# Foraging Behaviour of Apis mellifera scutellata and Hypotrigona gribodoi Bees in Monoculture and Polyculture Vegetable Gardens

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RESEARCH ARTICLE

# Foraging Behaviour of *Apis mellifera scutellata* and *Hypotrigona gribodoi* Bees in Monoculture and Polyculture Vegetable Gardens

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**Abstract** This study aimed to evaluate the influence of crop type, cropping systems and weather elements on foraging behaviour of pollinators, which is imperative for designing pollinator friendly agricultural systems. Generalised linear models were used to assess foraging time and visitation frequency of the honey bee *Apis mellifera scutellata* and the stingless bee *Hypotrigona gribodoi* across monocultures and polyculture systems of butternut, dry bean and mustard at two garden sites in Zvimba district, Zimbabwe. A total of 120 bee visitations across the crops and 103.4 min of foraging bouts were recorded. The honey bee had longer foraging bouts periods in monoculture system, but there were no differences in the stingless bee. Across the two bee species, mustard had the longest foraging bouts, and least in dry beans. Foraging time generally decreased with increasing temperatures, but the decreases in polyculture systems were less severe for the honey bee. Only the honey bee foraging time was shorter in the presence of competitors. We therefore conclude that there are possible negative impacts of projected increases in temperature due to global warming and agricultural intensification on foraging behaviour of important pollinators such as bees.

**Keywords** Pollinators · Foraging activities · Polycultures · Monocultures · Temperature

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## Introduction

Bee species (both wild and domesticated) are the most important pollinators globally (Fleming and Muchhala 2008) and their diversity and abundance also influence the pollination services to crops and wild plants (Garibaldi et al. 2013). However, several studies have documented the decline of bee species population and attribute it to land-use changes (Bommarco et al. 2014; Burkle et al. 2013; Senapathi et al. 2015) with agriculture listed amongst major threats to bees (Haines-Young 2009). Cropping may result in shifts in the composition and spatial configuration of habitat types resulting in decline in forage quantity and diversity while use of pesticides also affects pollinators (Fahrig et al. 2011). Developing countries are projected to increase agricultural land a further 10 % by 2030 (Faurès et al. 2002; Motzke et al. 2016), hence the need for urgent research on sustainable cropping systems for pollinator conservation that does not compromise food production.

Monoculture is currently one of the most dominant and most intensive food production systems. However, due to its simplicity, it reduces biodiversity (Jose 2012). There is, therefore, scope in assessing bee foraging behavior under different scenarios of cropping systems (e.g. monoculture versus polyculture) so that bee-friendly agricultural practices can be developed. Under polyculture agricultural practices, more than one species is grown at the same time and place, therefore, increasing flower diversity (Barbera

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and Cullotta 2016). Some of the advantages of polyculture systems include the possibility of diversifying crops that are important for human nutrition and health while maintaining more ecosystem services when compared to monoculture systems (Fanzo et al. 2013). As such entomophilous crops (insect-pollinated) can therefore be strategically intercropped with major crops to benefit bees. A more diverse plant community is better able to sustain diverse pollinators which have varying forage requirements and also offer diverse nutritional requirements (Hooper et al. 2005). In an experiment by Schmidt et al. (1995), old honey bees fed with a mixed pollen diet lived longer than those fed single species pollen. Bees have also been shown to have the ability to choose sites of higher forage returns and through experience can remember and return to those sites (Klein et al. 2019; Schowalter 2016). Such findings suggest that polyculture systems may be healthier for bee species when compared with monocultures, and bees may be able to detect that and therefore visit more such sites. However, information is still lacking to understand if bees show a clear preference for polyculture systems when compared to monocultures.

In Zimbabwe, the recent 2016 command agriculture program by the government incentivized farmers to grow specific crops to improve food security in the country (Shonhe 2019) and the resulting situation are large tracts of land under monoculture production for the few crops incentivized (such as maize *Zea mays* and soya beans *Glycine max*). Considering the large size of these farms coupled with the small home ranges of 1.5–5 km for bees (Wikelski et al. 2010) it potentially makes it difficult for bee species to effectively scan other areas for other food sources (Gill et al. 2016; Wikelski et al. 2010; Zhang et al. 2016). This may have implications on the overall forage varieties for the bees, particularly in monocultures of maize (Holzschuh et al. 2007). Although solitary bees and those with small colonies can still thrive while utilizing the few forage resources (Eckert et al. 1994) on weeds, field edges, and hedges, it might be more difficult for large bee colonies (Eckert et al. 1994). There is a dearth of information on crops preferred by bees while foraging (Fanzo et al. 2013; Olsen et al. 1979) yet highly important and sought after by farmers practicing apiculture (Carroll and Kinsella 2013).

Crops have different flower morphology (Duffield et al. 1993; Singer and Sazima 2001), concentrations of sugars, and pollen which may all affect bee foraging time on them (Zimmerman 1988). Large-flowered, brightly coloured crops such as the butternut (*Cucurbita moschata*), are expected to attract many insects (Galen and Cuba 2001) due to their visual conspicuousness (Duffield et al. 1993) and previous studies have noted a positive correlation between nectar production rates and flower size (Harder and Cruzan 1990). Numerous flowers per plant such as in mustard (*Brassica juncea*) may also attract more bees (Miyake and Sakai 2005) as competition is reduced (compared to the crops with fewer flowers). Information on the morphology of preferred crops is lacking yet it has important implications on the plant densities required for polyculture systems to prevent pollinator competition and enhance the system's capacity to host greater abundance and diversity of bees.

Abiotic factors such as weather have also been identified amongst major factors influencing bee behavior and ultimately affecting their survival (Alqarni 2020; Schua 1952). Several studies have reported species tolerance to different microclimatic ranges of temperature (Souza-Junior et al. 2020), humidity, light intensity (Jones et al. 2020), wind speed ranges (Hennessy et al. 2020) beyond which these ranges have proven to be lethal. However, impacts of weather on bee activities have mainly been assessed in laboratories (Cooper et al. 1985; Hennessy et al. 2020) or at a landscape scale (St Clair et al. 2020). Relatively less information exists on how weather influences foraging decisions made at a patch scale yet the information will give us an insight on how foraging strategies will change in the face of climate change.

Foraging behavior is an important distinguishing factor in bees (Abou-Shaara et al. 2017) and determines pollination success as well as the survival of bees. According to the optimal foraging theory (Pyke et al. 1977), animals may adopt a foraging strategy that provides the most benefit (energy) for the lowest cost, maximizing the net energy gained. Bees will therefore have to make decisions on where to forage (patch choice), when to leave, and what to eat (diet) (Pyke 1984). However, most studies have assessed foraging decisions of bees at a landscape scale (Laha et al. 2020; Shaw et al. 2020; Steffan-Dewenter 2002) with bee population abundance and diversities used as an index of foraging preference (Vides-Borrell et al. 2019). Little information exists on how foraging decisions are made at a patch scale (Lazaro and Totland 2010). This information may directly affect the fitness of crops and wild plants dependent on bees for reproduction and such knowledge can guide the development of bee-friendly habitats. The time spent foraging on a patch potentially informs conservationists about preference; perceived higher forage returns for the bees, quality of pollination service offered to plants, and also contribute to individual bee fitness and survival (Abou-Shaara 2014; Lazaro and Totland 2010; Pernal and Currie 2001; Sushil et al. 2013). This study hypothesized that polyculture systems would have a higher frequency of visitation and foraging time compared to monocultures for the honey bee *Apis mellifera scutellata* and the stingless bee species *Hypotrigona gribodoi*. Foraging time and visitation frequency were also expected to significantly differ across crops, with more preference being made for crops with more flowers (reduced competition level per flower). It was also hypothesized that bee visitation and foraging time will increase with increasing temperature, but only up to an optimum level, and beyond this point, visitation and foraging time would decrease with increasing temperature (i.e. a quadratic effect).

## Methods

### Study Area

The study was conducted in Zvimba district at two different sites; the first one near Murombedzi centre and the second near the city of Chinhoyi suburbs and these sites were 38 km apart (Fig. 1). Zvimba district has minimum temperatures of 15 °C in winter and a maximum of 24 °C in summer and receives between 750 and 1000 mm of rainfall per year (Mugandani et al. 2012). This area is in agro-ecological region II and is important for food security in the country, partly due to the good soils for crop production. Our surveys in this district revealed that the dominant bee genera in this area include *Apis, Xylocopa, Hypotrigona, Seladonia, Megachile*, and *Amegilla* (Tarakini et al. 2021). The major crop grown by the majority of farmers is maize *Zea mays*. The main vegetable species grown include mustard (*Brassica juncea*), tomatoes (*Solanum lycopersicon*), onions (*Allium cepa*), dry beans (*Phaseolus vulgaris*), and butternut (*Cucurbita moschata*) species (Tarakini et al. 2020).

### Study Design

At each site, we established four vegetable plots, each measuring 8 × 2 m and they were spaced 2 m apart. The first three plots were planted with 135 mustard plants (spacing 45 cm × 30 cm), 81 butternut plants (90 cm × 30 cm), and 805 dry beans plants (45 cm × 5 cm) in line with recommended spacing from the manufacturers of the vegetable seeds. These three plots represented monoculture scenarios for the concerned crops. In the fourth plot, 81 butternut plants were intercropped with 65 mustard plants and 65 dry beans plants, following spacing specifications outlined for the monoculture plots. This fourth plot

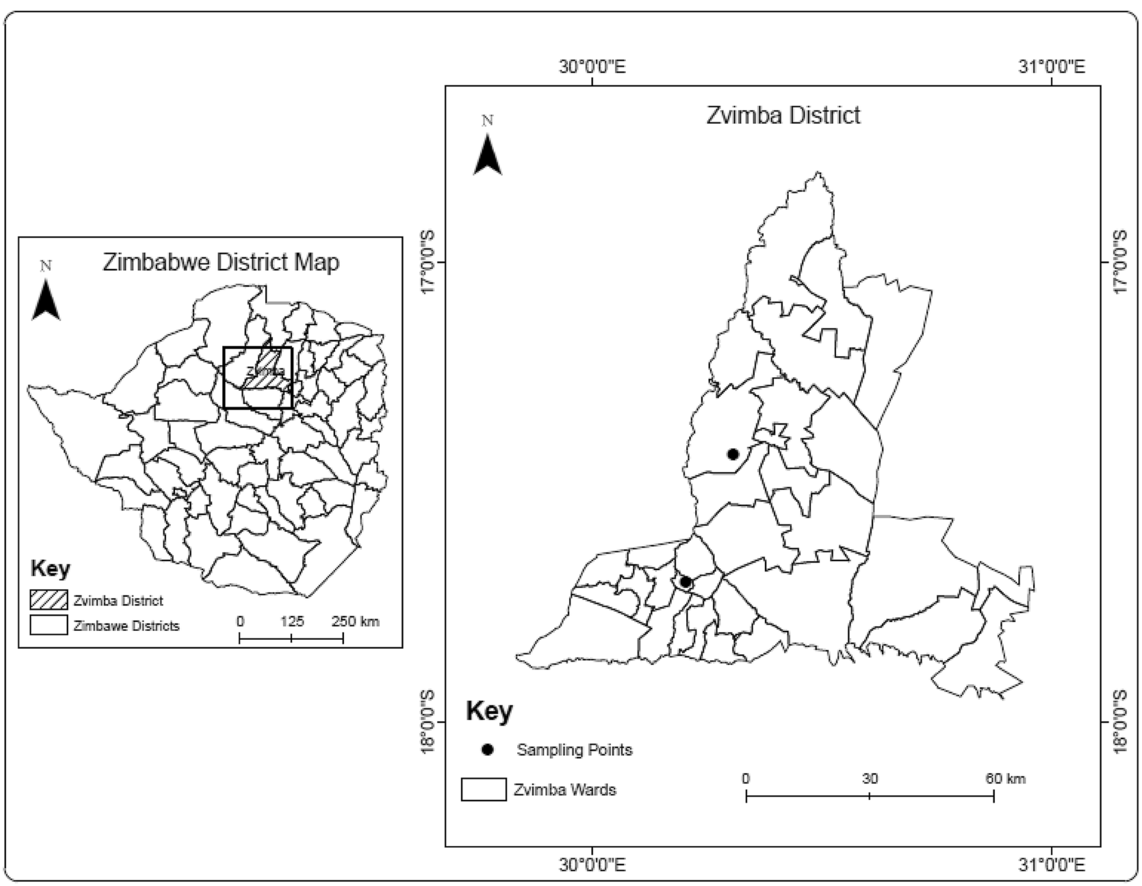


Fig. 1 Map showing Zvimba district and the sampling sites

represented a polyculture situation for the three vegetable crops. These vegetable crops were selected as they are commonly grown in the district (Tarakini et al. 2020) constituting an important part of the diet and they take the same time to flower. The small plot size selection was also informed by the dominant vegetable plot sizes used by farmers in the Zvimba district. Furthermore, according to Sowig (1989), small patch sizes have equal or higher visitation rates compared to bigger patches. About 90 kg of cow dung manure was incorporated into the soil in each plot before sowing the vegetables. Vegetables were sown around the same time across the two sites (i.e. 29 and 30 July 2019 in Murombedzi and Chinhoyi sites respectively). The plots, including spaces in between and outside the plots, were frequently weeded to prevent crop-weed competition as well as reduce insect pest infestation. No pesticides or herbicides were used in this experiment. All the plots were frequently watered until about 90 % of plants in each plot were flowering following methods by Sushil et al. (2013).

### Monitoring of Bee Visitations and Foraging

The flowering crops was monitored between 30 September and 17 October 2019 and the weather was mostly calm and sunny. Monitoring sessions were conducted for one hour between 0900 and 1000 h; 1300–1400 h and 1500–1600 h and classified as the morning, early afternoon, and late afternoon respectively for five days at each site. Two observers on each plot were assigned to monitor bees. The first observer monitored the species and number of bees visiting a plant in one minute (this included all bee species that visited the plant) (Petersen and Nault 2014). The first observer also took note of any interactions (such as fights, chases, and use of the same flower at the same time) which occurred on the plants under monitoring. Bee species interactions were recorded as interspecific, intraspecific, and no interaction. These visitation frequencies were recorded for 10 plants before the observer moved to the next plot.

The second observer monitored the foraging time spent on each flower (MacKenzie 1994). For this aspect, upon arrival on a plot, the observer selected a plant whose flower(s) were being attended by honey bees or stingless bee species. A stopwatch was used to record the foraging time, which was defined as the time (in seconds) during which a bee would spend foraging on a flower before flying to the next flower/plant. The observer would then randomly select the next plant that had bees for further monitoring. Records for as many bee foraging bouts as could fit in 15 min in one plot were made before moving to the next plot until all the four plots were covered. For both the foraging time and visitation frequencies, the order of monitoring was rotated daily among the plots at each site to minimise biases associated with bee activity and day time (Sushil et al. 2013). During the monitoring sessions, data on weather conditions were recorded (temperature, wind speed, wind direction, and humidity) using a handheld ambient weather meter model WM-4, (manufacturer-Ambient Weather, Chandler, Arizona, USA) and light intensity, Urceri handheld digital illuminance meter model number 4,332,004,118 (Grettenberger and Joseph 2019).

### Data Analysis

This study considered individual plants as in-plot replications as the unit of measurement was foraging and visitation on a flower of each individual plant. The foraging time and visitation frequencies were tested for consistency with normality assumptions using the Shapiro-Wilk test and they failed to conform even after various transformation attempts. Several tests were run to remove weather variables that could have been correlated. Using Pearson correlations, it was concluded that temperature was negatively correlated to humidity and wind speed, and the temperature was also significantly different across wind direction (determined using one-way analysis of variance). We, therefore, opted to use only temperature and light intensity in further analysis as temperature is important in other experiments (Cooper et al. 1985; Corbet et al. 1993; Langowska et al. 2017; Nürnberger et al. 2018). The visitation frequencies were low on dry bean plants (i.e. only 9 for the whole study), thus we dropped it from the modeling of factors influencing plant visitation frequencies. We, therefore, used generalised linear models to determine the relationships between plant visitation frequencies with crop type (butternut and mustard), cropping system (monoculture and polyculture) time of day (morning, early afternoon, and late afternoon), wind direction (northerly, southerly, easterly and westerly winds) and temperature. Although there was some evidence of a quadratic effect of temperature on visitation frequencies, including temperature as a squared variable did not make the model better, hence we used the untransformed temperature.

We also used the same independent variables used in the visitation frequencies model to investigate their relationship with flower foraging time using the generalised linear models. For the foraging time model, we included observations done on bean plants (as there were 132 foraging bouts recorded on them) and also included the interaction type as an independent variable (in this instance we used all the three levels i.e. interspecific, intraspecific, and no interaction as there was adequate data). However, we used re-categorisation of interactions type (interaction/no interaction) owing to the few frequencies (i.e. less than 15 % of all records) for interspecific interactions.

For all our analyses, we included single variables and all possible two or three-way interactions (between crop type, cropping system, time of day, temperature, wind direction, and bee interactions) in line with our main predictions in the models. We used the 'dredge' function in the *MuMln* package (Barton 2011) to select candidate models where delta Akaike Information Criteria (AIC) was less than 2 and then considered the best model from the list as the one with the lowest AIC (Burnham and Anderson 2002). All analysis was done in the R package for Statistical Computing (R Development Core Team 2020).

## Results

### Frequency of Visits and Weather Characteristics

A total of 87 bee visitations were recorded on mustard, 24 on butternut, and 9 on beans plants during the whole study period. We also recorded a total of 103.4 min of bee foraging bouts on the crops in our experiment. The average (± SD) weather parameters across time of day and site are presented in Table 1. The weather was mostly warm to hot, with temperatures ranging from 23.1–36.6°C. The most frequently recorded winds were southerly (n = 945), and the least was westerly (n = 116). Temperatures were negatively correlated to humidity (r = − 0.83, $P < 0.0001$) and wind speed (r = − 0.22, $P < 0.0001$), but the relationship of temperature with light intensity was insignificant (r = − 0.075, $P = 0.057$). Temperatures were significantly different across the cardinal directions (F = 27.61, d.f. = 3, $P < 0.0001$), with mean temperatures for the East, West, North, and South being 31.2, 30.2, 28.6, and 30.6 knots respectively. Insect species observed visiting the crops were the stingless bee *H. gribodoi* (75 % of observations, n = 267), the honey bee *A. m. scutellata*, (21.3 %, n = 76), an unclassified wasp (1.7 %, n = 6), the carpenter bee *Xylocopa inconstans*, and other unidentified solitary bees all contributed only 0.6 % (n = 2), and ants were recorded once (0.3 %).

### Factors Influencing Plant Visitation Frequency

There were significant differences in bee visitation frequencies recorded across the time of day (Wald $\chi2 = 7.671$, d.f = 2, $P = 0.022$), with early afternoons having the highest (3.0 ± 0.19) and mornings the least (1.6 ± 0.8) (Table 2).

There was a marginally significant interaction of crop type and temperature (Wald $\chi2 = 3.747$, d.f = 1, $P = 0.053$). In the butternut, there was a general decrease of visitation frequencies with an increase in temperature but in the mustard this relationship was positive (Fig. 2). There was also a significant interaction of temperature with cropping system (Wald $\chi2 = 6.610$, d.f = 1, $P = 0.010$). In the monoculture system, visitation frequency increased with an increase in temperature, but in the polyculture, visitation frequencies were decreasing with increasing temperature.

### Foraging Time in the Stingless Bees

Foraging time in the stingless bee ranged from 0.02 to 107.69 s. The best model explaining foraging time in the stingless bees retained temperature and interactive effects of crop species and cropping system. There was a significant decrease of foraging time with increases in temperature (t = -3.833, $P = 0.0001$). Foraging times were significantly different across the crop species ($F = 21.663$, d.f. = 2, $P < 0.0001$), with flowers on mustard plants having longer averages, and beans had the least (Table 3). There was a significant interaction of crop species and cropping system ($F = 8.899$, d.f = 2, $P = 0.0002$), with bees foraging for significantly longer periods in monoculture system compared to polyculture system as illustrated in Fig. 3a and b.

**Table 1** Summary of weather elements recorded at two sites in Zvimba district in September and October 2019

| Site | Time of day | Weather variable | | | |
|---|---|---|---|---|---|
| | | Temperature (°C) mean ± SE | Humidity mean ± SE | Light intensity mean ± SE | Wind speed (knots) mean ± SE |
| Chinhoyi | Morning | 26.9 ± 1.2 | 31.4 ± 4.1 | 78.3 ± 9.4 | 0.7 ± 0.5 |
| | Early afternoon | 31.6 ± 1.8 | 21.2 ± 1.3 | 88.7 ± 4.0 | 0.42 ± 0.3 |
| | Late afternoon | 30.6 ± 3.4 | 23.5 ± 8.9 | 82.2 ± 9.2 | 0.98 ± 0.7 |
| Murombedzi | Morning | 28.3 ± 2.7 | 36.3 ± 12.6 | 72.8 ± 10.1 | 0.72 ± 0.6 |
| | Early afternoon | 32.4 ± 2.8 | 27.1 ± 9.4 | 66.5 ± 26.8 | 1.2 ± 1.1 |
| | Late afternoon | 33 ± 3.1 | 26 ± 9.0 | 51.8 ± 25.7 | 0.96 ± 0.9 |

**Table 2** Selected model illustrating the relationship of plant visitation frequency to weather and cropping variables at two sites in Zvimba district

| Variable | Estimate (± SE) | Z value | *P* value |
|---|---|---|---|
| Intercept | − 1.893 ± 0.802 | − 2.360 | 0.018 |
| Temperature | 0.087 ± 0.03 | 3.099 | 0.002 |
| Butternut | 2.383 ± 1.74 | 1.368 | 0.171 |
| Early afternoon | 0.403 ± 0.19 | 2.150 | 0.032 |
| Late afternoon | 0.086 ± 0.21 | 0.412 | 0.680 |
| Polyculture | 5.364 ± 2.21 | 2.428 | 0.015 |
| Temperature × Butternut | − 0.095 ± 0.06 | − 1.652 | 0.098 |
| Temperature × Polyculture | − 0.177 ± 0.07 | − 2.493 | 0.013 |

### Foraging Time in the Honey Bee

Foraging time in the honey bee ranged from 1.02 to 18.09 s. The selected model describing the relationship between foraging times in the honey bee retained the type of bee interactions and the interactive effect of the cropping system with temperature and crop species. Foraging times tended to be long when there were no interaction with other bee species and least when there were interspecific interactions ($F = 12.05$, d.f = 2, $P < 0.0001$, Fig. 4a). There was a significant interaction between crop species and cropping system ($F = 5.995$, d.f = 2, $P = 0.003$), with the monoculture system having distinctively longer foraging times in mustard and butternut, but the difference was not significant in beans (Fig. 3). Temperature had a significant interaction with cropping system ($F = 58.223$, d.f = 1, $P < 0.0001$). Overall, the temperature was negatively correlated to foraging time, but foraging times declined faster in monoculture systems when compared to polyculture systems (Fig. 4b).

## Discussion

Our results showed that the stingless bees are more frequent visitors to the crops that were used in this study (contributing to 75 % of the observations). This is in contrast to the common perception that the honey bees are dominant pollinators in agricultural landscapes (Gross 2001) and highlights the possibility of managing stingless bee colonies for the business of crop pollination of large monoculture crops (Kazuhiro 2004; Slaa et al. 2006) which is currently a common practice with honey bee species. Conservation strategies should therefore not be focused on one pollinator species but all-encompassing. Indeed scientific focus has been biased towards the honey bees, probably due to their larger colonies and honey produced per colony especially in apiculture systems (Hoshide et al. 2018). This result is especially important in that many farmers indicate a fear of bees as a limiting factor their conservation in agricultural landscapes (Tarakini et al. 2020) and therefore there is a higher chance for stingless bees to be conserved in these farming landscapes.

Temperature, was the predominant abiotic factor influencing bee activities (Corbet et al. 1993; Reddy et al. 2012). In the present study, bee visitation frequency was marginally influenced by the interactive effect of crop species and temperature, with bee visitation in butternut crop declining as temperature increased, and the opposite was observed in mustard. This could be explained by the physiological mechanism of butternut plants that tend to

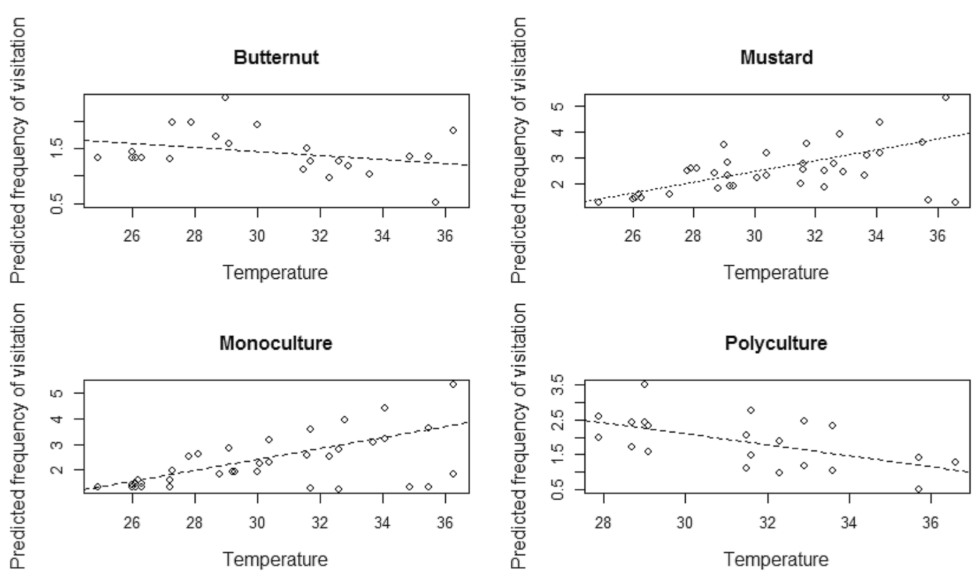


**Fig. 2** Illustration of the interactive effect of temperature with crop species (butternut and mustard in top panel) and cropping system (monoculture and polyculture on bottom panel) on bee visitation frequency

**Table 3** Models illustrating the variables that affected foraging times for the Stingless and Honey bees

| Model | Variable | Estimate(± SE) | t value | *P* value |
|---|---|---|---|---|
| Stingless bee | Intercept | 3.826 ± 0.52 | 7.297 | < 0.0001 |
| | Temperature | − 0.062 ± 0.02 | − 3.833 | 0.0002 |
| | Butternut | − 1.234 ± 0.22 | − 5.508 | < 0.0001 |
| | Beans | − 0.966 ± 0.22 | − 4.454 | < 0.0001 |
| | Polyculture | − 0.639 ± 0.14 | − 4.612 | < 0.0001 |
| | Butternut: Polyculture | 1.29 ± 0.21 | 4.098 | < 0.0001 |
| | Beans: Polyculture | 0.77 ± 0.31 | 2.496 | 0.013 |
| Honey bee | Intercept | 5.278 ± 0.28 | 18.574 | < 0.0001 |
| | Butternut | − 0.374 ± 0.06 | − 5.943 | < 0.0001 |
| | Beans | -0.514 ± 0.13 | − 3.867 | 0.0001 |
| | Interspecific competition | − 0.534 ± 0.18 | − 2.918 | 0.004 |
| | Intraspecific competition | − 0.244 ± 0.12 | − 2.083 | 0.038 |
| | Polyculture | − 3.957 ± 0.46 | − 8.664 | < 0.0001 |
| | Temperature | − 0.126 ± 0.01 | − 12.961 | < 0.0001 |
| | Polyculture: Temperature | 0.121 ± 0.02 | 7.65 | < 0.0001 |
| | Butternut: Polyculture | 0.338 ± 0.1 | 3.303 | 0.001 |
| | Beans: Polyculture | 0.379 ± 0.19 | 1.958 | 0.051 |

SE = Standard Error

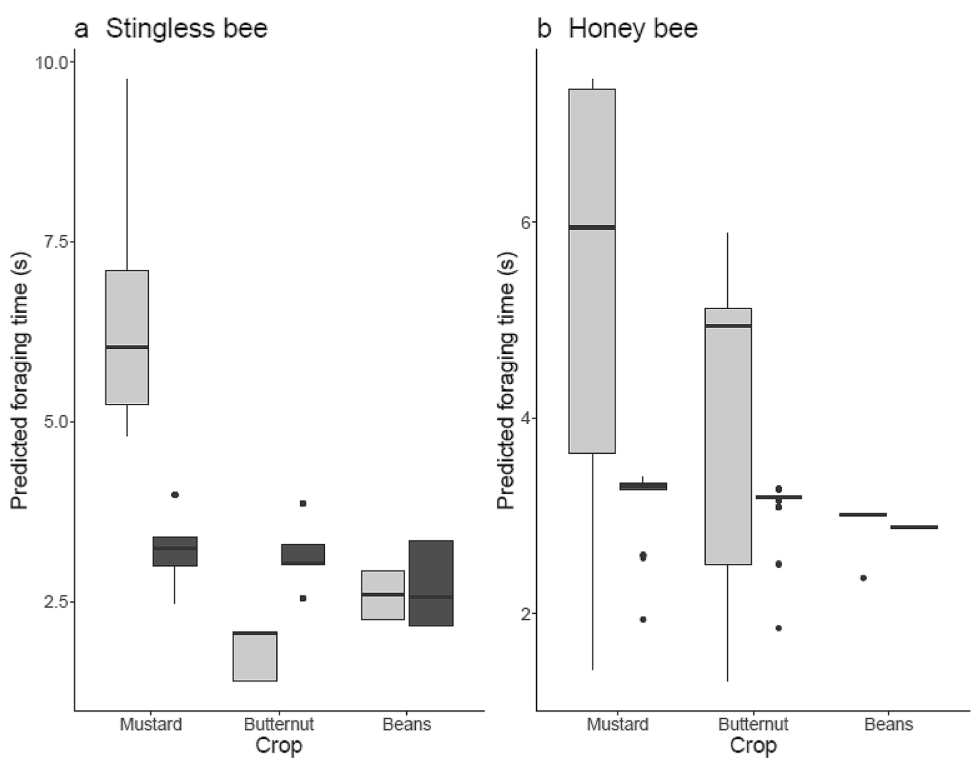


**Fig. 3** The interactive effects of crop species and cropping system on the foraging time spent by **a** the stingless bee and **b** the honey bee at two sites in Zvimba district

close their petals when the pollen viability and stigma receptivity is decreasing (Nepi and Pasini 1993), this was commonly noticed when the day begins to be hot around 1000 − 1100 h. This finding, therefore, emphasizes the importance of polycultures considering that bees can still switch to feeding on other plants when butternut and physiologically similar crops close their flowers (Guzman et al. 2019).

Within the confines of our data, we are compelled to reject the hypothesis of quadratic effects of temperature on bee visitation frequency. Although we detected the quadratic tendency, it was insignificant, probably because the

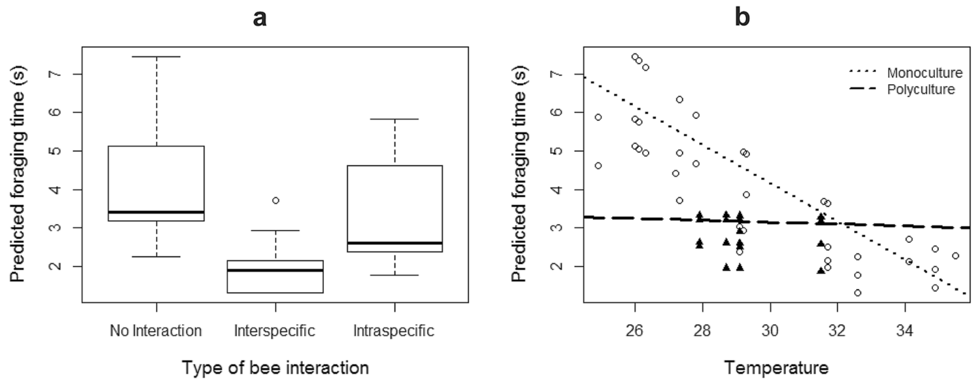


**Fig. 4** The predicted foraging time spent by the honey bee **a** under different types of interaction, and **b** the interactive effect of temperature of two types of cropping systems

temperature range we had in our experiment was small (23.1–36.6 °C). This also confirms findings by Souza-Junior et al. (2020) who noted that bees were only observed within a small temperature range of 23–36 °C. Given the climate change projections, and other recent events of very hot days (heat waves) with temperatures above 42 °C (Ngwenya 2019) more researches are needed to evaluate these temperature impacts. Already, other scientists have shown that at 45 °C *Apis dorsata* workers died within 48 h (Mardan and Kevan 2002).

The potential of the negative impacts of temperature is probably illustrated by considering the results of foraging time. Foraging time was negatively related to temperature for both bee species, with bees spending significantly lesser time foraging on each crop. These results indicate that climate change, characterised by the elevated temperature may greatly reduce the overall time of spent by bees foraging, thus bringing down their pollination efficiency and reducing their survival. However, in polyculture systems, there seemed to be a cushioning effect against the effects of increasing temperature (this only applied to the honey bee). The rate of declines in foraging time was less than those associated with monoculture systems. While it was beyond the scope of this study to monitor temperature at micro-levels (i.e. between the crops in a plot), this tendency in polyculture systems could create cooler micro-climates in comparison to monoculture systems. These results corroborate findings by Merchant (2010) who noted the creation of microclimates as plant diversity increased in mixed systems though the focus was on deterring pests. The honey bees, which had generally shorter feeding bouts (compared to stingless bees), seem to be benefiting from such a potential cooler micro-climate. Noting that our results do not allow us to make conclusive statements on the actual mechanisms regarding the relationship of foraging time and temperature, more experiments that monitor micro-climates and possibly more crops are needed. Also, the fact that stingless bees did not respond the same way is an indication of the differential impacts climate change will likely have on the various pollinators, hence the need for conservation strategies that take into account the different species requirements.

The results of our study also highlight the shortcomings of using bee visitations as an index of pollination, since foraging quality may vary with visits. According to our results, visitation frequency did not significantly differ across crops and crop systems yet time spent foraging per visit significantly differed with crops. The findings support observations by Schemske and Horvitz (1984), Ramsey (1988), Larsson (2005) that not all flower visitors will equally effectively pollinate a plant.

For both bee species foraging time significantly differed across crops. In line with our hypothesis that foraging time will be longer on plants with more flowers, the mustard, which usually has between 70 and 300 flowers per plant (Akter et al. 2007) compared to 5–20 flowers for dry bean and butternut, had the longest bouts of bees foraging on them. These findings also concur with previous studies by Essenberg (2013) who noted that group living foragers prefer dense resource patches to sparse ones. This may also be driven by the higher energy needs to sustain a colony highlighting the importance of not only improving forage quality but quantity i.e. ensuring its adequacy to sustain bee populations (Shackleton et al. 2016).

Contrary to our hypothesis, the stingless bees seemed to show no conclusive added advantage of using polyculture systems, as it was only higher in butternut relative to mustard, with beans not different across systems. Honey bees foraged longer in monoculture systems compared to polycultures which support theories that animals can only remember how to quickly manipulate few similar flowers at any given time (Lewis 1986; Waser 1986). As a result monoculture stands foraging efficiency increases due to reduced handling time (Wilson and Stine 1996). It is, therefore, possible that bees stay longer where there are fewer choices unlike in diverse polyculture systems where they want to maximise by visiting as many plant species as possible, thereby staying for a short time for each visitation.

It is also important to note that intraspecific competition had a higher negative impact on the foraging time of honey bees compared to inter-specific competition a scenario normally caused by high numbers of the same species within a given area (Pusceddu et al. 2018). This finding support reports on the importance of assessing the carrying capacity of an area before introducing bee colonies (Al-Ghamdi et al. 2016; Teklay 2011) as exceeding carrying capacity will increase competition and ultimately reduce the survival of species. This information is crucial for apiculturists to determine forage quantities required by their bee colonies as well as farmers to determine the number of colonies to higher for pollination of their fields.

### Study Limitations

We acknowledge that the study lacks data on individual bee selections across experimental plots which could have been achieved by marking the bees and following them. However, replications across time of day and site are expected to give general feeding trends and cater for any differences within the bees. Also, we did not have resources to mark individual bees and monitor their foraging behaviour across flowers and plants. This could have provided more information about the foraging patterns of the species. Future studies should therefore consider extending our research by using marked bees.

## Conclusions

In conclusion, the study established that visitation frequency was influenced by the interactive effect of temperature and cropping system contrary to our hypothesis of a quadratic relationship between temperature and bee visitation frequency and may be explained by the short temperature ranges within which the study was conducted. The relationship between temperature and foraging time was negative for both stingless and honey bees further highlighting the impacts that global warming might have on pollination ecosystem services. The study also established that, although polyculture sites could have shorter foraging time compared to monocultures, the polyculture sites have a higher possibility of offering forage across different times of the day due to alternative forage choices they offer. However, monocultures of plants such as butternuts which close flower petals later into the day offer forage at limited times of the day hence polyculture systems ensure forage availability at different times of the day. Finally, the study recommends further research on the microclimatic conditions of polycultures for possibilities of buffering negative temperature increases on bees, which is useful information to apiculturists and farmers in the face of global warming.

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**Availability of Data and Material** Data will be put in a repository after publication.

**Declarations**

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

**Ethics Approval** The study got approval from the District Administrator to conduct research in Zvimba district.

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