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Environmental conditions and bee foraging on watermelon crops in Panama

Juan Carlos Di Trani[a1] | **Virginia Meléndez Ramírez**[a] | **Yostin Añino**[b] | **Anovel Barba**[c2]

[a]Campus de Ciencias Biológicas y Agropecuarias, Universidad Autónoma de Yucatán, Mexico.
[b]Museo de Invertebrados G. B. Fairchild, Universidad de Panamá, Panama.
[c]Instituto de Innovación Agropecuaria de Panamá, Divisa, Panama.

Corresponding authors: [1]JuanDiTrani@yahoo.com; [2]anovel.barbaa@idiap.gob.pa

Abstract Watermelon is a crop highly dependent on bees for pollination, and environmental conditions are some of the most important factors affecting bee foraging. In this study, we analyze the effect of environmental conditions on the behavior of the most common bees visiting flowers of watermelon crops in Panama. We recorded the number of visits, visit duration, and the corresponding environmental conditions during the visits. Environmental conditions affected the observed groups of bees differently: honey bee visit proportion was remarkably higher at low temperatures, solar radiation, wind speed, and high relative humidity, early in the morning when they made about 90% of their flower visits. The other observed bees showed a more homogenous behavior during the day, with peaks representing about 25-35% of the daily visits. Visit number showed a correlation with temperature for all the most common bees except *Augochloropsis* spp., with solar radiation for *A. mellifera* and *Lasioglossum* spp., with humidity for all except *Lasioglossum* spp., and with wind speed for all of the analyzed bees. Visit durations were remarkably longer in *N. perilampoides* early on the day. At the same time, the rest of the bees showed less pronounced duration peaks, reaching their maximum at intermediate values of environmental conditions. Visit duration on honeybees did not correlate with environmental factors, but it did for most other bees. Environmental conditions showed a strong effect on the bee foraging behavior, with each group of bees concentrating their activities in favorable conditions depending on their biology, establishing their daily foraging patterns.

Keywords: duration, humidity, radiation, temperature, wind

1. Introduction

Bee foraging behavior is affected by a great variety of external factors interacting among each other (Iwama 1977; Gouw and Gimenes 2013). Probably, the most important abiotic factors affecting bee foraging activity are environmental conditions (Gouw and Gimenes 2013; Polatto et al 2014), especially temperature, solar radiation, and humidity (Iwama 1977; De Oliveira et al 2012; Reddy et al 2015; Clarke and Robert 2018; Soares et al 2019), and wind speed (Hilário et al 2007; Vicens and Bosch 2000; Reddy et al 2015). The effect of these conditions on the bee foraging behavior also seems to depend on the bee's characteristics and biology (Kaluza 2017). For instance, the temperature could special affect bees with different characteristics. Larger and darker bees show more tolerance to low temperatures (Pereboom and Biesmeijer 2003; Gouw and Gimenes 2013; Polatto et al 2014), and bees with smaller and lighter colored bodies could forage during higher temperatures without overheating (Willmer and Stone 2004). Temperature can restrict the flying capacity of bees. At very low temperatures, flying muscles fail to work (Heinrich 1993), while high temperatures can cause dehydration, lethal overheating (Pereboom and Biesmeijer 2003; Polatto et al 2014), or can prevent bees from exiting the nest, especially on social bees who frequently remain inside to ventilate the nest (Michener 1974).

Solar radiation also plays a crucial role in bee foraging because bees need to be able to avoid obstacles and find their targets in the environment (Baird 2020; Baird et al 2020). Thus, some bees have a minimum light threshold for foraging that depends on the bee characteristics, especially on their eye and ocelli size (Kelber et al 2006; Warrant et al 2006; Warrant 2008). While a few bee species of *Ptiloglossa*, *Megalopta,* and some *Xylocopa* can forage with very few light conditions, such as early in the morning or at dusk (Kerfoot 1967; Willmer and Stone 2004; Greiner et al 2007; Somanathan et al 2009; Berry et al 2011), most bees have to concentrate their foraging during lapses with abundant light (Heard and Hendrikz 1993; Willmer and Stone 2004; Gouw and Gimenes 2013).

It has been suggested that humidity can change foraging patterns in some bees, such as *A. mellifera* (Alves et al 2015), Megachilid bees (Abrol 1998), and some stingless bees, such as *Plebeia* (Kleinert-Giovannini 1982), *Tetragonisca* (Iwama 1977), *Trigona* (Contrera et al 2004; Soares et al 2019), *Geotrigona* (Gobatto and Knoll 2013), *Lepidotrigona* (Sung et al 2011) and *Melipona* (Hilário et al 2000; Guibu and Imperatriz-Fonseca 1984, Fidalgo and Kleinert 2007). In some of these cases, foraging behavior

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tended to be inversely proportional to relative humidity. Thereby, relative humidity can have a substantial effect on bee behavior. For example, low humidity conditions can cause dehydration in bees (Polatto et al 2014), and high humidity can interfere with the bee's capacity to manipulate and pack pollen loads (Corbet 1990). High wind speeds can force bees to invest large quantities of energy in stabilizing and countering wind gusts during the flight (Combes and Dudley 2009; Goodwin et al 2011) and hinder the bee from landing on the flowers for foraging (Chang et al 2016).

Despite the above considerations, environmental factors do not act separately in nature. Together, they could create conditions that can result favorably (or not) for bees, depending on their characteristics (biology, body size, color, pubescence, etc.), which can affect their daily foraging patterns (Willmer and Stone 2004; Polatto et al 2014). Although there are many studies on the influence of environmental conditions on bee foraging behavior, most of them focus on the impact of local conditions on an individual species of bee and on bee diversity (Meléndez 1997; Nikolova et al 2016; Tarakini et al 2021), or bee frequency on flowers (Meléndez 1997; Omoloye and Akinsola 2006; Thakur 2007; Abrol 2010; Sandoval-Molina et al 2020). Impacts of environmental conditions on other aspects of bee foraging behavior have not been studied yet, such as the number of visits and the duration of the visits to the flowers. Ecologically and economically, this is a crucial component of bee visitation, as there is a known correlation between the time that the bees spend in the flowers and the pollen grains deposited on the stigma (Thomson and Plowright 1980), as well as the pollination efficiency of bees on many plant species (Manetas and Petropoulou 2000; Sadeh et al 2007).

In this paper, we study the influence of environmental conditions on the foraging behavior of the most common bees visiting watermelon crops in Los Santos, in the Republic of Panama. This is especially important since watermelon is the most commercially important Cucurbit in Panama (MIDA 2017) and one of the most important fruits in the world (Yong and Guo 2016). This crop is highly dependent on bees for its pollination, so it is crucial to learn the most important factors affecting bee behavior on the crops, especially in the Neotropics, where very few studies have been made on the subject (Meléndez et al 2002). These studies can ultimately contribute to better management of the bees used to pollinate the region's crops.

2. Materials and Methods

2.1. Study Area

During 72 days (n=72), we observed watermelon crops in Villa Lourdes locality of Los Santos province in Panamá, with coordinates 7°48'59.8"N 80°28'30.8"W. The crops are located in Peninsula de Azuero, a mostly lowlands region (about 15 m.s.n.m.), with an average rainfall from 1000 a 1600 mm and a dry season from January to April, which is frequently used for cropping watermelon, melon, and other Cucurbits (Barba et al 2015). According to Holdridge classification, the zone corresponds to Dry forest (ANAM 2009). The original vegetation has been mostly degraded in favor of cattle ranching and crop agriculture (Bennett 1965) and actually consists of trees such as *Jatropha curcas*, *Bursera simaruba*, *Gliricidia sepium, Spondias mombin, Cedrela odorata, Guazuma lmifolia* y *Cordia alliadora* (Metzel and Montagnini 2014).

Observations were conducted in four contiguous parcels, each about one hectare, and planted alternatively, so the flowering did not coincide. In each crop, we made observations for about three weeks, between January and April 2020.

2.2. Bee observations

The observed plant was selected by dividing the crop into eight sections. Each day we randomly selected a number between 1 and 8; on the selected section, we chose a plant with at least one male and one female opened flowers. Observations of bee foraging behavior were conducted with a modified methodology by Veddeler et al (2006) and Polatto et al (2014). Each day we recorded bee visits on the selected flowers for 20 minutes each hour, from 7:00 to 13:00 h, by direct observation from a distance of 1 to 2 meters from the flowers. We registered the visiting bee's identity, the visit's duration, and the environmental conditions at the beginning of the 20 minutes period. We only accounted visits to the flowers when the bee touched the sexual structures of the flower and remained on the flower for more than 1 second. Environmental conditions were recorded with a BTMeter BT-881D termo-luxometer (temperature and solar radiation), Wintact WT83B hygrometer (relative humidity), and Davis WindScribe anemometer (wind speed).

A previous three-week survey and sampling of bees visiting the crops were made to identify bees. These bees were identified using Michener (2000) and Roubik (1992) identification keys.

2.3. Statistical analyses

To have a more robust statistical analysis, we only considered the bee groups who made more than 150 visits during the 72 observation days, representing more than 97% of the total registered visits (4795). Our data was processed using RStudio 1.4.1106 and MS Excel^{TM} of Office 2016. The Pearson correlation coefficient calculated the relationship between environmental conditions (Temperature, Solar Radiation, Relative Humidity, and Wind speed). To analyze the relationship between environmental conditions and the number of visits/duration, we used Generalized Lineal Model (GLM) with the Poisson distribution. We also determined collinearity between environmental conditions using the Variance Inflation Factor (VIF) as part of the GLM analysis. Relative Humidity showed very high collinearity with the rest of the measured environmental conditions, especially temperature (VIF = 12.2), and GLM showed a lower AIC when excluding Humidity of the model, so to avoid masked data, we carried an independent GLM test for humidity. Finally, we constructed graphics with proportional activity and duration of the visits for the most common groups of bees during the day and the average environmental conditions for the corresponding observation period. The proportional activity of the bees was calculated by dividing the visits of each group of bees during each hour against the total number of visits for the group during the 72 days of observations.

3. Results

During the 72 observation days, five groups of bees registered more than 150 visits. They were *Nannotrigona perilampoides* (3137)*, A. mellifera* (1007), *Lasioglossum* spp. (168), *Augochlora* spp*.* (179), y *Augochloropsis* spp*.* (156). Our study showed a very strong correlation between temperature and humidity (-0.95), solar radiation and humidity (-0.90), and temperature and solar radiation (0.88). A weaker correlation was observed between solar radiation and humidity (-0.67), solar radiation and wind speed (0.66), and temperature and wind speed (0.63). The relationship between environmental conditions and bee foraging was as follows.

3.1. Temperature

During the 72 observation days, the temperature increased as the day progressed (Figure 1). Visits of *A. mellifera*, *N. Perilampoides, Lasioglossum* spp., and *Augochlora* spp. showed a relationship with temperature ($P < 0.05$), while *Augochloropsis* spp did not (Table 1). On the other hand, the accumulated proportion of visits showed a maximum peak of visits for *A. mellifera* when average temperatures were about 26 and 29 °C (between 7:00 and 8:00 hs) and then dropped (Figure 1a). In contrast, the rest of the bees registered a less pronounced maximum peak of visits that typically occurred at middle temperatures, between 34 and 40 °C (about 9:00 and 11:00 h) (Figure 1a). Visit duration did not show a relationship with temperature for honey bees, but it did for the rest of the studied bees ($P < 0.05$, Table 2). Furthermore, the accumulated visit duration presented its maximum average peak for *N. perilampoides* at low temperatures between 26 and 29 °C, then decreasing as temperatures increased (Figure 2a). In contrast, *A. mellifera* and *Augochloropsis* spp. increased the time spent on visits until reaching its maximum at middle temperatures, about 40 °C (11:00 h), then decreasing again. Moreover, *Lasioglossum* spp and *Augochlora* spp bees showed two visit duration peaks, a secondary at 29 °C (8:00 h) and a primary at 40 °C (Figure 2a).

Table 1 GLM results for the environmental conditions and its relationship with the number of visits and visit duration for the most important bees observed during the observations (72 days).

		Number of Visits			Duration of Visits		
Bee Group		Estimate	Z-value	*P*-value	Estimate	Z-value	*P*-value
N. perilampoides	Intercept	2.108	14.76	<0.0001*	3.242	30.31	<0.0001*
	Temperature	-0.01546	-2.947	<0.01*	-0.02014	-5.077	<0.0001*
	Solar Radiation	$1.03x10^{-06}$	1.44	0.1498	$2.963x1^{0-06}$	5.653	<0.0001*
	Wind Speed	0.04584	5.584	<0.0001*	-0.01993	-3.188	<0.01*
A. mellifera	Intercept	6.153	16.69	<0.0001*	1.645	7.225	<0.0001
	Temperature	-0.148	-10.2	<0.0001*	0.0117	1.399	0.1617
	Solar Radiation	$-1.2x10^{-05}$	-5.847	<0.0001*	$-1.98x10^{-06}$	-1.77	0.07672
	Wind Speed	-0.1355	-5.77	<0.0001*	0.022	1.781	0.07491
Lasioglossum spp.	Intercept	0.4098	0.6475	0.5173	3.309	14.83	<0.0001*
	Temperature	-0.0716	-3.043	0.0023*	-0.02526	-3.047	<0.01*
	Solar Radiation	$7.55x10^{-06}$	2.421	0.0155*	$1.315x10^{-06}$	1.246	0.2128
	Wind Speed	0.0982	2.823	<0.01*	0.02289	1.857	0.06334
Augochlora spp.	Intercept	1.114	1.752	0.07979	3.687	14.23	<0.0001*
	Temperature	-0.08538	-3.58	<0.001*	-0.05665	-5.941	<0.0001*
	Solar Radiation	$-2.23x10^{-07}$	-0.0719	0.9427	$1.013x10^{-05}$	8.428	<0.0001*
	Wind Speed	0.2049	6.145	<0.0001*	0.01817	1.46	0.1442
Augochloropsis spp.	Intercept	-1.017	-1.582	0.1137	1.647	4.82	<00001*
	Temperature	-0.0199	-0.8478	0.3966	0.03861	2.974	<0.01*
	Solar Radiation	$4.35x10^{-07}$	0.1364	0.8915	$-3.31x10^{-06}$	-2.013	<0.05*
	Wind Speed	0.1182	3.289	<0.01*	-0.07532	-3.58	<0.001*

*Significant when $P < 0.05$.

3.2. Solar radiation

Solar radiation increased during the day, especially in the first hours, from 7:00 to 10:00 h (Figure 1). The relationship between visits and solar radiation showed variable results in the bees observed, with a high relationship for honey bees and a moderated relationship for *Lasioglossum* spp ($P < 0.05$). The other bees, *N. Perilampoides, Augochlora* spp., and *Augochloropsis* spp. did not show a significant relationship between visits and this environmental factor (Table 1). Honeybees showed they concentrate their foraging activity during low solar radiation levels during the first hours of observation (Figure 1b). In contrast, visits for the rest of the bees were more distributed during the observations, increasing with solar radiation until reaching its maximum at medium solar radiation levels, and then declining (Figure 1b). Visit duration revealed a relationship with solar radiation for *N. Perilampoides.*, *Augochlora* spp and *Augochloropsis* spp ($P < 0.05$), but not for honeybees and *Lasioglossum* spp (Table 1). Visit duration presented a peak at low solar radiation levels (10000 to 30000 Lux) for *N. perilampoides* and then declined when solar radiation increased. The visit duration for the rest of the bees is augmented with solar radiation until medium levels (10000 y 30000 Lux) and then decreases (Figure 2b).

3.3. Relative humidity

Relative humidity levels dropped throughout the day, starting at values around 75% and finishing at about 25% (Figure 1). Bee visits presented a strong correlation with humidity ($P < 0.05$), except for *Lasioglossum* spp. (Table 2). For honeybees, accumulated activity concentrated at high humidity values, between 75 and 65% (7:00 and 8:00 h), then dropped. Visit number was especially high at 80% relative humidity (7:00 h), constituting more than 65% of the visits during the day (Figure 1c). The other bee's activity increased as relative humidity decreased, reaching its maximum at 45% relative humidity (10:00 h), with a much less marked peak representing only between 25 and 35% of their activity during the day (Figure 1c). Visit duration was not related with humidity for most of the bees except *Augochlora* spp. (Table 2). Average visit duration was highest for *N. Perilampoides* at the highest humidities, between 75 and 65% (7:00 and 8:00 h), with very similar averages around 20%, and then declined (Figure 2c). Visit duration for the other bees increased between 60 and 30% relative humidity (8:00 and 11:00 h) (Figure 2c), with its maximum at 35%. *Lasioglossum* spp. and *Augochlora* spp. also presented secondary peaks at humidities around 65% (8:00 h) (Figure 2c).

3.4. Wind speed

The wind speed increased irregularly during the day (Figure 1). The number of visits indicated a strong relation with wind speed for all the bees studied ($P < 0.05$, Table 1). The maximum activity peak for *A. mellifera* happened at low wind speeds, between 0.5 and 1.2 km/h (7:00 and 8:00 h) (Figure 1d). The activity for the rest of the bees peaked at intermediate wind speeds around 2.5 and 3.5 km/h (9:00 and 11:00 h) (Figure 1d). Visit duration was strongly correlated with wind speed ($P < 0.05$) in *N. Perilampoides* and *Augochloropsis* spp, but not correlated for honey bees, *Augochlora* spp., and *Lasioglossum* spp. (Table 1). Average visit duration for *N. Perilampoides* reached its maximum when wind speed was lower, between 0.5 and 1.2 km/h (7:00 to 8:00 h) (Figure 2d). In contrast, the other bees showed the highest average durations at wind speeds around 1.2 and 3.4 km/h (8:00 to 11:00 h) (Figure 2d).

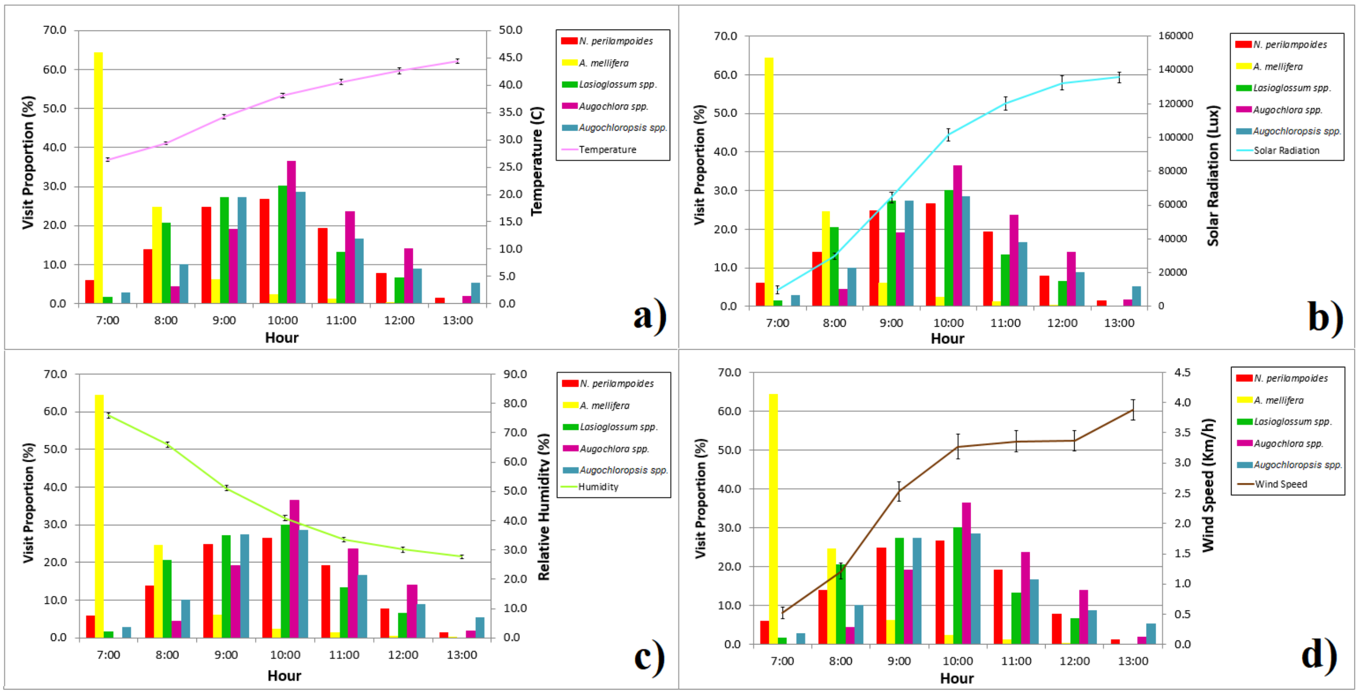

Figure 1 Visit proportion for each observation hour and its corresponding average environmental conditions of temperature (°C). (a) solar radiation (Lux), (b) relative humidity (%), (c) and (d) wind speed (km/h).

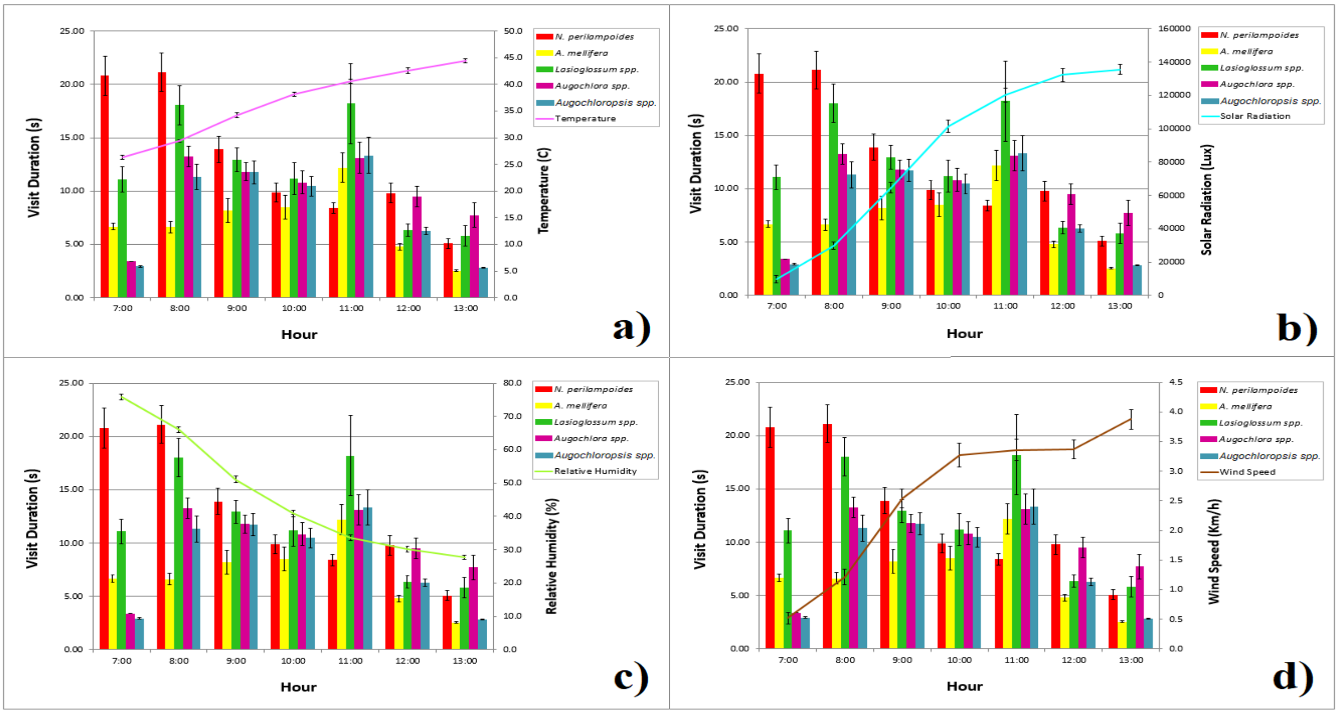

Figure 2 Average visit duration for each observation hour and its corresponding average environmental conditions of temperature (°C). (a) solar radiation (Lux), (b) relative humidity (%), (c) and (d) wind speed (km/h).

Table 2 GLM results for humidity and its relationship with the number of visits and average visit duration for the most important bees observed during the observations (72 days).

	Number of Visits				Visit Duration			
Bee Group	Estimate	Z Value	Intercept (Estimate)	*P*-value	Estimate	Z Value	Intercept (Estimate)	*P*-value
N. perilampoides	-0.002812	-2.904	1.957743	<0.01*	0.001094	1.528	2.625	0.1265
A. mellifera	0.09236	31.48	-5.02462	<0.0001*	-0.002222	-1.463	2.1	0.1433
Lasioglossum spp.	-0.006358	-1.492	-0.810087	0.1356	0.002093	1.465	2.506	0.143
Augochlora spp.	0.009852	2.532	-1.51	<0.05*	-0.0149	-7.9	3.274	<0.0001*
Augochloropsis spp.	-0.01162	-2.546	-0.6556	<0.05*	0.00143	0.654	2.359	0.5131

*Significant when $P < 0.05$.

4. Discussion

Our study showed for the first time that environmental factors play a major role in the bee foraging behavior of bees in a Neotropical area like Panama, in Central America, affecting both the number of visits and the duration of visits.

Most of the bees we studied presented a clear relationship between visit number and temperature (Table 1). This relationship has also been reported in studies for bees in temperate and subtropical zones on honeybees (Wratt 1968; Abrol 2006; Alqarni 2015), Halictid bees *Halictus ligatus* (Richards 2004), and some stingless bees in Brazil, on *Scaptotrigona depilis* (Aleixo et al 2017) and *Plebeia pugnax* (Hilário et al 2001).

We observed that honey bees started foraging even before the first observation period (7:00h) and were more active at lower temperatures than other bees with smaller bodies, particularly between 26 °C (7:00h) and 29 °C (8:00h) (Figure 1a). A similar trend was described by Pereboom and Biesmeijer (2003), Gouw and Gimenes (2013), Polatto et al (2014), and it is usually attributed to the fact that larger bees can regulate their temperature by buzzing their flying muscles, warming their bodies for reaching the threshold flying temperature. Because of this, they are frequently considered "endothermic" (Willmer and Stone 2004; Polatto et al 2014). However, our study site is located in the tropics, and temperatures were never below 22 °C, so it is possible that temperature is not the only or the most important factor determining when bees start foraging. Still, it maybe is a combination of the environmental factors acting on the bees. Thus, we observed that honey bees practically stop foraging at temperatures above 29 °C (representing less than 10% of the visits) and were not observed foraging at those conditions in the nearby vegetation. This temperature is below the reported temperature tolerated by foraging honey bees, about 40 °C (Cooper and Schaffter 1985; Blažytė-Čereškienė et al 2010).

In contrast, the foraging activity of the other observed bees (all with smaller sizes) started at warmer temperatures and presented less pronounced activity peaks representing only about 25 to 35% of the total visits during the day. These bees also remained active at higher temperatures than honeybees, showing greater tolerance to heat. Some studies have found that small bees and other insects tolerate higher temperatures (Linsley 1978; Willmer 1983; Herrera 1990; Hart and Eckhart 2010), suggesting that smaller insects generate less metabolic heat from flying. Small bees also have more surface per volume proportion, so they tend to dissipate heat easier, decreasing the risk of lethal over-heating during flying at high temperatures (Digby 1955; Willmer 1981; Willmer and Stone 2004; Bishop and Armbruster 1999; Pereboom and Biesmeijer 2003; Hrncir and Maia-Silva 2013).

Visit duration of honeybees did not show a relationship with temperature or the other environmental factors studied. This can be explained by considering larger bees can forage more independently of environmental conditions, as pointed by Polatto et al (2014). On the other hand, *N. perilampoides* duration peak at low temperatures (25 to 30 °C) could be related to the food source they are foraging. Pollen collection is typically more complicated than nectar, requiring more time per visit (Raine and Chittka 2007). Yet, this can't explain why other observed small bees did not show a similar duration pattern. Pollen availability normally declines once male flowers open early in the morning (Roubik 1989). Its gathering is probably a top priority for highly social bees such as *N. perilampoides* since they require large amounts of pollen for feeding the larvae. In contrast, the other small bees observed (Halictids) are typically solitary or primitively eusocial, so they probably have less pollen requirements during the day.

The number of visits of *N. perilampoides, Augochlora* spp., and *Augochloropsis* spp. did not have a relationship with solar radiation (Table 1). This was unexpected because, in general, is considered smaller bees are more affected by low light levels (Streinzer et al 2016). For example, Sung et al (2011) observed that *Lepidotrigona hoozana* remained foraging late on the day, as long as the amount of light was enough for navigating. However, we can see a clear pattern of honeybees start foraging earlier and at lower light conditions than smaller bees (Figure 1). It has been demonstrated that larger bodies, and consequently larger eyes and ocelli (Kerfoot 1967), are more acute and sensitive at low light levels, allowing them to navigate under darker conditions (Jander and Jander 2002; Kapustjanskij et al 2007; Streinzer et al 2016). This ability has been used by some bee species (including, in some cases, honeybees) for exploiting food resources available in low light conditions to avoid competition (Dyer 1985; Sihag 1993; Wcislo et al 2004; Kelber et al 2005; Somanathan et al 2008; Smith et al 2017).

The visit duration of *N. perilampoides* at low illumination levels contrasts with the rest of the observed bees. It's also remarkable that the secondary peak of visit duration for *Lasioglossum* spp. and *Augochlora* spp. at 8:00 h, and it could be related to species biology. For example, male bees can use flowers as perch for mating, a behavior reported in some species of *Lasioglossum* (Barrows 1975; 1976).

Humidity could be one of the most important environmental factors in bee foraging behavior, especially considering the strong humidity gradient during the day, as shown in our study (Figure 1,2). Many studies agree on the relationship between relative humidity and bee foraging activity (Erickson and Buchmann 1983; Corbet 1990, Sung et al 2011; Alves et al 2015) and point direct and indirect effects on the bees (Corbet 1990). Directly, the flight can be difficult for bees under humid conditions, and pollen collection can also be problematic, as pollen grains can fail to adhere to a humid body because of electrostatic charges, which makes it harder for corbiculated bees to pack humid pollen loads (Erickson and Buchmann 1983; Corbet 1990). Indirectly, humidity can strongly affect flowers since humidity can change the color and structure of flowers and change nectar secretion or sugar concentration of nectar, making flowers less attractive to bees (Corbet 1990). This has been reported in watermelon crops before (Carr 1967).

In our study, visit numbers revealed a high negative relationship with humidity for most bees, except *Lasioglossum* spp. (Table 2). The Figure direct relationship between humidity and honey bee visits, and the inverse for smaller bees (Figure 1c), is consistent with the pattern Burdine and McCluney (2019) observed between the small *Agapostemon sericeus* and the larger honey bees. Other studies also found small bees prefer foraging at low humidity levels, as observed for *Tetragonisca* spp. (Iwama 1977), *Plebeia* spp. (De Oliveira 1973; Kleinert-Giovanini 1982; Pick and Blochtein 2002) and *Partamona bilineata* (Meléndez 1997). This pattern could result from both humidity and temperature interacting over the bees and creating conditions more adequate for small bees at high temperatures and low humidity levels.

Bee activity of small bees was less affected by wind speed (Figure 1d), contrasting with observations of Viana and Kleinert (2005) and coinciding with the results of Hilário et al (2007), who found *Plebeia remota* small bees registered activity peaks at high wind speed conditions. This trend could be related to high-speed gusts helping smaller bees to dissipate heat by convective action of air, as it has been suggested by Digby (1955), Willmer and Unwin (1981), Bishop and Armbruster (1999), Pereboom and Biesmeijer (2003), Polatto et al (2014).

5. Conclusions

We can conclude environmental conditions strongly affect the foraging behavior of bees visiting watermelon crops in Los Santos, Panama, both in the number of visits and in the duration of the events. Environmental conditions act together, forging particular foraging patterns for each group of bees, depending on their characteristics. Bees concentrate their activities at particular environmental conditions according to their biology, avoiding times that can hinder their foraging or even be dangerous. Smaller bees focused their visits on avoiding extreme conditions early and late in the day; meanwhile, honeybees focused their activity early in the morning, helping to avoid high temperatures, solar radiation, wind speed, low humidity, and possibly competition with other bees. Understanding the foraging patterns of bees on watermelon crops requires consideration of other important factors in future studies, such as availability of floral rewards, food choice by bees (pollen/nectar), visits to male/female flowers, and competition of bees for flowers. The results of this study can be useful for making more efficient use of the bees managed for pollinating watermelon crops in Panama and other countries in the region, regulating crop management. Hence, human activities have a lower impact on the bee pollination of the flowers.

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Conflict of Interest

No potential conflict of interest was reported by the authors.

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