and increased human population (Raven and Wagner, 2021). These have destroyed many natural habitats, foraging and nesting resources for insect pollinators (Potts *et al.*, 2010). Changes in land use lead to the elimination of certain pollinator species, thereby altering the structure and function of plant-pollinator communities (Rafferty, 2017). Furthermore, the study by Wafubwa and Millicent (2019) in Kenya discovered that anthropogenic activities

due to increased human populations which hastened land-use changes led to biodiversity loss.

1.1.4.2 Use of agrochemical pollutants and declines in insect pollinators

The use of systemic pesticides particularly neonicotinoids which are commonly applied as a coating to seeds and sprayed on the crops translocate through plant tissues and accumulate in plant nectars and pollens (Chen *et al.*, 2021; Pecenka *et al.*, 2021; Tschoeke *et al.*, 2019). The sub lethal produced have negative effects on pollinator performance and behaviour (Mondal *et al.*, 2020; van der Sluijs and Vaage, 2016; Walker and Wu, 2017). The impairment of pollinator performance subsequently reduce crop yield (Wu and Atallah, 2019). The investigation by Vanbergen *et al.* (2013) revealed that species abundance and richness tend to decrease where there is the intensive use of pesticides.

1.1.4.3 Climate change and insect pollinators

Climate change has drastic impacts on biodiversity, it induces mismatches between plants and pollinators by changing the plants growing patterns and pollinator reproduction. It affects their distribution, phenology, abundance, physiology and morphology (Rafferty, 2017). Additionally, climate change may alter the synchrony between flower opening and pollinator flight periods thus, hampering food availability which consequently leads to the loss of pollinators (van der Sluijs and Vaage, 2016; Vanbergen *et al.*, 2013). The investigation by Burkle and Runyon (2016) discovered that drought affects floral volatility and reduces flower size and display.

1.1.4.4 Socio-cultural perception of insect pollinators

Insects are invertebrates that provide ecosystem services including nutrient cycling, pollination and biological indicators. Despite the enormous importance of pollinators in the ecosystem, little attention is paid to them, this is due to negative perceptions that many people have (Le *et al.*, 2021). Many insects are viewed as pests that cause detrimental effects on both crops and humans therefore, their conservation measures are given little consideration (Burns *et al.*, 2021; Leandro and Jay-Robert, 2019).

1.2 Justification of the Study

The decline in the pollination ability of honeybees (*A. mellifera*) in cucurbits worldwide has raised concerns about other insect pollinators that have valuable services in natural ecosystems and agriculture (Potts *et al.*, 2010; Zattara and Aizen, 2021). Honeybees are the major pollinators, however, their population is declining (Mallinger *et al.*, 2017). Consequently, it is unlikely that the demand for pollination services can be sustainably met in terms of adequate quantity and quality of pollen at the appropriate time and place (Dorjay and Abrol, 2022; Knapp and Osborne, 2019). This is because multiple visits to female flowers are required to deposit enough pollens to set optimal fruit (Belavadi, 2019; Halvorson *et al.*, 2021; Knapp and Osborne, 2019). The efforts for enhancing the abundance of honeybees by facilitating pollination services have so far failed to provide hopes for sustainable pollination (Mpondo *et al.*, 2021; Sawe *et al.*, 2020). Therefore, there is a need of investigating alternative insect pollinators that provide additional pollination services to honeybees for sustainable insect-dependent crop production, particularly cucurbits.

Studies conducted on insect pollinators have discovered that Syrphidae (hoverflies) under order Diptera is one of the most biologically diverse that provide ecosystem services such

as pollination, bio-control and bio-indicators of site quality (Dunn *et al.*, 2020; Emtia & Ohno, 2017). The pollination ability of hoverflies is due to their body being covered with hair which assists in the transferring of pollen grains from one flower to another during scavenging (Cook *et al.*, 2020). They rank second after bees as pollinators which contribute to 19% of all insect pollinators (Bashir *et al.*, 2019; Dawah *et al.*, 2020). Syrphidae consists of 202 genera and around 6000 described species under four subfamilies; Eristalinae, Microdontinae, Pipizinae and Syrphinae (Djellab *et al.*, 2019; Gautam and Kumar, 2018). However, there are insufficient studies regarding ecological requirements for most hoverflies, particularly on how cucurbit species, environment variables and management practices during cucurbit production affect their foraging behaviour in Tanzania.

So far, the study by Kabota (2021) investigated communities of pollinating flies under the order Diptera foraging cucurbits for the development of their conservation strategies. The findings revealed that, *Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus* and *Toxomerus floralis* under the family Syrphidae have pollination potentials on cucurbits. Therefore, this study aimed at assessing the ecological requirements of hoverflies along with honeybees including floral visitation amongst the selected cucurbit species, the effect of environmental factors on diurnal visitation patterns and the influence of cucurbits management practices on foraging activities. The results will serve as a precursor to establishing sound agricultural management practices that minimize negative impacts and contribute to their biodiversity for cucurbits productivity enhancement.

1.3 Objectives

1.3.1 Overall objective

Contribution to increased pollination efficiency in cucurbits through pollinators of the order Diptera and Hymenoptera.

1.3.2 Specific objectives

- i) To examine the floral visitation of honeybees and hoverflies on selected cucurbit crops.
- ii) To determine the influence of abiotic factors on diurnal visitation patterns of honeybees and hoverflies in selected cucurbit crops.
- iii) To determine the effects of cucurbits management practices on foraging activities of honeybees and hoverflies.

CHAPTER TWO

Manuscript one

**Floral Visitation of Honeybees and Hoverflies in Selected Cultivated Cucurbitaceous
Vegetables in Morogoro, Eastern-Central Tanzania**

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Abstract

Cucurbit production in many parts of the world is constrained by the absence of effective pollinators. There is a need to explore other to supplement honeybees (*Apis mellifera*) as pollinators of cucurbits. Studies were carried out in the two agroecological zones of Morogoro Region, Eastern - Central Tanzania to assess visitation abundance, frequency and rate of five pollinator species (*Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus*, *Toxomerus floralis* and *A. mellifera*) on cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*) and squash (*Cucurbita moschata*). Field trials were conducted in a 3 × 2 factorial arrangement in a randomized complete block design for two seasons. Results showed a significant relationship between visitation abundance with flower density and relative humidity. Also, the interaction of agroecological zones × cucurbit species × season × pollinator species had a significant ($p < 0.0001$) influence on both visitation frequency and visitation rate. *Apis mellifera* was the dominant species in cucurbit flowers at both agroecological zones during the two growing seasons. *Toxomerus floralis* is a promising hoverfly species to be used in the pollination of *C. sativus* and *C. lanatus*.

Keywords: Cucurbits, pollinators, pollination, *Toxomerus floralis*, *Apis mellifera*.

2.0 Introduction

Cucurbits are fruit vegetables that belong to the family *Cucurbitaceae* which comprises different species whose, fruits are used for salad, cooking and/or as dessert. They are among the most important plant families supplying humans with edible products rich in vitamins A, C and vital minerals such as copper, phosphorus, zinc, iron, and magnesium (Mondal *et al.*, 2020). Furthermore, cucurbits contain phyto-protective compounds that function as antioxidants, antimicrobials, anti-inflammatory, and anticancer to humans (McCreight, 2016; Rolnik and Olas, 2020). Production of cucurbits has increased worldwide due to the growing demand attributed to the consumers' preferences motivated by health concerns (Nordey *et al.*, 2017; Parajuli *et al.*, 2019; Sawe *et al.*, 2020). However, the production of cucurbits is affected by both abiotic and biotic factors including climate change, inadequate soil fertility, diseases, pests and insufficient pollination services (Anandhabhairavi *et al.*, 2020; Christmann *et al.*, 2017; Sawe *et al.*, 2020).

Cucurbits are predominantly monoecious crops having male and female flowers on the same plant. Male flowers have heavy and sticky pollen grains which cannot be carried by wind easily thus, require insect pollinators to carry them to pistillate for pollination (Atibita *et al.*, 2020; Dorjay *et al.*, 2017). Pollinating flies provide essential services to cucurbits. Inadequate pollination can cause poor fruit setting, as well as the formation of small and deformed fruits (Knapp and Osborne, 2019). Honeybees (*Apis mellifera* Linnaeus) are known to be the most efficient pollinating agent of cucurbits which are believed to contribute to nearly 80% of the total insect pollination community (Dan *et al.*, 2019) although, their populations are declining (Singh *et al.*, 2022; Zattara and Aizen, 2021). Thus, it is unlikely that the demand for pollination services in cucurbits can be sustainably met in terms of adequate quantity and quality of pollens at the appropriate

time and place. This is due to the fact that multiple visits to female flowers are required to deposit enough pollens to set optimal fruit (Halvorson *et al.*, 2021; Knapp and Osborne, 2019). The efforts to enhance the abundance of honeybees by facilitating pollination services have so far failed to provide hopes for sustainable pollination (Mpondo *et al.*, 2021; Sawe *et al.*, 2020).

Cucurbits are visited by diverse insect pollinators whose abundance and distribution depend on cucurbits species, geographic location and season of the year (Lobo and Bravo-Méndez, 2021). Studies conducted in different places in the world have reported hoverflies (Diptera; *Syrphidae*) as ecosystem service provider such as pollination (Cook *et al.*, 2020; Emtia and Ohno, 2017; Kabota, 2021). They rank second after bees visiting 52% of global crop plants and they constitute 19% of all insect pollinators (Bashir *et al.*, 2019; Dawah *et al.*, 2020; Doyle *et al.*, 2020). Hoverflies' bodies are covered with bristles and are capable of carrying pollens over a long distance since they don't have a confined home range like honeybees (Doyle *et al.*, 2020). However, their role in cucurbits pollination is not well known for most of the hoverfly species. So far, the study by Sawe *et al.* (2020) in northern Tanzania found that the dominant pollinators in watermelon were honeybees (87.8%) followed by hoverflies (8.5%). Additionally, a study by Kabota (2021) revealed that hoverflies; (*Eristalinus megacephalus* Rossi, *Mesembrius caffer* Loew, *Paragus borbonicus* Macquart and *Toxomerus floralis* Fabricius) were abundantly foraging cucurbits but didn't specify which cucurbit species was highly preferred over the other.

Pollinators often forage non-randomly among plant species using floral indicators such as colour, shape, size (inflorescence height and corolla depth) and smell (Guzmán *et al.*, 2017; Ishii *et al.*, 2019; Revanasidda and Belavadi, 2019). Moreover, flower density,

floral rewards, elevation and season affect pollinators' distribution, abundance and foraging activities (Babaei *et al.*, 2018; Rodríguez-Gasol *et al.*, 2020; Štípková *et al.*, 2020; Tarakini *et al.*, 2021). Therefore, this study investigated the floral visitation of four dominant hoverfly species; *M. caffer*, *E. megacephalus*, *P. borbonicus* and *T. floralis* along with *A. mellifera* on the selected cucurbits species commonly cultivated in the country which are: - cucumber (*Cucumis sativus* Linnaeus), watermelon (*Citrullus lanatus* Thunb.) and squash (*Cucurbita moschata* Duchesne). Specifically, the study (1) assessed the visitation abundance of honeybees and hoverflies on flowers of the three cucurbit species, (2) evaluated the relationship between cucurbit flowers variables and weather parameters on the visitation abundance honeybees and hoverflies on the three cucurbits species and (3) evaluated the effects of the agroecological zones, seasons and cucurbit species on visitation frequency and visitation rate of honeybees and hoverflies on the three cucurbit flowers.

2.1 Materials and Methods

2.1.1 Description of study area

The study was conducted in two agroecological zones of Morogoro, Eastern-Central Tanzania; the Plateau and Mountainous zone located between latitudes 6° 49' 49.3428" S and longitudes 37° 40' 14.1204" E (URT, 2002). The plateau zone is characterized by roughly flat to rolling plains associated with strongly dissected uplands and low hills. It has an elevation ranging from 200 m to 600 m a.s.l, with annual rainfall ranging from 800 mm to 1000 mm and annual average temperature ranging from 19°C to 31°C. The mountainous zone is characterized by very strongly dissected mountain block with steep to very steep slopes. The elevation range is from 800 m to 2000 m a.s.l, with annual rainfall ranging from 1000 mm to 1200 mm and annual average temperature ranging from 10°C to 25°C. The region has a bimodal type of rainfall with short rains in October -

December and long rains from March – May (De Pauw, 1984). The experimental plots were established at each agroecological zones measured 45 m x 45 m each and situated at least a distance of 1 km apart from each other.

2.1.2 Experimental layout and treatment

A Randomized Complete Block Design (RCBD) was used in a 3 x 2 factorial arrangement with four replications. Trials were conducted for two seasons from March to June, 2021 (rainy season) and September to November, 2021 (dry season), where three cucurbit species (*C. sativus*, *C. lanatus* and *C. moschata*) were studied in the two agroecological zones of Morogoro Morogoro (Plateau and Mountainous zone).

2.1.3 Crop establishment and cucurbits flower visitors assessment

Three cucurbit species were planted on 23 March, 2021 and 2 September, 2021 for the rainy and dry seasons, respectively, at a spacing of 1.5 m x 1.0 m and two seeds per hole. Agronomic practices like weeding and irrigation for the dry season were similar in all the plots. Assessment of honeybees and hoverflies visitation in cucurbits commenced when 10% of the crops had flowered which was about 30 – 35 days after planting and continued to the end of the blooming period. We established eight spots of 4 m² each, five meters apart, on transects formed on each plot of cucurbit species. We observed pollinators once a week by walking on a transect at three different hours of the day, from 0800 to 0900 h, 1200 to 1300 h and 1600 to 1700 h. The sampling procedures were adopted from Zameer *et al.* (2017) with slight modifications.

2.1.4 Data collection

Before the start of the observation on insect pollinators, 10 opened flowers per cucurbit species were randomly selected for determining the average corolla height and corolla diameter.

We then recorded:

Flower density: - Total number of opened flowers from each 4 m² spot per cucurbit species.

Pollinator abundance: - Total number of pollinators per plot of cucurbit species. It was recorded by counting each pollinating species that landed on the cucurbit flowers in a 4 m² spot within three minutes of observation regardless of its previous visits.

Visitation frequency: - To determine visitation frequency, a flower was closely observed for a maximum of one minute and the number of visits per pollinating species were recorded. A total of 24 flowers per cucurbit species were observed per day.

Average number of visits on a single cucurbit flower per cucurbit species by individual pollinating species was determined following the method described by Zameer *et al.* (2017):

$$VF = \frac{TNV}{TFO} \dots\dots\dots (i)$$

Where: VF is visitation frequency, TNV is total number of visits and TFO is total number of flowers observed.

Visitation rate: - To establish visitation rate, an individual pollinator was closely followed for a maximum of one minute from the moment it landed on the first flower. We then recorded for each pollinator species, all flowers visited within a 4 m² spot, time (seconds) spent on each visited flower and time spent in flight between consecutive flowers. Three visual observations were made for each pollinating species per cucurbit species per day.

Average number of flowers visited per pollinating species was determined following the formula described by Meerabai (2012):

$$VR = \frac{TNFV}{TSF + TFBCF} \dots\dots\dots$$

(ii)

Where: VR is visitation rate, TNFV is the total number of flowers visited, TSF is the time spent on flowers and TFBCF is the time in flight between consecutive flowers.

We also recorded data on the weather (rainfall, relative humidity and temperature) using a data logger (iButton, Maxim Integrated Products, Sunnyvale, CA, USA) in the mountainous zone. Weather data for the plateau zone were obtained from Tanzania Meteorological Authority (TMA).

2.1.5 Statistical analysis

The obtained data were checked for normality using the Shapiro-Wilk test. Since they did not conform to a normal distribution, then Analysis of variance (ANOVA) was performed using Generalized Linear Mixed Models (GLMMs) procedures to examine the effect of agroecological zones, seasons and cucurbit species on honeybees and hoverflies' visitation frequency and visitation rate on cucurbit flowers. To validate the significance between the factors, the *post hoc* test was performed where the means were compared using Tukey's HSD test at 5% level of confidence. Multiple linear regression was performed to envisage how weather and cucurbits flower parameters influenced the honeybees' and hoverflies' visitation abundance on the selected three cucurbit species. Minimum, mean and maximum temperature were highly correlated with each other; therefore, minimum and maximum temperature were skipped from further analysis. The same applied to cucurbit corolla diameter and corolla length, they showed a high correlation with each other, therefore, corolla diameter was skipped for further analysis. All analyses were performed using R software version 4.1.0 (R Core Team, 2021).

2.2 Results

2.2.1 Temporal variation on the visitation abundance of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the period of May-June and October-November

The results showed that, during the May – June cropping season, *A. mellifera* was the most abundant visitor of cucurbit plots in the mountainous zone, while all other species were less prevalent. Of all pollinator species, *M. caffer* was the least abundant visitor. There was a notable variation in the plateau zone, where the visitation of *T. floralis* increased considerably to almost match that of *A. mellifera*. (Fig. 2.1). The trends recorded during the October-November season, showed dominance of *A. mellifera* in both altitudes. Visitation abundance of all other pollinator species remained very low (Fig. 2.2). Generally, abundance of prevalent species increased from the beginning and dropped towards the end cropping season (Fig. 2.1 and 2.2).

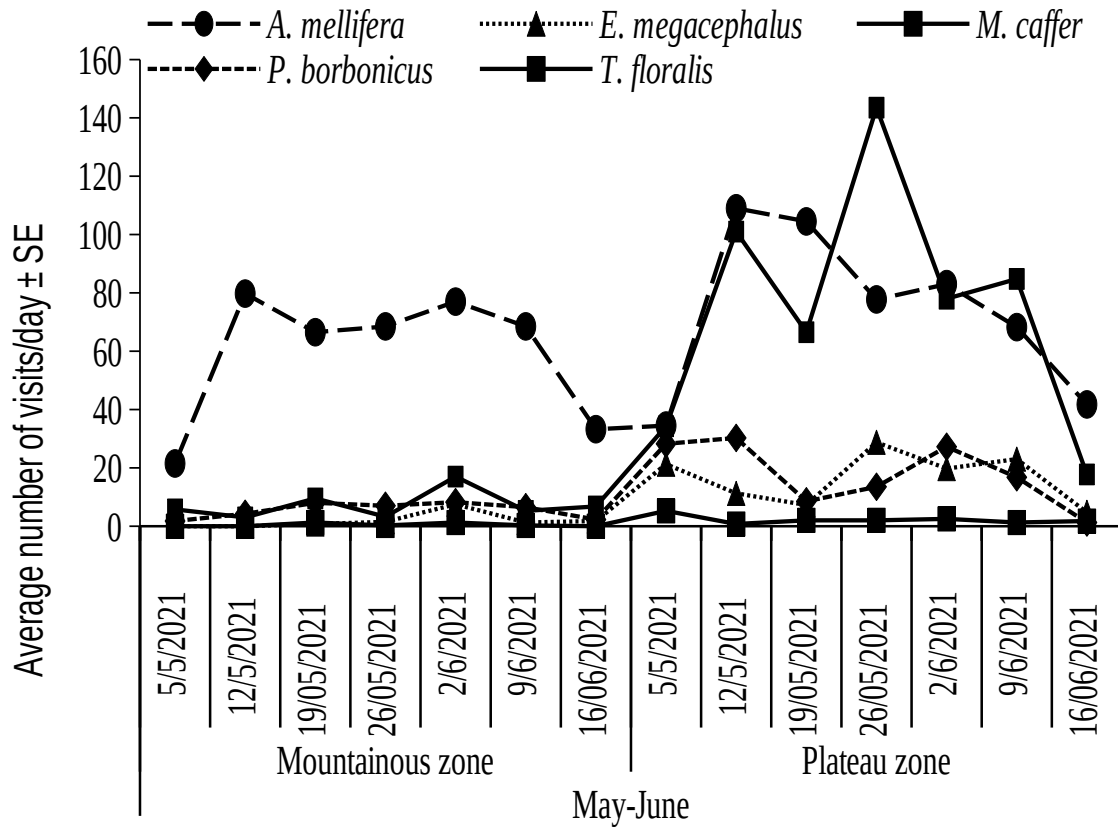


Figure 2.1: Temporal variation on the visitation abundance of honeybees and hoverflies on cucurbit flowers in the mountainous and plateau zone during the May-June

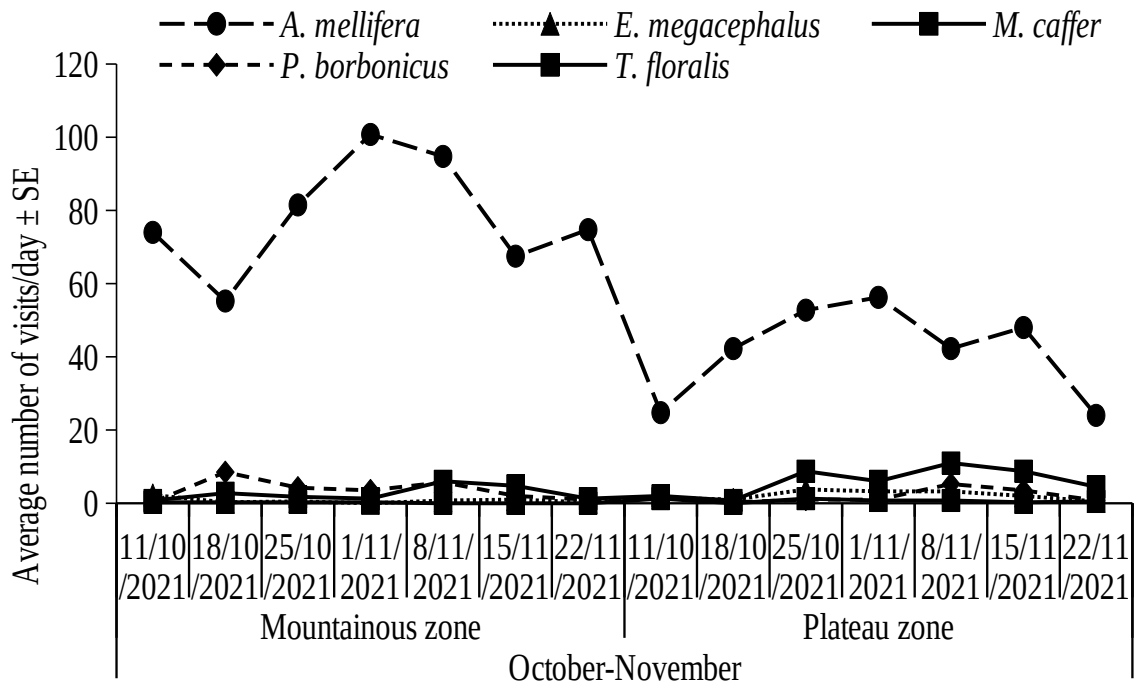


Figure 2.2: Temporal variation on the visitation abundance of honeybees and hoverflies on cucurbit flowers in the mountainous and plateau zone during the October-November

2.2.2 Abundance of honeybees and hoverflies on cucurbit species

A total of 13 171 visits of honeybees and hoverflies were recorded on *C. sativus*, *C. moschata* and *C. lanatus* flowers for the whole study period in the mountain and plateau zones of Morogoro in eight fields (Table 2.1). *Apis mellifera* constituted 56.94% of all pollinating species and hoverflies 43.06%. Furthermore, 37.9%, 21.08% and 41.02% of all pollinating species were observed on *C. sativus*, *C. moschata* and *C. lanatus* flowers, respectively. *Apis mellifera* recorded the highest number of visits on each cucurbit species; 61.3%, 64.45% and 49.07%, and the lowest number of visits were recorded for *M. caffer* 0.7%, 1.37% and 1.07% *C. sativus*, *C. moschata* and *C. lanatus* flowers, respectively. For hoverflies, *T. floralis* were dominant (26.1%) followed by *P. borbonicus* (8.3%), *E. megacephalus* (7.6%) and lastly *M. caffer* (1%).

Table 2.1: Abundance honeybees and hoverflies in three cucurbit species

| Pollinators | Cucurbit species | | | Total | Proportion number of visits (%) |
|---------------------------------|-------------------|---------------------|-------------------|-------|---------------------------------|
| | <i>C. sativus</i> | <i>C. moschat a</i> | <i>C. lanatus</i> | | |
| <i>A. mellifera</i> | 3060 | 1789 | 2651 | 7500 | 56.94 |
| <i>E. megacephalus</i> | 240 | 264 | 500 | 1004 | 7.62 |
| <i>M. caffer</i> | 35 | 38 | 58 | 131 | 0.99 |
| <i>P. borbonicus</i> | 471 | 158 | 470 | 1099 | 8.34 |
| <i>T. floralis</i> | 1186 | 527 | 1724 | 3437 | 26.10 |
| | | | | 1317 | |
| Total | 4992 | 2776 | 5403 | 1 | 100 |
| Proportion number of visits (%) | 37.9 | 21.08 | 41.02 | 100 | |

2.2.3 The relationship between cucurbit flowers variables, weather parameters and visitation abundance of honeybees and hoverflies on the three cucurbits species

The cucurbits flower variables under the study indicated in Table 2.2 shows average flower density found in 4 m², average corolla height and corolla diameter of 10 flowers. During the May-June season, average temperature, relative humidity and rainfall recorded in the mountainous zone ranged from 18°C to 24°C, 70% to 89% and 0 mm to 2.16 mm, respectively, in the plateau zone ranged from 22°C to 25°C, 69% to 82% and 0 mm to 0.75 mm, respectively. During the October-November season, average temperature, relative humidity and rainfall recorded in the mountainous zone ranged from 20°C to 25°C, 70% to 80% and 0 mm to 0.59 mm, respectively, in the plateau zone ranged from 26°C to 30°C, 63% to 71% and 0 mm to 0.1 mm, respectively.

The regression analysis revealed a significant positive association between flower density, relative humidity with pollinators visitation abundance ($p < 0.001$). The increase in number of cucurbit flowers by 1 unit was expected to the increase in the number of visits of pollinators on cucurbits flowers by 7 units when other factors are kept constant. Likewise, the increase of relative humidity by 1% was expected to increase number of visits of

pollinators on cucurbit flowers by almost 40%, when all other factors were kept constant. Visitation abundance had non-significant relationship with corolla height, temperature and rainfall (Table 2.3).

Table 2.2: Flowers parameters of the three cucurbits under the study

| Flowers parameters | Cucurbit species | | |
|---------------------------------|-------------------|-------------------|--------------------|
| | <i>C. lanatus</i> | <i>C. sativus</i> | <i>C. moschata</i> |
| Flower density/4 m ² | 97.29 ± 6.89 | 87.29 ± 9.21 | 21.00 ± 1.88 |
| Corolla height (cm) | 1.93 ± 0.07 | 2.21 ± 0.22 | 5.36 ± 0.13 |
| Corolla diameter (cm) | 2.17 ± 0.07 | 2.42 ± 0.25 | 7.07 ± 0.25 |

Table 2.3: The relationship between cucurbit flowers variables, weather parameters and the visitation abundance of honeybees and hoverflies on the three cucurbits species

| Factors | Coefficient | SE coefficient | T value | P value | VIF |
|-------------------|-------------|----------------|---------|----------|-------|
| Intercept | -25.902 | 15.130 | -1.712 | 0.087 | |
| Flower density | 0.077 | 0.006 | 13.152 | 0.000*** | 1.050 |
| Flower height | -0.227 | 0.153 | -1.478 | 0.140 ns | 1.060 |
| Mean temperature | -0.045 | 0.250 | 0.180 | 0.857 ns | 2.940 |
| Relative humidity | 0.394 | 0.136 | 2.909 | 0.004** | 2.627 |
| Rainfall | -1.283 | 0.866 | -1.482 | 0.139 ns | 1.220 |

SE = standard error, VIF = Variance Inflation Factor, Significance codes: 0 '***' 0.001 '**' 0.01 '*' p≥0.05 'ns'

2.2.4 Temporal variation on the visitation frequency of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June and October-November

The visitation frequency of *A. mellifera* was generally higher than other pollinating species in both agroecological zones and during both seasons. Visitation frequencies were relatively stable over time without any strong pattern during the May – June cropping season. Likewise, the frequencies of visits by *A. mellifera* and *T. floralis* were higher than the other species in the plateau zone (Fig. 2.3). Distinctively higher visitation frequency by *A. mellifera* was recorded in the mountainous zone. Except for *A. mellifera*, visitation frequencies of most species were very low and without any strong pattern during the

October – November cropping season. Frequency by *A. mellifera* increased from the beginning of the season, and dropped towards the end of the season (Fig. 2.4).

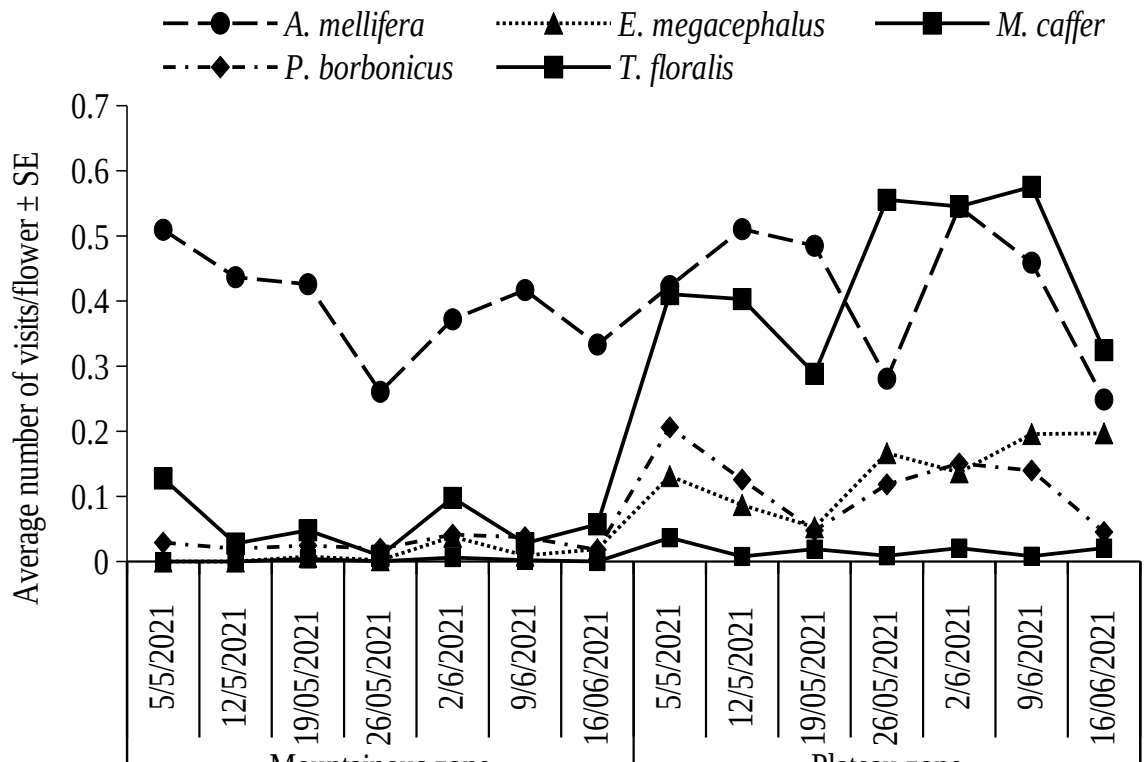


Figure 2.3: Temporal variation on the visitation frequency of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June

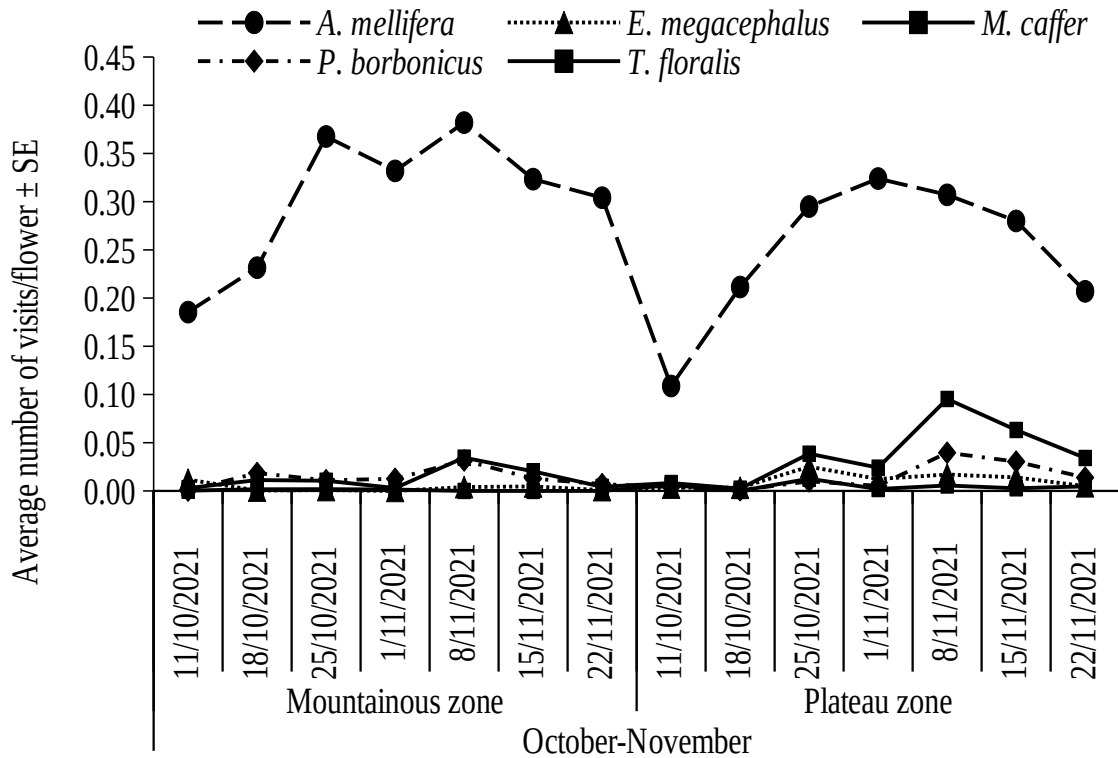


Figure 2.4: Temporal variation on the visitation frequency of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of October-November

2.2.5 Effects of agroecological zone, season, cucurbit species and pollinator species on visitation frequency of honeybees and hoverflies on three cucurbit flowers

Results showed significant effects of agroecological zone × season × cucurbit species × pollinator species interaction on visitation frequency of pollinators on cucurbit flowers ($p < 0.0001$). The effects of all factors and interactions were also significant, except the season × cucurbit species interaction (Table 2.4). Further results (Fig. 2.5 and 2.6) showed significantly higher visitation frequency by *A. mellifera* on all cucurbit species than other pollinating species in both the agroecological zones and during both seasons (*Post hoc* test, Tukey's HSD). Notable exception is the significantly higher visitation frequency by *T. Floralis* on *C. lanatus* flowers, in the plateau zone during the May – June cropping season (Fig. 2.5). Frequency of visits by all species were significantly higher in

the plateau zone than the mountainous zone during the May – June cropping season (Fig. 2.5).

Table 2.4: Effects of agroecological zones, seasons and cucurbit species on visitation frequency honeybees and hoverflies on cucurbit flowers

| Factors | DF | Statistics | |
|--------------------------|----|------------|--------------|
| | | F value | P value |
| Agroecological zone (Az) | 1 | 45.917 | < 0.0001 *** |
| Season (Se) | 1 | 109.720 | < 0.0001 *** |
| Cucurbit species (Cr) | 2 | 5.603 | 0.004 ** |
| Pollinator species (Pol) | 4 | 170.256 | < 0.0001 *** |
| Az × Se | 1 | 50.913 | < 0.0001 *** |
| Az × Cr | 2 | 18.277 | < 0.0001 *** |
| Az × Pol | 4 | 16.935 | < 0.0001 *** |
| Se × Cr | 2 | 1.508 | 0.222 ns |
| Se × Pol | 4 | 16.035 | < 0.0001 *** |
| Cr × Pol | 8 | 7.394 | < 0.0001 *** |
| Az × Se × Cr | 2 | 18.537 | < 0.0001 *** |
| Az × Se × Pol | 4 | 10.204 | < 0.0001 *** |
| Az × Cr × Pol | 8 | 4.768 | < 0.0001 *** |
| Se × Cr × Pol | 8 | 4.938 | < 0.0001 *** |
| Az × Se × Cr × Pol | 8 | 4.337 | < 0.0001 *** |

DF: Degrees of freedom, significance codes: 0 '****' 0.001 '**' 0.01 '*' p≥0.05 'ns'

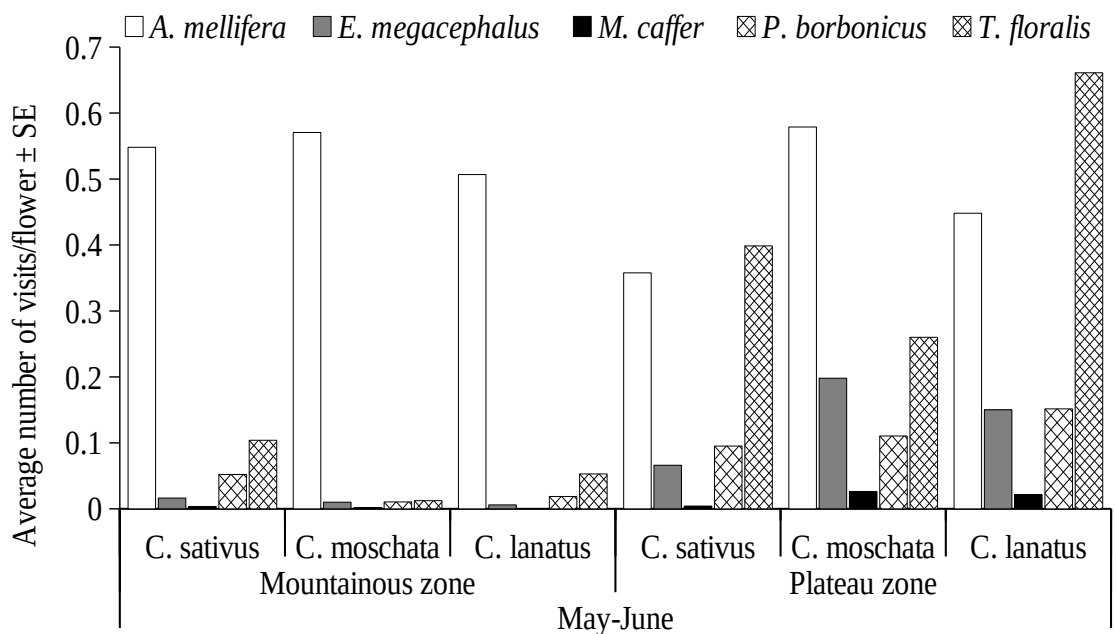


Figure 2.5: Visitation frequency of pollinators on cucurbit flowers as affected by agroecological zones and cucurbit species

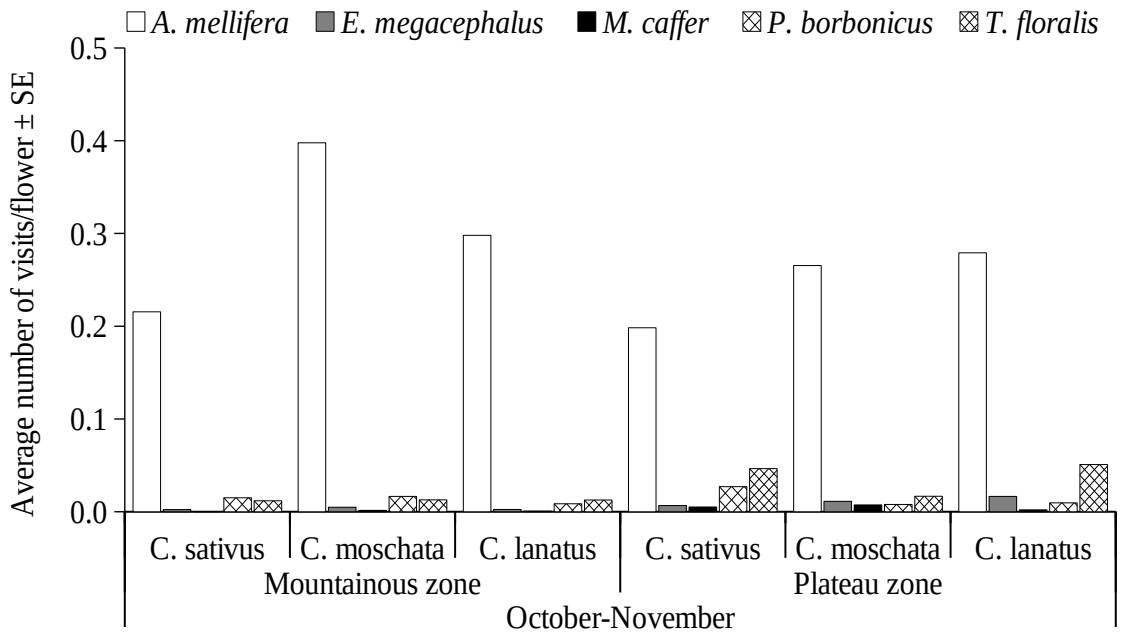


Figure 2.6: Visitation frequency of pollinators on cucurbit flowers as affected by agroecological zones and cucurbit species

2.2.6 Temporal variation on the visitation rate of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June and October-November

During the May-June season, *A. mellifera* and *T. floralis* visited the highest number of flowers in both the plateau and mountainous zones (Fig. 2.7). The visitation rate of *A. mellifera* peaked during the fourth week in both the plateau and mountainous zones while *T. floralis* peaked during the fourth and fifth week in the plateau and mountainous zone, respectively. The visitation rates of *E. megacephalus* and *P. borbonicus* on cucurbits flowers were higher in the plateau zone. The lowest number of flowers visited were recorded for *M. caffer* and the visitation patterns were fairly stable in both agroecological zones. During the October-November season, *A. mellifera* showed the

highest visitation rate on cucurbits flowers in both agroecological zones. Other pollinating species' visitation rates were extremely low, with no discernible pattern (Fig. 2.8).

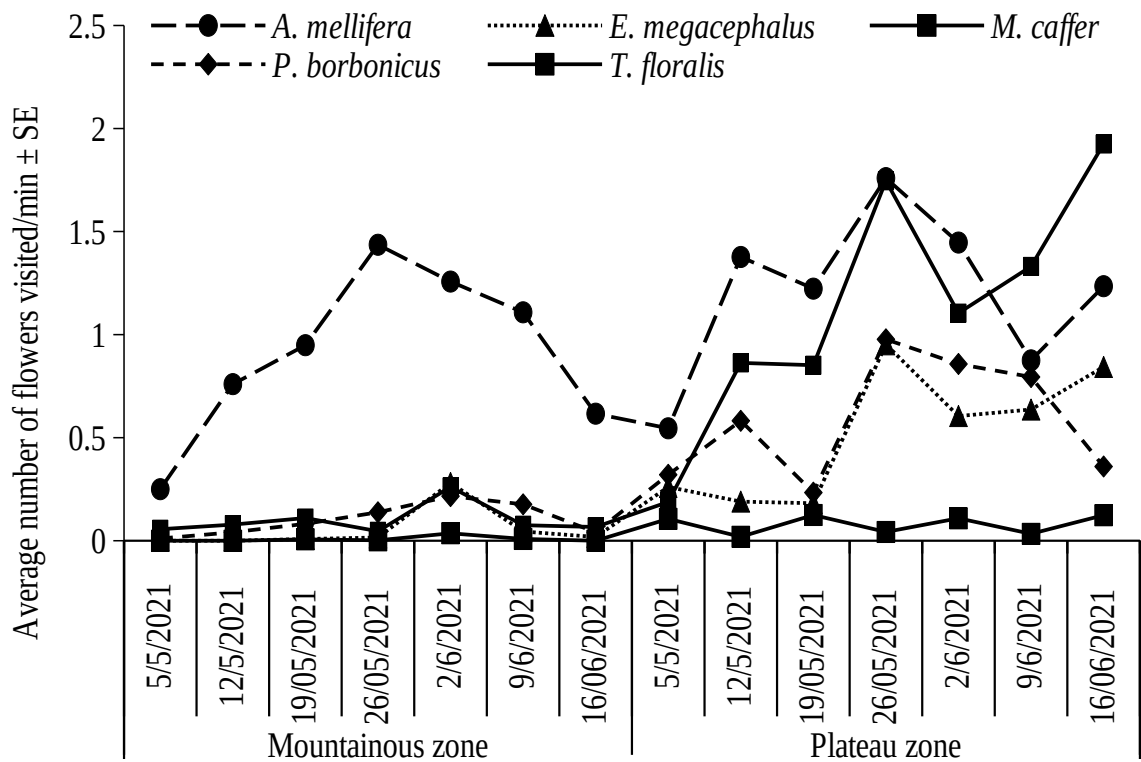


Figure 2.7: Temporal variation on the visitation rate of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of May-June

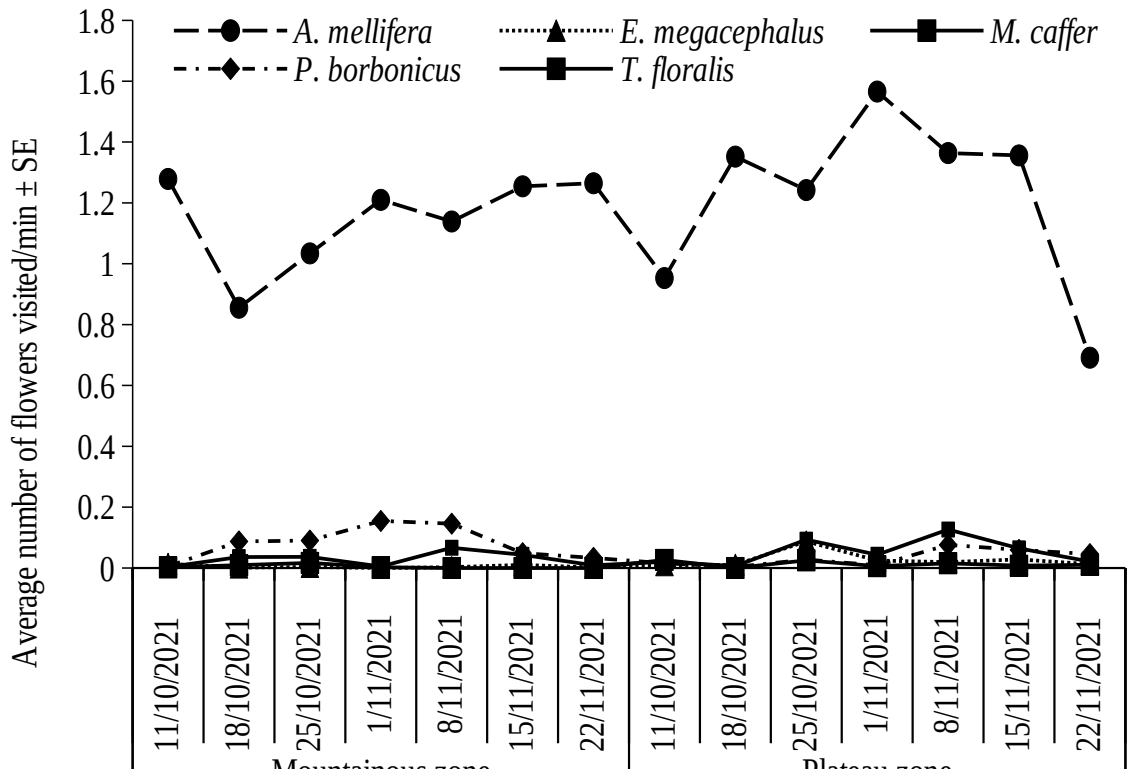


Figure 2.8: Temporal variation on the visitation rate of honeybees and hoverflies on cucurbit flowers in the plateau and mountainous zones during the season of October-November

2.2.7 Effects of agroecological zone, season, pollinator species and cucurbit species on visitation rate of honeybees and hoverflies on three cucurbit flowers

Our results showed that all the factors and all the interactions had significant effects on the number of cucurbit flowers visited by pollinators except cucurbit species ($p = 0.080$; Table 2.5). We therefore further examined the significant effects of agroecological zone \times cucurbit species \times pollinator species during the two seasons (Fig. 2.9 and 2.10). Visitation rates were generally higher in the plateau than the mountainous zone during the May – June cropping season (*Post hoc* test, Tukey's HSD). *Apis mellifera* had significantly higher visitation rates than the rest except *T. floralis* on *C. lanatus* in the plateau zone. Further results showed that *A. mellifera* was the most dominant species

during the October – November cropping season, with the significantly higher number of *C. lanatus* and *C. sativus* flowers visited than *C. moschata* (Fig. 2.10).

Table 2.5: Effects of agroecological zones, seasons and cucurbit species on visitation rate honeybees and hoverflies on cucurbit flowers

| Factors | DF | Statistics | |
|--------------------------|----|------------|--------------|
| | | value | F |
| Agroecological zone (Az) | 1 | 57.415 | < 0.0001 *** |
| Season (Se) | 1 | 42.177 | < 0.0001 *** |
| Cucurbit species (Cr) | 2 | 2.523 | 0.080 ns |
| Pollinator species (Pol) | 4 | 144.857 | < 0.0001 *** |
| Az × Se | 1 | 50.231 | < 0.0001 *** |
| Az × Cr | 2 | 6.351 | 0.002** |
| Az × Pol | 4 | 6.211 | < 0.0001 *** |
| Se × Cr | 2 | 13.247 | < 0.0001 *** |
| Se × Pol | 4 | 13.757 | < 0.0001 *** |
| Cr × Pol | 8 | 23.678 | < 0.0001 *** |
| Az × Se × Cr | 2 | 8.044 | < 0.0001 *** |
| Az × Se × Pol | 4 | 6.317 | < 0.0001 *** |
| Az × Cr × Pol | 8 | 6.825 | < 0.0001 *** |
| Se × Cr × Pol | 8 | 4.603 | < 0.0001 *** |
| Az × Se × Cr × Pol | 8 | 4.644 | < 0.0001 *** |

DF: Degrees of freedom, significance codes: 0 '***' 0.001 '**' 0.01 '*' p≥0.05 'ns'

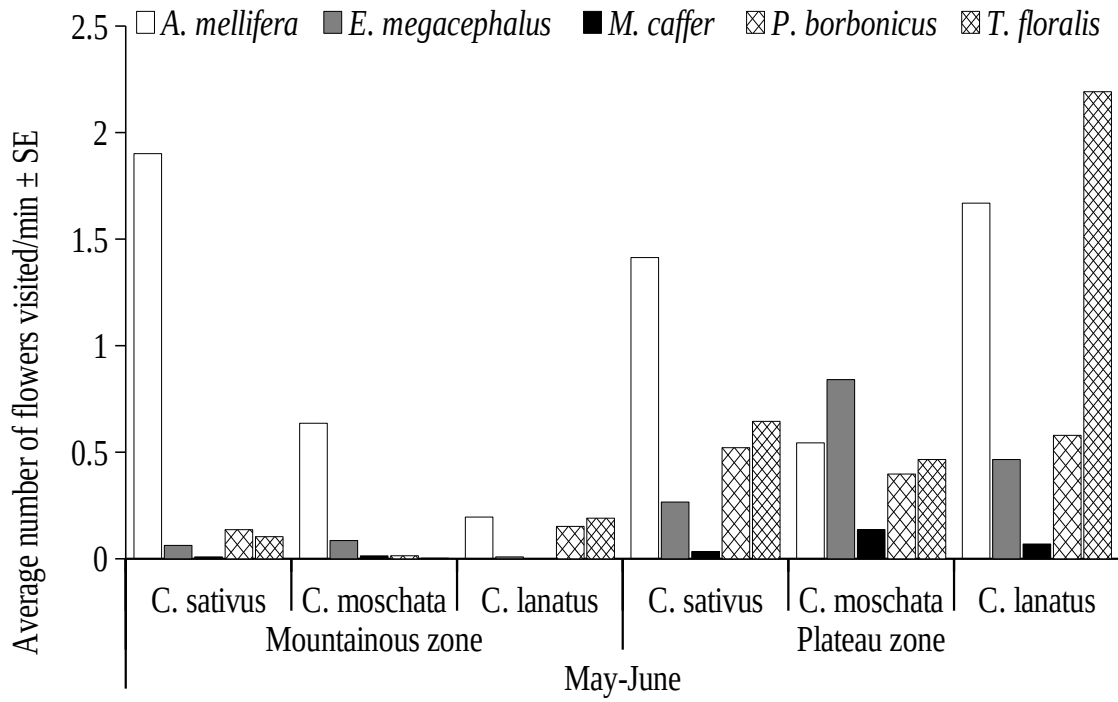


Figure 2.9: Visitation rate of honeybees and hoverflies on cucurbit flowers as affected by agroecological zone and cucurbit species

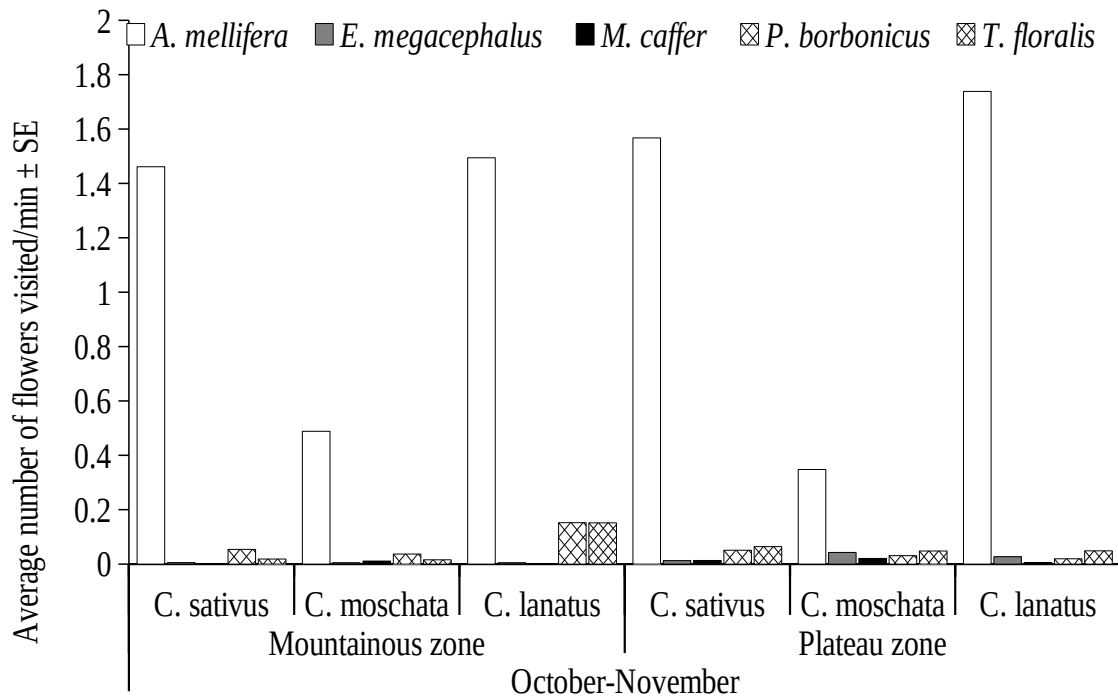


Figure 2.10: Visitation rate of honeybees and hoverflies on cucurbit flowers as affected by agroecological zone and cucurbit species

2.3 Discussion

The visitation abundance of honeybees and hoverflies on cucurbits flowers did not vary considerably along the sampling weeks, except *A. mellifera* and in a few cases *T. floralis*. The visitation abundance of *A. mellifera* increased at the beginning and dropped at the season. This is because, a few weeks after planting, most of the cucurbits had high number of opened flowers which attracted more pollinators compared to the first week when the crops had 10% flowered and the seventh week when most of the cucurbits were terminating the blooming and had reached senescence. Most of cucurbits start flowering in 30 - 45 days after planting and last for 8 to 10 weeks (Mondal *et al.*, 2020).

The results revealed a different in the visitation abundance of honeybees and hoverflies on the three cucurbit species. The number of visits of honeybees and hoverflies recorded on *C. sativus* and *C. lanatus* flowers were generally higher than on *C. moschata* flowers. Results further showed that visitation abundance significantly increased with flower density. Compared to flower density among three cucurbit species, *C. lanatus* had a higher flower density followed by *C. sativus* and lastly *C. moschata*. The presence of enough floral resources has been reported to increase visitation of pollinators on a crop since it reduces competition between and within pollinators and provide hoverflies (larvae and adults) good habitat for breeding sites (Ansari *et al.*, 2017; Babaei *et al.*, 2018; Kumar and Rai, 2020; Lucas *et al.*, 2017; Tommasi *et al.*, 2021). Generally, our findings revealed that *A. mellifera* was the most abundance visitor of all the three cucurbit species. This is because honeybees are considered good scavengers and major pollinators of cucurbits (Quinn *et al.*, 2017).

Moreover, relative humidity significantly affected number of visits of honeybees and hoverflies on cucurbit flowers. Honeybees are unable to forage during the time when relative humidity is low due to dehydration which adversely impact on their flight. It is also worth noting that bodies of hoverflies are covered in fine yellow hairs which assist in thermal balance (Shyamna and Nasser 2019; Majeed *et al.*, 2020; Cook *et al.*, 2020).

Temporal trends showed that *A. mellifera* was the most frequent visitor of cucurbits. We also found the significant effects of the interactions among agroecological zone, season, cucurbit species and pollinator species on visitation frequency of honeybees and hoverflies. The highest visitation frequencies were by *A. mellifera* on all flowers of the three cucurbit species in both the plateau and mountainous zone and during both seasons. This is because bees are the primary pollinators of cucurbits (Dorjay *et al.*, 2017; Quinn *et al.*, 2017). Generally, the higher visitation frequencies on cucurbits flowers were recorded during the May-June season in the plateau zone. This is because, habitat heterogeneity and environmental variables affects distribution and abundance of insect pollinators (Babaei *et al.*, 2018; Conrad *et al.*, 2021; Milić *et al.*, 2019; Sengupta *et al.*, 2018). According to Štípková *et al.* (2020), Goodwin *et al.* (2021) and Tarakini *et al.* (2021), season and elevation influence the distribution and population of pollinators due to variations of floral resources, whereby other seasons lack appropriate floral resources that limit species populations and different flowers visitors differ in ecological requirements.

Visitation rate of all pollinating species were relatively stable over time without any strong patterns during both seasons and agroecological zones except in the plateau zone during the season of May-June. *Apis mellifera* and *T. floralis* visited higher number of flowers at both agroecological zones and during both seasons. Furthermore, the interactions of agroecological zones, season and cucurbit species significantly affected the

visitation rate of honeybees and hoverflies on cucurbit flowers. *Apis mellifera* recorded higher visitation rates than other species in most cases.

A notable difference was low visitation rate of *A. mellifera* in *C. moschata* and high visitation rate of *T. floralis* on *C. lanatus*. The lower visitation rate of *A. mellifera* on *C. moschata* flowers was clarified by the study of Jachula *et al.* (2019) who reported that flowers with long corolla produce more nectars which makes honeybees to spend longer time foraging on a single flower. *Toxomerus floralis* prefer to forage on flowers with short corolla for easy accessibility of floral rewards (Azo'o Ela *et al.*, 2022; Dunn *et al.*, 2020). A study by Klecka *et al.* (2018) classified *T. floralis* under small syrphids whose foraging behavior is influenced by morphological features of flowers such as corolla length, corolla diameter and floral shape.

Moreover, high number of cucurbit flowers visited during the May-June season at the plateau. This was because during May-June season in the mountains and October-November season at both zones, weather conditions had negative effects on the flowering rate of cucurbits and flight time of the pollinators between different cucurbits flowers (Adedoja *et al.*, 2020; Bucher and Römermann, 2020; Budhathoki *et al.*, 2021; Czenze and Thurley, 2018; Dellinger *et al.*, 2021).

2.4 Conclusions

It was concluded from this study that agroecological zone, season, cucurbit species and weather parameters play vital roles in determining the visitation of honeybees and hoverflies. The low number of visits of hoverflies was recorded on the cucurbit flowers in the mountainous zone, while a slight difference was observed in *A. mellifera*. Likewise for the season, high number of visits of honeybees and hoverflies were recorded during May-June (rainy season). Cucurbit species significantly affected the visitation of

hoverflies in which *T. floralis* and *P. borbonicus* preferred to forage on *C. sativus* and *C. lanatus* flowers than on *C. moschata* flowers. Amongst the studied pollinators, *A. mellifera* occupied the highest proportion in the number of visits of cucurbit flowers followed by *T. floralis*, this signifies that, despite the decline in population, cucurbits fruit setting and seeds formation are hampered without *A. mellifera*. These findings suggested for conservation of the studied pollinators for enhanced cucurbits pollination and the production of cucurbits is advised to be performed during May-June season in the plateau zone where pollinators are abundantly available to perform pollination services.

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CHAPTER THREE

Manuscript two

**Influence of Abiotic Factors on Diurnal Visitation Patterns of Honeybees and
Hoverflies in Selected Cucurbit Crops in Morogoro, Eastern-Central Tanzania**

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Status:

Abstract

Cucurbits are cross-pollinated crops that predominantly require insect pollinators for successful fruit setting and seed formation. Honeybees (*Apis mellifera*) and hoverflies (*Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus* and *Toxomerus floralis*) are believed to be potential pollinators of cucurbits although, little is known about how environmental variables affect the cucurbit flowers–hoverflies interactions. Therefore, this study assessed the influence of cucurbits flower densities, temperature, relative humidity, and rainfall on diurnal visitation patterns of *A. mellifera*, *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis* on *Cucumis sativus*, *Citrullus lanatus*, and *Cucurbita moschata*. Diurnal visitation patterns were assessed based on the visitation abundance of pollinators on cucurbits per specific time slot along the day. The experiment was laid down as a 5×3×2×2 factorial arrangement in a Randomized Complete Block Design (RCBD) with four replications. The results showed that temperature had significant negative effects on the diurnal visitation patterns of *A. mellifera*, while relative humidity and cucurbit flower density significantly affected its diurnal visitation patterns positively. Temperature, relative humidity and flower density had insignificant effects on the diurnal visitation patterns of all hoverflies species except *T. floralis*. The highest number of visits of all pollinating species was recorded between 0800 – 1100 h and the lowest between 1600 – 1700 h. However, *T. floralis* was less affected by temperature and relative humidity as compared to honeybees. Therefore, these hoverflies may be potential pollinators of cucurbits since they can provide pollination services throughout the day. This study proposes the conservation of the studied pollinating species to enhance their abundance for optimal pollination in cucurbits and further investigation on temporal variation in cucurbit floral rewards and receptiveness.

Keywords: Cucurbits, hoverflies, honeybees, temperature, relative humidity, diurnal visitation patterns

3.0 Introduction

Abiotic factors are agro-ecosystem parameters essential for the growth and productivity of crops worldwide (Kumar *et al.*, 2019). Some of these parameters include relative air humidity, temperature, rainfall, pH, solar radiation and wind velocity (Pereira *et al.*, 2017). They have numerous impacts on the relationship between plants and pollinators for the insect pollinator dependent crops such as cucurbits. The abiotic conditions vary during the time of the day, and adverse conditions at the time of flowering reduce crop yields by affecting the interactions between plants and their pollinators (Saroj and Choudhary, 2020). For example, flowers that are exposed to rain, their nectars become diluted and lower the pollen's viability which obstructs pollinators from foraging (Nikolova *et al.*, 2019).

Diurnal visitation patterns of pollinators are also influenced by climatic conditions and the availability of floral resources. Various flowering plants have different daytime lengths of flower receptiveness and that can have a strong influence on pollinator visitation patterns (Kumar and Reddy, 2021). The duration of flower opening in most cucurbit species ranges from 6 – 12 hours (Knapp and Osborne, 2019). Thus, different pollinators adapt their foraging activity to optimize the time of resource collection during the time of flower receptiveness to maximize their efficiency when the environmental conditions are favorable (Malerbo-Souza *et al.*, 2019; Xu *et al.*, 2021).

Extreme weather conditions such as very high or low temperatures, high humidity or continuous precipitation reduce pollinator visitation frequencies to flowers thus, impair pollination services (Kumar and Reddy, 2021). A reduced number of visits to female flower during receptiveness throughout the day cause a lower deposition of pollens which ultimately affects crop yield (Dorjay *et al.*, 2017; Lobo, 2021). Female flowers in most cucurbit species require more than 18 visits by *Apis mellifera* for successful pollination

(Bomfim *et al.*, 2016). Furthermore, elevation and season modulate the richness, distribution, abundance and visitation patterns of pollinators. Abiotic factors vary between and within elevation and season which affect pollinator visitation patterns (Howlett *et al.*, 2017; Mertens *et al.*, 2021).

Insect pollinators are of great importance in cucurbits for yield enhancement since male flowers have heavy and sticky pollen grains which cannot be carried by wind easily to pistillate for pollination (Atibita *et al.*, 2020; Dorjay *et al.*, 2017). *Apis mellifera* are known to be major pollinators of cucurbits although, there is increasing evidence that their populations are declining worldwide (Raguso, 2020). This raises the concern for the investigation of other pollinators that are attracted to cucurbits. Different studies discovered that members under the Syrphidae family are the important group representing a potential alternative or supplemental pollination services to bees due to their highly abundant and diversity (Cook *et al.*, 2020; Emtia and Ohno, 2017; Raguso, 2020). However, there is limited information regarding their diurnal visitation patterns in cucurbit crops under the influence of weather conditions in Tanzania.

Currently, the study by Kabota (2021) explored the flower-visiting flies (Diptera) communities associated with cucurbits in Morogoro and *Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus* and *Toxomerus floralis* were among the dominant syrphids observed foraging cucurbits. Therefore, this study aimed at assessing the effect of the specific meteorological factors (air temperature, relative humidity and rainfall) on diurnal visitation patterns of *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis* along with *A. mellifera* in the selected three cucurbit species. The findings will provide valuable information on the diurnal visitation patterns to ensure appropriate levels of pollination of the cucurbits and help farmers in planning the time for other management like pesticide application.

3.1 Materials and Methods

3.1.1 Description of the study area

Studies on assessing pollinators' visitation patterns were conducted for two seasons (wet and dry) from March to October 2021 in Morogoro Region, Eastern-Central Tanzania located between latitudes 5°58'S - 10°0'S and longitudes 35°25'E - 38°30'E (United Republic of Tanzania, 2002). The experimental plots were situated at two agroecological zones of Morogoro region which are the Plateau zone and Mountainous zone between altitudes ranging from 450 m to 539 m and 955 m to 1270 m above sea level respectively. Four fields of 45 m x 45 m each at a distance of at least 1 km apart at each agro-ecological zone were selected for cucurbits establishment:

3.1.2 Experimental layout and treatment

An experiment was designed as a 5 x 3 x 2 x 2 factorial in a Randomized Complete Block Design (RCBD) with four replications. Sources of variation were time of a day (five-time slot at the interval of one hour from 0800 hours to 1700hours), cucurbit crop species: cucumber (*Cucumis sativus* Linnaeus), watermelon (*Citrullus lanatus* Thunb.) and squash (*Cucurbita moschata* Duchesne) and agroecological zone of Morogoro (Plateau and Mountainous) and cucurbit growing season (rainy and dry season). Watermelon “crimson sweet” variety, Cucumber “Ashley” variety and Squash “Waltham butternut” variety used in this study were purchased from Agro-dealer in Morogoro town.

3.1.3 Crop establishment

Three cucurbit species were planted on 23 March, 2021 for the rainy season and 2 September, 2021 for the dry season at a spacing of 1.5 m x 1.0 m, two seeds per hole. Each experimental plot was divided into 15 m x 15 m to accommodate the three cucurbit species. Agronomic practices like weeding and irrigation during the dry season were followed in all plots.

3.1.4 Assessment of pollinator diurnal visitation patterns

Assessment of diurnal visitation patterns in three cucurbit species commenced when 10% of the crops had flowered 30 – 35 days after planting until the end of the blooming period. Visual observations were made on the number of visits per individual pollinating species per time slot under 5-time slots between 0800 and 1700 h at 0800, 1000, 1200, 1400, and 1600 hours. It was done in a transect walk on 8 spots of 4 m² each per cucurbit species. Observation time was 3 minutes for each spot and a time gap of 2 minutes to the next spot which was established at the interval of every 5 m. The sampling procedure was adopted from Zameer *et al.* (2017) with modification of observation time per 4 m² spot and a time gap between two consecutive spots.

3.1.5 Data collection

From each 4 m² spot per cucurbit species, the total number of open flowers was recorded, and the total number of visits per individual pollinating species per time slot. Each flower visitor came in a 4 m² during the 3 minutes of observation was recorded. Data on climatic conditions (temperature, rainfall and relative humidity) were monitored during each cucurbits production season by an automatic data logger (iButton, Maxim Integrated Products, Sunnyvale, CA, USA) in the mountainous zone, and weather data for the plateau zone were obtained from Tanzania Meteorological Authority (TMA) found at Sokoine University of Agriculture in Morogoro.

3.1.6 Statistical analysis

To determine the effect of the agro-ecological zone, season, cucurbits and time of a day on honeybees and hoverflies diurnal visitation patterns, the analysis of variance (ANOVA) at a 5% level of confidence was performed using Generalized Linear Mixed Models (GLMMs) procedures. Means were compared using Turkey's Honestly Significant Difference test at 5%. Spearman correlations were performed to examine how

weather variables and cucurbits flower densities affect honeybees' and hoverflies' visitation patterns along the time of day. All analyses were performed using R software version 4.1.0 (R Core Team, 2021).

3.2 Results

3.2.1 Diurnal visitation patterns of pollinators on cucurbit flowers

Mean number of visits by pollinators in cucurbit flowers during different hours of the day from 0800 – 1700 h are presented in Figure 3.1. The highest number of visits was recorded from 0800 – 1100 h while the lowest number of visits was recorded from 1400 – 1700 h. However, from 0800 to 1300 h *A. mellifera* exhibited higher number of visits than *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis*, whereas the lowest number of visits were observed for *M. caffer* throughout the observation hours. The visitation of both honey bees and hoverflies on cucurbit flowers peaked at 1100 h, but from 1600 – 1700 h the number of visits by *A. mellifera* on cucurbit flowers was lower than the number of visits by *T. floralis*.

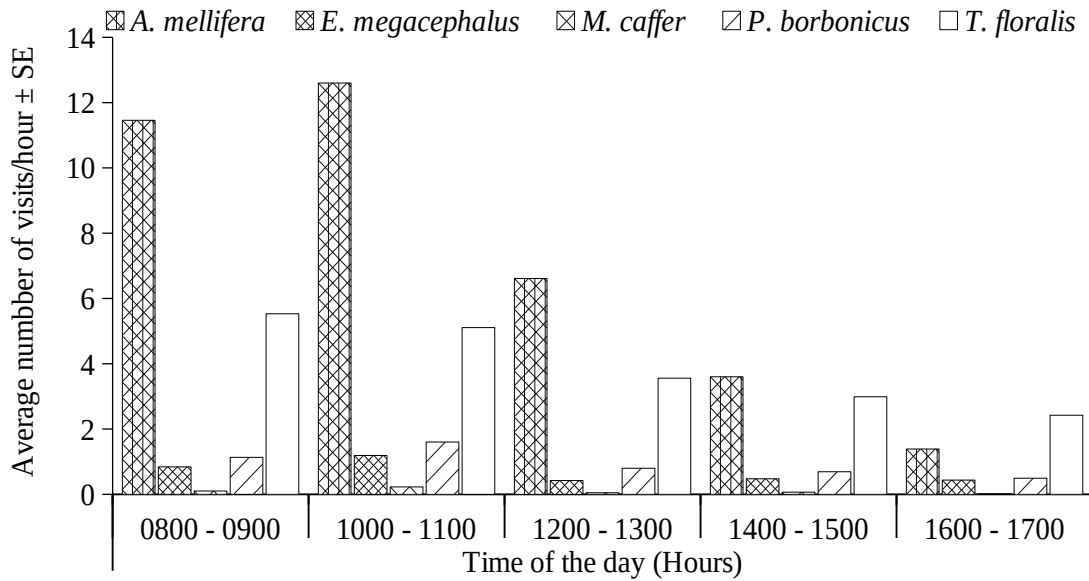


Figure 3.1: Mean number of visits by pollinators on cucurbit flowers at different hours of the day

3.2.2 Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *A. mellifera* on cucurbits flowers

The results showed significant effects of the interaction of agroecological zone × cucurbit species × time of a day × season on diurnal visitation patterns of *A. mellifera* (Table 3.1). The effect of season on visitation patterns of *A. mellifera* is beyond control, therefore, the significant interactions of agroecological zone × cucurbit species × time of the day ($p < 0.0001$) were further examined. The results revealed that, the number of visits by *A. mellifera* on cucumber flowers from 1600 – 1700 h at the mountains were more than the number of visits on cucumber flowers from 1600 – 1700 h at the plateau ($p < 0.0001$) (*Post hoc* test, Tukey's HSD). The number of visits by *A. mellifera* on squash flowers from 1600 – 1700 h at the mountains significantly ($p = 0.006$) differ with the number of visits on squash flowers from 1600 – 1700 h at the plateau by 5.18. Whereas no significant different was found between the number of visits by *A. mellifera* on

watermelon flowers from 1600 – 1700 hours at the mountains and the number of visits on watermelon flowers from 1600 – 1700 h at the plateau ($p = 0.998$).

Additionally, the significant different in the number of visits by *A. mellifera* were found within the specific cucurbit species at different hours of the day. The number of visits by *A. mellifera* on cucumber flowers from 0800 – 0900 h was lower than the number of visits by *A. mellifera* from 1000 – 1100 h and higher than the number of visits from 1200 – 1700 h (*Post hoc* test, Tukey's HSD). Generally, the highest number of visits was observed on cucumber flowers from 1000 – 1100 h and the lowest on squash flowers from 1600 – 1700 h (Fig. 3.2).

Table 3.1: Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *A. mellifera*

| Factors | DF | Statistics | |
|--------------------------|----|------------|------------|
| | | F-value | P-value |
| Agroecological zone (Az) | 1 | 21.809 | <0.0001*** |
| Season (Se) | 1 | 0.008 | 0.928 ns |
| Crop species (Cr) | 2 | 23.371 | <0.0001*** |
| Time of a day (Tmd) | 4 | 26.472 | <0.0001*** |
| Az × Se | 1 | 12.606 | <0.0001*** |
| Az × Cr | 2 | 0.162 | 0.850 ns |
| Az × Tmd | 4 | 82.111 | <0.0001*** |
| Se × Cr | 2 | 10.070 | <0.0001*** |
| Se × Tmd | 4 | 50.066 | <0.0001*** |
| Cr × Tmd | 8 | 11.088 | <0.0001*** |
| Az × Se × Cr | 2 | 29.966 | <0.0001*** |
| Az × Se × Tmd | 4 | 57.277 | <0.0001*** |
| Az × Cr × Tmd | 8 | 13.388 | <0.0001*** |
| Se × Cr × Tm | 8 | 10.152 | <0.0001*** |
| Az × Se × Cr × Tm | 8 | 6.845 | <0.0001*** |

DF: Degrees of freedom, ns; not significant, significance codes: 0 '****' 0.001 '***' 0.01 '**' $p \geq 0.05$ 'ns'

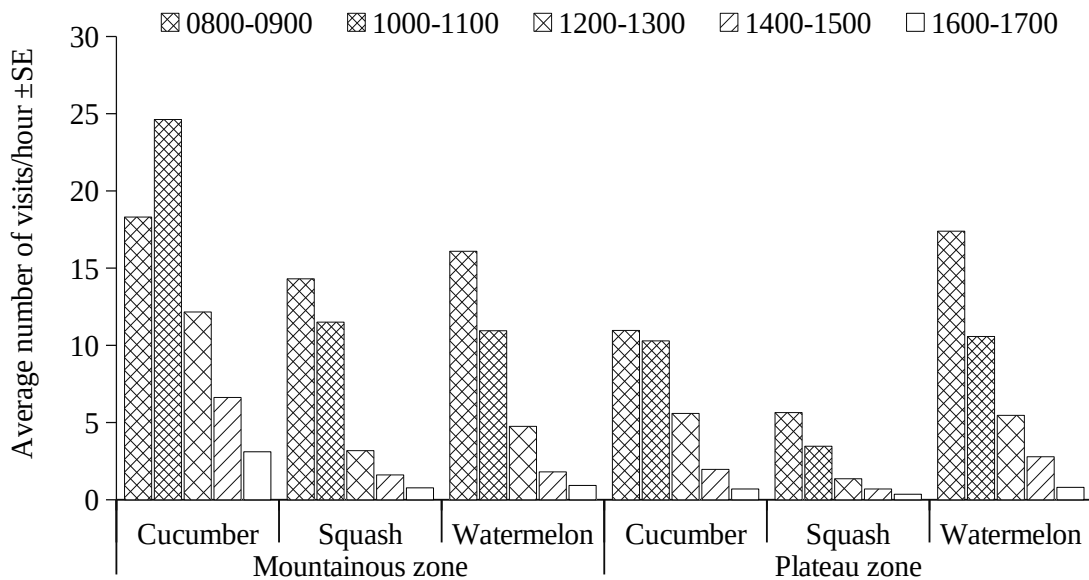


Figure 3.2: Effects of the interaction of agroecological zone, cucurbit species and time of a day on diurnal visitation patterns of *A. mellifera* on cucurbits flowers

3.2.3 Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *P. borbonicus* on cucurbits flowers

There were significant effects ($p < 0.0001$) of the interaction of agroecological zone \times cucurbit species \times time of a day \times season on diurnal visitation patterns of *P. borbonicus* (Table 3.2). The significant ($p < 0.0001$) interactions of agroecological zone \times cucurbit species \times time of the day were further explored. The *post hoc* analysis showed that, the number of visits by *P. borbonicus* on cucumber flowers from 1600- 1700 h at the mountainous were higher than the number of visits on squash flowers from 1600- 1700 h at both the plateau and mountainous zone ($p < 0.0001$). The highest number of visits was found on cucumber flowers at the mountainous zone and watermelon flowers at the plateau zone from 1000 – 1100 h where the lowest number of visits was observed on squash flowers at the plateau zone from 1600 – 1700 h (Fig. 3.3). Furthermore, from

0800 – 1100 h, there were no significant different ($p>0.05$) in the number of visits by *P. borbonicus* on flowers of all cucurbit species at both the plateau and mountainous zone. Likewise, from 1400 – 1700 h except on squash flowers at the plateau ($p<0.0001$).

Table 3.2: Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *P. borbonicus*

| Statistics | | | |
|--------------------------|----|---------|------------|
| Factors | DF | F-value | P-value |
| Agroecological zone (Az) | 1 | 7.916 | 0.005** |
| Season (Se) | 1 | 26.010 | <0.0001*** |
| Crop species (Cr) | 2 | 14.246 | <0.0001*** |
| Time of a day (Tmd) | 4 | 22.799 | <0.0001*** |
| Az × Se | 1 | 3.759 | 0.053 ns |
| Az × Cr | 2 | 11.499 | <0.0001*** |
| Az × Tmd | 4 | 49.496 | <0.0001*** |
| Se × Cr | 2 | 10.965 | <0.0001*** |
| Se × Tmd | 4 | 12.214 | <0.0001*** |
| Cr × Tmd | 8 | 10.800 | <0.0001*** |
| Az × Se × Cr | 2 | 5.525 | 0.004** |
| Az × Se × Tmd | 4 | 28.991 | <0.0001*** |
| Az × Cr × Tmd | 8 | 6.997 | <0.0001*** |
| Se × Cr × Tm | 8 | 3.495 | 0.001** |
| Az × Se × Cr × Tm | 8 | 7.374 | <0.0001*** |

DF: Degrees of freedom, ns; not significant, significance codes: 0 '***'
0.001 '**' 0.01 '*' $p \geq 0.05$ 'ns'

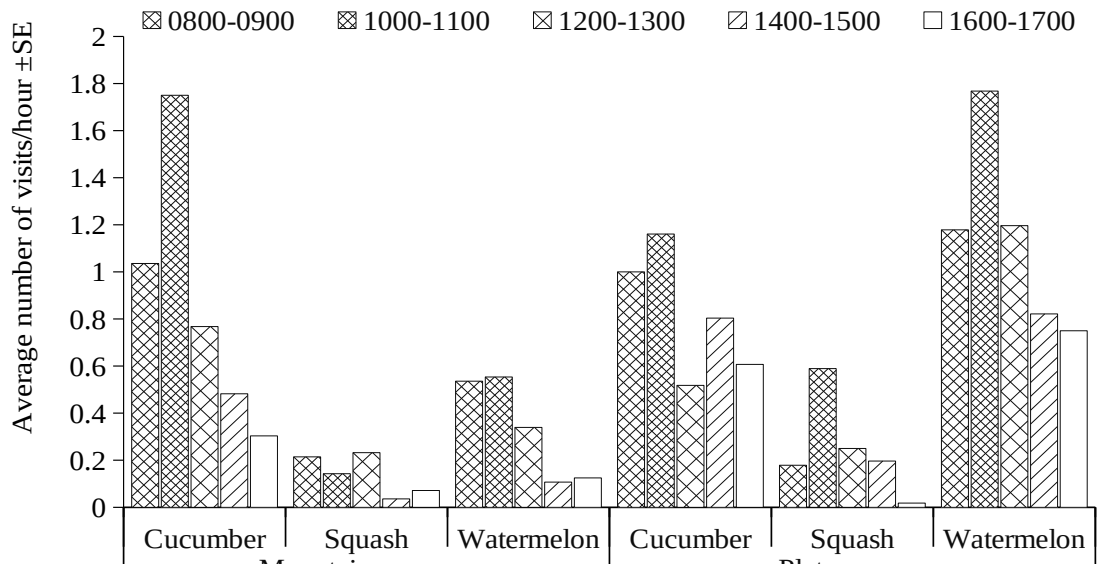


Figure 3.3: Effects of the interaction of agroecological zone, cucurbit species and time of a day on diurnal visitation patterns of *P. borbonicus* on cucurbits flowers

3.2.4 Effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *T. floralis* on cucurbits flowers

The four-way interactions of agroecological zone × cucurbit species × time of a day × season significant ($p < 0.0001$, Table 3.3) effected the diurnal visitation patterns of *T. floralis*. The significant ($p < 0.0001$) interactions of agroecological zone × cucurbit species × time of the day were further investigated due to the fact that the effect of season on diurnal visitation patterns of *T. floralis* cannot be regulated. The results showed that, the highest number of visits by *T. floralis* was found on watermelon flowers from 0800-0900 h at the plateau zone and the lowest on squash flowers from 1600 – 1700 h at the mountainous zone. There were no significant different in the number of visits on all cucurbit flowers from 0800- 1100 h at both the plateau and mountainous zone ($p > 0.05$). Also, no significant different in the number of visits on all cucurbit flowers from 1200- 1700 h at both the plateau and mountainous zone ($p > 0.05$) were observed except on cucumber flowers at the plateau zone where the significant different ($p < 0.0001$) was found from 1200 – 1300 h and from 1600 -1700 h (Fig. 3.4).

Table 3.3: Analysis of variance on the effect of agroecological zone, season, cucurbit species and time of a day on diurnal visitation patterns of *T. floralis*

| Factors | DF | Statistics | |
|--------------------------|----|------------|------------|
| | | F-value | P-value |
| Agroecological zone (Az) | 1 | 2.412 | 0.121 ns |
| Season (Se) | 1 | 26.213 | <0.0001*** |
| Crop species (Cr) | 2 | 9.097 | <0.0001*** |
| Time of a day (Tmd) | 4 | 17.048 | <0.0001*** |
| Az × Se | 1 | 0.825 | 0.364 ns |
| Az × Cr | 2 | 11.843 | <0.0001*** |
| Az × Tmd | 4 | 41.073 | <0.0001*** |
| Se × Cr | 2 | 7.642 | <0.0001*** |
| Se × Tmd | 4 | 14.102 | <0.0001*** |
| Cr × Tmd | 8 | 10.042 | <0.0001*** |
| Az × Se × Cr | 2 | 6.751 | 0.001** |
| Az × Se × Tmd | 4 | 24.884 | <0.0001*** |
| Az × Cr × Tmd | 8 | 8.288 | <0.0001*** |
| Se × Cr × Tm | 8 | 6.890 | <0.0001*** |
| Az × Se × Cr × Tm | 8 | 7.836 | <0.0001*** |

DF: Degrees of freedom, ns; not significant, significance codes: 0 '***' 0.001 '**' 0.01 '*' $p \geq 0.05$ 'ns'

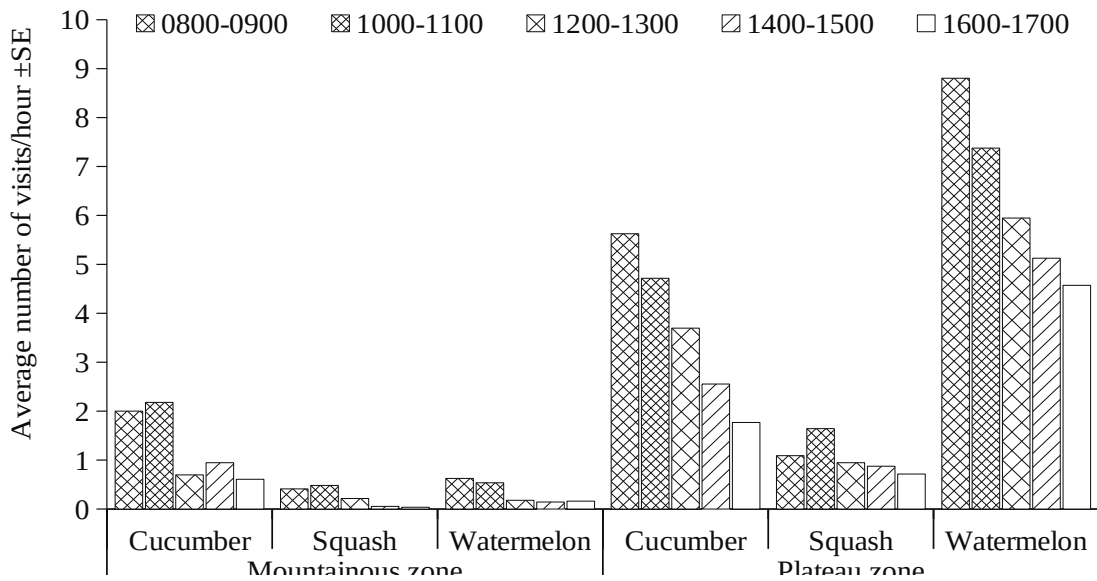


Figure 3.4: Effects of the interaction of agroecological zone, cucurbit species and time of a day on diurnal visitation patterns of *T. floralis* on cucurbits flowers

3.2.5 Effect of weather parameters and cucurbit flower densities on visitation patterns of honey bees and hoverflies

The results revealed that, there was significant correlation between the environmental variables and pollinators visitation patterns along the different time of the day. *Apis mellifera* visitation patterns were significantly associated with temperature negatively and with relative humidity and cucurbit flower density positively. *Eristalinus megacephalus*, *M. caffer* and *Paragus borbonicus* were insignificantly associated with relative humidity negatively and with temperature and flower density positively. *Toxomerus floralis* visitation patterns were significantly correlated with relative humidity negatively and positively associated with flower density and temperature (Table 3.4).

Table 3.4: Spearman's correlation coefficient between environmental variables and diurnal visitation patterns of the studied pollinators

| Environmental variables | Pollinators | | | | |
|-------------------------|---------------------|------------------------|-----------------|----------------------|--------------------|
| | <i>A. mellifera</i> | <i>E. megacephalus</i> | <i>M.caffer</i> | <i>P. bobornicus</i> | <i>T. floralis</i> |
| Temperature | -0.966** | 0.227 ns | 0.521 ns | 0.439 ns | 0.949* |
| Relative humidity | 0.927** | -0.227 ns | ns | -0.766 ns | -0.981** |
| Flower density | 1.000* | 0.910 ns | 0.800 ns | 0.901 ns | 1.000** |

Significance codes: 0.001 '***' 0.01 '**' $p \geq 0.05$ 'ns'

3.3 Discussion

The results showed that the visitation patterns of honeybees were highly affected at a different time of the day compared to hoverflies during the study period. The visitation abundance of *A. mellifera*, *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis* peaked at 1100 h. From 1600 – 1700 h the number of visits by *A. mellifera* was less than the number of visits by *T. floralis*. These findings are supported by Cook *et al.* (2020) who reported that many hoverflies' bodies are covered in fine yellow hairs, which contribute to thermal reflectance properties of the insect cuticle and aid in thermal balance and are thus, active in the mid of the day when temperatures peak. Also, the study by Majeed *et al.* (2020) reported that the inability of honeybees to forage when the temperature is high and low relative humidity is because these conditions cause the dehydration of their bodies which adversely impacts their flight. The temperature and relative humidity between 21°C to 35°C, 22% to 60%, respectively, favors *A. mellifera* foraging activities (Kumar and Soniya, 2020)

Among the environmental variables, the temperature is the most important factor that affects the visitation patterns of pollinators. The number of insect visitor increases as the day progressed when the temperature is low and decline during the late time when the temperature increase (Shyamna and Nasser, 2019). Furthermore, this study discovered

that cucurbits species significantly affect the visitation patterns of pollinators at different times of the day. This is because there are variations in climatic conditions at different times along the day which have a great impact on cucurbits flower opening and closing, also the quality and quantity of floral resources (Malerbo-Souza *et al.*, 2019). During the investigation of diurnal visitation patterns of pollinators in cucurbits along the day, it has been observed that flowers in watermelon and squash started to close from 1000 h during the dry season and 1200 h during the rainy season. This might be the reason why the number of visits by pollinators was decreasing from 1200 h onwards. These findings are in correlation with the study by (HeLeNa *et al.*, 2016) which found that the increase in air temperature hastens the closing of watermelon flowers while cloudy time slower flowers closing.

The results of this study also showed a significant effect of environmental variables and flower density on diurnal visitation patterns of honeybees and hoverflies. The effects of environmental variables on the visitation patterns of insect pollinators are influenced by insect physiological status. Hoverflies are less influenced by environmental parameters compared to honeybees (Azo'o Ela *et al.*, 2022), hoverflies have greater thermal tolerance and physiological flexibility due to possessing yellow hairs that assist in thermal reflection (Cook *et al.*, 2020). It was revealed by this study, that the number of visits by hoverflies on cucurbit flowers during the evening from 1600 h to 1700 h was higher compared to that of honeybees.

Floral density positively affected honeybees' and hoverflies' diurnal visitation patterns. Insect pollinators can be found in the field almost throughout the day where flowers are abundantly available. Moreover, flower opening and closing are influenced by both environmental variables and physic-biological characteristics of the plant. During the study, it was observed that when air temperature raised influenced the closing of

watermelon flowers therefore negatively impacted pollinator visitation. This is in line with the findings by Malerbo-Souza *et al.* (2019) who reported that watermelon flowers open at 0600 h and remain open until 1200 h when male flowers start to close then female flowers follow when the air temperature is high.

3.4 Conclusions and Recommendations

This study concluded that environmental variables affected the diurnal visitation patterns of honeybees and hoverflies. It has been found that the number of visits by honeybees and hoverflies peaked at 1100 h. The temperature had more effect on honeybees compared on hoverflies. The decrease in the number of visits by honeybees on cucurbit flowers was higher compared to hoverflies from 1600 h to 1700 h. Since most hoverflies were observed abundantly foraging during the morning hours, this study suggested the proper management practices like pesticide application in cucurbits during the inactive foraging time of pollinators. Also, this study recommends further investigation on temporal variation in cucurbits' floral rewards and receptiveness, and the effect of environmental variables on hoverflies' reproduction.

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CHAPTER FOUR

Manuscript three

**Effects of Management Practices in Cucurbits on Foraging Activities of Honeybees
and Hoverflies in Morogoro, Eastern-Central Tanzania**

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Abstract

Poor agricultural practices have drastically threatened insect pollinators' biodiversity. Little is known in Tanzania about how different agricultural practices affect pollinators foraging activities. This study investigated the effects of the agroecological zone, season, cucurbit species and management practices on visitation frequency, rate and time spent on cucurbit flowers by five pollinator species viz. *Apis mellifera*, *Eristalinus megacephalus*, *Mesembrius caffer*, *Paragus borbonicus* and *Toxomerus floralis*. The experiment was designed as a 5×3×3×2×2 factorial arrangement in a Randomized Complete Block Design (RCBD) with four replications. GAMOUR-Agroecology was tested against conventional practices and untreated control. Results showed significant effects of agroecological zone × season × cucurbit species × management practice on pollinators' visitation frequency ($p = 0.007$) and time spent on flowers ($p = 0.005$). Also, agroecological zone × season × cucurbit species × pollinator species significantly ($p < 0.0001$) affected pollinators' visitation frequency. Agroecological zones × season × cucurbit species × cucurbits management practices × pollinators significantly ($p = 0.001$) affected pollinators' visitation rate. Pollinators foraging activities were enhanced by GAMOUR-Agroecology practices. Therefore, this study recommended that cucurbit growers should consider management practices that positively influence pollinator foraging activities for sustainable cucurbit production.

Keywords: GAMOUR-Agroecology, visitation rate, visitation frequency, pollinators, pollination.

4.0 Introduction

Insect pollinators are of economic importance in numerous cross-pollinated crops including cucurbits for sustainable food production (Das *et al.*, 2018). They contribute to growth, improvement of fruit quality and setting of seeds (Atibita *et al.*, 2020). Cucurbits are among the fruit vegetables whose production is increasing worldwide due to an elevated market demand motivated by consumers' health concerns (Nordey *et al.*, 2017). However, the production of cucurbits is hampered by several factors including insufficient pollination services (Chan & Raine, 2021). The deficit of pollination services is linked to a variety of issues, including poor agricultural practices that have reduced the number and foraging behaviour of insect pollinators (Karamaouna *et al.*, 2021). The global meta-analysis by the Intergovernmental Science-Policy Platform for Biodiversity and Ecosystem Services (IPBES) on the status and threats against pollinators and pollination have identified intensive agriculture as a major threat against pollinators (Kim *et al.*, 2018). Farm management directly affects the availability and quality of foraging and nesting resources for pollinators in the agricultural fields (Vanbergen *et al.*, 2013). Since the 1960s, modern agriculture has rapidly intensified, and the dominant agriculture in many parts of the world uses large amounts of chemical fertilizers, pesticides and other technologies that directly or indirectly affect insect pollinator biodiversity (Brittain *et al.*, 2010; Eggleton, 2020).

In Tanzania, less attention has been paid to insect pollinator conservation during crop production, this was revealed from the survey conducted by Sawe *et al.* (2020a) in Northern Tanzania which documented that the majority of the local farmers are aware of neither the role of pollinating insects nor their conservation strategies and the survey by Mkenda *et al.* (2020) in Northern Tanzania discovered that farmers are not able to distinguish beneficial insects from insect pests. In addition, the emphasis on the

agricultural sector in the country is greatly given to soil fertility improvement, pest control and irrigation water availability (Sawe, Nielsen, *et al.*, 2020). Therefore, more studies are needed on the effect of agricultural management practices on insect pollinator biodiversity and foraging activities for sustainable production of insect pollinator-mediated crops such as cucurbits.

Many studies have attempted to explore the effect of different agricultural management practices on insect pollinator biodiversity. For example, the investigation by Kovács-Hostyánszki *et al.* (2017), Montoya *et al.* (2020) and Karamaouna *et al.* (2021) revealed that the reduced level of inorganic fertilizer use, pesticides and diverse edge vegetation have substantial effects on pollinator communities with subsequent positive effects on agricultural productivity. Moreover, a study by Karamaouna *et al.* (2021) suggested that sustainable agronomic practices can create suitable habitats that provide food and shelter to pollinators and natural enemies of insect pests in agro-ecosystems. However, there are limited studies in Tanzania on the effect of different management practices that are applied during cucurbits production on insect pollinator foraging activities. Therefore, this study assessed the effects of GAMOUR-Agroecology and conventional practices in cucurbits production on the foraging activities of four dominant hoverflies; *Eristalinus megacephalus* Rossi, *Mesembrius caffer* Loew, *Paragus borbonicus* Macquart and *Toxomerus floralis* Fabricius, which were revealed from the study by Kabota (2021) that are potential pollinators in cucurbits along with *Apis mellifera* Linnaeus.

4.1 Material and Methods

4.1.1 Description of the study area

The study was carried out in two agroecological zones of Morogoro region, Eastern-Central Tanzania, namely Plateau and Mountainous, from March to June, 2021 (rainy season) and September to November, 2021 (dry season). The area's climatic conditions

are characterized by bimodal rainfall, with short rains from October to December and long rains from March to May. During the period of study for the May-June season, the average temperature and relative humidity ranged from 18°C to 24°C and 70% to 89%, respectively in the mountainous zone, and from 22°C to 25°C and 69% to 82%, respectively, in the plateau zone. While during the October-November season, average temperature and relative humidity ranged from 20°C to 25°C and 70% to 80%, respectively in the mountainous zone, and from 26°C to 30°C and 63% to 71%, respectively, in the plateau zone. Table 4.1 indicates the characteristics of the study area. The experimental plots were established between 06°47'26"S 37°38'08"E and 06°51'01"S 37°39'17"E, in the plateau zone and between 06°52'32"S 37°40'16"E and 06°53'20"S 37°40'14"E, in the mountainous zone.

Table 4.1: Characteristics of the study area

| | Mountainous zone | Plateau zone |
|------------------------------|-------------------------|---------------------|
| Elevation (m a.s.l) | 800 - 2000 | 200 - 600 |
| Average annual rainfall (mm) | 1000 - 1200 | 800 - 1000 |
| Average temperature (°C) | 10 - 25 | 19 - 31 |

4.1.2 Experimental layout and crop establishment

An experiment was designed as a 5 x 3 x 3 x 2 x 2 factorial in a Randomized Complete Block Design (RCBD) with four replications. Where five pollinating species (*A. mellifera*, *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis*) were assessed under three cucurbit management practices (GAMOUR- Agroecology, Conventional and control) on three cucurbit species; cucumber (*Cucumis sativus* Linnaeus), watermelon (*Citrullus lanatus* Thunb.) and squash (*Cucurbita moschata* Duchesne), in the two agroecological zones of Morogoro (Plateau and Mountainous zone) for two cucurbit

growing seasons (March - June and September – November 2021 (rainy and dry season, respectively).

GAMOUR-Agroecology practices involved the use of border crop (maize) for attracting insect pollinators and trapping cucurbit fruit flies, mass trapping and killing of fruit flies using success bait GF120 (Spinosad 0.24 g/l) and Bio lure placed on border crop, use of organic mulches, use of augmentation for field sanitation, and the use of organic fertilizers (farmyard manure). Conventional practices involved the use of insecticide (Dimethoate 400 g/l) and fungicide (Chlorothalonil 720 g/l,) industrial fertilizers (N: P: K 15:9:20 and CAN 15:4:26). Plots without any management practices except irrigation during the dry season and weeding were used as controls. Watermelon “crimson sweet” variety, Cucumber “Ashley” variety, Squash “Waltham butternut” variety and Maize “Tumbili” variety used in this study were purchased from Agro-dealer in Morogoro town. Sowing of maize and cucurbit seeds was done on 23 March, 2021 for the rainy season and 2 September, 2021 for the dry season at a spacing of 0.3 m × 0.3 m and 1.5 m × 1.0 m respectively on a 45 m × 45 m plot. For maize, one seed per hole and cucurbits two seeds per hole sowing was observed. Each experimental plot per specific management practice was located at least 100 m away from each other to avoid spray drift from the conventional plots.

4.1.3 Assessment of honeybees’ and hoverflies’ foraging activities

The assessment of cucurbits flowers visitors' foraging activities began when the crop attained 10% flowering and continued until the end of the flowering period. The foraging activities were assessed in terms of: -

Visitation frequency: the number of visits on a single cucurbit flower by individual flowers visitors for each cucurbit management practice.

Visitation rate: the number of cucurbit flowers visited by individual flowers visitors for each cucurbit management practice.

Handling time: the time (seconds) spent on each cucurbit flower by individual flowers visitors for each cucurbit management practice.

The investigation was conducted through visual observation under three phases between 0800 and 1700 hours at 0800 - 0900, 1200 - 1300 and 1600 – 1700 hours on 8 spots of 4 m² each which were established after every 5 m within the experimental plot per cucurbit species per management practices. The observations were conducted weekly following the procedures adopted from Meerabai (2012) and Yogapriya *et al.* (2019).

4.1.4 Data collection

Pollinator abundance – Total number of pollinating species visited cucurbit flowers in a 4 m² per cucurbit species and management practices during 3 minutes of observations.

Visitation frequency – It was determined by observing a single flower at a close range for a maximum of 1 minute and the number of visits per pollinating species was recorded. On each cucurbit management practice, a total of 72 flowers were observed per day in which 24 flowers were selected from each cucurbit species. An average number of visits on a single cucurbit flower per cucurbit species per management practices by individual pollinating species was calculated by the formula described by Zameer *et al.* (2017):

$$VF = \frac{TNV}{TFO} \dots\dots\dots$$

(i)

Where: VF is visitation frequency, TNV is total number of visits and TFO is the total number of flowers observed.

Visitation rate – This was determined by tracking an individual pollinating species for a maximum of 1 minute from the time it arrived on the first flower within a 4 m² spot and

the following information was recorded: the total number of flowers visited, time (seconds) spent on each visited flower and time spent in flight between consecutive flowers. A total of 9 observations were performed for each pollinating species per cucurbit management practice per day in which each pollinating species was observed three times per cucurbit species. An average number of flowers visited per pollinating species was determined following the formula described by Meerabai (2012):

$$VR = \frac{TNFV}{TSF + TFBCF} \dots\dots\dots$$

(ii)

Where: VR is the visitation rate, TNFV is the total number of flowers visited, TSF is the time spent on flowers and TFBCF is the time in flight between consecutive flowers.

The average time spent on each visited flower (handling time) was processed as per the formulas described by Meerabai (2012).

$$HT = \frac{TSF}{TNFV} \dots\dots\dots \text{(iii)}$$

Where: HT is handling time, TSF is the total time spent on flowers and TNFV is the total number of flowers visited.

4.1.5 Statistical analysis

The data were subjected to analysis of variance (ANOVA) at a 5% level of confidence using Generalized Linear Mixed Models (GLMMs) procedures to check the effect of agroecological zones, seasons, cucurbit species and cucurbits management practices on honeybees and hoverflies foraging activities. To validate the significance of the factors *post hoc* test was performed, and means were compared using Tukey's Honest Significant Difference at 5%.

4.2 Results

4.2.1 Abundance of honeybees and hoverflies on cucurbit flowers across the three cucurbits management practices

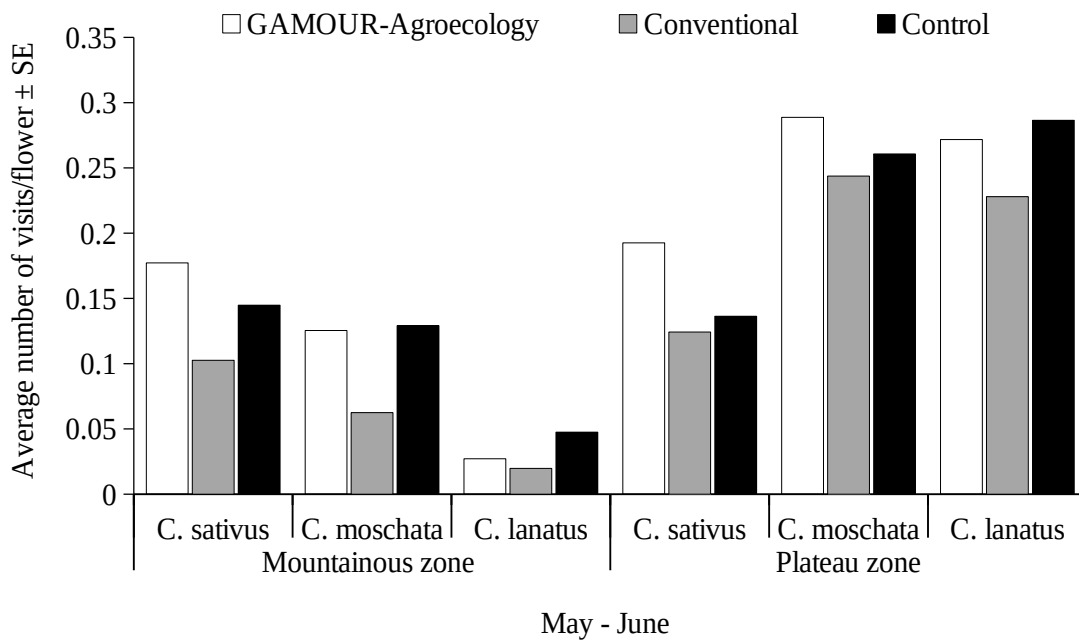
A total of 43 510 visit counts of honeybees and hoverflies were recorded on cucurbit flowers for the whole study period in all the plots of each management practice (GAMOUR-Agroecology, conventional and control. The number of visits by individual flowers visitors was in proportion of 60.3%, 25.14%, 7.56%, 6.0% and 1.0%, *A. mellifera*, *T. floralis*, *P. borbonicus*, *E. megacephalus* and *M. caffer*, respectively.

4.2.2 Effects of agroecological zones, seasons, cucurbit species and cucurbits management practices on the visitation frequency of honeybees and hoverflies on cucurbits flowers

Our results showed non-significant effects of the interaction of agroecological zone, season, cucurbit species, management practice and pollinator species on the visitation frequency of the pollinators. We, therefore, examined the effects of four-way interactions among treatments. Results showed significant ($p = 0.007$) effects of agroecological zone \times season \times cucurbit species \times management practice on visitation frequency of pollinators on cucurbit flowers (Fig. 4.1a and b). Further examination showed the variations in visitation frequency were significant within both seasons. We found that visitation frequencies in *C. moschata* and *C. lanatus* plots in the plateau zone, during the May – June season were not significantly different among management practices, but were significantly higher than in all other situations (*Post hoc* test, Tukey's HSD). Generally, the highest visitation frequency was recorded in *C. moschata* plots treated with GAMOUR- Agroecology in the plateau zone, while the least was recorded in *C. lanatus* plots treated with conventional practices in the mountainous zone during May- June

season. The only exception was pollinator visitation frequency in *C. lanatus* plots under control in the mountainous zone during the May – June cropping season (Fig. 4.1a).

The effects of agroecological zone \times season \times cucurbit species \times pollinator species were also significant ($p < 0.0001$) (Fig. 4.2a and b). *Apis mellifera* was significantly the most frequent visitor during both seasons and agroecological zones (*Post hoc* test, Tukey's HSD). A notable exception was the visitation frequency of *T. floralis* to *C. lanatus* plots, in the plateau zone during the May – June season (Fig. 4.2a).



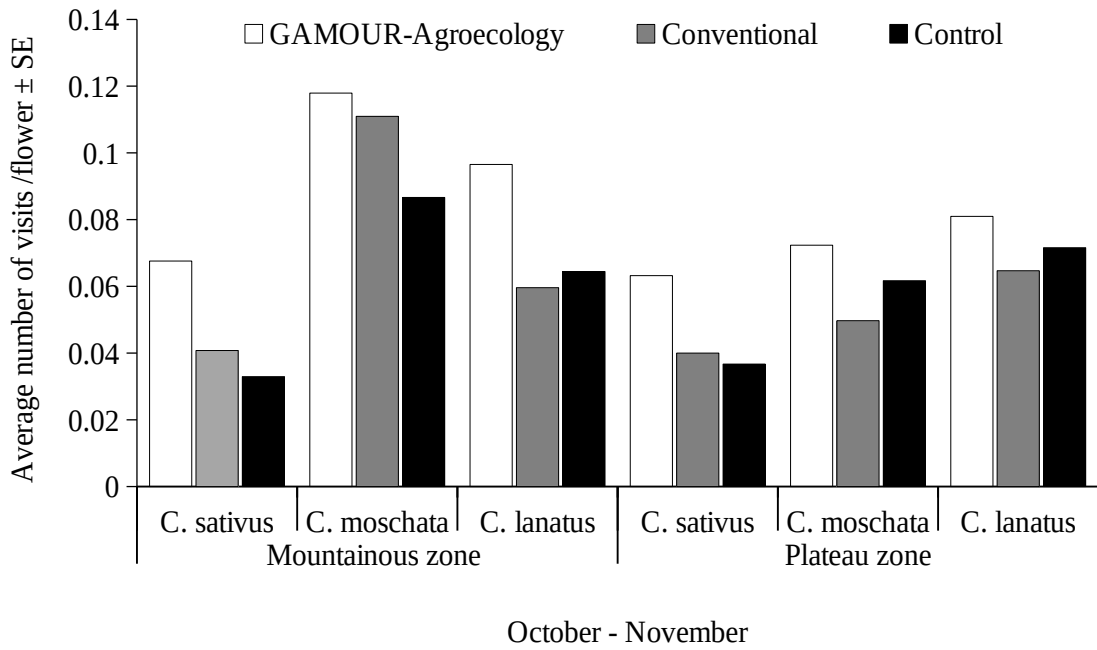
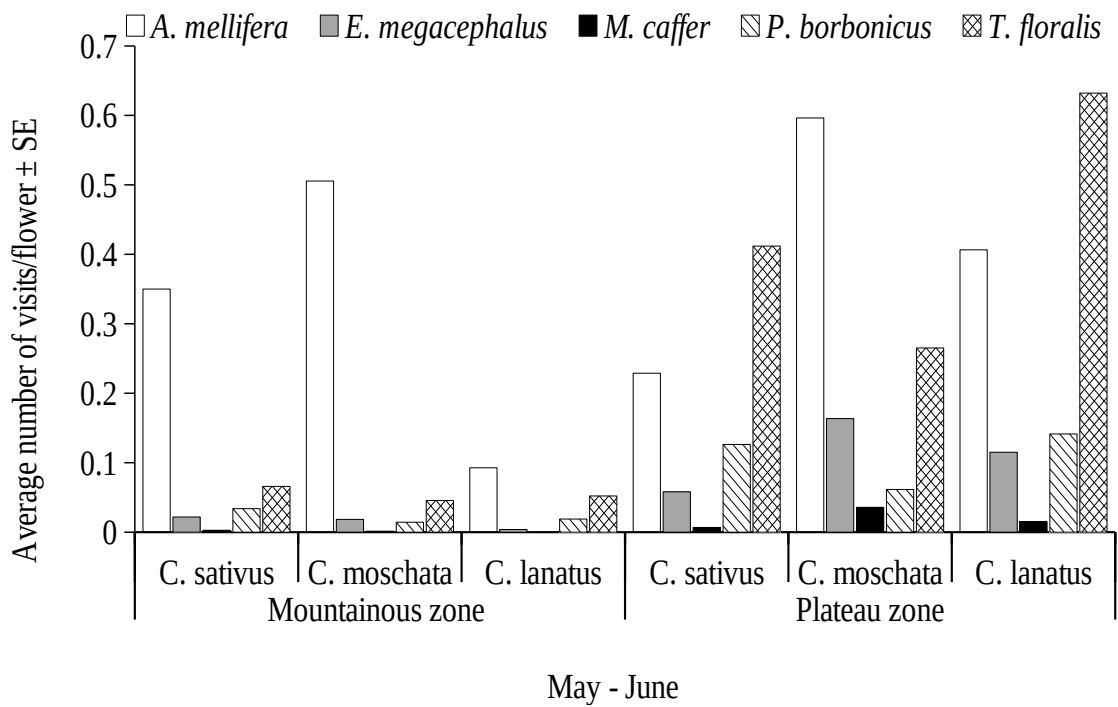


Figure 4.1a and b: Visitation frequency of pollinators on cucurbit flowers as affected by agroecological zones, cucurbit species and management practices



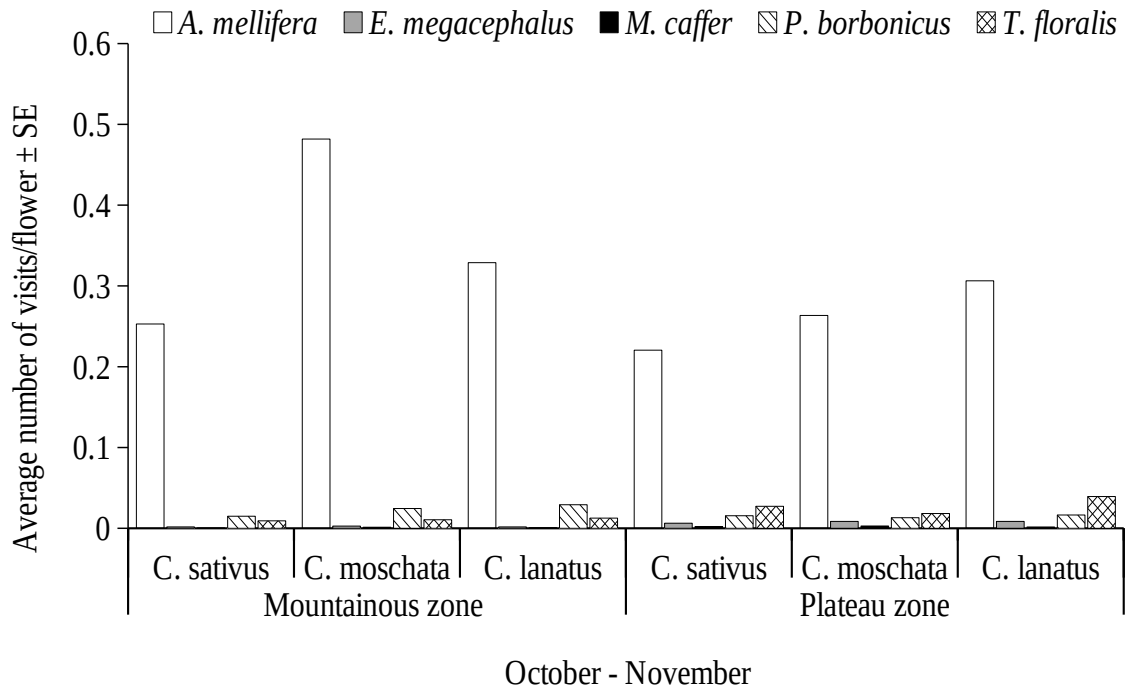
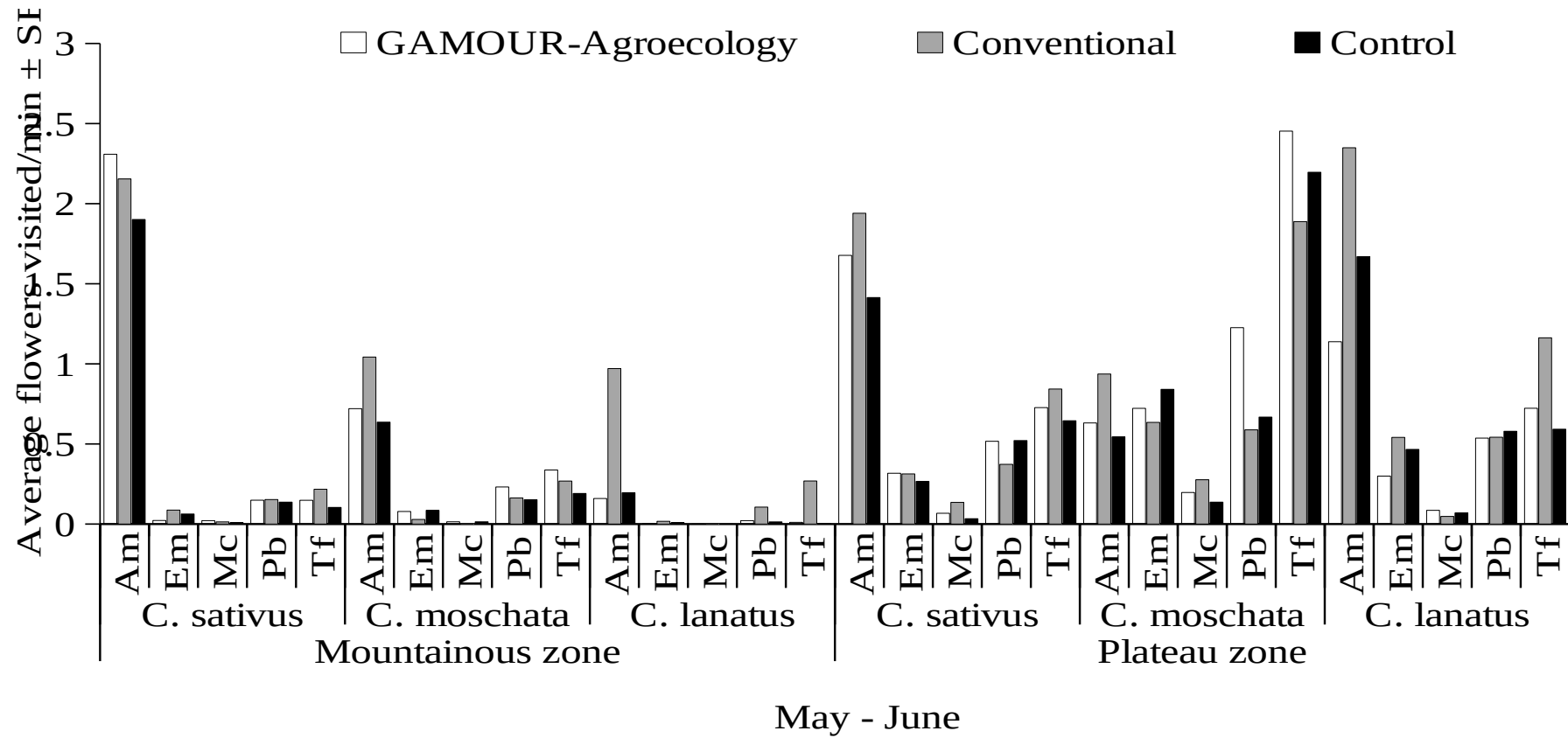


Figure 4.2a and b: Visitation frequency of pollinators on cucurbit flowers as affected by agroecological zones and cucurbit species

4.2.3 Effects of agroecological zones, seasons, cucurbit species and cucurbits management practices on the visitation rate of honeybees and hoverflies on cucurbits flowers

There were significant effects of the five-way interaction of agroecological zones × season × cucurbit species × cucurbits management practices × pollinators ($p = 0.001$) on the visitation rate of pollinators on cucurbit flowers. The variations were significant within both seasons. Visitation rates by *A. mellifera*, in *C. sativus* plots, were similar among management practices but were significantly higher than all other combinations in the mountainous zone (*Post hoc* test, Tukey's HSD). A notable exception was the visitation rate of *T. floralis* to *C. moschata* plots, in the plateau zone during the May – June season (Fig. 4.3a). A similar situation was observed in the October – November season, rates by *A. mellifera* were significantly higher regardless of zone and cucurbit

species. Variations among practices, in that case, were not significantly different except in *C. sativus*. Highest visitation rates were revealed by *A. mellifera* in *C. sativus* plots under GAMOUR-Agroecology practices in the mountainous zone during the October - November season (Fig. 4.3b). In contrast, visitation rates were the lowest for *E. megacephalus* and *M. caffer* in *C. lanatus*, under all practices in the mountainous zone during both seasons (Fig. 4.3a and b).



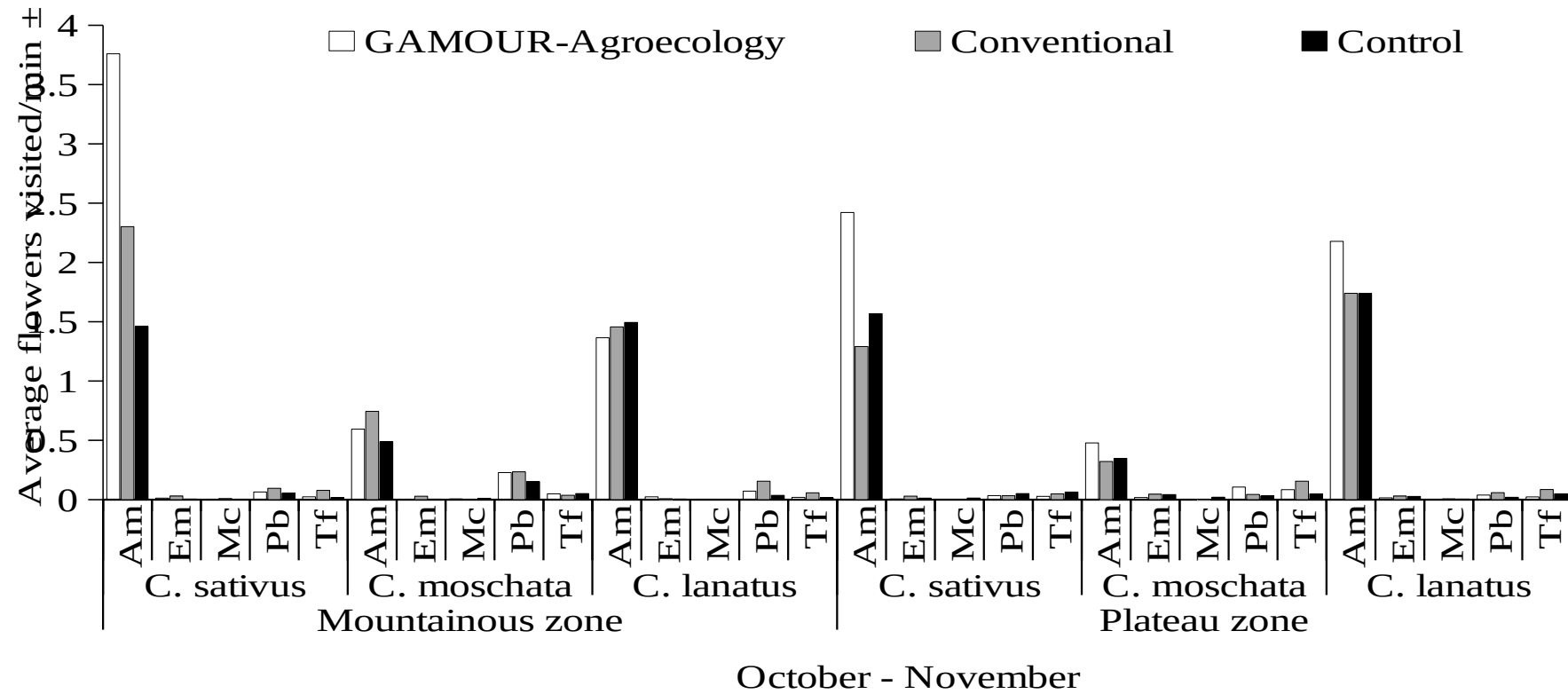


Figure 4.3a and b: Visitation rate of pollinators on cucurbit flowers as affected by agroecological zones, cucurbit species and management practices.

Key: Am is *A. mellifera*, Em is *E. megacephalus*, Mc is *M. caffer*, Pb is *P. bobornicus* and Tf is *T. floralis*

4.2.4 Effect of agroecological zones, seasons, cucurbit species and cucurbits management practices on time spent on cucurbit flowers (handling time) by honeybees and hoverflies

The four-way interactions of agroecological zones × season × cucurbit species × management practices significantly ($p = 0.005$) affected the time spent by pollinators on cucurbit flowers. The differences in time spent by pollinators were significant among factors when analyzed by season. Time spent by pollinators in *C. sativus* under control in the mountainous zone, during the May - June season was significantly the longest (*Post hoc* test, Tukey's HSD) (Fig. 4.4a). Furthermore, time spent by pollinators in crops under GAMOUR - Agroecology and control practices was statistically similar, but significantly higher than in crops under conventional practices during the October – November cropping season (Fig. 4.4b). Exceptions were time spent in *C. lanatus* in plateau zone and *C. moschata* in mountainous zone. In general, pollinators spent more time in *C. sativus* under control in the mountainous zone, and the least time in *C. moschata* under conventional and GAMOUR-Agroecology practices, in both zones During the May- June season (Fig. 4.4a). Furthermore, during the October-November season, pollinators spent more time in *C. lanatus* under GAMOUR-Agroecology practices in the plateau zone and the least time in *C. moschata* under conventional practices in the plateau zone (Fig. 4.4b).

We also examined three-way interactions involving pollinator species as a factor. Time spent by a pollinator species was significantly dependent on agroecological zone × season ($p = 0.02$) as well as agroecological zone × cucurbit species ($p < 0.0001$). *T. floralis* spent more time in *C. sativus* and *C. lanatus* in the mountainous zone during the season October-November and the least time by *A. mellifera* in *C. sativus* in the plateau zone during the season of May – June (Fig. 4.5 and 4.6). Season × cucurbit species also

determined the time spent by a pollinator species on cucurbit flowers ($p < 0.0001$). The time spent by *T. floralis* in *C. lanatus* was significantly higher than the time spent by the rest with the lowest time spent by *A. mellifera* in *C. sativus* during the season of May – June (Fig. 4.7). Finally, the time spent by a pollinator species significantly ($p = 0.007$) varied with cucurbit species \times management practices (Fig. 4.8)

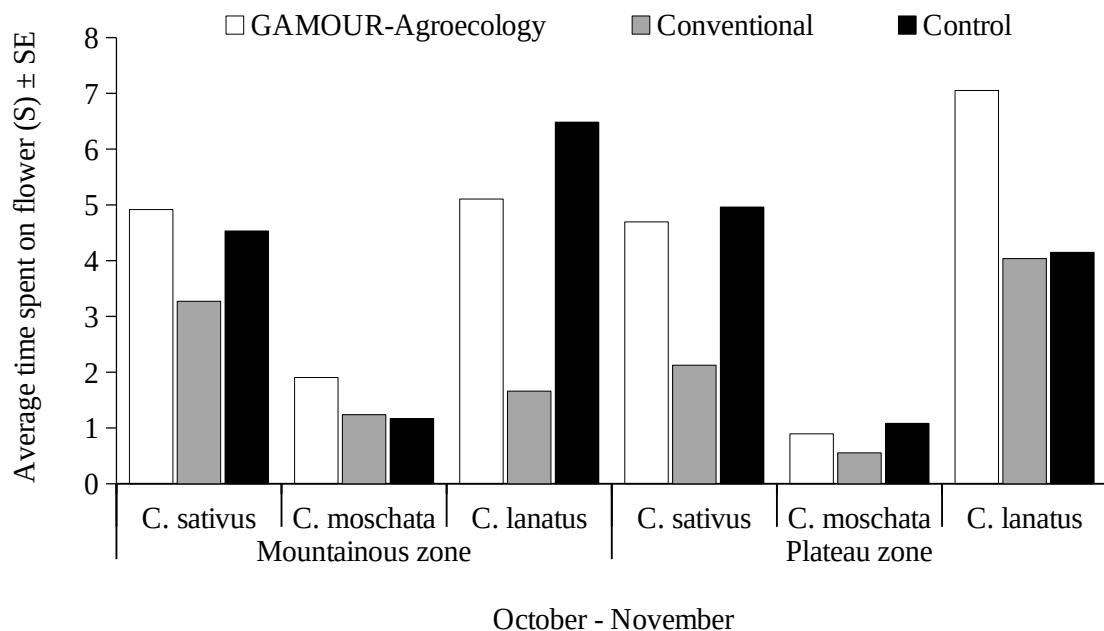
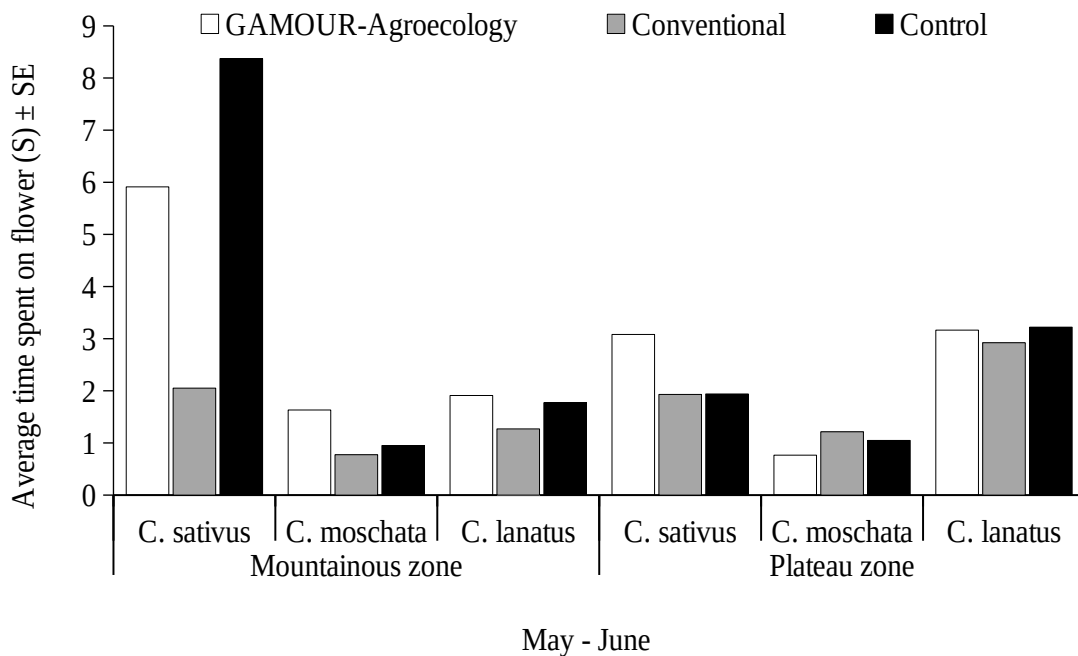


Figure 4.4a and b: Time spent on flowers by pollinators as affected by agroecological zones, cucurbit species and management practices

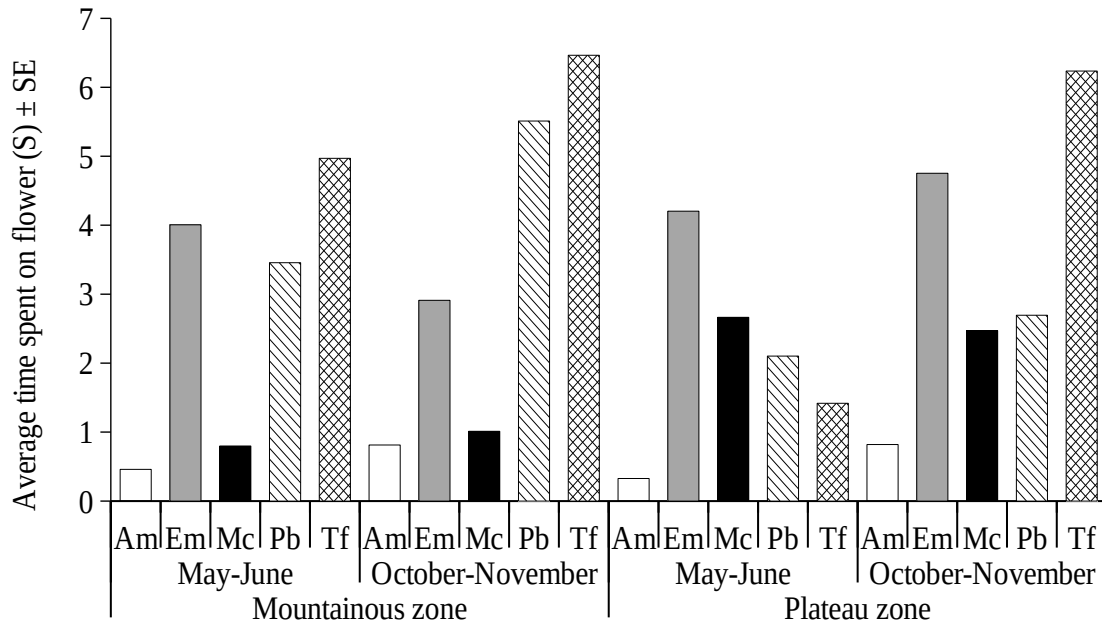


Figure 4.5: Time spent on flowers by pollinators as affected by agroecological zones and season. Key: Am is *A. mellifera*, Em is *E. megacephalus*, Mc is *M. caffer*, Pb is *P. bobornicus* and Tf is *T. floralis*

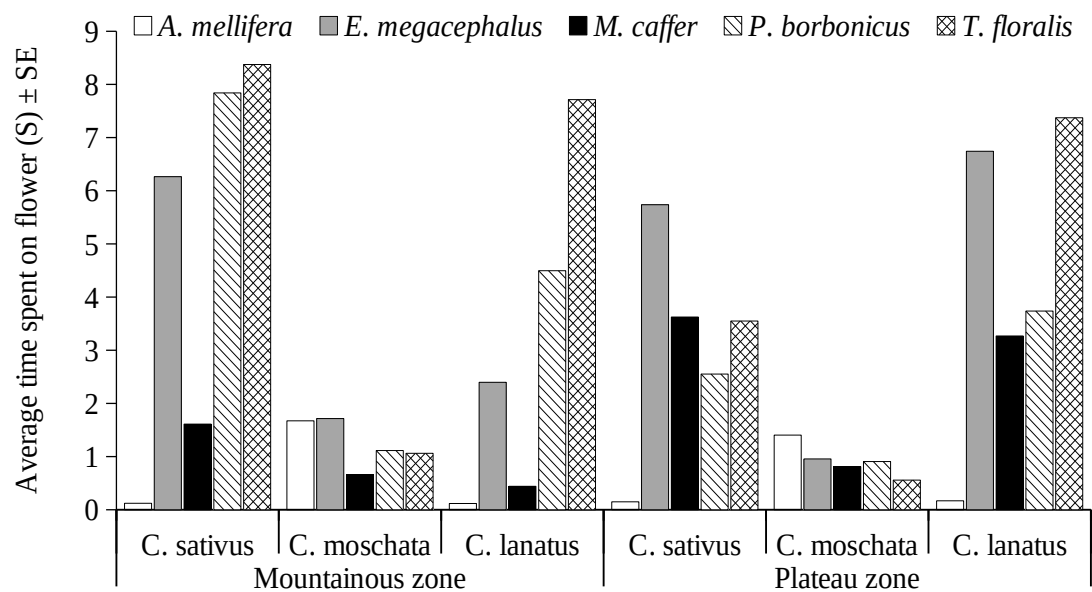


Figure 4.6: Time spent on flowers by pollinators as affected by agroecological zones and cucurbit species

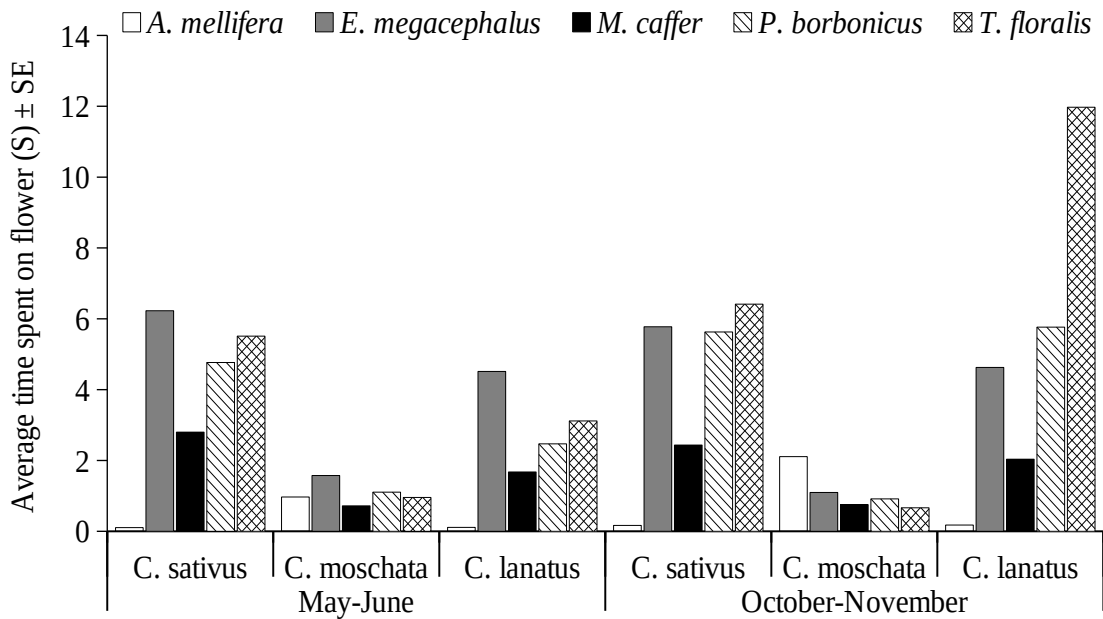


Figure 4.7: Time spent on flowers by pollinators as affected by season and cucurbit species

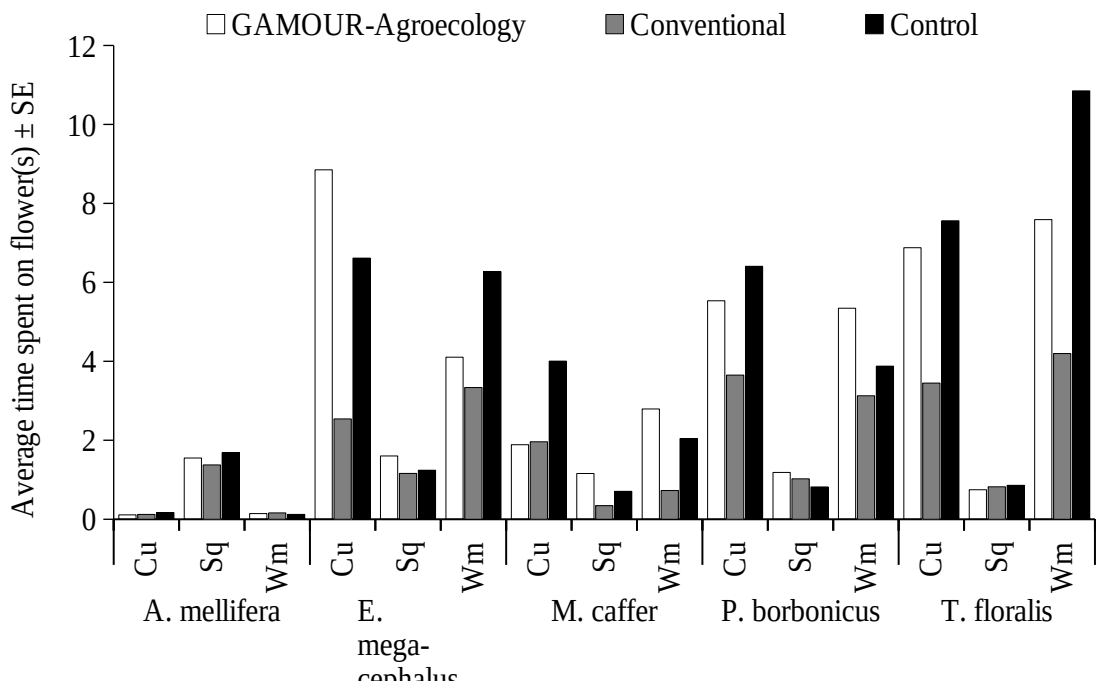


Figure 4.8: Time spent on flowers by pollinators as affected by cucurbit species and management practices. Key: Cu is *C. sativus*, Sq is *C. moschata* and Wm is *C. lanatus*

4.3 Discussion

The present study found that visitation frequency was significantly affected by interactions of the agroecological zone, season, cucurbit species and management practice. Likewise, the interaction of agroecological zone, season, cucurbit species and pollinator species significantly affected visitation frequency. All cucurbit flowers per management practice were frequently visited by pollinators during May – June season in the plateau zone compared to the rest. In the mountainous zone and during October – November, pollinator abundance had low number because, the cucurbit flowering rate was lower compared to the plateau zone (Kumar and Reddy, 2021), this translated to fewer visits. Pollinator abundance and visitation frequency to flowers are influenced by weather conditions (Forcella *et al.*, 2021; Kehrberger and Holzschuh, 2019; Lu and Huang, 2022) and the presence of floral resources (Kolkman *et al.*, 2021; Lucas *et al.*, 2017; Sentil *et al.*, 2022). These findings correlate with the findings in the studies by Doyle *et al.* (2020), Mertens *et al.* (2021) and Pi *et al.* (2021) who reported the presence of a low number of pollinators at a higher elevation and during the dry season. Furthermore, the visitation frequency was higher in cucurbits under GAMOUR-Agroecology practices and control. This is because, the presence of flowering border crops and lack of use of synthetic inputs provided additional floral resources and created favorable conditions for pollinators hence contributing to their visitation frequency (Azpiazu *et al.*, 2020; de Oliveira *et al.*, 2018; Ostandie *et al.*, 2021; Pecenka *et al.*, 2021; Souza *et al.*, 2018).

The study findings also revealed significant effects of the interaction of agroecological zones, season, cucurbit species, cucurbits management practice and pollinator species on visitation rates. The visitation rate of *A. mellifera* was significantly higher in *C. sativus* plots under GAMOUR-Agroecology practices in the mountainous zone during the October - November season compared to the rest. The high visitation rate of *A. mellifera* is attributable to its feeding mechanism involving the engagement of several bee workers to exploit the nutritional resources of the colony (Ghosh *et al.*, 2020). Also, the higher visitation rate of *A. mellifera* in plots under GAMOUR-Agroecology occurred because of the use of low synthetic inputs and additional flower strips at the borders creating a pollinator-friendly habitat thus, stimulating their foraging activities (Chen *et al.*, 2021; Image *et al.*, 2022; Pfiffner *et al.*, 2018). Pesticide application in the fields when coming into contact with insect pollinators reduces their foraging performance including flight time and visitation rate (Boff *et al.*, 2021; Tamburini *et al.*, 2021). Likewise, the pollens/nectars on flowers treated with pesticides have higher neonicotinoids residuals which consequently have negative effects on the central nervous system of pollinators (Chen *et al.*, 2021; Pecenka *et al.*, 2021; Tschoeke *et al.*, 2019).

From this study, we further found that the interaction of agroecological zone, season, cucurbit species and management affected the time spent on cucurbit flowers by honeybees and hoverflies. Pollinators spent more time on cucurbit flowers on the control plots and the plots under GAMOUR-Agroecology in which *A. mellifera* stayed longer on *C. moschata* flowers and hoverflies on *C. lanatus* and *C. sativus* flowers. The shorter time spent by pollinators on cucurbit flowers on the plots where synthetic inputs were applied could be related to the deterrent of pollinators to the residual effect of pesticides. This finding is consistent with findings in other studies which reported that systemic pesticide application to crops translocate throughout the plant tissues and accumulates in plant

nectars and pollens, thus once taken by pollinators it brings negative effects on their foraging behaviour (Heller *et al.*, 2020; Thompson *et al.*, 2022; Uhl and Brühl, 2019; van der Sluijs and Vaage, 2016).

Time spent on a crop by a pollinator species was significantly dependent on season and cucurbit species as well as season and agroecological zone. Furthermore, interactions between cucurbit species and agroecological zone as well as cucurbit species and management practices affected pollinator species' time spent on crops. *Apis mellifera* spent more time on *C. moschata* flowers due to the availability of more nectars compared to in *C. lanatus* and *C. sativus* flowers because honey bees prefer more nectars to pollens (HeLeNa *et al.*, 2016; Knapp and Osborne, 2019). Hoverflies spent more time on *C. lanatus* and *C. sativus* flowers than on squash flowers due to the easy accessibility of pollens (Cook *et al.*, 2020; Dunn *et al.*, 2020).

4.4 Conclusions

In conclusion, we found that cucurbit management practices affected the number of flowers visited by pollinators and the time spent on the individual flowers but had a slight effect on the number of visits per cucurbit flower. GAMOUR - Agroecological practices enhanced the foraging activities of pollinators. Agroecological zones, and seasons also significantly affected the foraging behaviour of pollinators. The higher number of visits per flower and flowers visited was higher in the plateau zone during the May-June season. Therefore, cucurbit growers should consider management practices that might positively influence pollinator foraging activities for sustainable cucurbit production and grow cucurbits in the plateau zone during the season of May-June when pollinators are abundantly available.

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Authors' contributions: All authors designed the experiment; EWR collected the data, performed the analysis and wrote the first draft of the manuscript; MWM and GMT facilitated the data collection, reviewed and amended all versions of the manuscript.

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Conflict interest: The authors declare no conflicts of interest.

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CHAPTER FIVE

5.0 General Discussion

Pollinator abundance varied over the sampling weeks. From the second to the fifth weeks after the cucurbits had reached 10% blooming, there was an increase in the number of visits. This is due to the crops having higher floral density throughout these weeks as opposed to the preceding weeks when the crop had fewer opened flowers and the sixth week when the crops were finishing flowering (Mondal *et al.*, 2020). *Apis mellifera* was the generalist frequent visitor, visiting more cucurbit flowers than hoverflies. This is because honeybees are key pollinators of cucurbits (Dorjay *et al.*, 2017; Quinn *et al.*, 2017) and have an inclination to acquire floral resources for the colony's survival. *P. borbonicus* and *T. floralis*, on the other hand, were frequent visitors of *C. sativus* and *C. lanatus* due to easy accessibility of floral resources (Azo'o Ela *et al.*, 2022; Dunn *et al.*, 2020).

Pollinator abundance, visiting frequency, and rate were all regulated by agroecological zones and seasons. During the season of May - June, the plateau zone had the most visitors. Because habitat variability and environmental factors influence insect pollinator foraging behaviors, distribution, and abundance (Babaei *et al.*, 2018; Conrad *et al.*, 2021; Majeed *et al.*, 2020; Mili *et al.*, 2019; Sengupta *et al.*, 2018). Season and elevation influence the distribution and population of pollinators due to variations in floral resources, whereby other seasons lack appropriate floral resources, limiting species populations, and different flowers visitors have different ecological requirements, according to Tpková *et al.* (2020), Goodwin *et al.* (2021), and Tarakini *et al.* (2021).

Pollinators' foraging activity were also influenced by cucurbit management strategies. The use of minimal synthetic inputs and extra flower strips at the borders in the plots

treated with GAMOUR-Agroecology created a pollinator-friendly environment, increasing their foraging activities (Chen *et al.*, 2021; Image *et al.*, 2022; Pfiffner *et al.*, 2018). Furthermore, when insect pollinators come into touch with pesticides in the field, their foraging performance, including flight time and visitation rate, is reduced (Boff *et al.*, 2021; Tamburini *et al.*, 2021). Pollens/nectars from pesticide-treated flowers contain greater neonicotinoids residuals, which have a deleterious impact on pollinators' central nervous systems (Chen *et al.*, 2021; Heller *et al.*, 2020; Pecenka *et al.*, 2021; Thompson *et al.*, 2022; Tschoeke *et al.*, 2019).

CHAPTER SIX

6.0 General Conclusions and Recommendations

6.1 Conclusions

The study revealed that honeybees were generalist foragers of cucurbits since their visitation frequencies did not differ significantly among the three cucurbit species (cucumber, watermelon and squash). Hoverflies showed foraging preferences among the three cucurbits, *P. bobornicus* and *T. floralis* preferred to forage on cucumber and watermelon flowers compared to squash flowers, therefore, regarded to have pollination potentials in cucumber and watermelon. *Eristalinus megacephalus* and *M. caffer* abundances did not differ significantly among the three cucurbit species studied.

Environmental parameters (temperature, relative humidity, rainfall) significantly affected the foraging behavior of both honeybees and hoverflies. They were abundantly foraging during the morning time when temperature and relative humidity ranged from 25⁰C – 29⁰C and 77% - 93% respectively. Visitation frequencies for both honeybees and hoverflies peaked at 1100 hours. Air temperature and relative humidity had less effects on diurnal visitation patterns of hoverflies since from 1200 hours to 1700 hours, low variation in visitation frequencies were observed as compared to honey bees.

Management practices in cucurbits significantly affected honeybees and hoverflies' foraging activities. Where GAMOUR-agroecology practices were applied enhanced pollinators in terms of visitation frequencies and time spent on flowers while conventional practices discouraged their foraging activities.

6.2 Recommendations

The studied hoverflies were found to have pollination potential in cucurbits, therefore this study suggested proper management practices in cucurbit production which will enhance pollinator abundance and foraging activities. Furthermore, this study recommend more investigation on 1) pollination efficiency of these hoverflies in the preferred cucurbit species, 2) the effects of temporal variations on cucurbit floral rewards 3) effects of environmental variables on hoverflies reproduction 4) the effects of the management practices on cucurbits floral rewards quality and receptive longevity.

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