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Original Research Paper

Temporal and weather impacts on the rock bee, *Apis dorsata* Fab. (Hymenoptera, Apidae) visitations in urban green spaces in Bengaluru, India

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ABSTRACT

Bengaluru, acclaimed as the Garden city of India, is an agglomerate of continuous development, and metropolitan gardens serve as a refuge for insect pollinators. These ecological green spaces are subject to the influence of weather and anthropogenic activity. To understand the impact of abiotic factors on the rock bee, *Apis dorsata* Fab, a study was carried out from 2014 to 2018 in two urban gardens, and the visitation of wild honey bees on flowers was correlated with abiotic factors as well as species of flora. The study showed temperature had a positive correlation ($R^2 = 0.55$ in site 1 and $R^2 = 0.45$ in site 2) to bee visits, while, relative humidity and rain had a negative correlation ($R^2 = 0.50$ and R^2 0.50) in site 1. Pooled analysis of visitation on flowers showed that *Jacquemontia pentanthos* had the highest mean visits (1.7 insects/m^2/2 minutes), followed by *H. patens* (1.4 mean of insects/ m^2/2 minutes) in site 1. In study site 2, *P. lanceolate* had the highest mean visits, 0.9 mean of insects/m^2/2 minutes, and *Hibiscus* species showed a mean of 0.6 mean of insects/m^2/2 minutes in the analysis from 2014-2018.

Keywords: Abiotic factors, *Apis dorsata*, urban gardens

INTRODUCTION

Green landscapes in cities, such as urban gardens, are known for their aesthetic features and are also crucial for the conservation of insect fauna especially pollinators (Ollerton et al., 2011). The design and maintenance of these urban green spaces as key components of green infrastructure play a crucial role in nesting opportunities and foraging of insects (Daniels et al., 2020). Urban areas play an important role in the conservation of various insect pollinators, and recent studies have shown that these urban areas are potentially attractive habitats for pollinators (Baldock et al., 2015).

Insect pollinators are keystone species, providing vital ecosystem services to crops and wild plants. The rock bee or giant honey bee, *Apis dorsata* Fabricius (Apidae, Apinae) is known for its ecosystem services. This honeybee is a vital crop pollinator known to visit several plants to collect nectar and pollen (Robinson, 2012). Foraging is a necessary behavior of pollinator species and searching for suitable floral resources is essential for its sustenance. There is clear evidence of recent declines in both wild and domesticated pollinators, parallel declines in the plants that rely upon them (Potts et al., 2010), and urbanization, which has been identified as a threat to pollinator biodiversity. Recent studies have shown that *A. dorsata*, too, is declining in a semi-arid environment of northeast India (Sihag, 2014).

Generally, honey bees are known to be affected by weather. Studies showed that *A. dorsata* is negatively affected by temperature and positively with floral resources (Cui & Corlett, 2016). The wind is an important environmental factor that can help and hinder foraging. (Hennessy et al., 2020). Foraging is also affected by many other environmental factors, which exert an influence directly and indirectly. Direct examples include the effects of light and temperature on the time of day at which animals forage (Hennessy et al., 2020). *Apis mellifera* activity was impacted by temperature, solar radiation, and wind speed (Vicens & Bosch, 2000). The amount of floral resources available throughout the day regulates the activity of foraging by bees (Polatto et al., 2014).

Climate change influences the behavior of honeybees. The monthly abundance of bees was positively correlated to the floral resources, and negatively related to relative humidity while their abundance was not significantly related to temperature (Ali et al., 2017). The foraging activity of honeybees was positively correlated with air temperature, light intensity, solar radiation, and inversely with relative humidity (Abrol, 2006). Several environmental factors influenced the foraging of honeybees.

The objective of the study was to document the visitation of *Apis dorsata* to flowers in the urban garden and to evaluate the effects of abiotic factors on *A. dorsata*.

MATERIALS AND METHODS

The field studies were conducted in two urban gardens in Bengaluru, Karnataka, India from 2014 to 2018. These gardens were selected as they were located in urban land, had many flowering plants, were manured and watered regularly. The study site-1 was a garden within Cubbon Park (12°58^1 29 N^{11} 77°35^1 26^{11} E) of about 2000 m^2 area and had several cultivated ornamental plants. The plants observed are as follows in study site 1.

Table 1a : List of flowering plants documented in the study site 1

Botanical Name	Family
Jacquemontia pentanthos (Jacq.) G. Don	Convolvulaceae
Hamelia patens (Jacq.)	Rubiaceae
Tecoma capensis (Thunb.)	Bignoniaceae
Tridax procumbens (L.)	Asteraceae
Allamanda sp.	Apocynaceae
Mussaenda sp.	Rubiaceae
Turnera ulmifolia (L.)	Passifloraceae
Jatropha sp.	Euphorbiaceae
Ixora coccinea (Roxb.)	Rubiaceae
Euryops sp.	Asteraceae
Pachystachys lutea (Nees.)	Acanthaceae

Table 1b : List of flowering plants documented in the study site 2

Botanical Name	Family
Hibiscus sp.	Malvaceae
P. lanceolate (Forssk.) Deflers	Rubiaceae
Chrysanthemum sp.	Asteraceae
Tagetes sp.	Asteraceae
Nymphaea sp.	Nymphaeaceae
Begonia sp.	Begoniaceae
Gazania rigens (L.) Gaertn.	Asteraceae
Lantana sp.	Verbenaceae
Rosa sp.	Rosaceae
Portulaca glandiflora Hook.	Portulacaceae
Cuphea hyssopifolia Kunth	Lythraceae
Euphorbia milii Des Moul	Euphorbiaceae
Salvia splendens Sellow ex Roem. & Schult	Lamiaceae
Dianthus sp.	Caryophyllaceae

Study site 2 was in the *Lal bagh* plant nursery, about 5 km from study site 1. The observatory area was about 2000 m^2. The nursery mainly cultivated ornamental, native, and nonnative plants and common garden plants used in urban spaces for aesthetics. The plants were manured and watered regularly. The individual floral beds measured an area of 6 m^2. In both gardens, pesticide sprays were avoided as these were public gardens.

A transect sampling method was adopted to record the presence/absence of *A. dorsata*. Transect sampling involves walking slowly along the transect (Southwood, 1978). While moving along the transect, the number of insect species was recorded. The transects by foot were in between the beds and observations were carried out along the individual beds of these plants at 10 am. The transect was about 25-50 m stretch. Observations were made once a week. The path of the transect was unidirectional and was not retraced. The transect remained the same at each sampling. The data from the morning hours were used for further analysis as maximum *A. dorsata* were recorded in the morning hours. The study areas would be referred to as sites 1 and 2. Data were recorded from a patch of flowers measuring a one-meter square quadrat. The one-meter square quadrat was visually scanned for 2 minutes and the *A. dorsata* landing on a flower were counted. For each species of plant, three such quadrats were observed and averaged. This observation was carried out once every week for three years from April, 2014 to March, 2018. The results of the observation is represented as number of insects/m^2/2 minutes.

Preservation of insects

Apis dorsata were collected from an adjacent non-study area by sweep net sampling. Sweep net sampling is a standard insect net that traps insects (Hwang et al., 2022). The insects were identified at the ICAR-National Bureau of Agricultural Insect Resources, Bengaluru, India.

Studies on population fluctuation on a temporal scale

Studies on population change on a temporal scale in urban gardens were determined by the mean values of *A. dorsata* every month to understand the population fluctuation over the years from 2014-2018.

Studies on the effects of abiotic factors

The weather parameters *viz.*, maximum and minimum temperatures (^oC), relative humidity (%), total rainfall (mm), and wind speed (km/h) for the study period were collected from the National Bureau of Agricultural Insect Resources, Bangalore, India. The mean data of *A. dorsata* were subjected to correlation analysis with abiotic factors. The recordings of the weather parameters were used for the analysis except for rainfall. For rainfall, cumulative recordings of a week before the observation date were calculated (Jayanthi et al., 2014). The correlation coefficient 'r' was tested for significance at p= 0.05, and those significant were further subjected to linear and non-linear models using scatter plot and trend line analysis. In the scatter plots, outliers were removed from the data set. Multiple factors were subjected to multiple regression. To analyze the relationship between weather parameters on the visitation of the bee, the data were subjected to correlation and regression analysis.

Studies to determine the flora preferred by *A. dorsata*

To study the insect-plant association, the daily visit data of the *A. dorsata* were subjected to ANOVA. The data were subjected to analysis and the CD value was calculated to determine whether insect visitation was significant or not.

RESULTS AND DISCUSSION

Apis dorsata was recorded in the study sites 1 and 2 and their foraging activity was recorded during the day. The population dynamics showed a temporal variation over months from 2014-2018 for different insect flower visitors. Fig. 1a depicts the population dynamics on a temporal scale of *A. dorsata* in study site 1. The study recorded the presence of *A. dorsata* from April and May and a decline from July to December. The month of February recorded highest numbers of *A. dorsata* (35.2/m^2/2 min in 2014-15 and 8.5/m^2/2 min in 2016-2017). In the years 2015-2018, *Apis dorsata* was not observed during August to December. In study site 2, a similar trend was observed. The number of *A. dorsata* in site 2 steadily increased from January and peaked in February 9.25/m^2/2 min in 2014-2015. They were observed in March and April (Fig. 1b). Their numbers dipped from June to almost nil during July to December. In December 2015, occasional visits of the insect were observed. In the two study sites, *A. dorsata* was recorded from January to April, peaking in February and then dipping to almost nil during July to November. A decline in the population of *A. dorsata* was observed in the study sites. The population of *A. dorsata* was 8.8 mean of insects/m^2/2 min in 2014-2015, 6.6, 4.5, and 3.5 mean of insects/m^2/2 min in the consecutive years 2015-2018 in site-1 and 2.06 mean of insects/m^2/2 min during 2014-2015, 2.7, 1.8 during 2015 to 2017 and 0.85 during 2017-2018 (Fig. 1c).

Correlation of *A. dorsata* foraging with weather factors

In study site 1, correlation analysis showed that *A. dorsata* was positively correlated with maximum temperature and negatively correlated with relative humidity and rainfall. Wind speed did not show any correlation (Table 2a). In the site 2, correlation analysis showed that *A. dorsata* was positively correlated with maximum temperature and negatively correlated with minimum temperature, relative humidity rainfall, and wind speed (Table 2b).

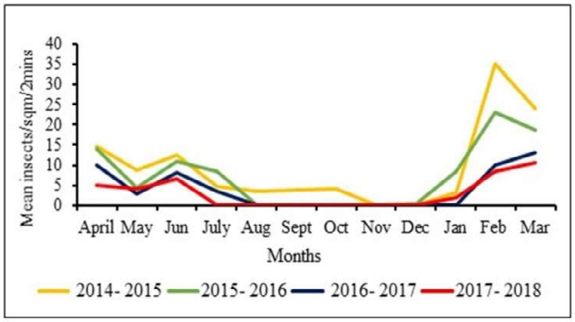


Fig. 1 a. Population fluctuation of *Apis dorsata* (Site-1)

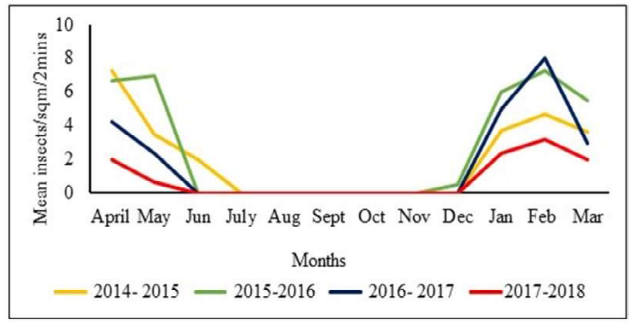


Fig. 1 b. Population fluctuation of *A. dorsata* (Site-2)

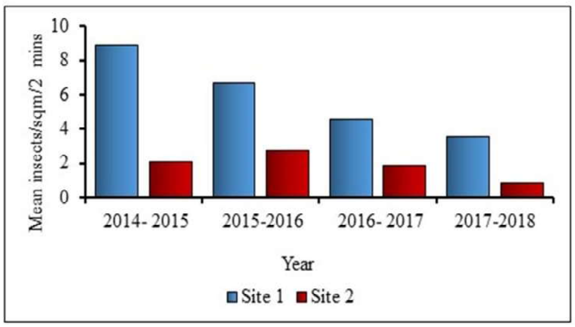


Fig. 1c. Population trends of *A. dorsata* from 2014-2018

Fig. 1 : Population fluctuation and trend of *Apis dorsata*

Table 2a : Correlation of weather parameters to *A. dorsata* at site 1

Weather Parameter	r value
Maximum Temperature (ºC)	0.26*
Minimum Temperature (ºC)	-0.12
Relative Humidity (%)	-0.29*
Wind speed (km/h)	0.12
Rain (mm)	-0.17*

*Significance at p=0.05

Table 2b : Correlation of weather parameters to *A. dorsata* at site 2

Weather parameter	r value
Maximum Temperature (ºC)	0.27*
.Minimum Temperature (ºC)	-0.25*
Relative Humidity (%)	-0.27*
Wind speed (km/h)	-0.15*
Rain (mm)	-0.24*

*Significance at p=0.05

The individual parameters were regressed for *A. dorsata* visits, maximum temperature showed an R^2 value of 0.55 and 0.45, respectively in sites 1 and 2. The variability in the number of visits could be accounted for 55% and 45%, respectively (Fig. 2a&b), and when the visits were regressed against relative humidity, R^2 of 0.50, 0. 46 in sites 1 and 2, respectively (Fig 3a&b) and wind speed showed an influence of 0.51% (Fig. 4). When insect numbers were regressed against rainfall, the analysis showed lower visits with rainfall with R^2 of 0.50 and 0.45 (Fig. 5a&b). The variability due to rainfall can be explained by 50, 45%, respectively in sites 1 and 2. R^2 = 0.46 was obtained in multiple regression of abiotic factors against visits of *A. dorsata* in site 1 and is determined by the equation

$$y = 0.01 + 0.56\, x_1 - 0.32\, x_2 - 0.08\, x_3 + 0.43\, x_4 - 0.03\, x_5$$

In site 2, the R^2 = 0.49 was obtained in multiple regression of abiotic factors against visits of *A. dorsata* in site 2 and is determined by the equation

$y = 0.01 + 0.24\, x_1 - 0.15\, x_2 - 0.02\, x_3 - 0.11\, x_4 - 0.02\, x_5$ where x_1 is maximum temperature x_2 is minimum temperature x_3 is maximum relative humidity x_4 is wind speed and x_5 is rainfall.

Fig. 2 a. Relationship of *A. dorsata* with maximum temperature (Site-1)

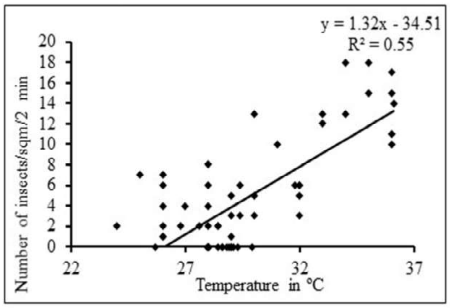


Fig. 2 b. Relationship of *A. dorsata* with maximum temperature (Site-2)

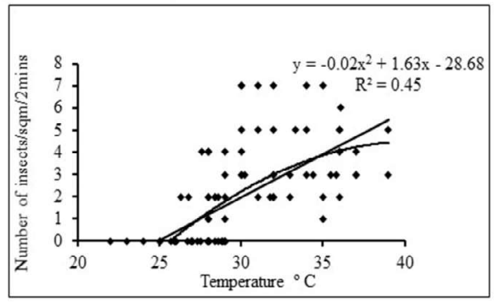


Fig. 3 a. Relationship of *A. dorsata* with relative humidity (Site-1)

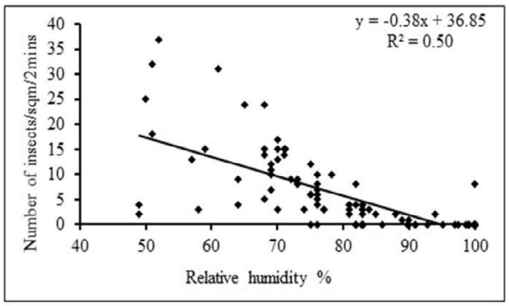


Fig. 3 b. Relationship of *A. dorsata* with relative humidity (Site-2)

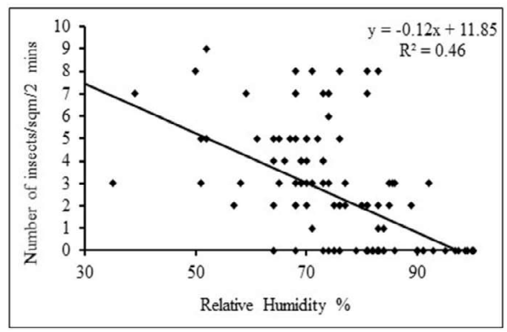


Fig. 2 & 3 a, b: Relationship of *A. dorsata* with relative humidity (Site 1, 2)

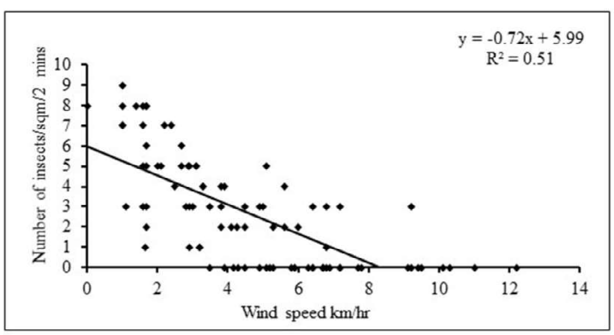
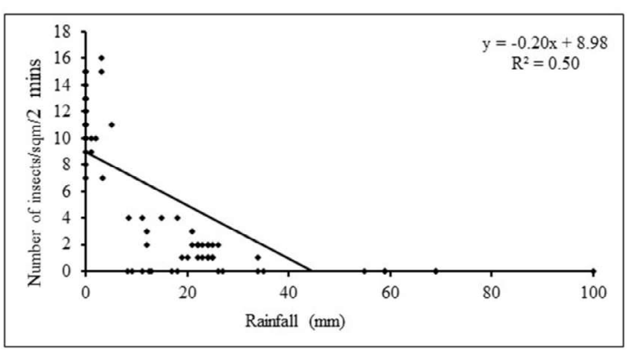


Fig. 4. Relationship of *A. dorsata* with wind speed (Site-2)

Fig. 5 a b. Relationship of *A. dorsata* with rainfall (Site-1, 2)



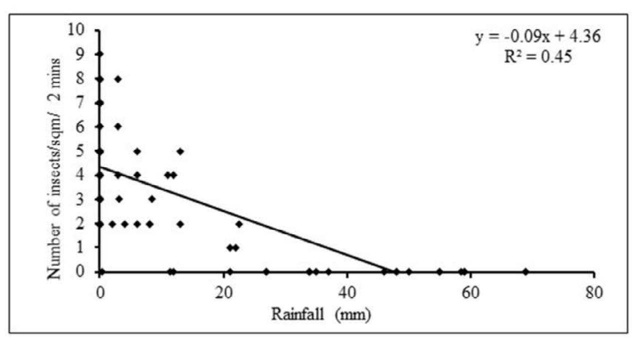


Fig. 4 & 5 a, b: Relationship of *A. dorsata* with rainfall (Site 1, 2)

Flora visited by *A. dorsata*

In study site 1, it was found that five species of plants were visited by *A. dorsata* (Table 3a) There were significantly more visits to *H. patens* (2.14 mean of insects/m^2/2 min) followed by *J. pentanthos* (1.64 mean of insects/m^2/2 min) in the year 2014. The pooled analysis showed that *J. pentanthos* recorded highest mean visits (1.7 mean of insects/m^2/2 min), followed by *H. patens* (1.4 mean of insects/ m^2/2 min). *T. ulmifolia* and *Euryops* sp. were on par with each other in their visits of insects. The least preferred was *Jatropha* sp. with 0.2 (mean of insects/m^2/2 min). In study site 2, *C. hyssopifolia* recorded highest mean visits 0.2 mean of insects/m^2/2 min and *Nymphaea* sp. showed a mean of 0.08 in the pooled analysis from 2014-2018 (Table 3b). The number of plants that were foraged by *A. dorsata* was *J. pentanthos*, *Jatropha* sp., *Hibiscus* sp., *T. ulmifolia*, *H. patens*, and *C. hyssopifolia* and *Nymphaea*.

Green spaces are crucial components of an urban ecosystem playing an important role for foraging insects. Gardens have a high potential to provide floral

Table 3a : Association of *A. dorsata* with plants (mean of insects/m^2/2 min at site-1)

Plants	2014-15	2015-16	2016-17	2017-18	Pooled
H. patens	2.14	1.23	0.98	1.15	1.4
J. pentanthos	1.64	2.2	1.7	1.4	1.7
T. ulmifolia	2	1.3	0.4	0.1	0.9
Euryops sp.	2	1.3	0.4	0.1	0.9
Jatropha sp.	0.4	0.1	0.08	0.2	0.2
Allamanda sp.	0.0	0.0	0.0	0.0	0.0
T. capensis	0.0	0.0	0.0	0.0	0.0
P. lanceolata	0.0	0.0	0.0	0.0	0.0
Tr. procumbens	0.0	0.0	0.0	0.0	0.0
Mussaenda sp.	0.0	0.0	0.0	0.0	0.0
I. coccinea	0.0	0.0	0.0	0.0	0.0
CD (p=0.05)	0.17	0.08	0.04	0.03	0.02

Table 3b : Association of *A. dorsata* with plants (mean of insects/m^2/2 min at site 2)

Plants	2014-15	2015-16	2016-17	2017-18	Pooled
Hibiscus sp.	0.53	0.74	0.90	0.19	0.61
P. lanceolata	1.01	1.4	0.7	0.7	0.98
Nymphaea sp.	0.05	0.1	0.1	0.0	0.08
C. hyssopifolia	0.2	0.3	0.4	0.01	0.2
Ch. Indicum	0.0	0.0	0.0	0.0	0.0
Begonia sp.	0.0	0.0	0.0	0.0	0.0
T. erecta	0.0	0.0	0.0	0.0	0.0
P. glandiflora	0.0	0.0	0.0	0.0	0.0
G. rigens	0.0	0.0	0.0	0.0	0.0
Rosa sp.	0.0	0.0	0.0	0.0	0.0
Dianthus sp.	0.0	0.0	0.0	0.0	0.0
E. mili	0.0	0.0	0.0	0.0	0.0
S. splendens	0.0	0.0	0.0	0.0	0.0
Lantana sp.	0.0	0.0	0.0	0.0	0.0
CD (p=0.05)	0.01	0.02	0.01	0.04	0.01

resources for insect pollinators. The gardens have to be designed and maintained with flower diversity that can enrich and argument insect pollinators.

The results demonstrate that *Apis dorsata* was found foraging in urban gardens during the day and being active in the morning. Our study also showed that *A. dorsata* was less active during the afternoons. This reduced activity of *A. dorsata* could be attributed to thermal stress (Young et al., 2021). These foraging patterns were also recorded in studies conducted by Somanathan et al. (2009). Certain studies have recorded their foraging activity at night (Young et al. 2021). The population of *A. dorsata* varies with season. The present study showed that January, February, and March showed a higher amount of foraging visits of the honeybee with a peak in February. These months coincide with the flowering of many angiosperms. The visitations of *A. dorsata* were not seen during August to November in the study sites. The study showed a temporal and spatial consistency over the years, and a trend was observed in the study sites.

The observations also showed a decreasing bee population over study periods, especially in study site 2. A reduction in the mean insect pollinators was recorded from 2014 to 2018. The decline was observed, although floral resources were available. It is important to identify the reasons for the decline. Sandilyan (2014) found that honeybees declined rapidly in southern India, and Sihag (2014) reported drastic declines in *Apis dorsata* colonies. The bee abundance and species richness showed that bees are less impacted by urbanization, as also mirrored in the observations (Deguines et al., 2012). This implies that there are many other drivers of pollinator decrease like climate change, pesticide use, habitat loss, and pathogens (Potts et al., 2010). The analysis of the impact of abiotic factors on the foraging of bees in the urban environment showed that relative humidity and rainfall negatively impacted the visits but positively correlated with temperature. This positive correlation with temperature (25° – 35!) coincided with the flowering of many plants; however, very high temperature shows a decline in visits, seen in May, where the temperatures are very high. The bees responded negatively to humidity and rainfall. Studies showed that temperature is one of the main abiotic factors regulating the foraging activities of bees. The decline in numbers may not be attributed to temperature; however, bees seem to be affected by relative humidity and rainfall.

From the analysis, the plants that could be used as the floral resource for *A. dorsata* were *H. patens*, *J. pentanthos*, *T. ulmifolia*, *Euryops* sp, and *Jatropha* sp., while, *P. lancoelata* and *Hibiscus* sp. from site 2. Overall *H. patens* and *J. pentanthos* had higher mean visit of the insect and can be a potential in the conservation for *A. dorsata*.

CONCLUSION

The present study emphasizes the potential of urban gardens to provide a habitat for *A. dorsata*. It establishes that urban green areas can substantially provide floral resources for the bee. The study highlights the various floral prospects for *A. dorsata* conservation in existing gardens and the relationship between abiotic parameters in an urban environment. A know-how in floral resources and urban area planning could facilitate *Apis dorsata* conservation.

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