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Original article

Yearlong association of insect pollinator, *Pseudapis oxybeloides* with flowering plants: Planted forest vs. agricultural landscape

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A B S T R A C T

The yearlong association of a native bee, *Pseudapis oxybeloides* (Halictidae: Hymenoptera) was studied with 72 plant species in a sub-tropical planted forest and some adjacent agricultural landscapes at Multan, Pakistan. The study resulted in 66 interactions of *P. oxybeloides* with only 24 plant species in 15 families while other 48 plant species were not visited by this bee. The maximum abundance of *P. oxybeloides* (7–9 individuals) was recorded on *Achyranthes aspera* and *Launaea procumbens* followed by *Ageratum conyzoides*, *Trianthema portulacastrum* and *Cleome viscosa* (5–6 individuals). Majority (19) of plant species were visited by only 1–4 individuals. The bee activity was started in the month of March which attained its peak in May followed by a gradual decline until September. No bees were observed during the months of January and February. There was a significant positive relationship between bee abundance and number of flowering plant species. Bee abundance had a strong positive relationship with temperature while it had a strong negative relationship with relative humidity (%). Floral abundance increased with the number of flowering plant species while it was not influenced by floral span of plant species. Besides giving the floral host plants of *P. oxybeloides*, the current study also gives a better understanding of its seasonality along with its relationships with different biotic and abiotic factors under local conditions. These findings can help in maintaining and managing *P. oxybeloides* population particularly and other native bees in general at local scale.

1. Introduction

Pseudapis is a genus of the family Halictidae (Nomiinae) consisting of 73 known species from different parts of the world, particularly from Africa, Europe, Australia and Asia (Michener, 2000). *Pseudapis oxybeloides* Smith, 1875 is a common bee in India, Pakistan, Sri Lanka and Yemen (Sharma et al., 2016). *Nomia oxybeloides* Smith, 1875 is a commonly used synonym of this bee. It is a quasi-social and ground-nesting bee; it mostly prefers sandy, alkaline soil with little vegetation (Parker et al., 1986). The main burrow (3.0–3.5 mm in diameter) is vertical, un-branched and lined with a water-repellent secretion. The nest runs to a depth of about 51 cm (Batra, 1966). This bee is polylectic and gathers pollen and nectar from the variety of available flowers within a short distance from its nest (Raju and Rao, 2002).

There is little known about the foraging behavior and ecology of *P. oxybeloides* including its floral host preferences and population dynamics in relation with biotic and abiotic factors. Few efforts have been made regarding enlisting the floral host plants of *P. oxybeloides* in neighboring India. The factors which determine

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the floral host utilization of *P. oxybeloides* include flower color and amount of pollen and nectar (Raju and Rao, 2002).

Batra (1967) for the first time working with plant-pollinator interaction in agriculture landscapes- reported that *P. oxybeloides* contributes to crop pollination while gathering floral rewards from different crop plants. Following this, several host plants have been reported from India i.e. *Cleome chelidonii, C. viscose, Jatropha gossypiifolia, Phyllanthus pinnatus, Anisomeles indica, Hyptis suaveolens, Ocimum americanum, O. basilicum* and *Helicteres isora* (Raju and Rao, 2002). In a recent study from southern Punjab of Pakistan, Ali et al. (2016) regarded *P. oxybeloides* as a most efficient pollinator of cucurbit crops in terms of pollen deposition on stigma during its single visit.

In the light of the established fact that pollinators are declining as a result of agricultural intensification and habitat loss, Raju and Rao (2002) focused the floral hosts and nesting places of *P. oxybeloides* and concluded that both have drastically been reduced in Indian Punjab due to various development activities such as building and highway construction, trampling, digging. For the conservation and efficient utilization of useful biodiversity such as pollinators, there is a need to gather species-specific baseline information on floral host plant preferences, seasonal dynamics, ecological relationships with host plants and environmental factors. This baseline information can be utilized in devising different conservation and management strategies such as 'making agricultural habitats bee-friendly' by providing habitat suitable for nesting along with offering blooms across their active season (Isaacs and Tuell, 2007).

The current study was planned in the same context, aiming to enlist the floral host plants of *P. oxybeloides* in quantitative terms for the first time from Pakistan. The study also explored the relationship of seasonal population fluctuation with floral resources (i.e. monthly availability of flowering plant species and flower density) and environmental factors (i.e. temperature and relative humidity).

2. Materials and methods

2.1. Study area

The study was conducted in a planted forest of 20 hectares and an adjacent agricultural farm at Bahauddin Zakariya University campus Multan (30.255°N; 71.513°E; 114 ± 6 meter above sea level), Pakistan from January to December, 2013. The area has sub-tropical climate with hot summers and cold winters; the mean daily maximum and minimum temperatures range from 38 °C to 50 °C and 8 °C to 12 °C, respectively (Khan et al., 2010). The mean annual rainfall is *ca.* 300–500 mm (PARC, 1980). Most plant species (ca. 60%) flower during spring season followed by summer, autumn and winter (Sajjad et al., 2010; Sajjad et al., 2012).

2.2. Sampling units and floral abundance

A variety of annual wild plants and perennial shrubs naturally grow in the forest. Since plant species belonged to different categories i.e. (trees, shrubs, herbs, etc.) and had different inflorescence types (i.e. umbels, heads, etc.), we defined the sampling units for each plant species separately and each time recorded observations from those sampling units i.e. entire plant, specific number of branches per tree, one-meter square area on plant, etc. Floral abundance was estimated by randomly selecting and tagging 15 sampling units of each plant species and counting total floral units (i.e. umbels, heads, bunch of inflorescence, individual flowers, etc.) fortnightly.

Table 1
Monthly abundance of *Pseudapis oxybeloides* on 24 flowering plant species at Bahauddin Zakariya University Multan campus from January to December, 2013. Grey highlighted portion shows the floral span of each plant species.

Plant species	Families	Flower color	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Trianthema portulacastrum	Aizoaceae	White						1	2	3					6
Achyranthes aspera	Amaranthaceae	Purple					3					1	5		9
Oxystelma esculentum	Asclepiadaceae	White+purple							1						1
Launaea procumbens	Asteraceae	Yellow					2		2	3					7
Ageratum conyzoides		Purple					6								6
Helianthus annuus		Yellow					1								1
Sonchus asper		Yellow				1									1
Parthenium hysterophorus		Green					1	2							3
Heliotropium europaeum	Boraginaceae	White					1								1
Sisymbrium irio	Brassicaceae	Yellow				1									1
Cleome viscosa	Cleomaceae	Yellow					1	4	1						6
Convolvulus arvensis	Convolvulaceae	White					1	1							2
Momordica charantia	Cucurbitaceae	Yellow						1	1						2
Cucumis prophetarum		Yellow					1				1				2
Alhagi graecorum	Fabaceae	Pink					2								2
Malvastrum coromendelianum	Malvaceae	Yellow					2						1		3
Portulaca oleracea	Portulacaeae	Yellow							1						1
Solanum nigrum	Solanaceae	White					2	1							3
Solanum surattense		Purple						1							1
Physalis peruviana		Yellow+brown						2							2
Phyla nodiflora	Verbenaceae	White+pnik					1	1	1						3
Lantana camara		Yellow+pink					1								1
Verbena officinalis		White+pink					1								1
Tribulus terrestris	Zygophyllaceae	Yellow							1						1

2.3. Data recording

During each fortnightly census, random walks in forest were made and selected 15 plants of each plant species at their flowering stage. For agricultural crops, 15 plants were selected randomly from the margins of the field. Each plant was observed for 60 s in its floral units for any visit of *P. oxybeloides*. In this way there was a total of 15 min of observation per plant species in one census. Only those plant species were selected which were in the phase of flowering. For each plant, the number of visiting individuals of *P. oxybeloides* were counted by visual observation. A fortnightly census of each flowering plant species was carried out throughout the flowering period. The observations were done on clear sunny days.

To avoid the phenomenon of floral constancy i.e. insects tend to visit single plant species even in the presence of many other flowering plant species in that particular area (Gruter and Ratnieks, 2011), wild plants of a particular species at a considerable distance from each other (>50 m) were selected. This practice was not followed for agricultural crops as floral constancy increases with the decreasing distance between plants (Marden and Waddington, 1981). Weekly meteorological data (i.e. average relative humidity and temperature) were obtained from nearby Central Cotton Research Institute (CCRI), Multan.

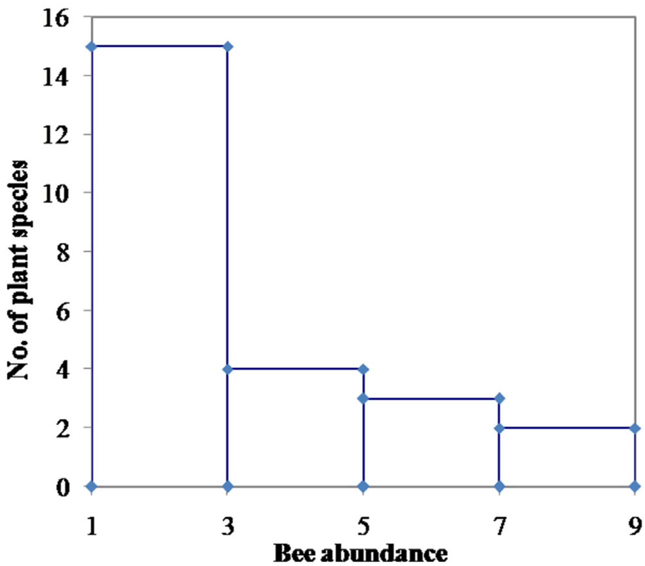

Fig. 1. Frequency distribution of 24 flowering plant species based on abundance of *Pseudapis oxybeloides* at Bahauddin Zakariya University Campus, Multan, Pakistan during January to December, 2013.

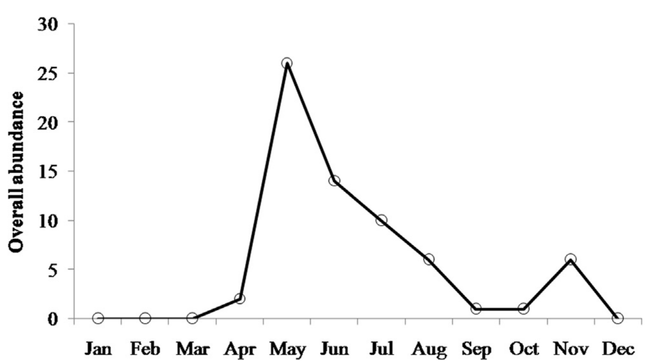

Fig. 2. Monthly abundance of *Pseudapis oxybeloides* at Bahauddin Zakariya University Campus, Multan, Pakistan during January to December, 2013.

2.4. Statistical analysis

Frequency distribution test was applied to identify various classes of plant species based on abundance of *P. oxybeloides*. Linear regression analysis was used to explore the relationship between abundance of *P. oxybeloides* and abiotic (relative humidity and temperature) and biotic (number of plant species in flowering and total floral abundance) factors. Pearson's correlation was applied to see the relationship of floral abundance with number of flowering plant species and with their floral spans (i.e. length of flowering periods). XLSTAT computer software (XLSTAT, 2008) was used for all analysis.

3. Results

A total of 72 flowering plant species in 30 families were observed for recording visitation of *P. oxybeloides*. The total sampling efforts of 121 h however, yielded 66 interactions of *P. oxybeloides* with only 24 plant species in 15 families (Table 1). Forty-eight plant species were not visited by *P. oxybeloides*. Frequency distribution test of abundance of *P. oxybeloides* on 24 plant species showed that 15 plant species were visited by only 1–3 individuals, 4 plant species by 3–5 individuals, 3 plant species (*Ageratum conyzoides*, *T. portulacastrum*, and *C. viscosa*) by 5–7 plant species and only 2 plant species (*A. aspera* and *L. procumbens*) by the maximum of 7–9 individuals of *P. oxybeloides* (Fig. 1; Table 1).

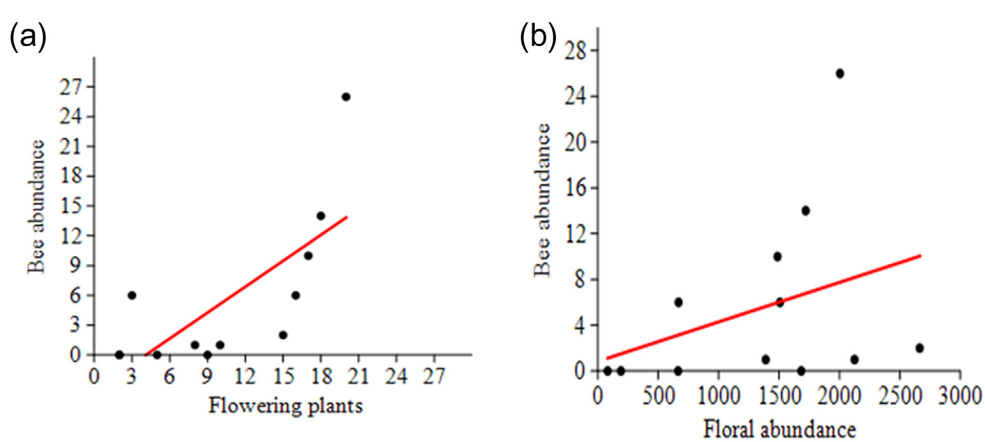

Fig. 3. (a and b) Relationship between biotic factors (number of flowering plant species and floral abundance per month) and abundance of *Pseudapis oxybeloides* over the year at Bahauddin Zakariya University Campus, Multan, Pakistan during January to December, 2013.

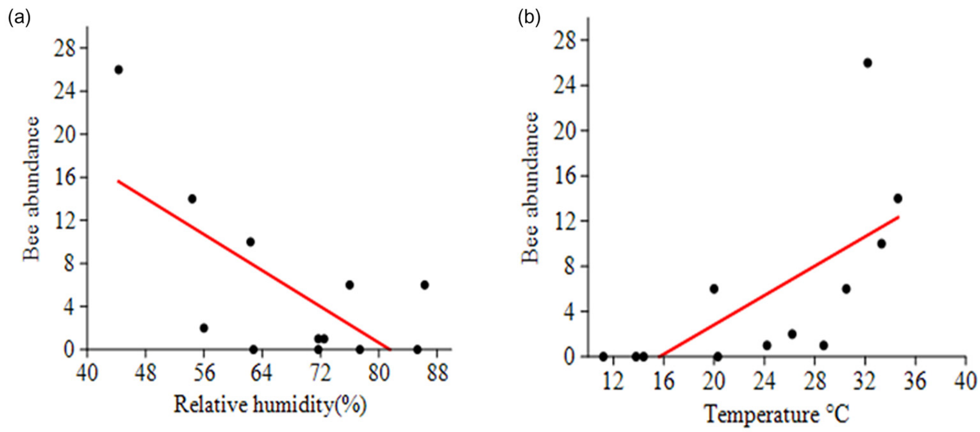

Fig. 4. (a and b) Relationship between abiotic factors (average temperature °C and relative humidity %) and abundance of *Pseudapis oxybeloides* over the year at Bahauddin Zakariya University Campus, Multan, Pakistan during January to December, 2013.

The bee activity began in the month of March and attained its peak in May which was followed by a gradual decline until September. A little rise in population was obvious in October which ended in December. No bees were observed during the months of January and February (Fig. 2).

There was a significant positive relationship (y = −3.56 + 0.87; F = 11.15; P = 0.007) between bee abundance and number of flowering plant species however, it was not significant in the case of bee abundance and floral abundance (y = 0.84 + 3.4x; F = 1.36; P = 0.27) (Fig. 3a and b). Similarly, bee abundance had strong positive relationship with temperature (y = −10.17 + 0.65x; F = 8.05; P = 0.018) while it had a strong negative relationship with relative humidity (%) (y = 34.18–0.42x; F = 8.38; P = 0.016) (Fig. 4a and b). Floral abundance increased with the number of flowering plant species (Pearson's correlation coefficient = 0.78; P = 0.003) while it was not influenced by floral span of plant species (Pearson's correlation coefficient = 0.185; P = 0.386).

4. Discussion

A total of 66 individuals of *P. oxybeloides* were recorded on 24 plant species in 15 families during the entire year. A majority (48) of plant species were not visited by *P. oxybeloides*. The most visited plant species by *P. oxybeloides* were *A. aspera* and *L. procumbens* followed by *Ageratum conyzoides*, *T. portulacastrum* and *Cleome viscose*. Previously, no such interactions of *P. oxybeloides* with flowering plants have been reported from Pakistan except few diversity records from forested ecosystems of Punjab (Bashir et al., 2019). However, from neighboring India its interactions have been reported with few plant species i.e. *Cleome chelidonii, C. viscose, J. gossypiifolia, Phyllanthus pinnatus, Anisomeles indica, H. suaveolens, O. americanum, O. basilicum, Helicteres isora* (Raju and Rao, 2002), *Prosopis cineraria* (Gorain et al., 2012), *Medicago sativa* (Kapil et al., 1974) and *Solanum melongena* (Batra, 1977). Raju and Rao (2002) concluded that *P. oxybeloides* remained active throughout the year as different plants flowered during different times of the year and this enabled bee to forage throughout the year. However, in present study, no individual of *P. oxybeloides* was observed during December, January, and February. This might be due to less availability of floral resources during these months in the study area (Sajjad et al., 2010; Sajjad et al., 2012).

P. oxybeloides can forage from both complex and simple flowers of many colors; indiscriminately probing the sigma and anthers it ensures pollination (Raju and Rao, 2002). Most of the flowers in this study were yellow and white, besides few purple and pink flowers (Table 1). The most visited plant species '*A. aspera* and *L. procumbens*' had purple and yellow flowers. All the plant species except *Alhgi graecorum* were actinomorphic having shallow base and exposed sex organs. Other factors which determine the floral host preference of *P. oxybeloides* are the amount of pollen and nectar, yet the higher nectar quantity is preferred over the pollen (Raju and Rao, 2002). Like other bees, *P. oxybeloides* can also successfully trip the explosive floral mechanism in *H. suaveolens* (Raju and Rao, 2002).

In the present study *P. oxybeloides* did not visit a majority (48) of plant species observed, growing in the same forest. This might be because the bees are largely selective and utilize only a few plants as pollen or nectar sources (Ali et al., 2015). Raju and Rao (2006) reported that *Xylocopa latipes* and *X. pubescens* utilized some specific flowering plant species out of 442 dicotyledonous plant species occurring in Visakhapatnam, India. Such consolidated information is essential to prepare a floral calendar and sustain floral sources for use by bees throughout the year (Tilman et al., 2002). The optimal foraging theory suggests that the phenomenon of floral selectivity (or floral constancy) in bees helps them to attain the maximal net energy intake (Stephens and Krebs, 1986) while other factors such as nutrient requirements, risk of predation or starvation, mate searching, nest provisioning and landscape features may cause the observed foraging behavior of bees to differ from the predictions of energy maximization (Amaya-Marquez, 2009).

The peak bee activity was recorded in the month of May which gradually declined until September. This was also supported by our finding of presence of a significant positive relationship between abundance of *P. oxybeloides* and number of flowering plant species. Similar findings have already been reported by Sajjad et al. (2017) for honey bees, Sajjad et al. (2012) for butterflies and Sajjad et al. (2010) for syrphid flies in the study area. This could be due to the more availability of foraging resources in summer as compared to the winter since there was a significant positive relationship between monthly bee abundance and the floral resources (number of plant species in flowering and availability of floral units) in our study. Understanding the seasonality in bees (i.e. individual lifespan of adult bees) and the corresponding seasonality of their associated floral hosts along with adult flight and foraging patterns help in maintaining and managing bee communities at a specific location (Shepherd et al., 2003).

P. oxybeloides, on the other hand, had a strong positive relationship with temperature but a negative relationship with relative humidity (%). Moreover, bee abundance was not influenced by floral span of plant species. The relationship between bee activity and weather factors has been intensively studied for honey bees

(*Apis mellifera*) while it is rarely documented for non-apis bees. Previous studies suggest that there is no hard and fast rule in predicting the way bees respond to climatic factors. However, most studies suggest a slight negative relationship of honey bee abundance with temperature (Abou-Shaara et al., 2012; Gebremedhn et al., 2014). For *P. oxybeloides* such information is given for the first time in the present study.

5. Conclusion

Since *P. oxybeloides* along with some other native bee species have previously been reported as important pollinators of cucurbits and some other crops, the current baseline data of year-long floral host plants of *P. oxybeloides* can be helpful in devising in-situ conservation strategies for this bee species specifically and other bees in general. Future studies should focus on understanding the bee-plant interactions for other bee species together with their impacts on crop pollination and yields.

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