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Daily activity patterns of visits by males of four species of *Eulaema* (Apidae: Euglossina) to odor baits in a tropical forest fragment in Bahia, Brasil

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ABSTRACT. Several studies have been conducted with bees of the subtribe Euglossina using odor baits as attractants. The objective of this study was to analyze the daily activity pattern of visits by males of four species of *Eulaema* – *Eulaema nigrita* Lepeletier, 1841, *Eulaema flavescens* (Friese, 1899), *Eulaema cingulata* (Fabricius, 1804) and *Eulaema bombiformis* (Packard, 1869) – to vanillin and benzyl acetate baits, and their relationship with climatic and environmental factors throughout the day in different months of the year in a tropical forest fragment in Bahia. *Eulaema nigrita* was the most frequent species on vanillin baits and *E. flavescens* was the most frequent species on benzyl acetate baits. The highest frequency of visits was observed in February and December. Activities started between 5:00 and 9:00 h. In February and November, visits of *E. nigrita* to the bait were observed daily, following a bimodal pattern. The same activity pattern was observed for *E. bombiformis* in December. Males of four species of *Eulaema* occurred in all remaining months in a unimodal daily activity pattern, with a higher frequency before 9:30 h. The correlation between the visiting activity to odor baits and climatic factors was low. This result can be due to bee flight activity occurring within a range of adequate climatic variation, particularly temperature, which in our study ranged from 23 to 32ºC. Daily activity patterns of Euglossina males on odor baits can represent patterns of flower fragrance collection under natural conditions, with visits usually at the time of highest production.

KEY WORDS. *Eulaema*; odor baits; ombrophylous forest; orchid bees.

Bees of the subtribe Euglossina (Hymenoptera, Apidae, Apini) are widespread in the Neotropical Region, occurring from northern Argentina to southern United States. It is composed of five genera (*Aglae* Lepeletier & Serville, 1825, *Exaerete* Hoffmannsegg, 1817, *Eulaema* Lepeletier, 1841, *Eufriesea* Cockerell, 1908, and *Euglossa* Latreille, 1802), and includes around 175 species (Rebêlo 2001). Although occurring in different biomes, Euglossina presents higher diversity in humid forests (Silveira *et al*. 2002). Their body size is moderate to very large, moderately to densely hairy, and some species are brilliantly metallic and hairless (Michener, 2000, Rebêlo 2001).

Some species of Euglossina are non-social, whereas others form small aggregations (Zucchi *et al*.1969, Rebêlo 2001). Males and females are able to fly long distances in the environment (Dressler 1968, Ackerman *et al*. 1982). Unlike females, males do not return to the nest after leaving it (Williams & Whitten 1983, Ramírez *et al*. 2002, Rebêlo 2001).

Euglossina males are specialized in collecting fragrances from a variety of angiosperm flowers, mainly orchids (Dressler 1968, 1982, Williams & Whitten 1983). These males can also collect fragrances from fruits, rotten wood and roots, trunks of live trees, exposed roots (Dodson 1966, Dressler 1982, Ackerman 1989), and leaf mesophyll (Ramalho *et al*. 2006). Flower fragrance collection by Euglossina males is an important event for pollination of several species of plant (Dodson *et al*. 1969, Ackerman 1983a, b). Some authors suggest that males can use the fragrance for sexual attraction (e.g. Brito 2001), as a precursor of the pheromone used in attracting females (Ackerman 1989) and also as attractive to other conspecific males to form aggregations that possibly work as a predator deterrents (Eltz *et al*. 2005).

Bee and flower encounters, which can result in flower pollination, require morphological and temporal adjustments between both biological systems. The influence of climatic factors and environmental cycles on the temporal adjustments between bee visits to flowers, particularly temperature and photoperiod, has been reported by Gimenes (2002, 2003) and Gimenes *et al*. (1993, 1996), in studies on daily and annual bee activity on flowers of *Ludwigia elegans* (Camb.) Hara (Onagraceae). Several authors observed the effect of climatic factors on bee foraging activities. Imperatriz-Fonseca *et al.* (1985) studied the relationship between climatic factors (temperature and relative humidity) and the flight activity of eusocial bee *Plebeia remota* Holmberg, 1903 (Apidae: Meliponinae) at the nest entrance. Kajobe & Echazarreta (2005) did similar studies in *Meliponula ferruginea* (Lepeletier, 1841) and *Meliponula nebulata* (Smith, 1854). All of these studies show a positive relationship between number of bees leaving the nest and temperature, but until reaching a plateau when further increase in temperature has the opposite effect.

The use of artificial fragrances in odor baits to attract Euglossina males is a standard methodology used different types of studies. These artificial odors mimic a number of natural fragrances of angiosperms, particularly those of Orchidaceae (Dressler 1968, 1982, Williams & Whitten 1983). Studies using these odor baits have advanced our understanding of climatic and environmental factors affecting the flight activities of Euglossina males (Armbruster & McCormic 1990, Santos & Sofia 2002, Silva & Rebêlo 2002, Viana *et al*. 2002).

This study aims to analyze the daily activity patterns of four species of Euglossina males – *Eulaema nigrita* Lepeletier, 1841, *Eulaema flavescens* (Friese, 1899), *Eulaema cingulata* (Fabricius, 1804) and *Eulaema bombiformis* (Packard, 1869) – visiting vanillin and benzyl acetate baits and to evaluate the effects of climatic (temperature, relative humidity, and light intensity) and environmental factors (sunrise and sunset times) on their activity pattern.

MATERIAL AND METHODS

The study was conducted in 2006, in an approximately 165.6-ha urban fragment of a dense, secondary ombrophylous forest with palm trees (Brazil 1981) and exotic species, in Salvador, state of Bahia (12°57’33”S, 38°27’34”W, altitude between 11 and 64 m). The area is delimited by streets, avenues, and inhabited areas; some of the area belongs to the Brazilian Army, 19º Batalhão de Caçadores (19 BC).

According to Köppen’s classification, Salvador has a hot and humid tropical climate. In 2006, the year of this study, monthly mean temperatures varied between 20.2°C (minimum) in June and 32.6°C (maximum) in February. The rainy season was from April to June, coinciding with the lowest temperatures in May and June. In the dry season, from December to March, temperatures were higher (Fig. 1).

During the day, the lowest average temperature (24°C) and the highest average relative humidity (86%) were observed between 5:00 and 6:00 h. The lowest average relative humidity (65%) and the highest average temperature (29°C) were recorded between 11:00 and 13:00 h.

The data were collected from 5:00 to 18:00 h. (approximately from sunrise to sunset), during three days in the months of February, April, June, September, November, and December 2006, for a total of eighteen observation days in a shady and cleared forest area. The visits of Euglossina males to the odor baits were recorded for 25 min for each kind of fragrance, every hour. A visit was recorded every time the bee touched the exterior of the trap collector with the legs.

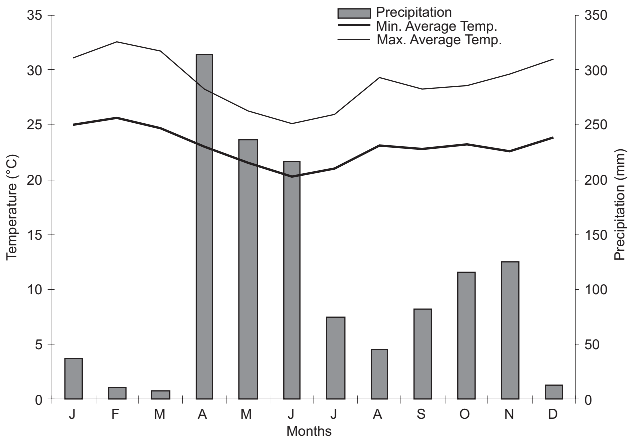

Figure 1. Climatic data referring to average temperature (maximum and minimum) and rainfall in the municipality of Salvador, from February to December 2006. Source: www.agritempo.gov.br.

Preliminary trials with six fragrances (vanillin, benzyl acetate, betaianone, methyl salicilate, eugenol, and eucalyptol) were conducted for three days in January 2006, to select most attractive fragrances for bees. Two fragrances were the most visited by bees and were therefore selected for the study: vanillin and benzyl acetate. The daily activity pattern was based on the four most common species in the baits: *E. nigrita*, *E. cingulata*, *E. bombiformis*, and *E. flavescens*.

A system of sheltered odor baits was developed to attract Euglossina males. Each system consisted of a cotton ball approximately 2 cm in diameter embedded in one of the fragrances (the bait), and placed within a white plastic container normally used for clinical analyses. The bait container had eight holes (3 cm diameters). A nylon thread attached each container to a metal hook, which was epoxy-glued to a plastic lid covered with aluminium foil. The traps were put in open areas in the forest. Each bait container was placed on a tree branch suspended 1.5 m from the ground and in a place without direct sunlight (following Rebêlo 2001).

Two bait containers, each with different essences, were placed usually between 10 to 22 m apart. The odor baits were supplied throughout the day and checked to replenish the essence whenever necessary.

Voucher specimens have been deposited at the Museu de Zoologia do Instituto de Biologia, Universidade Federal da Bahia (UFBA), and at the Entomological Collection of the Universidade Estadual de Feira de Santana (UEFS).

The analysis of daily activity patterns of bee visits to odor baits was done by means of the Rayleigh test and the Circular Statistics method (Batschelet 1980), considering the mean vector (r) significant at 0.7 (varying from 0 to 1, which indicates data dispersion). The analyses only included N values (number of visits) greater than 10.

Data normality was assessed by the Kolmogorov-Smirnov and the Shapiro-Wilk tests. The correlation between each climatic factor (temperature, relative humidity, or light intensity) and the number of visits was analysed by means of the Pearson (r) Correlation Coefficient. The Coefficient of Determination (R^2) was used for determining (%) the influence of all three climatic factors on the number of visits. Statistical analyses were conducted using SPSS 9.0.

The 2006 macroclimatic data on average temperature and monthly rainfall were obtained from www.agritempo.gov.br. Sunrise and sunset times were obtained at www.geobusca.net. Daily microclimatic data (temperature, relative humidity, and light intensity) were recorded every 15 minutes during observations.

RESULTS AND DISCUSSION

The vanillin and benzyl acetate baits were visited by males of *E. nigrita*, *E. flavescens*, *E. cingulata*, and *E. bombiformis*. *E. nigrita* was the most frequent species in vanillin baits, whereas the remaining species were most frequent in benzyl acetate baits. Previous studies on Euglossina bees visiting odor baits in forest fragment in the city of Salvador found high frequencies of visit by *E. nigrita* (Raw 1989, Viana *et al*. 2002, Neves & Viana 2003).

Data obtained in our study on the number of bee visits to baits are presented in table I. In general, the highest number of bee visits to odor baits was recorded in February for all four species, particularly for *E. nigrita*, *E. flavescens*, and *E. cingulata* (Tab. I). The smallest number of visits by Euglossina males to vanillin and benzyl acetate baits was recorded in June. Rainfall and temperature could affect bee activity during the year because months with higher numbers of visits to baits were also months of low rainfall and high temperature. The month with fewest visits was also the month with highest rainfall and lower temperature (Fig. 1). Ackerman (1983c) observed in Panama increased activity of males of species of *Eulaema* in odor baits during the dry season and beginning of the rainy season and he recorded the lowest level of activity in the rainy season. It is possible that the increased visits to the odor baits could be also due to the flowering of angiosperms with similar fragrance to those used in the odor baits. Ackerman (1983b) reasoned that increased visits of Euglossina males to odor baits in the tropical rainforest of Barro Colorado Island might be also linked to orchids flowering.

The daily visits of Euglossina males to the benzyl acetate and vanillin baits usually occurred after sunrise. Activities started generally earlier in November, December and February, between 5:00 and 7:00 h., and later in April and September, usually between 5:30 and 9:00 h. At those hours, the temperature varied from 23 to 28°C, light intensity from 19 to 7190 lux, and relative air humidity between 58% and 90% (Tab. II).

Variation in climatic factors apparently did not have an effect on the beginning of activities by the bees when visiting the odor baits (Tab. II). Temperature values during the first bee visits to baits were near the interval considered by several authors as suitable for their foraging activity in tropical regions. Armbruster & McCormick (1990), working with males of species of *Euglossa*, *Eulaema* and *Exaerete* in Suriname, Trinidad and Costa Rica; Armbruster & Berg (1994), working in plains of a tropical rainforest in Venezuela; and Silva & Rêbelo 2002 in Maranhão, Northeast Brazil, found that these bees started the flight activity at temperatures above 23°C.

In February, most visits of *E. nigrita* to the vanillin baits were made approximately from 6:00 to 10:00 h. and from 13:00 to 16:00 h; in November, from 5:00 to 8:00 h. and from 13:00 to 14:00 h (Fig. 2). The same activity pattern was observed for *E. bombiformis* in December for visits to the benzyl acetate bait, with most visits between 8:00 and 9:00 h. and 14:00 and 17:00 h (Fig. 3). At these hours, the temperature ranged from 24 to 32ºC.

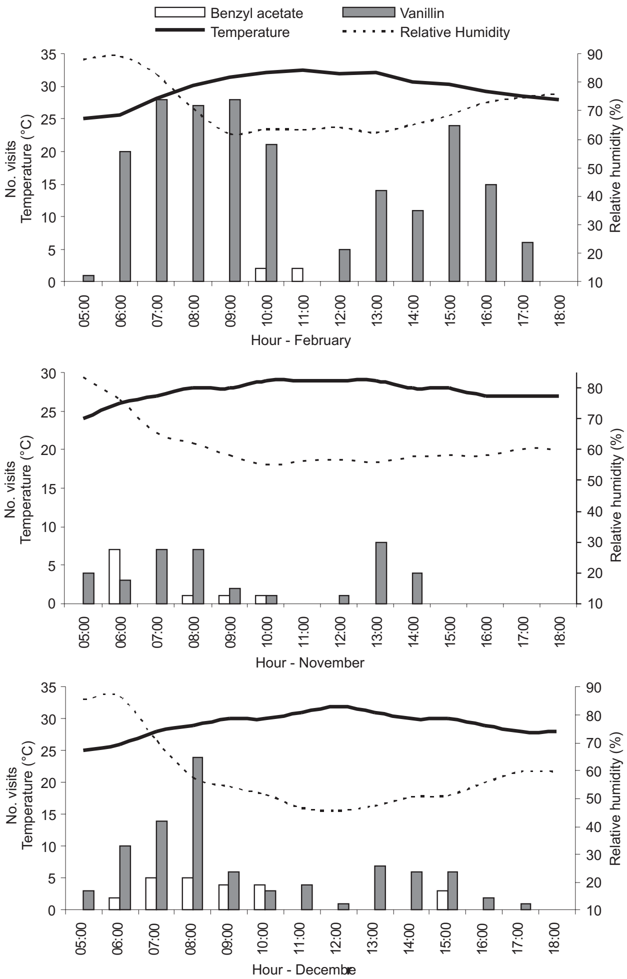

Figure 2. Distribution of *Eulaema nigrita* visits to vanillin and benzyl acetate baits during photophase in February, November and December 2006.

Table I. Number of visits of Euglossina males to vanillin and benzyl acetate odor baits in 2006. BA (benzyl acetate), VAN (vanillin), *E. nigr.* (*E. nigrita*), *E. flav.* (*E. flavescens*), *E. cing.* (*E. cingulata*), *E. bomb.* (*E. bombiformis*).

Months	*E. nigr.* BA	*E. nigr.* VAN	*E. flav.* BA	*E. flav.* VAN	*E. cing.* BA	*E. cing.* VAN	*E. bomb.* BA	*E. bomb.* VAN	Total
Feb.	4	200	57	4	54	21	33	2	375
Apr.	4	14	8	3	8	3	1	0	41
Jun.	0	0	2	0	11	1	0	0	14
Sep.	2	18	12	1	9	0	2	0	44
Nov.	10	37	5	7	3	1	8	0	71
Dec.	23	87	19	12	10	1	26	0	178
Total	49	382	126	29	108	31	73	2	800

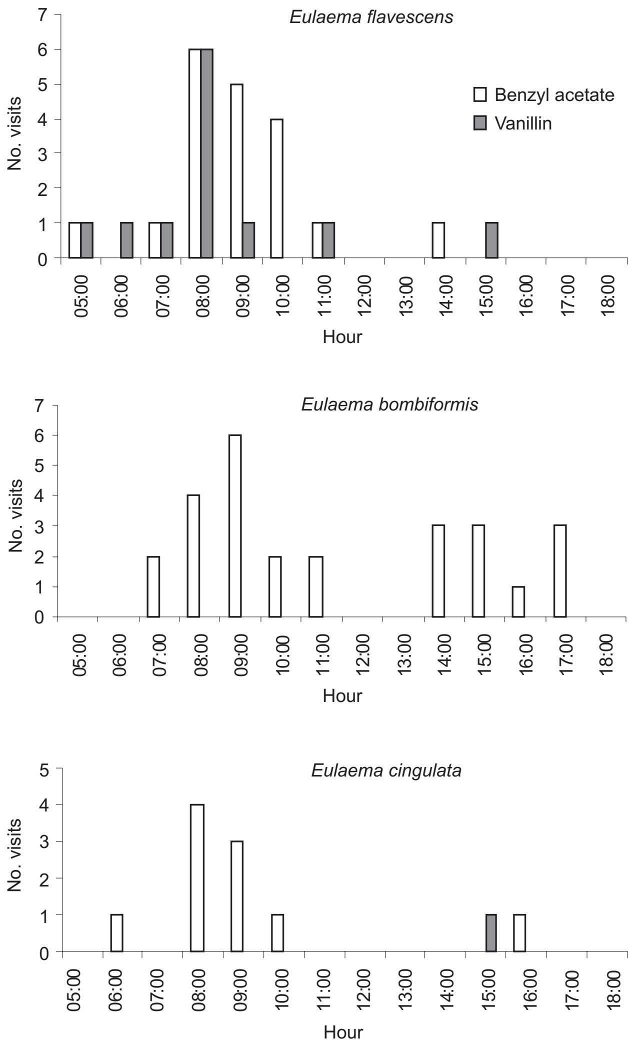

Figure 3. Distribution of *Eulaema bombiformis*, *E. flavescens* and *E. cingulata* visits to benzyl acetate and vanillin baits during photophase in December 2006.

Table II. Times of first visits of *E. nigrita* (*E. nigr.*), *E. bombiformis* (*E. bomb.*), *E. flavescens* (*E. flav.*), and *E. cingulata* (*E. cing.*) in February, April, September, November and December 2006 and respective values for climatic variables. (VAN) vanillin, (BA) benzyl acetate, (RH) relative air humidity, (T) temperature, (LI) light intensity.

Variables	*E.nigr.*(VAN)	*E.bomb.*(BA)	*E.flav.*(BA)	*E.cing.*(BA)
February				
Hour	5:45	6:00	5:42	5:42
T (°C)	25	24	24	24
RH (%)	90	90	90	90
LI (lux)	147	206	67	67
April				
Hour	6:42	7:00	7:16	7:00
T	24	24	25	24
RH	90	90	90	90
LI	107	662	827	662
September				
Hour	7:45	9:00	5:30	8:00
T	26	27	23	26
RH	60	58	82	67
LI	2940	7190	134	1900
November				
Hour	5:30	5:15	7:00	8:00
T	23	23	27	28
RH	88	86	72	58
LI	150	73	626	919
December				
Hour	5:20	7:00	05:04	6:30
T	24	27	25	26
RH	84	69	80	90
LI	80	573	19	504

The tendency for male visiting activity on baits to be bimodal in February, November and December can also be inferred by their departure from a normal distribution, as indicated by the Shapiro-Wilk and the Kolmogorov-Smirnov tests, and by the absence of significance according to the Rayleigh test of the Circular Statistics method (Tab. III).

In this study, the bimodal daily activity pattern of *E. nigrita* and *E. bombiformis* males visiting odor baits cannot be explained by weather variations given that no correlation was found between frequency of visits to baits and climatic factors (temperature, relative humidity, or light intensity during February, November and December. This pattern could be due to the availability of floral resources produced at that moment. Both explanations, climatic factors and the time when floral fragrances are released, should be taken into account to explain bimodal patterns of visits by bees.

Gottlieb *et al*. (2005) also observed that the bimodal activity pattern of *Proxylocopa olivieri* (Lepeletier, 1841) (Apidae, Xylocopini) in semi-arid areas in Israel were associated with the timing of nectar production by flowers of *Antirrhinum majus* Linnaeus (Scrophulariaceae), their main food source, and with the joint effect of high temperature (25 to 35ºC) and low light intensity, as these activities only occurred at dusk. Armbruster & Berg (1994) found that *Eulaema* spp. males avoided direct sunlight in spite of their endothermic regulation ability, because overheating could decrease their foraging activity.

Stone *et al* (1999) studied *Anthophora pauperata* Walker, 1871 (Apidae, Anthophorini) and found a clear daily bimodal foraging pattern with two activity peaks: one in the morning and the other in the afternoon, with an interval of two to three hours in the middle of the day, when the bee built nest cells in the ground. The authors concluded that the bee foraging pattern could not be explained only by the action of environmental temperature, which was considered moderate during the study, but also by the daily pattern of pollen release from its main food resource (*Alkanna orientalis* (Linnaeus) Boiss, Boraginaceae).

Collection activities of *E. nigrita* for the other months followed an unimodal daily activity pattern, with times referring to mean angles varying from 9:04 h. in December to 10:23 h. in April (Tab. III) on the vanillin bait, and from 6:51 h. in November to 8:45 h. in December for the benzyl acetate bait. In April, a negative correlation with relative humidity for collection on vanillin baits, and a positive correlations with light intensity for vanillin and benzyl acetate baits were observed. In September, light intensity was positively correlated with vanillin collection, although the number of visits was low in these two months (Tab. I).

The daily activities of *E. flavescens*, *E. Bombiformis*, and *E. cingulata* in February and December on benzyl acetate and vanillin are shown in figures 3 and 4. The daily activity patterns during these months was unimodal for these bees, with mean angles varying from 8:08 and 8:48 h for benzyl acetate and at

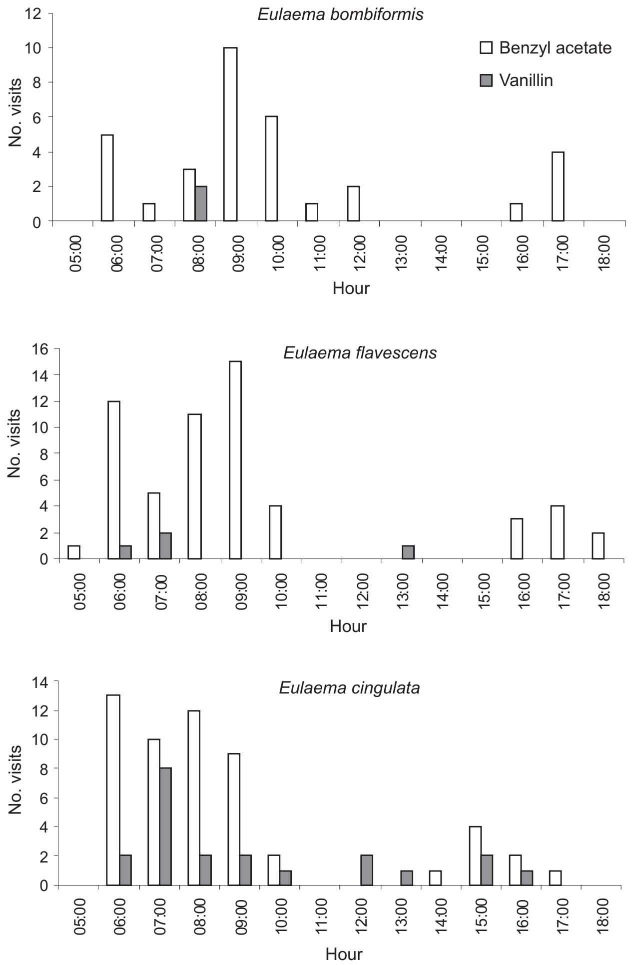

Figure 4. Distribution of *Eulaema bombiformis*, *E. flavescens* and *E. cingulata* visits to benzyl acetate and vanillin baits during photophase in February 2006.

8:53 h. for *E. cingulata* in vanillin (Tab. III). The mean angle of daily activity for *E. bombiformis* on benzyl acetate occurred at 9:30 h in February. A negative correlation with temperature and a positive correlation with relative humidity were found for *E. cingulata* in February and for *E. bombiformis* in November, on the benzyl acetate bait. Those months had the highest temperatures of the year, although still within a suitable range for bee foraging activities (average maximum temperatures: 33ºC).

Although sporadic correlations between bee activity and climatic factors were found (Tab. IV), they still cannot explain the daily activity pattern of the studied bees. This result could be due to bee flight activity within a range of climatic factor variation considered adequate by several authors, particularly temperature, which in this study ranged from 23 to 32ºC. Stone *et al*. (1999) called the suitable temperature interval for bee foraging activity as thermal window. Armbruster & McCormick

(1990) also considered the temperature interval 25 to 31ºC as ideal for Euglossina flight in tropical regions. Ackerman (1989) and Armbruster & Berg (1994) highlighted the strong relationship between this temperature and time for Euglossina males to collect fragrances in tropical rainforest areas. Fragrance volatization tends to increase in high temperatures, thus increasing the volume of odor vapors, which could expand the attractiveness radius of each fragrance at specific hours of the day and months of the year.

All four species of *Eulaema* observed here were in general, large (length 18-31 mm), robust, and conspicuously hairy (Michener 2000) and with a dark tegument, traits that can be related to flight activity and control of body temperature. For Heinrich (1993), some of the largest Euglossina species, such as those in *Eulaema*, are dark and densely pubescent, thus with greater capacity to maintain the thoracic temperature high and to survive at very low temperatures as compared with bees of *Euglossa*, which are smaller, with lighter and metallic colours. These characteristics allowed *Eulaema* bees to visit the baits early.

All four species of *Eulaema* usually arrived early in the odor baits with the mean angle occurring in the morning, often before 7:00 h., thus being classified as diurnal and matinal bees according to Pittendrigh (1974) classification. This activity pattern was also observed for other tropical Euglossina species in other locations in Brazil, such as Maranhão (Silva & Rebêlo 2002), Bahia (Viana *et al*. 2002) and Paraiba (Farias *et al*. 2007) in northeastern Brazil, and Paraná (Santos & Sofia 2002) in the South.

The onset of visits by the four bee species occurred in the morning, usually shortly after sunrise, as soon as the temperature was suitable for flight (Tab. II).The visits occurred earlier in months with longer days (November, December and February), and later in months with shorter days (April, June and September). The same pattern was observed in relation to the mean angles and suggests a daily activity rhythm of approximately 24 hours, where the daily light/dark cycle can influence such activities during the day.

The influence of the daily light/dark cycle and the annual photoperiod has been observed in several studies on the daily and annual foraging activities of bees on flowers. Studies on *Ludwigia elegans* (Camb.) Hara (Onagraceae) in Southeast Brazil report that the light-dark cycle and the daily temperature cycle affected the opening time of flowers and bee activities on flowers (Gimenes *et al*. 1993, 1996, Gimenes 2002, 2003). Oliveira-Rebouças & Gimenes (2004) observed that the beginning of the foraging activities of *Centris leprieuri* Spinola in a 'restinga' area in Bahia was synchronized with sunrise and the flower opening times in *Comolia ovalifolia* Triana. Gottlieb *et al*. (2005) concluded that the daily activities of *P. olivieri* bees were af-

Table III. Mean angle (Ma) in hours, mean vector (r), angular deviation (S), number of bees (N) collecting odor baits (Rayleigh Test, Circular Statistics) in February, April, June, September, November and December 2006, in an ombrophylous forest in Salvador. *Eulaema nigrita*, *E. cingulata*, *E. flavescens*, *E. bombiformis*, (VAN) vanillin, (BA) benzyl acetate. Significance of r > 0.7.

Species	Ma (VAN)	r	S	N	Ma (BA)	r	S	N
February								
E. nigrita	10:12	0.630	03:17	200	–	–	–	–
E. cingulata	08:53	0.710	02:54	21	08:08	0.752	02:41	54
E. flavescens	–	–	–	–	08:25	0.785	02:30	60
E. bombiformis	–	–	–	–	09:30	0.707	02:55	33
April								
E. nigrita	10:23	0.795	02:26	14	–	–	–	–
June								
E. cingulata	–	–	–	–	11:02	0.703	02:56	11
September								
E. nigrita	09:40	0.670	01:58	18	–	–	–	–
E. flavescens					09:12	0.855	02:30	12
November								
E. nigrita	09:07	0.694	02:59	37	06:51	0.931	01:25	10
December								
E. nigrita	09:04	0.701	02:57	87	08:45	0.803	02:23	23
E. bombiformis	–	–	–	–	11:08	0.648	03:12	26
E. flavescens	08:10	0.830	02:13	12	08:48	0.902	01:41	20
E. cingulata	–	–	–	–	08:45	0.829	02:13	10

Table IV. Relationship between climatic variables and number of visits by Euglossina males to odors benzyl acetate and vanillin baits in February, April, September and November 2006. Only values with significant correlation ($p < 0.05$, $p < 0.01$) and regression referring to the correlations are presented. (BA) benzyl acetate, (VAN) vanillin , (LI) light intensity, (RH) relative humidity, (T) Temperature.

Species/variables	Correlation Coefficient			Correlation Significant			Multiple Regression	
	T	RH	LI	T	RH	LI	R	R2
February								
E. cingulata								
BA	-0.314 [a]	0.376 [a]	–	0.049	0.017	–	0.405	0.164
April,								
E. nigrita								
BA	–	–	0.354 [a]	–	–	0.027	0.374	0.140
VAN	–	0.370 [a]	0.413 [b]	–	0.021	0.009	0.478	0.229
September								
E. nigrita								
VAN	–	–	0.496 [b]	–	–	0.001	0.593	0.351
E. flavescens								
VAN	–	–	0.386 [a]	–	–	0.012	0.432	0.186
November								
E. nigrita								
BA	–	0.391 [a]	– –	–	0.011	–	0.449	0.201
E. bombiformis								
BA	-0.310 [a]	0.417 [b]	–	0.046	0.006	–	0.438	0.192

a) Correlation significant at 0.05; b) Correlation significant at 0.01.

fected by the daily light-dark cycle because they only occurred during sunrise and sunset hours.

The activity patterns of Euglossina males on baits probably is the same one could expect occurring naturally in flowers that produce fragrances, in which the hours with highest visit frequencies are also those with greater fragrance production. Male activity and fragrance production are probably synchronized and both could be influenced by the daily light-dark cycle, as long as they are within an optimal temperature window. Male activity and fragrance production hours are probably adjusted to the photoperiodic cycle and depend on the occurrence of bee and plant species in each area. Future studies could be conducted to test this hypothesis.

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