RESEARCH ARTICLE

Floral visitation of European honey bees and hoverflies in selected cultivated cucurbitaceous crops in Morogoro, Eastern-Central Tanzania

Elvillah William Rweyemamu[1]*, Sija Kabota[1,2], George Muhamba Tryphone[1], Marc De Meyer[3], Maulid Walad Mwatawala[1]

1 Department of Crop Science and Horticulture, Sokoine University of Agriculture (SUA), Morogoro, Tanzania, **2** Research, Consultancy and Publication Unit, National Sugar Institute (NSI), Kidatu-Morogoro, Tanzania, **3** Royal Museum for Central Africa, Invertebrates Section and JEMU, Leuvensesteenweg 13, Tervuren, Belgium

* elvillah.rweyemamu@gmail.com

Check for updates

OPEN ACCESS

Citation: Rweyemamu EW, Kabota S, Tryphone GM, Meyer MD, Mwatawala MW (2025) Floral visitation of European honey bees and hoverflies in selected cultivated cucurbitaceous crops in Morogoro, Eastern-Central Tanzania. PLoS One 20(5): e0322219. https://doi.org/10.1371/journal.pone.0322219

Editor: Muzafar Riyaz, Saint Xavier's College, INDIA

Received: February 7, 2024

Accepted: March 18, 2025

Published: May 12, 2025

Copyright: © 2025 Rweyemamu et al. This is an open access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author and source are credited.

Data availability statement: All data underlying this study are available at Figshare: https://doi.org/10.6084/m9.figshare.28633976.

Funding: The author(s) received no specific funding for this work.

Abstract

Cucurbit production in many parts of the world is constrained by the absence of effective pollinators. Due to the decline of European honey bees (*Apis mellifera*), main pollinators of cucurbits, there is a need to explore other cucurbits flowers visiting insects to supplement pollination services and for their conservation. Studies were carried out in the two agroecological zones of Morogoro Region, Eastern - Central Tanzania. We assessed visitation abundance, visitation frequency and visitation rate of four cucurbits flowers visiting insects under the family Syrphidae [*Eristalinus megacephalus, Mesembrius caffer, Paragus borbonicus* and *Toxomerus floralis*] and *A. mellifera* on cucumber (*Cucumis sativus*), watermelon (*Citrullus lanatus*) and squash (*Cucurbita moschata*). Field trials were conducted in a 5 × 3 × 2 × 2 factorial arrangement in a randomized complete block design for two seasons. Results showed significant effects of the interaction between agroecological zones × cucurbit species × season × flowers visiting insects on visitation abundance, visitation frequency and visitation rate ($p < 0.0001$) of flower visiting species. *Apis mellifera* was the dominant species in cucurbit flowers at both agroecological zones during the two growing seasons. Given its relatively higher visitation, *T. floralis* is a promising hoverfly species to be explored for its role in the pollination of *C. sativus* and *C. lanatus*. Agroecological zone, season and cucurbit species determined the visitation of European honey bees and hoverflies on cucurbits flowers. Cucurbit growers are suggested to employ management practices on farms that favour the abundance and foraging activities of these flower visiting insects for improved and sustainable cucurbit production.

Competing interests: The authors have declared that no competing interests exist.

1. Introduction

Insect pollination of flowering plants is significant in terrestrial environments, as it provides vital ecosystem services for human well-being such as crop production [1,2]. Insect pollinators (managed and wild), particularly species belonging to families Diptera, Hymenoptera, and Lepidoptera play a crucial role in over a third of global food production [2,3]. However, several studies have reported a decline in these pollinators due to abiotic and biotic factors [4–7]. Consequently, the production of insect-pollinated crops including cucurbits has been negatively impacted [8,9].

Cucurbit is a generic term for fruit vegetables that belong to the family Cucurbitaceae. They are among the most important plant families supplying humans with edible products rich in essential vitamins and minerals [10–12]. There is an increased demand for cucurbit products worldwide attributed to the consumers' preferences motivated by health concerns [13–15]. However, the production of cucurbits is affected by several factors including insufficient pollination services [15–17].

Cucurbits are predominantly monoecious crops having male flowers with heavy and sticky pollen grains that cannot be carried easily by wind [8,18,19]. Thus, cucurbits are obligatorily dependent on insect pollinators, and in an open system, they show a significant pollination deficit [20]. Globally, European honey bees (*Apis mellifera* Linnaeus) are known to be the most efficient pollinating agents of cucurbits and are believed to contribute to nearly 80% of the total insect pollination community [21–23]. However, populations of *A. mellifera* are declining because of several factors including farming intensification, application of agrochemical pollutants, urbanization, climate change and socio-cultural perceptions [6,24–31]. Thus, it is unlikely that the demand for pollination services by European honey bees in cucurbits can be sustained, and this may affect the transfer and deposit of pollen. Efforts to enhance the abundance of the European honey bee have so far yielded limited results, and hopes for sustainable pollination have been reduced [15,32]. Therefore, there is a need to investigate alternative flower visiting insects to supplement pollination services to cucurbits.

Cucurbits are visited by diverse insect pollinators whose abundance and distribution depend on various factors such as the efficiency of a visiting insect species [33], intra and inter-specific competition [34], flower density and morphology [35,36], quality of floral resources [37–41], abiotic environment [34], weather [42–48], altitude and landscape [49–55] and habitat heterogeneity [56–59]. Studies conducted in different parts of the world have reported hoverflies (Diptera: Syrphidae) as providers of ecosystem services such as pollination [60–62]. They rank second after bees by visiting 52% of global crop plants and constituting 19% of all insect pollinators [63–65]. Hoverflies exhibit a strong preference for yellow color, pollen and more rewarding flowers [66]. Their bodies are covered with hairs and bristles capable of carrying pollen over long distances since they don't have a confined home range like the European honey bees [63]. Furthermore, most hoverflies are migratory and are capable of escaping non-conducive environments. Therefore, with the decline of the European honey bee populations, the arrivals and departures of hoverflies may play crucial roles in maintaining ecosystem services such as pollination and pest control

[67–69]. However, the role of hoverfly species in cucurbit pollination is not well known. Sawe et al. [15] in northern Tanzania reported dominant pollinators in watermelon that include European honey bees (87.8%) followed by hoverflies (8.5%). A study by Kabota [62] reported hoverflies; [*Eristalinus megacephalus* Rossi, *Mesembrius caffer* (Loew), *Paragus borbonicus* Macquart and *Toxomerus floralis* (Fabricius)] as the most abundant species foraging on cucurbits. However, this study did not determine the preference of hoverflies among cucurbit species.

Therefore, this study aimed at investigating 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: - cucumber (*Cucumis sativus* Linnaeus), watermelon [(*Citrullus lanatus* (Thunb.) Matsum. & Nakai)] and squash (*Cucurbita moschata* Duchesne). These cucurbit species were selected because they are commonly cultivated in the country as cash and food crops. We hypothesized that visitation abundance, visitation frequencies and visitation rate of the European honey bees and hoverflies are influenced by cucurbit species, season and agroecological zones. We expected the visitation abundance and visitation rate of flower visiting species to be lower on cucurbit species with low flower density and during dry season. The results of this study will help in providing understanding to farmers on other useful flower visiting insects for their conservation.

2. Materials and methods

2.1. Description of the study area

The study was conducted in two agroecological zones (i.e., Plateau and Mountainous zones) of Morogoro, Eastern-Central Tanzania located between latitudes 6° 49' 49.3428'' S and longitudes 37° 40' 14.1204'' E [70]. The Plateau zone 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 has elevation ranging 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 [71]. This study was conducted on the plots established under the Agroecological Methodology in Vegetable crops (AGROVEG) project with the permission approved by the project leaders.

2.2. Experimental design

Trials were conducted for two seasons from March to June 2021 (predominantly the rainy season) and September to November 2021 (predominantly the dry season). Four experimental plots of 45 m × 45 m each were established at each agroecological zone. The distance between plots was approximately 1 km. Each plot was divided into three subplots of 15 m × 45 m to accommodate the three cucurbit species. A Randomized Complete Block Design (RCBD) in a 5 × 3 × 2 × 2 factorial arrangement was used with four replications.

2.3. Crop establishment and observation of cucurbits flower visitors

Three cucurbit species were planted on 23rd March 2021 and 2nd September 2021 during the rainy and dry seasons, respectively. Agronomic practices such as weeding and irrigation were similar in all plots. Observations of European honey bees and hoverflies visitation in cucurbits commenced at 30–35 days (when 10% of the crops had flowered) and continued until the end of the blooming period. We established 8 spots, 4 m^2 each at a spacing of 5 m on transects formed on each subplot per cucurbit species. We observed flower visiting insects once a week by walking on the transect at three time slots, from 0800 to 0900 hours, 1200–1300 hours and 1600–1700 hours. The time slots allowed observations of flower visiting insects with different diurnal activity patterns [72]. Each plot was allocated three observers, one on each cucurbit species. The observation was conducted simultaneously in all plots and for both agroecological zones. The sampling procedures were adopted from Zameer et al. [73] with a slight modification on the observation time.

On a 4 m^2 spot, we counted the number of visits paid by each flower visiting species on a flower for one minute. We also counted flowers visited by each flower visiting species, including time (seconds) spent on a flower and time spent in flight between consecutive flowers. We determined the total number of opened flowers, average corolla height and corolla diameter per cucurbit species. We also recorded data on the weather (rainfall, relative humidity and temperature) during each day of sampling. A data logger (iButton, Maxim Integrated Products, Sunnyvale, CA, USA) was used to record relative humidity and temperature, rainfall was recorded using a rain gauge which was installed in one of the locations where experimental plots were established in the Mountainous zone. Weather data for the Plateau zone were obtained from the Tanzania Meteorological Authority (TMA).

Then, the following variables were processed:

Visitation abundance: - Total number of flower visiting insects per plot observed visiting each cucurbit species flowers within three minutes of observation regardless of its previous visits.

Visitation frequency**: -** A total number of visits by each flower visiting species per selected cucurbit flower. It was determined by closely observing a single flower for a maximum of one minute and recording the number of visits per flower visiting species. 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. [73]

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

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

Visitation rate**: -** Total number of flowers of each cucurbit species visited by each flower visiting insects within one minute. To establish visitation rate, an individual flower visiting insect was closely followed for a maximum of one minute from the moment it landed on the first flower. We then recorded for each flower visiting species, all flowers visited within a 4 m^2 spot, time (seconds) spent on each visited flower and time spent in flight between consecutive flowers. Three visual observations were made for each flower visiting species per cucurbit species per day.

Average number of flowers visited per flower visiting species was determined following the formula described by Meerabai [74]:

$$VR = \frac{TNFV}{TSF + TFBCF} \quad \text{(ii)}$$

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.

2.4. Statistical analysis

We computed total number of visits of each flower-visiting species on the flowers of three cucurbits species for the whole study period. Then, we determined the effects of the agroecological zones, seasons and cucurbit species on visitation abundance, visitation frequency and visitation rate of European honey bees and hoverflies on the three cucurbit flowers. Analysis of variance (ANOVA) was performed using Generalized Linear Mixed Models (GLMMs) procedures at a significant level of 5%. GLMMs account for non-normal data that have both fixed and random effects and where data transformation can violate the assumptions of normality [75]. Normality test was performed using Shapiro-Wilk and the data did not conform to a normal distribution. Agroecological zones, seasons and cucurbit species were treated as fixed factors and sampling week as a random factor. Model selection was performed using Akaike's information criterion. 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. All analyses were performed using R software version 4.1.0 [76].

3. Results

3.1. Visitation abundance

A total of 13171 visits of European honey bees and hoverflies were recorded on *C. sativus*, *C. moschata* and *C. lanatus* flowers for the whole study period in the Mountainous and Plateau zones of Morogoro in 8 fields (Table 1). *Apis mellifera* constituted 56.94% and hoverflies 43.06% number of visits of all flower visiting species on the three cucurbit species combined. By crop, 4992, 2776 and 5403 of all number of visits by flowers visiting 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; 3060, 1789 and 1789 followed by *T. floralis* 1186, 527 and 1724 for *C. sativus*, *C. moschata* and *C. lanatus*, respectively. The lowest number of visits on all the three cucurbit species were recorded for *M. caffer* 35, 38 and 58 *C. sativus*, *C. moschata* and *C. lanatus* flowers, respectively. For hoverflies, *T. floralis* was dominant (3437) followed by *P. borbonicus* (1099), *E. megacephalus* (1004) and lastly *M. caffer* (131).

3.2. Cucurbit flowers variables and weather parameters

The cucurbits flower variables under the study indicated in Table 2 shows average flower density found in 4 m^2, 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. 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.

3.3. Temporal variation on the visitation abundance, frequency and rate

The results showed that, during the May – June cropping season, *A. mellifera* was the most abundant visitor of all cucurbit species, while all other species were less prevalent (Fig 1A, B and C). Of all flowers visiting species, *M. caffer* was the

Table 1. Visitation abundance of European honey bees and hoverflies in three cucurbit species.

Pollinators	Number of visits			Total	Proportion number of visits (%)
	C. sativus	*C. moschata*	*C. lanatus*		
A. mellifera	3060	1789	2651	**7500**	**56.94**
E. megacephalus	240	264	500	**1004**	**7.62**
M. caffer	35	38	58	**131**	**0.99**
P. borbonicus	471	158	470	**1099**	**8.34**
T. floralis	1186	527	1724	**3437**	**26.10**
Total	**4992**	**2776**	**5403**	**13171**	**100**
Proportion number of visits (%)	**37.90**	**21.08**	**41.02**	**100**	

https://doi.org/10.1371/journal.pone.0322219.t001

Table 2. Flowers variables of the three cucurbits under the study.

Flowers variables	Cucurbit species		
	C. lanatus	*C. sativus*	*C. moschata*
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

https://doi.org/10.1371/journal.pone.0322219.t002

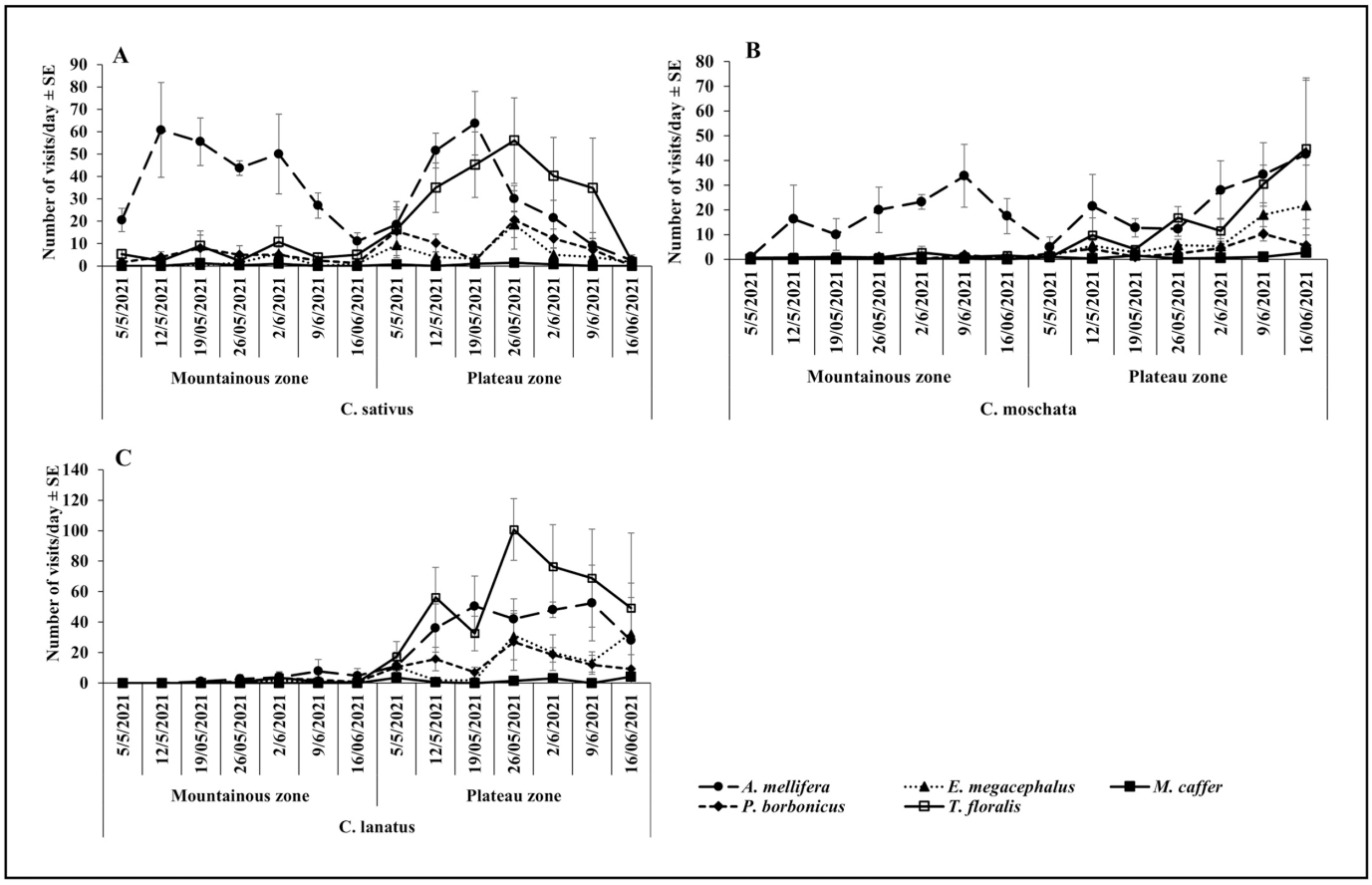


Fig 1. Temporal variation on the visitation abundance in the Mountainous and Plateau zone during the May-June.

https://doi.org/10.1371/journal.pone.0322219.g001

least abundant visitor on all cucurbit species. There was a notable variation in the Plateau zone, where the visitation of *T. floralis* on *C. lanatus* increased considerably (100.75 ± 20.25) to exceed that of *A. mellifera* (Fig 1C). The trends recorded during the October-November season, showed dominance of *A. mellifera* in both zones and all cucurbit species. Visitation abundance of all other flowers visiting species remained very low (Fig 2A, B and C). Generally, abundance of prevalent species increased from the beginning and dropped towards the end cropping season (Figs 1A, B, C and 2A, B, C).

The visitation frequency of *A. mellifera* was generally higher than other flowers visiting species in both agroecological zones, all cucurbit species and during both seasons (Figs 3A, B, C and 5A, B, C). Visitation frequencies were relatively stable over time without any strong pattern during all cropping seasons and on all cucurbit species. Except for *A mellifera*, visitation frequencies of most species were very low and without any strong pattern during both seasons in the Mountainous zone. Frequency by *A. mellifera* increased from the beginning of the season, and dropped towards the end of the season in both agroecological zones, seasons and on all cucurbit species flowers (Figs 3A, B, C and 4A, B, C).

During the May-June season, *A. mellifera* visited the highest number of *C. sativus* flowers in both the plateau and mountainous zones (Fig 5A) and all cucurbit species during the October-November season (Fig 6A, B and C). The visitation rates of *E. megacephalus* and *P. borbonicus* on all cucurbits flowers were higher in the plateau zone during the May-June season (Fig 5A, B and C). The lowest number of flowers visited were recorded for *M. caffer* and the visitation

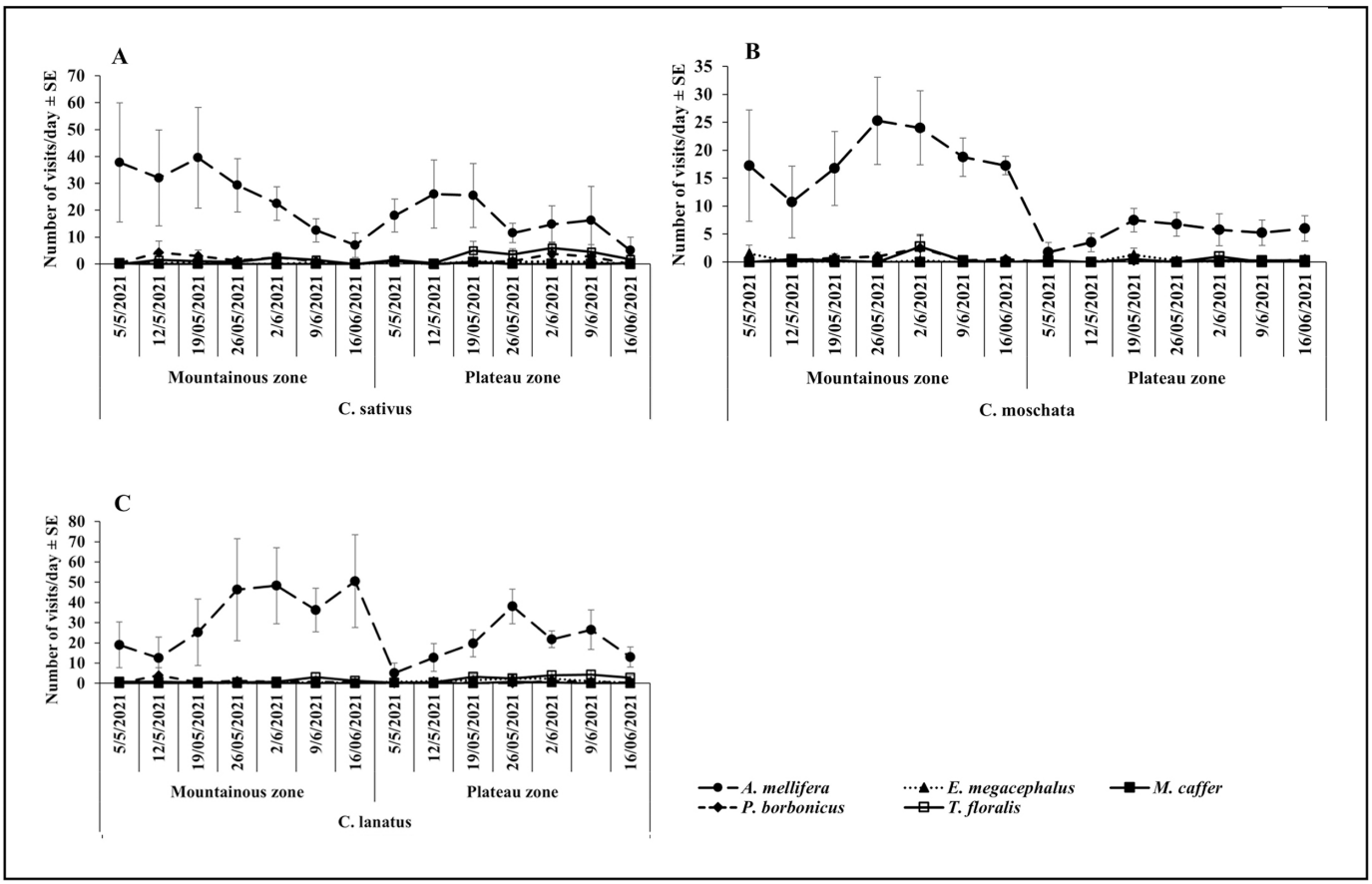


Fig 2. Temporal variation on the visitation abundance in the Mountainous and Plateau zone during the October-November.

https://doi.org/10.1371/journal.pone.0322219.g002

patterns were fairly stable in both agroecological zones and seasons. In most cases, *A. mellifera* showed the highest visitation rate on cucurbits flowers with a noticeable pattern along the sampling weeks while other flowers visiting species' visitation rates were extremely low, with no discernible pattern.

3.4. Effects of agroecological zone, season, cucurbit species and flowers visiting species on visitation abundance, frequency and rate

There was a significant effect of agroecological zone × season × cucurbit species × flowers visiting species interaction on visitation abundance of European honey bees and hoverflies on cucurbit flowers ($p < 0.0001$). Also, all other factors and interactions were significant, except the season × cucurbit species interaction (Table 3). *Apis mellifera* recorded higher visitation on *C. sativus* during May – June season in the Plateau zone (Fig 7B) (*Post hoc* test, Tukey HSD). The lowest visitation abundance on all cucurbit species during both season and agroecological zones was recorded for *M. caffer* (Fig 7A, B, C and D).

Results showed significant effects of agroecological zone × season × cucurbit species × flowers visiting species interaction on visitation frequency of European honey bees and hoverflies on cucurbit flowers ($p < 0.0001$). The effects of all factors and interactions were also significant, except the season × cucurbit species interaction (Table 4). Further results (Fig 8A, B, C and D) showed significantly higher visitation frequency by *A. mellifera* on all cucurbit species than

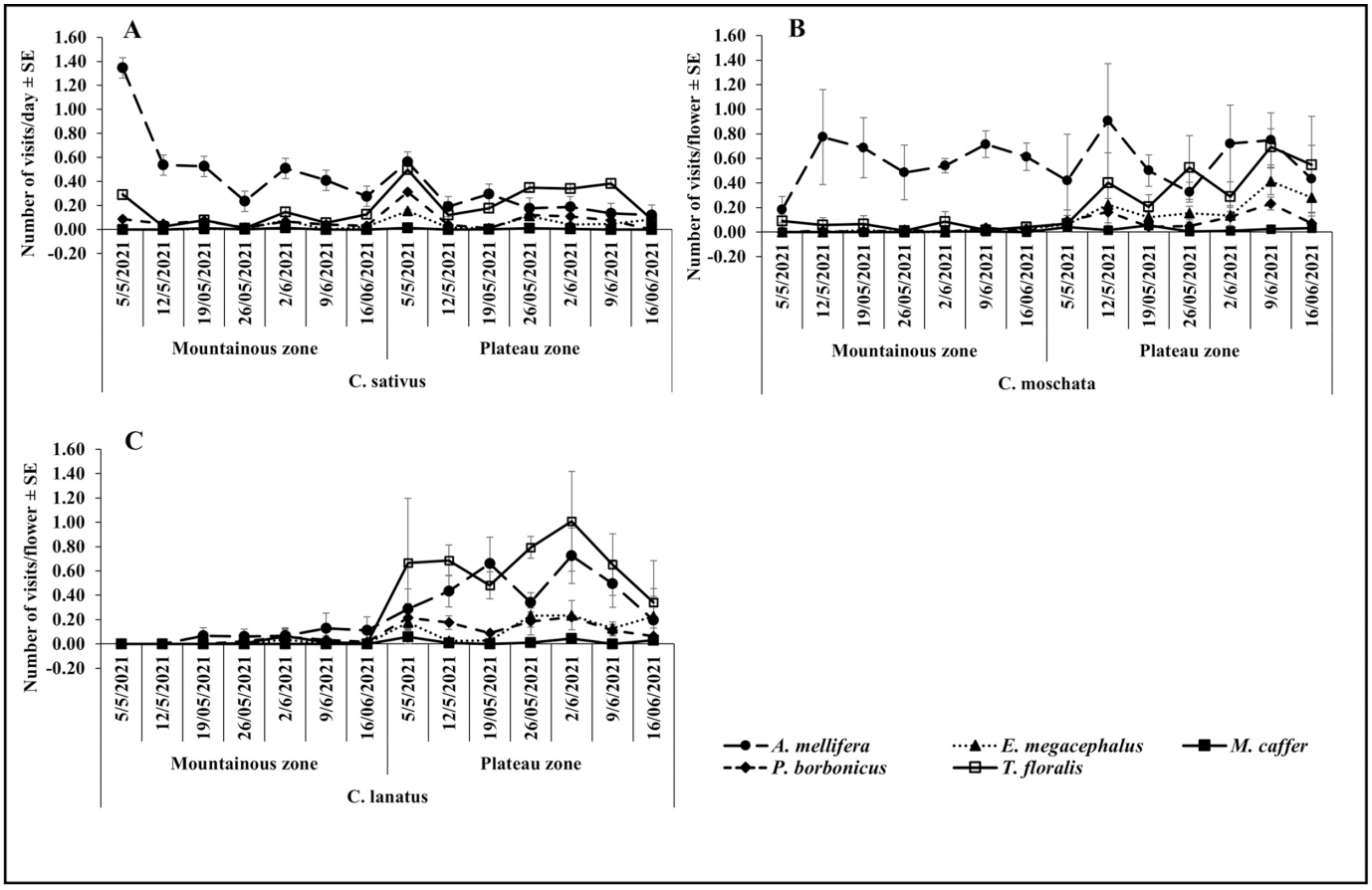


Fig 3. Temporal variation on the visitation frequency in the Plateau and Mountainous zones during the season of May-June.

https://doi.org/10.1371/journal.pone.0322219.g003

other flowers visiting species in both the agroecological zones and during both seasons (*Post hoc* test, Tukey HSD). A 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 8B). The frequencies of visits by all species were significantly higher in the Plateau zone than in the Mountainous zone during the May – June cropping season (Fig 6B). *Mesembrius caffer* showed the lowest visitation frequency on all cucurbit species, in both the agroecological zones and during both seasons (Fig 8A, B, C and D).

Our results also showed that all the factors and all the interactions had significant effects on the number of cucurbit flowers visited by flowers visiting species except cucurbit species ($p = 0.080$; Table 5). We therefore further examined the significant effects of agroecological zone × cucurbit species × flowers visiting species during the two seasons. Visitation rates were generally higher in the Plateau than the Mountainous zone during the May – June cropping season (Fig 9A and B) (*Post hoc* test, Tukey HSD). *Apis mellifera* had significantly higher visitation rates than the rest except *T. floralis* on *C. lanatus* in the Plateau zone (Fig 9A, B, C and D). Further results showed that *A. mellifera* was the most dominant species during the October – November cropping season, with a significantly higher number of *C. lanatus* and *C. sativus* flowers visited than *C. moschata* (Fig 9C and D).

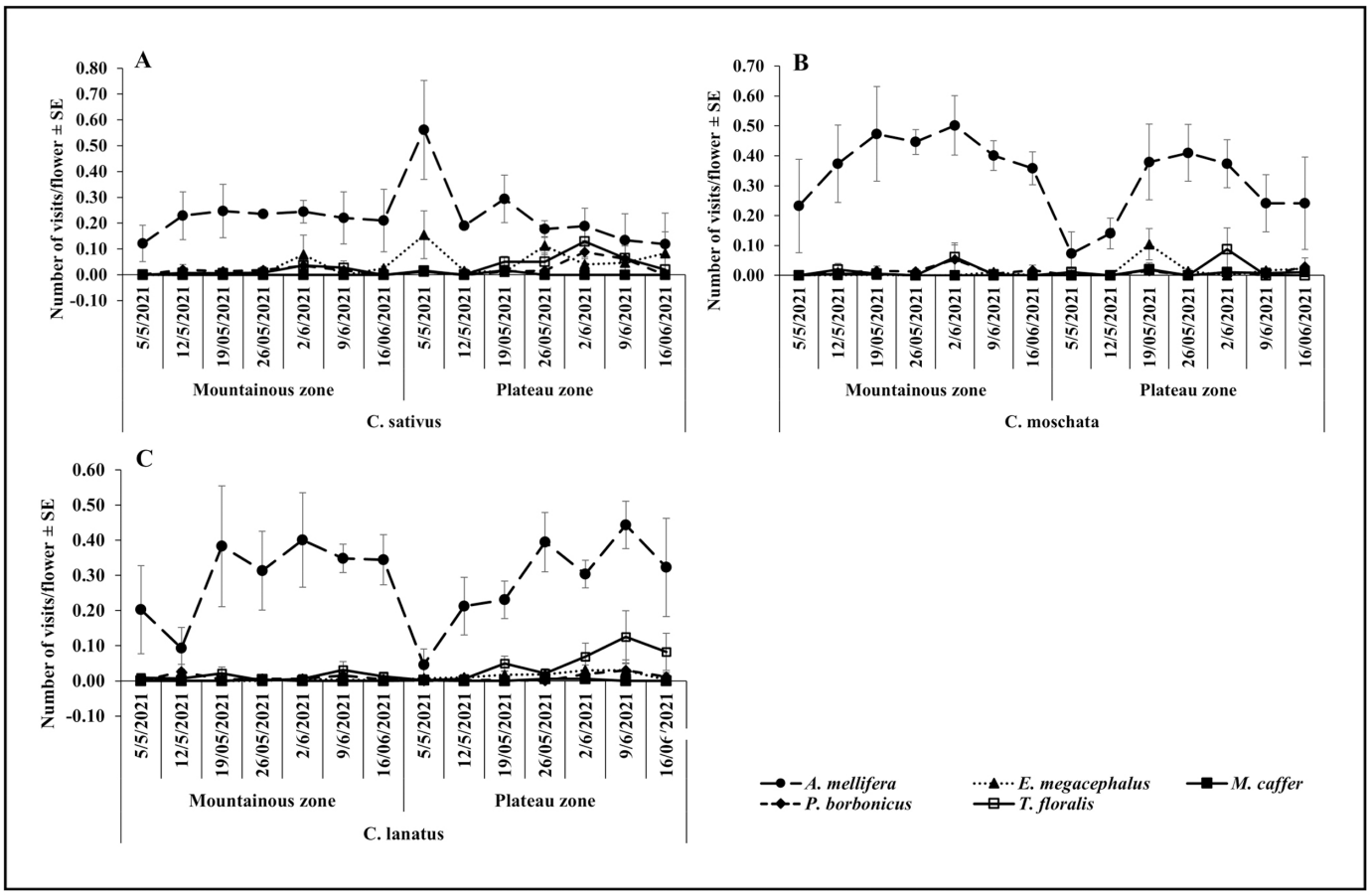


Fig 4. Temporal variation on the visitation frequency in the Plateau and Mountainous zones during the season of October-November.

https://doi.org/10.1371/journal.pone.0322219.g004

4. Discussion

Our results revealed the overall dominance of European honey bees over hoverflies on visitation abundance. The general number of visits of European honey bees was higher than hoverflies on all three cucurbit species. *Mesembrius caffer* recorded the lowest visitation abundance on all cucurbits species. We attributed this dominance to the population structure of *A. mellifera*. Honey bees maintain high populations relative to other species in many flower-visiting insect communities [77]. According to Wignall et al. [78], European honey bees can even create artificially high densities and exert competitive pressure on floral resources to other flower-visiting insects. In some cases, they forage over extensive ranges [79] and deplete floral resources [80]. These explain why European honey bees were more abundant visitors than hoverflies.

Temporal visitation abundance, visitation frequency and visitation rate of European honey bees 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 of *A. mellifera* increased at the beginning and dropped at end of the season. This is because, most of cucurbits start flowering at 30–45 days after planting. As the plants grow, the number of flowers also increases and the abundance of flower visiting insects increases. This situation last for 8–10 weeks when fruits start to set [11]. The results of this study are in consistent with the findings of some of the research which reported that higher visitation abundance of flower

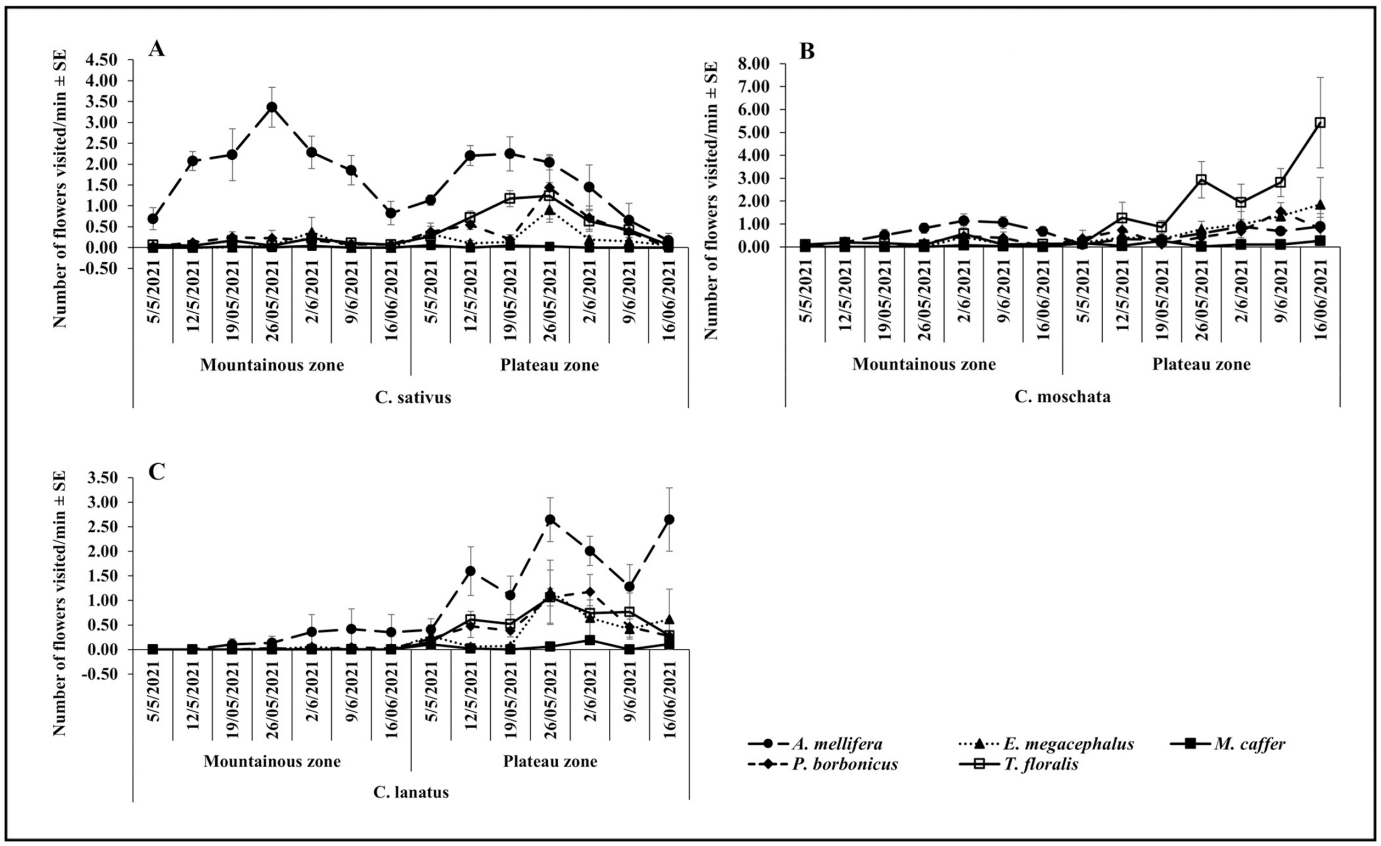


Fig 5. Temporal variation on the visitation rate in the Plateau and Mountainous zones during May-June season.

https://doi.org/10.1371/journal.pone.0322219.g005

visiting species is influenced by the presence of high flower density at the foraging site [73,81] and the foraging distance is reduced when there is high floral resources [82].

We found significant effects of interactions of agroecological zone, season, cucurbit species and flower visiting species on visitation abundance, visitation frequency and visitation rate of European honey bees and hoverflies. Our study allows the examination of three different but related concepts of visitation. Our discussion is therefore based on attributes of a visited flower versus a flower visiting species as affected by season and agroecological zone. *A. mellifera* was significantly dominant and frequent flowers visitor than other species in most cases. Previous studies reported that European honey bees are good foragers and primary pollinators of cucurbits [83–85]. An efficient pollinator must visit several flowers of the same species in succession and move frequently from one flower to another. Hoverflies do not consistently work the same on flowers as bees [33]. European honey bees have higher requirements for pollen and nectars because they live in colonies with large populations. Workers carry food for the entire brood, drones and queen. In contrast, flies require food for individual uses. Also, honey bees remain close to their colonies while flies are not limited in their foraging range [78].

Flowers of *C. lanatus* hosted more visitors than other cucurbits. A notable difference was low visitation rate of *A. mellifera* in *C. moschata* and the high visitation rate of *T. floralis* in *C. lanatus*. Flower morphology, density, and size determine

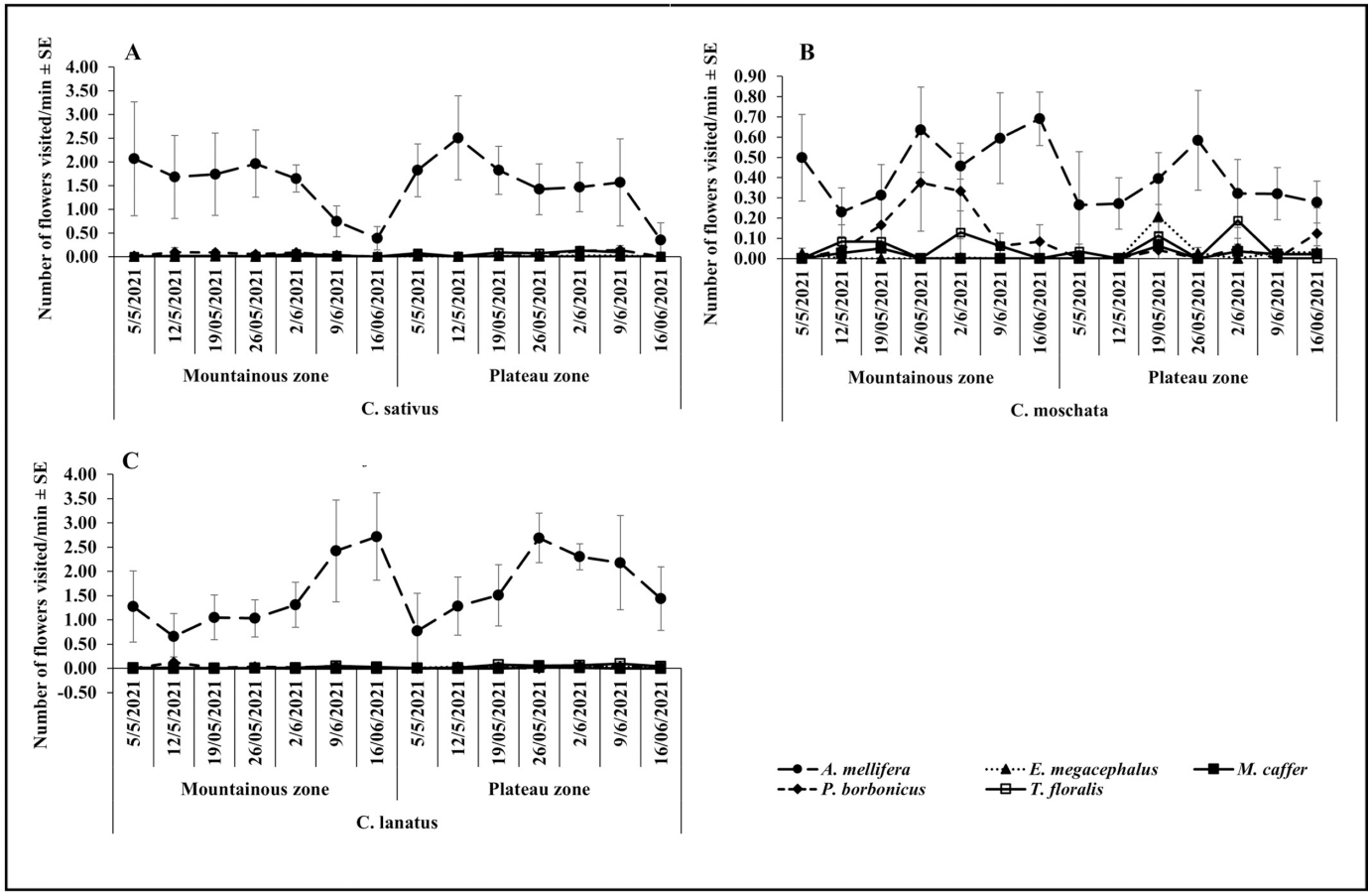


Fig 6. Temporal variation on the visitation rate in the Plateau and Mountainous zones during October-November season.

https://doi.org/10.1371/journal.pone.0322219.g006

the choice of flower visiting insects. Most of cucurbits have cup- or bell-shaped flowers with different corolla size and height [86]. Compared to flower density among three cucurbit species, *C. lanatus* had a higher flower density followed by *C. sativus* and lastly *C. moschata*. Previous studies reported the presence of high flower density increases visitation of flowers visiting species on a crop since it reduces competition between and within flowers visiting species and provides hoverflies (larvae and adults) a good habitat for breeding sites [38,87–90]. European honey bees have relatively long proboscis compared to non-specialists flies. The latter prefer to forage on open bowl flowers with short corollas for easy accessibility of floral rewards [55,91] and for laying eggs since emerging larvae are believed to feed on pollen [53]. Klecka et al. [92] 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. However, there were few variations. For example, the lower visitation rate of *A. mellifera* on *C. moschata* flowers can be explained by the study of Jachuła et al. [93] who reported that flowers with long corolla produce more nectars which makes European honey bees spend longer time foraging on a single flower.

We further examine the agroecological zone × season effects, as it qualifies the flower visiting species and cucurbit species effects. Our studies were conducted in two agroecological zones differentiated by altitude. The Mountainous (high altitude) zone

Table 3. Effects of agroecological zones, seasons and cucurbit species on visitation abundance of European honey bees and hoverflies on cucurbit flowers.

Factors	Statistics		
	df	F value	P value
Agroecological zone (Az)	1	51.19216	< 0.0001 ***
Season (Se)	1	86.7283	< 0.0001 ***
Cucurbit species (Cr)	2	17.0849	< 0.0001 ***
Flowers visiting species (Pol)	4	135.7771	< 0.0001 ***
Az × Se	1	108.5727	< 0.0001 ***
Az × Cr	2	17.25811	< 0.0001 ***
Az × Pol	4	20.33909	< 0.0001 ***
Se × Cr	2	1.658678	0.191 ns
Se × Pol	4	16.08716	< 0.0001 ***
Cr × Pol	8	4.429034	< 0.0001 ***
Az × Se × Cr	2	19.33815	< 0.0001 ***
Az × Se × Pol	4	15.24765	< 0.0001 ***
Az × Cr × Pol	8	3.404252	0.001 **
Se × Cr × Pol	8	5.633144	< 0.0001 ***
Az × Se × Cr × Pol	8	4.475659	< 0.0001 ***

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

https://doi.org/10.1371/journal.pone.0322219.t003

and the Plateau (a low altitude) zone. European honey bees had higher visitation on all cucurbits in both agroecological zones and during all seasons. Habitat heterogeneity and environmental variables affect the distribution and abundance of insect pollinators [57–59,87]. According to Štípková et al. [94], Goodwin et al. [95] and Tarakini et al. [96], season and elevation influence the distribution and population of pollinators. Bees prefer to forage on the lower (warmer) altitudes while flies prefer the higher (colder) altitudes, especially in temperate and subtropical regions [97]. Previous studies showed hoverfly species abundance is highest during colder months [97–99], while European honey bees increase their activity during warmer periods of the year [100]. Thus, hoverflies are especially abundant during the colder time of the year when other native floral visitors are less active [97]. Our results showed dominance over seasons and agroecological zones. The reason could be altitudinal variation (500 m.a.s.l.) and seasonal weather changes were within the ranges of favorable conditions for the European honey bees.

5. Conclusions

In conclusion, our findings revealed that *A. Mellifera* was the most abundant and frequent visitors in all cases than hoverflies. However, higher visitation of honey bee may not necessarily have a high impact on pollination since they carry more pollen to feed the brood, queen and drones, whereas hoverflies can be effective pollinators since they only require floral resources for individual energy. This study further confirms results by Sawe et al. [15] that honey bees are dominant pollinators of in watermelon in northern Tanzania, followed by hoverflies. We further confirm results by Kabota [62] that among hoverflies, *E. megacephalus*, *M. caffer*, *P. borbonicus* and *T. floralis* as the most abundant species foraging on cucurbits. Hoverflies can play a complimentary pollination role to bees. However, further studies are needed to confirm the role in pollination and check the pollination efficiency of these flowers visiting species on cucurbits. Conservation of alternative (potential) pollinators is necessary because European honey bees remain important pollinators but their impact is under threat because of their declining populations as reported by other studies.

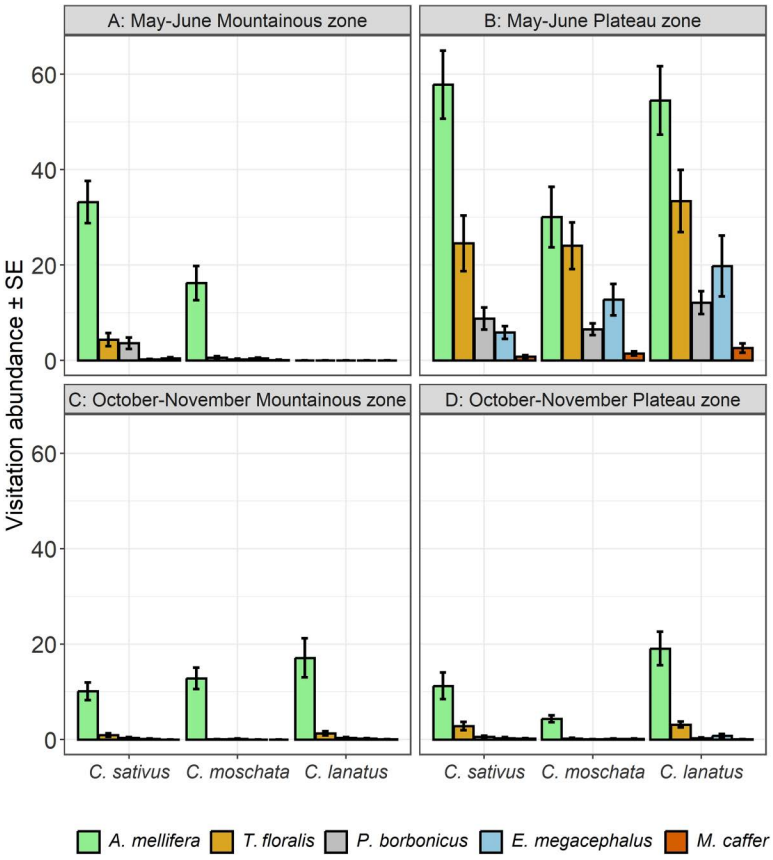


Fig 7. Visitation abundance on cucurbit flowers as affected by season, agroecological zones and cucurbit species.

https://doi.org/10.1371/journal.pone.0322219.g007

Table 4. Effects of agroecological zones, seasons and cucurbit species on visitation frequency European honey bees and hoverflies on cucurbit flowers.

Factors	Statistics		
	df	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 **
Flowers visiting 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 ***

(Continued)

Table 4. (Continued)

Factors	Statistics		
	df	F value	P value
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’.

https://doi.org/10.1371/journal.pone.0322219.t004

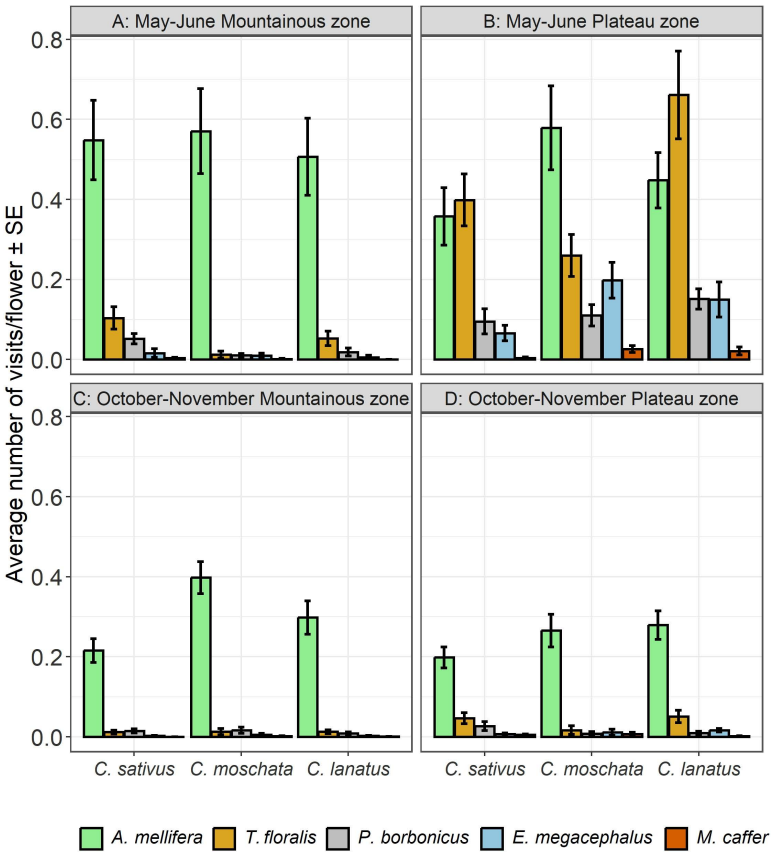


Fig 8. Visitation frequency on cucurbit flowers as affected by season, agroecological zones and cucurbit species.

https://doi.org/10.1371/journal.pone.0322219.g008

Table 5. Effects of agroecological zones, seasons and cucurbit species on visitation rate European honey bees and hoverflies on cucurbit flowers.

Factors	Statistics		
	df	F value	P value
Agroecological zone (Az)	1	57.415	< 0.0001 ***
Season (Se)	1	42.177	< 0.0001 ***
Cucurbit species (Cr)	2	2.523	0.080 ns
Flowers visiting 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'

https://doi.org/10.1371/journal.pone.0322219.t005

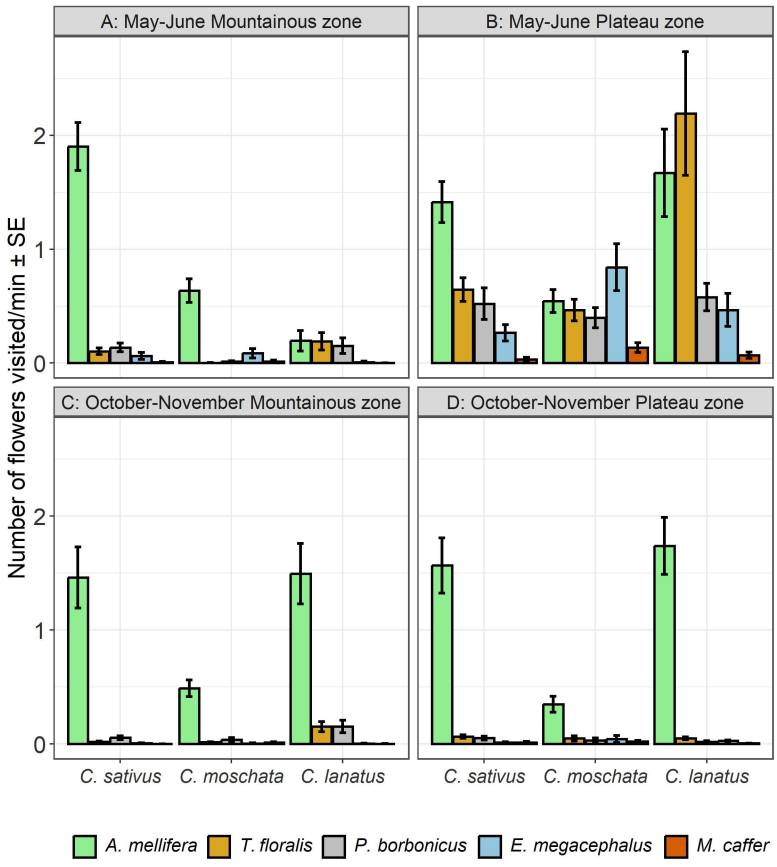


Fig 9. Visitation rate on cucurbit flowers as affected by season, agroecological zones and cucurbit species.

https://doi.org/10.1371/journal.pone.0322219.g009

Acknowledgments

The authors are thankful to Agroecological Methodology in Vegetable crops (AGROVEG) project team for logistics support and permission to conduct this study on the plots established under the project.

Author contributions

Conceptualization: Elvillah William Rweyemamu, George Muhamba Tryphone, Marc De Meyer, Maulid Walad Mwatawala.

Data curation: Elvillah William Rweyemamu.

Formal analysis: Elvillah William Rweyemamu, Sija Kabota, Marc De Meyer, Maulid Walad Mwatawala.

Funding acquisition: Marc De Meyer, Maulid Walad Mwatawala.

Investigation: Elvillah William Rweyemamu.

Methodology: Elvillah William Rweyemamu, Sija Kabota, George Muhamba Tryphone, Marc De Meyer, Maulid Walad Mwatawala.

Software: Elvillah William Rweyemamu, Sija Kabota.

Supervision: Marc De Meyer, Maulid Walad Mwatawala.

Validation: Elvillah William Rweyemamu, George Muhamba Tryphone, Maulid Walad Mwatawala.

Visualization: Elvillah William Rweyemamu, George Muhamba Tryphone, Marc De Meyer, Maulid Walad Mwatawala.

Writing – original draft: Elvillah William Rweyemamu.

Writing – review & editing: Elvillah William Rweyemamu, Sija Kabota, George Muhamba Tryphone, Marc De Meyer, Maulid Walad Mwatawala.

References

1. Scudder GGE. The importance of insects. In: Foottit RG, Adler PH. (Editors). Insect Biodiversity: Science and Society. Second. 2017:9–43.
2. DeMaynadier P, Schlesinger MD, Hardy SP, McFarland KP, Saucier L, White EL, et al. Insect pollinators: The time is now for identifying species of greatest conservation need. Wildl Soc Bull. 2024;48(3):e1537.
3. Rader R, Cunningham SA, Howlett BG, Inouye DW. Non-Bee Insects as Visitors and Pollinators of Crops: Biology, Ecology, and Management. Annu Rev Entomol. 2020;65:391–407. https://doi.org/10.1146/annurev-ento-011019-025055 PMID: 31610136
4. Dicks LV, Breeze TD, Ngo HT, Senapathi D, An J, Aizen MA, et al. A global-scale expert assessment of drivers and risks associated with pollinator decline. Nat Ecol Evol. 2021;5(10):1453–61. https://doi.org/10.1038/s41559-021-01534-9 PMID: 34400826
5. Haq IU, Ali S, Ali A, Ali H. Effect of Climate Change on Insect Pollinator. In: Climate Change and Insect Biodiversity. 1st ed. CRC Press; 2024:179–95.
6. Potts SG, Biesmeijer JC, Kremen C, Neumann P, Schweiger O, Kunin WE. Global pollinator declines: trends, impacts and drivers. Trends Ecol Evol. 2010 Jun 1;25(6):345–53.
7. Vanbergen AJ, Garratt MP, Vanbergen AJ, Baude M, Biesmeijer JC, Britton NF, et al. Threats to an ecosystem service: pressures on pollinators. Front Ecol Environ [Internet]. 2013 Jun 1 [cited 2022 Sep 27];11(5):251–9. Available from: https://onlinelibrary.wiley.com/doi/full/10.1890/120126
8. Knapp JL, Osborne JL. Cucurbits as a model system for crop pollination management. J Pollinat Ecol [Internet]. 2019 Nov 13 [cited 2022 Sep 27];25(9):89–102. Available from: https://pollinationecology.org/index.php/jpe/article/view/535
9. Aizen MA, Aguiar S, Biesmeijer JC, Garibaldi LA, Inouye DW, Jung C, et al. Global agricultural productivity is threatened by increasing pollinator dependence without a parallel increase in crop diversification. Glob Chang Biol. 2019;25(10):3516–27. https://doi.org/10.1111/gcb.14736 PMID: 31293015
10. McCreight JD. Cultivation and uses of cucurbits. In: Grumet R, Katzir N, Garcia-Mas J, (Editors). Genetics and Genomics of Cucurbitaceae Plant Genetics and Genomics: Crops and Models. Cham: Springer; 2016;20:1–12. [cited 2022 Sep 3]. Available from: https://link.springer.com/chapter/10.1007/7397_2016_2
11. Mondal B, Mondal CK, Mondal P. An Introduction to Cucurbits. In: Stresses of Cucurbits: Current Status and Management. Singapore: Springer; 2020:1–46.

12. Rolnik A, Olas B. Vegetables from the Cucurbitaceae family and their products: Positive effect on human health. Nutrition. 2020 Oct 1;78:110788.
13. Nordey T, Basset-Mens C, De Bon H, Martin T, Déletré E, Simon S, et al. Protected cultivation of vegetable crops in sub-Saharan Africa: limits and prospects for smallholders. A review. Agron Sustain Dev. 2017;37(6). https://doi.org/10.1007/s13593-017-0460-8
14. Parajuli R, Thoma G, Matlock MD. Environmental sustainability of fruit and vegetable production supply chains in the face of climate change: A review. Sci Total Environ. 2019 Feb 10;650:2863–79.
15. Sawe T, Nielsen A, Eldegard K. Crop Pollination in Small-Scale Agriculture in Tanzania: Household Dependence, Awareness and Conservation. Sustainability [Internet]. 2020 Mar 12 [cited 2022 Sep 1];12(6):2228. Available from: https://www.mdpi.com/2071-1050/12/6/2228/
16. Christmann S, Aw-Hassan A, Rajabov T, Khamraev AS, Tsivelikas A. Farming with alternative pollinators increases yields and incomes of cucumber and sour cherry. Agron Sustain Dev. 2017;37(4). https://doi.org/10.1007/s13593-017-0433-y
17. Anandhabhairavi N, Ambethgar V, Philip SR. Foraging behavior of *Apis cerana indica* Fab.(Apidae Hymenoptera) on Cucumber. J Entomol Zool Stud. 2020 [cited 2022 Sep 1];8(6):189–92. Available from: https://www.academia.edu/download/64906816/Foraging_behavior_of_Indian_bee_on_cucumber.pdf
18. Dorjay N, Abrol DP, Shankar U. Insect visitors on cucumber and bittergourd flowers and impact on quantity of crop production by different pollination treatment. J Apic. 2017;32(2):77–88.
19. Atibita E, Djieto-Lordon C, Fohouo FNT. Insects associated with cucumbers (*Cucumis Sativus* L.) At Bamunka-Ndop (North West Region, Cameroon). J Adv Agric [Internet]. 2020 [cited 2022 Sep 1];11:145–59. Available from: https://core.ac.uk/download/pdf/335264261.pdf
20. Layek U, Baghira NK, Das A, Kundu A, Karmakar P. Dependency of crops on pollinators and pollination deficits: An approach to measurement considering the influence of various reproductive traits. Agriculture. 2023;13(8):1563. https://doi.org/10.3390/agriculture13081563
21. Dorjay N, Abrol DP. Insect pollination in cucurbit crops. J Palynol [Internet]. 2022 [cited 2022 Oct 15];58:63–77. Available from: https://www.researchgate.net/publication/363210983
22. Harisha E, Shanas S. Relative abundance and foraging activity of hymenopteran pollinators in cucurbitaceous vegetables. Entomon. 2020;44(4):259–68. https://doi.org/10.33307/entomon.v44i4.477
23. More KS, Maree JP, Mahlangu M. Cost-effective leachate treatment and resource recovery in hazardous waste landfills through pipe freeze crystallization. Environ Process. 2025;12(2):15. https://doi.org/10.1007/s40710-025-00757-3 PMID: 40166775
24. Burns KLW, Fitzpatrick Ú, Stanley DA. Public perceptions of Ireland's pollinators: A case for more inclusive pollinator conservation initiatives. J Nat Conserv. 2021 Jun 1;61:125999.
25. Chen K, Fijen TPM, Kleijn D, Scheper J. Insect pollination and soil organic matter improve raspberry production independently of the effects of fertilizers. Agric Ecosyst Environ. 2021 Apr 1;309:107270.
26. Grubisic M, van Grunsven RHA, Kyba CCM, Manfrin A, Hölker F. Insect declines and agroecosystems: does light pollution matter?. Annals of Applied Biology. 2018;173(2):180–9. https://doi.org/10.1111/aab.12440
27. Pecenka JR, Ingwell LL, Foster RE, Krupke CH, Kaplan I. IPM reduces insecticide applications by 95% while maintaining or enhancing crop yields through wild pollinator conservation. Proc Natl Acad Sci U S A. 2021;118(44):e2108429118. https://doi.org/10.1073/pnas.2108429118 PMID: 34697238
28. Singh AP, Chandra A, De K, Uniyal VP, Sathyakumar S. Decreasing potential suitable habitat of bumble bees in the Great Himalayan National Park Conservation area. Oriental Insects. 2022;57(1):36–53. https://doi.org/10.1080/00305316.2022.2040631
29. Tschoeke PH, Oliveira EE, Dalcin MS, Silveira-Tschoeke MCAC, Sarmento RA, Santos GR. Botanical and synthetic pesticides alter the flower visitation rates of pollinator bees in Neotropical melon fields. Environ Pollut. 2019 Aug 1;251:591–9.
30. Vanbergen AJ, the Insect Pollinators Initiative. Threats to an ecosystem service: pressures on pollinators. Frontiers in Ecol & Environ. 2013;11(5):251–9. https://doi.org/10.1890/120126
31. Zattara EE, Aizen MA. Worldwide occurrence records suggest a global decline in bee species richness. One Earth. 2021;4(1):114–23. https://doi.org/10.1016/j.oneear.2020.12.005
32. Mpondo FT, Ndakidemi PA, Treydte AC. Balancing bees and livestock: Pastoralist knowledge, perceptions and implications for pollinator conservation in Rangelands, Northern Tanzania. Tropical Conservation Science. 2021;14. https://doi.org/10.1177/19400829211028127
33. Osborne JL, Free JB. Flowering and Reproduction | Pollination. Encycl Appl Plant Sci. 2003;315–25.
34. Inouye DW, Larson BMH, Ssymank A, Kevan PG. Flies and Flowers III: Ecology of foraging and pollination. J Pollinat Ecol. 2015;16(16):115–33.
35. Junker RR, Blüthgen N, Brehm T, Binkenstein J, Paulus J, Schaefer HM, et al. Specialization on traits as basis for the niche-breadth of flower visitors and as structuring mechanism of ecological networks. Funct Ecol. 2013;27(2):329–41.
36. Xiang G-J, Lázaro A, Dai X-K, Xia J, Yang C-F. Pollinator Proboscis Length Plays a Key Role in Floral Integration of Honeysuckle Flowers (Lonicera spp.). Plants (Basel). 2023;12(8):1629. https://doi.org/10.3390/plants12081629 PMID: 37111853
37. Kolkman A, Dopagne C, Piqueray J. Sown wildflower strips offer promising long term results for butterfly conservation. J Insect Conserv. 2021;26(3):387–400. https://doi.org/10.1007/s10841-021-00347-2
38. Lucas A, Bull JC, de Vere N, Neyland PJ, Forman DW. Flower resource and land management drives hoverfly communities and bee abundance in seminatural and agricultural grasslands. Ecol Evol. 2017;7(19):8073–86. https://doi.org/10.1002/ece3.3303 PMID: 29043057

39. Revanasidda BVV. Floral biology and pollination in *Cucumis melo* L., a tropical andromonoecious cucurbit. J Asia Pac Entomol. 2019 Mar 1;22(1):215–25.
40. Sentil A, Lhomme P, Michez D, Reverté S, Rasmont P, Christmann S. "Farming with Alternative Pollinators" approach increases pollinator abundance and diversity in faba bean fields. J Insect Conserv. 2021;26(3):401–14. https://doi.org/10.1007/s10841-021-00351-6
41. Vaudo AD, Erickson E, Patch HM, Grozinger CM, Mu J. Impacts of soil nutrition on floral traits, pollinator attraction, and fitness in cucumbers (Cucumis sativus L.). Sci Rep. 2022;12(1):21802. https://doi.org/10.1038/s41598-022-26164-4 PMID: 36526706
42. Clarke D, Robert D. Predictive modelling of honey bee foraging activity using local weather conditions. Apidologie. 2018;49(3):386–96. https://doi.org/10.1007/s13592-018-0565-3
43. Forcella F, Patel S, Lenssen AW, Hoerning C, Wells MS, Gesch RW, et al. Weather and landscape influences on pollinator visitation of flowering winter oilseeds (field pennycress and winter camelina). J Applied Entomology. 2020;145(4):286–94. https://doi.org/10.1111/jen.12854
44. Kehrberger S, Holzschuh A. How does timing of flowering affect competition for pollinators, flower visitation and seed set in an early spring grassland plant? Sci Rep [Internet]. 2019 Oct 30 [cited 2022 Sep 17];9(1):1–9. Available from: https://www.nature.com/articles/s41598-019-51916-0
45. Lawson DA, Rands SA. The effects of rainfall on plant–pollinator interactions. Arthropod-Plant Interactions. 2019;13(4):561–9. https://doi.org/10.1007/s11829-019-09686-z
46. Lu M-L, Huang J-Y. Predicting negative effects of climate change on Taiwan's endemic Bumblebee Bombus formosellus. J Insect Conserv. 2022;27(1):193–203. https://doi.org/10.1007/s10841-022-00415-1
47. Plos C, Stelbrink N, Römermann C, Knight TM, Hensen I. Abiotic conditions affect nectar properties and flower visitation in four herbaceous plant species. Flora. 2023;303:152279. https://doi.org/10.1016/j.flora.2023.152279
48. Wu Y, Duan X, Tong Z, Li Q. Pollinator-mediated selection on floral traits of Primula tibetica differs between sites with different soil water contents and among different levels of nutrient availability. Front Plant Sci. 2022;13:807689. https://doi.org/10.3389/fpls.2022.807689 PMID: 35300008
49. Toivonen M, Karimaa A-E, Herzon I, Kuussaari M. Flies are important pollinators of mass-flowering caraway and respond to landscape and floral factors differently from honeybees. Agriculture, Ecosystems & Environment. 2022;323:107698. https://doi.org/10.1016/j.agee.2021.107698
50. Rweyemamu EW, Mwatawala MW, Tryphone GM, De Meyer M, Kabota S, Bwire PM. Impact of cucurbit crop management techniques on the foraging behavior of honeybees and hoverflies in Morogoro, Tanzania. BMC Ecol Evol. 2024;24(1):9. https://doi.org/10.1186/s12862-024-02202-9 PMID: 38233768
51. Pi H, Quan Q, Wu B, Lv X, Shen L, Huang S. Altitude-related shift of relative abundance from insect to sunbird pollination in Elaeagnus umbellata (Elaeagnaceae). J of Sytematics Evolution. 2020;59(6):1266–75. https://doi.org/10.1111/jse.12685
52. Mertens JEJ, Brisson L, Janeček Š, Klomberg Y, Maicher V, Sáfián S, et al. Elevational and seasonal patterns of butterflies and hawkmoths in plant-pollinator networks in tropical rainforests of Mount Cameroon. Sci Rep [Internet]. 2021 May 6 [cited 2022 Sep 17];11(1):1–12. Available from: https://www.nature.com/articles/s41598-021-89012-x
53. Jordaens K, Goergen G, Kirk-Spriggs AH, Vokaer A, Backeljau T, De Meyer M. A second New World hoverfly, Toxomerus floralis (Fabricius) (Diptera: Syrphidae), recorded from the Old World, with description of larval pollen-feeding ecology. Zootaxa. 2015;4044(4):567–76. https://doi.org/10.11646/zootaxa.4044.4.6 PMID: 26624726
54. Doyle T, Hawkes WLS, Massy R, Powney GD, Menz MHM, Wotton KR. Pollination by hoverflies in the Anthropocene: Pollination by Hoverflies. Proc R Soc B Biol Sci. 2020;287(1927).
55. Azo'o EM, Bissou WB, Jordaens K. Diversity of flower-visiting hoverflies (Diptera: Syrphidae) on ground cover vegetation from the market-gardening area of Meskine (Far-North Region, Cameroon). Afr J Ecol. 2022 Mar 1;60(1):58–66.
56. Babaei M-R, Asghar Fathi SA, Gilasian E, Barimani Varandi H. Floral preferences of hoverflies (Diptera: Syrphidae) in response to the abundance and species richness of flowering plants. Zoology in the Middle East. 2018;64(3):228–37. https://doi.org/10.1080/09397140.2018.1484010
57. Conrad KM, Peters VE, Rehan SM. Tropical bee species abundance differs within a narrow elevational gradient. Sci Rep [Internet]. 2021 Dec 3 [cited 2022 Sep 1];11(1):1–12. Available from: https://www.nature.com/articles/s41598-021-02727-9
58. Milić D, Radenković S, Radišić D, Andrić A, Nikolić T, Vujić A. Stability and changes in the distribution of Pipiza hoverflies (Diptera, Syrphidae) in Europe under projected future climate conditions. PLoS One. 2019;14(9):e0221934. https://doi.org/10.1371/journal.pone.0221934 PMID: 31483815
59. Sengupta J, Naskar A, Maity A, Banerjee D. Effects of selected environmental variable upon the distribution of hover fly (Insecta: Diptera: Syrphidae) along with an altitudinal gradient. IJALSR. 2018;1(3):1–6. https://doi.org/10.31632/ijalsr.2018v01i03.001
60. Cook DF, Voss SC, Finch JT, Rader RC, Cook JM, Spurr CJ. The role of flies as pollinators of horticultural crops: An Australian case study with worldwide relevance. Insects. 2020;11(6):341. https://doi.org/10.3390/insects11060341 PMID: 32498457
61. Emtia C, Ohno K. Diurnal foraging behavior of an aphidophagous hoverfly in an insectary plant patch. J Biopestic. 2017;10(2):154–62.
62. Kabota SA Flower visiting flies (Insecta: Diptera) communities in cucurbit production systems in Morogoro region, eastern central Tanzania. [Internet] Morogoro: Sokoine University of Agriculture; 2021. 2022 Sep 3 http://www.suaire.sua.ac.tz/handle/123456789/3942
63. Doyle T, Hawkes WLS, Massy R, Powney GD, Menz MHM, Wotton KR. Pollination by hoverflies in the Anthropocene. Proc Biol Sci. 2020;287(1927):20200508. https://doi.org/10.1098/rspb.2020.0508 PMID: 32429807
64. Dawah HA, Abdullah MA, Ahmad SK, Al-Dhafer H, Turner J. An overview of the Syrphidae (Diptera) of Saudi Arabia. Zootaxa [Internet]. 2020 Sep 25 [cited 2022 Sep 1];4855(1):1–69. Available from: https://www.mapress.com/zt/article/view/zootaxa.4855.1.1

65. Bashir MA, Saeed S, Sajjad A, Khan KA, Ghramh HA, Shehzad MA, et al. Insect pollinator diversity in four forested ecosystems of Southern Punjab, Pakistan. Saudi J Biol Sci. 2019 Nov 1;26(7):1835–42.
66. Rodríguez-Gasol N, Alins G, Veronesi ER, Wratten S. The ecology of predatory hoverflies as ecosystem-service providers in agricultural systems. Biological Control. 2020;151:104405. https://doi.org/10.1016/j.biocontrol.2020.104405
67. Reynolds SK, Clem CS, Fitz-Gerald B, Young AD. A comprehensive review of long-distance hover fly migration (Diptera: Syrphidae). Ecol Entomol. 2024;49(6):749–67.
68. Wotton KR, Doyle T, Hawkes WLS, Massy R, Powney GD, Menz MHM. Pollination by hoverflies in the Anthropocene. 2020.
69. Clem CS, Hobson KA, Harmon-Threatt AN. Do Nearctic hover flies (Diptera: Syrphidae) engage in long-distance migration? An assessment of evidence and mechanisms. Ecol Monogr. 2022;92(4):e1542.
70. United Republic of Tanzania. Morogoro Regional Socio-Economic Profile. Morogoro Regional Commissioner's Office, Morogoro. [Internet]. 2002 [cited 2022 Sep 4]. 229. Available from: https://www.google.com/search?q=United+Republic+of+Tanzania+(2002).+Morogoro+Regional+Socio-Economic+Profile.+Morogoro+Regional+Commissioner's+Office%2C+Morogoro.+229pp.&rlz=1C1BNSD_enTZ948TZ950&oq=United+Republic+of+Tanzania+(2002).+Morogoro+Regional+Socio-Economic+Profile.+Morogoro+Regional+Commissioner's+Office%2C+Morogoro.+229pp.&aqs=chrome.0.69i59.2951j0j7&sourceid=chrome&ie=UTF-8
71. De Pauw E. Soils, Physiography and Agroecological Zones of Tanzania. Tanzania/FAO, Rome: Ministry of Agriculture, Dar-es-Salaam. In: Scientific Research. 1984 [cited 2022 Sep 3]. Available from: https://scirp.org/reference/referencespapers.aspx?referenceid=1994440
72. Mpondo FT, Ndakidemi PA, Mukama SC, Treydte A. Insect visitation and pollination networks across traditional rangeland management categories in a Northern Tanzanian rangeland. Glob Ecol Conserv. 2023;46:e02581.
73. Zameer SU, Bilal M, Fazal MI, Sajjad A. Foraging behavior of pollinators leads to effective pollination in radish *Raphanus sativus* L. Asian J Agricuture Biol. 2017;5(4):221–7.
74. Meerabai G. Visitation rate, effectiveness and efficiency of pollinators to *Canaba fruiticosa* (Linn) Druce. The Bioscan [Internet]. 2012 [cited 2022 Sep 2];7(3):483–5. Available from: www.thebioscan.in
75. Bolker BM, Brooks ME, Clark CJ, Geange SW, Poulsen JR, Stevens MHH, et al. Generalized linear mixed models: a practical guide for ecology and evolution. Trends Ecol Evol. 2009;24(3):127–35. https://doi.org/10.1016/j.tree.2008.10.008 PMID: 19185386
76. R Core Team. R: A language and environment for statistical computing. Vienna, Austria: R Foundation for Statistical Computing. https://www.R-project.org/. [Internet]. 2024 [cited 2022 Sep 4]. Available from: https://cir.nii.ac.jp/crid/1574231874043578752
77. Balfour NJ, Fensome KA, Samuelson EEW, Ratnieks FLW. Following the dance: Ground survey of flowers and flower-visiting insects in a summer foraging hotspot identified via honey bee waggle dance decoding. Agriculture, Ecosystems Environment. 2015;213:265–71. https://doi.org/10.1016/j.agee.2015.08.007
78. Wignall VR, Brolly M, Uthoff C, Norton KE, Chipperfield HM, Balfour NJ, et al. Exploitative competition and displacement mediated by eusocial bees: experimental evidence in a wild pollinator community. Behav Ecol Sociobiol. 2020;74(12).
79. Walther-Hellwig K, Frankl R. Foraging habitats and foraging distances of bumblebees, *Bombus spp*. (Hymenoptera, Apidae), in an agricultural landscape. J Appl Entomol. 2000;124(7–8):299–306.
80. Torné-Noguera A, Rodrigo A, Osorio S, Bosch J. Collateral effects of beekeeping: Impacts on pollen-nectar resources and wild bee communities. Basic and Applied Ecology. 2016;17(3):199–209. https://doi.org/10.1016/j.baae.2015.11.004
81. Doublet V, Doyle T, Refoy I, Hedges S, Carvell C, Brown MJF, et al. Increasing flower species richness in agricultural landscapes alters insect pollinator networks: Implications for bee health and competition. Ecol Evol. 2022;12(10):e9442. https://doi.org/10.1002/ece3.9442 PMID: 36311409
82. Bänsch S, Tscharntke T, Ratnieks FL, Härtel S, Westphal C. Foraging of honey bees in agricultural landscapes with changing patterns of flower resources. Agric Ecosyst Environ. 2020;291:106792.
83. Dorjay N, Abrol DP, Shankar U. Insect visitors on cucumber and bittergourd flowers and impact on quantity of crop production by different pollination treatment. J Apic [Internet]. 2017 [cited 2022 Sep 1];32(2):77–88. Available from: https://www.researchgate.net/publication/318373609
84. Quinn NF, Brainard DC, Szendrei Z. Floral strips attract beneficial insects but do not enhance yield in cucumber fields. J Econ Entomol [Internet]. 2017 Apr 1 [cited 2022 Sep 2];110(2):517–24. Available from: https://academic.oup.com/jee/article/110/2/517/3041106
85. Tommasi N, Biella P, Guzzetti L, Lasway JV, Njovu HK, Tapparo A, et al. Impact of land use intensification and local features on plants and pollinators in Sub-Saharan smallholder farms. Agric Ecosyst Environ. 2021 Oct 1;319:107560.
86. Wehner TC, P NR, R MJ, Narinder PS, Crosby K. Cucurbits. 2nd ed. Russell R, McCann E, Kapp T (Editors). London, UK:CABI; 2020;274.
87. Babaei MR, Asghar Fathi SA, Gilasian E, Barimani Varandi H. Floral preferences of hoverflies (Diptera: Syrphidae) in response to the abundance and species richness of flowering plants. Zool Middle East. 2018 Jul 3;64(3):228–37.
88. Ansari A, Memon N, Shah MA, Amur A, Mal B. Seasonal variation and diversity of hoverflies fauna (dipter: syrphidae) in Central Sindh, Pakistan. Sarhad J Agric [Internet]. 2017 [cited 2022 Sep 1];33(4):653–60. Available from: http://researcherslinks.com/current-issues/Effect-of-Adding-Different-Levels-of-Dietary-Electrolyte/20/1/837/html
89. Kumar M, Rai CP. Pollinator diversity and foraging behaviour of insect visitors on fennel (*Foeniculum vulgare* L.) bloom. J Entomol Zool Stud [Internet]. 2020 [cited 2022 Sep 2];8(5):2545–8. Available from: https://www.entomoljournal.com/archives/2020/vol8issue5/PartAG/8-5-329-365.pdf

90. Tommasi N, Biella P, Guzzetti L, Lasway JV, Njovu HK, Tapparo A, et al. Impact of land use intensification and local features on plants and pollinators in Sub-Saharan smallholder farms. Agric Ecosyst Environ. 2021 Oct 1;319:107560.
91. Dunn L, Lequerica M, Reid CR, Latty T. Dual ecosystem services of syrphid flies (Diptera: Syrphidae): pollinators and biological control agents. Pest Manag Sci. 2020;76(6):1973–9. https://doi.org/10.1002/ps.5807 PMID: 32115861
92. Klecka J, Hadrava J, Biella P, Akter A. Flower visitation by hoverflies (Diptera: Syrphidae) in a temperate plant-pollinator network. PeerJ [Internet]. 2018 Dec 3 [cited 2022 Sep 2];6:e6025. Available from: https://peerj.com/articles/6025
93. Jachuła J, Denisow B, Strzałkowska-Abramek M. Floral reward and insect visitors in six ornamental *Lonicera* species – Plants suitable for urban bee-friendly gardens. Urban For Urban Green. 2019 Aug 1;44:126390.
94. Štípková Z, Tsiftsis S, Kindlmann P. Pollination mechanisms are driving orchid distribution in space. Sci Rep [Internet]. 2020 Jan 21 [cited 2022 Sep 3];10(1):1–13. Available from: https://www.nature.com/articles/s41598-020-57871-5
95. Goodwin EK, Rader R, Encinas-Viso F, Saunders ME. Weather conditions affect the visitation frequency, richness and detectability of insect flower visitors in the Australian Alpine Zone. Environ Entomol [Internet]. 2021 Apr 23 [cited 2022 Sep 2];50(2):348–58. Available from: https://academic.oup.com/ee/article/50/2/348/6106190
96. Tarakini G, Chemura A, Tarakini T, Musundire R. Drivers of diversity and community structure of bees in an agroecological region of Zimbabwe. Ecol Evol. 2021;11(11):6415–26. https://doi.org/10.1002/ece3.7492 PMID: 34141228
97. Lequerica Tamara ME, Latty T, Threlfall CG, Young A, Hochuli DF. Responses of hover fly diversity and abundance to urbanisation and local attributes of urban greenspaces. Basic and Applied Ecology. 2023;70:12–26. https://doi.org/10.1016/j.baae.2023.04.002
98. Skevington JH, Locke MM, Young AD, Moran K, Crins WJ, Marshall SA. Field guide to the flower flies of northeastern North America. New Jersey: Princeton University Press; 2019. 511.
99. McCravy KW, Clem CS, Bailey JB, Elgar SA, Blaauw BR. Hover fly (Diptera: Syrphidae) diversity and seasonality in North Georgia apple and peach orchards. J Econ Entomol. 2024;117(4):1572–81. https://doi.org/10.1093/jee/toae103 PMID: 38779977
100. Neave MJ, Brown J, Batley M, Rao S, Cunningham SA. Phenology of a bee (Hymenoptera: Apoidea) community over a 10 year period in south-eastern Australia. Austral Entomol. 2020;59(3):602–11. https://doi.org/10.1111/aen.12488