During the last few years, India has experienced the spread of two exotic thrips, namely *Frankliniella occidentalis* (Pergande)[13] and *T. parvispinus*[5,8], of which the former is an unequivocally established vector of tospovirus besides causing feeding injury to the plant[14]. Both the species have spread across the world during the last two decades and are reported to be highly polyphagous[4]. However, *F. occidentalis* has been reported only on a few occasions in India, especially after its first appearance, and no serious economic damage on crops has been reported as yet[15,16]. On the contrary, the invasion of *T. parvispinus* has led to the lag phase. As a result, its population has increased alarmingly within a short duration of four years, also being influenced by its adaptability on diverse plant hosts, in addition to its tendency to expand in geographical range within the country. Lag times related to biological invasions of other exotic species documented earlier also exhibited almost the same trend[17–19]. The invasion by a specific taxon in yet another new environment/ country is considered to be a biotic threat for the native flora and fauna. Even though trade of different commodities is essential to boost the economic growth of a country, careful vigilance would prevent the entry and dispersal of alien species into a new terrain. Further, it is imperative that the domestic quarantine mechanisms should be stringent to check the spread of this notorious pest to the rest of India.

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Temporal consistency in foraging time and bouts of a carpenter bee in a specialized pollination system

Neethu Sinu[1] and Palatty Allesh Sinu[1,2,*]

[1]438/XIIIA, Mutthappanarkavu, Kanhangad South 671 531, India
[2]Department of Zoology, Central University of Kerala, Padannakad 671 314, India

While site and plant fidelity are reported for bees, consistency in foraging pattern is less studied in field conditions. We monitored three marked carpenter bees – one female and two males – on the sword bean for 25 straight days of flowering to examine whether

*For correspondence. (e-mail: sinu@cukerala.ac.in)

(1) the bee is consistent on the time of its first visit and the number of foraging bouts and (2) the number of flowers on the plant predicts foraging bouts of the bees. The female bee was consistent on the first arrival time and the number of visitation bouts, but the male bees were not. The median first arrival time of the female bee was 06:22 h. Number of visitation bouts of female bee was unaffected by the crop size. The duration the bees spent on the plant on subsequent visits increased with the duration they spent on the first visit. This study suggests that the carpenter bee, in particular the female, has a consistent visitation pattern to the flowers.

Keywords: Carpenter bees, flower constancy, foraging, sword bean, visitation rate.

BEES demonstrate exceptional species and site fidelity in the ways they use renewable and predictable resources[1–5]. Pollinators' foraging bouts over time are affected by both extrinsic and intrinsic factors. The extrinsic factors include weather conditions, crop size and diurnal patterns of flowering[6–8]. The intrinsic factors include experience and the ability of the bees to learn cues and retrieve them from short-term memory[9–11].

Only a few studies have examined temporal foraging pattern of solitary bees under field conditions[3]. To the best of our knowledge, there are no studies on the consistency in the foraging time and visitation bout of bees under field conditions. In the present study, we seek to examine whether (a) the bees maintain consistency with regard to the time of their maiden visits and in the number of their visitation bouts across a day, and (b) the number of flowers on the plant predicts the number of visitation bouts and foraging time of the bees. We studied the male and female carpenter bees of *Xylocopa latipes* (Druray) in the carpenter bee–sword bean (*Canavala gladiata* (Jacq.) DC.) pollination system to understand whether the visitation characteristics change according to the sex of the bees. Carpenter bee is the predominant pollinator of sword bean flowers in the Asia-Pacific region[12]. The sword bean is a climbing annual with papilionaceous blue flower in axillary racemes, a trait typical for *Xylocopa* bees' visits[13]. It secretes 10–30 µl nectar of sugar concentration, about 50 Brix (ref. 14). The nectar secretion started by anther dehiscence in the mature bud and half-opened flowers at around 06:00 h (LUX 50) in our study. The flowers completely opened by around 09:00 h (LUX 900). We recorded the light intensity by holding a LUX meter (Sigma-Aldrich) in an open field close to the focal plant. The stigma turned receptive in completely opened flowers. The nectar secretion continued until flower senescence (24 h after anthesis) or pollination. The visitors made bouts to both half-opened and completely opened flowers.

X. latipes was responsible for 95–100% of the visits across days. *Xylocopa bryorum*, two species of butterflies – *Pelopidas mathias* and *Jamides celeno*, and an unidentified sphingid moth contributed to the remaining number of visits to the flowers (Sinu and Sinu, unpublished). However, due to operational difficulties, all the experimental observations on the marked bees reported in the present study were performed on one plant in the backyard of the authors' house located in south Kanhangad (12°25.8382′N; 075°13.2949′E; 16.7 m amsl) in South India.

The study was carried out between 4 September and 2 October 2015 during the peak phase of flowering of the plant (Figure 1). We marked three *X. latipes* bees using a white, non-toxic paint on their smooth first abdominal tergal segment, while they were foraging nectar (Figure 2). The bees were distinguished by the mark type and size. The female bee was larger than the males. We remarked the bee when the marks were fading on their bodies. Sometimes the first visits of the three bees had coincided, but that of the males were mostly inconsistent. Often, the males visited the plants along with the female for mating rather than foraging nectar. Due to this, we used the visitation data of male bees only for drawing some descriptive measures of their first visit.

We manually monitored the bees during 06:00 to 13:00 h daily for 25 days on our focal plant. We recorded the arrival time and the time that the bees spent on the flowers and the plant for foraging nectar. We recorded the precise time of their maiden visit, the number of visitation bouts/day, the time spent by the bees on the plant and flowers during each bout, and the number of open flowers on the plant daily.

We used a generalized linear model with Poisson distribution as the error type in the model to test whether the number of visitation bouts of male and female bees was

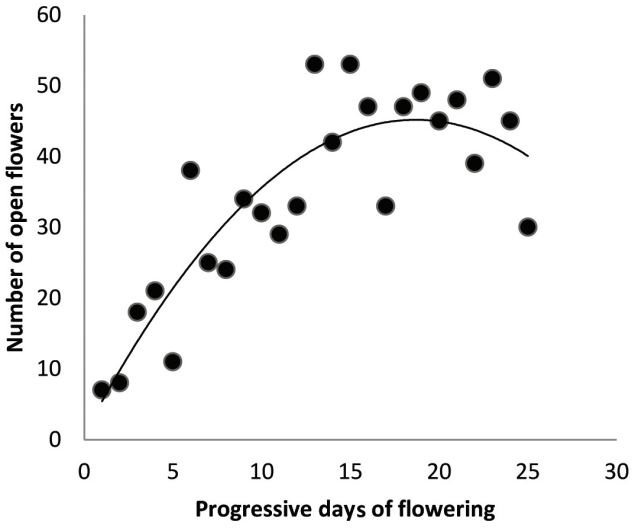

Figure 1. The number of open flowers versus days of observation. The study covered the peak flowering period of the plant. Second-order polynomial regression line is fitted.

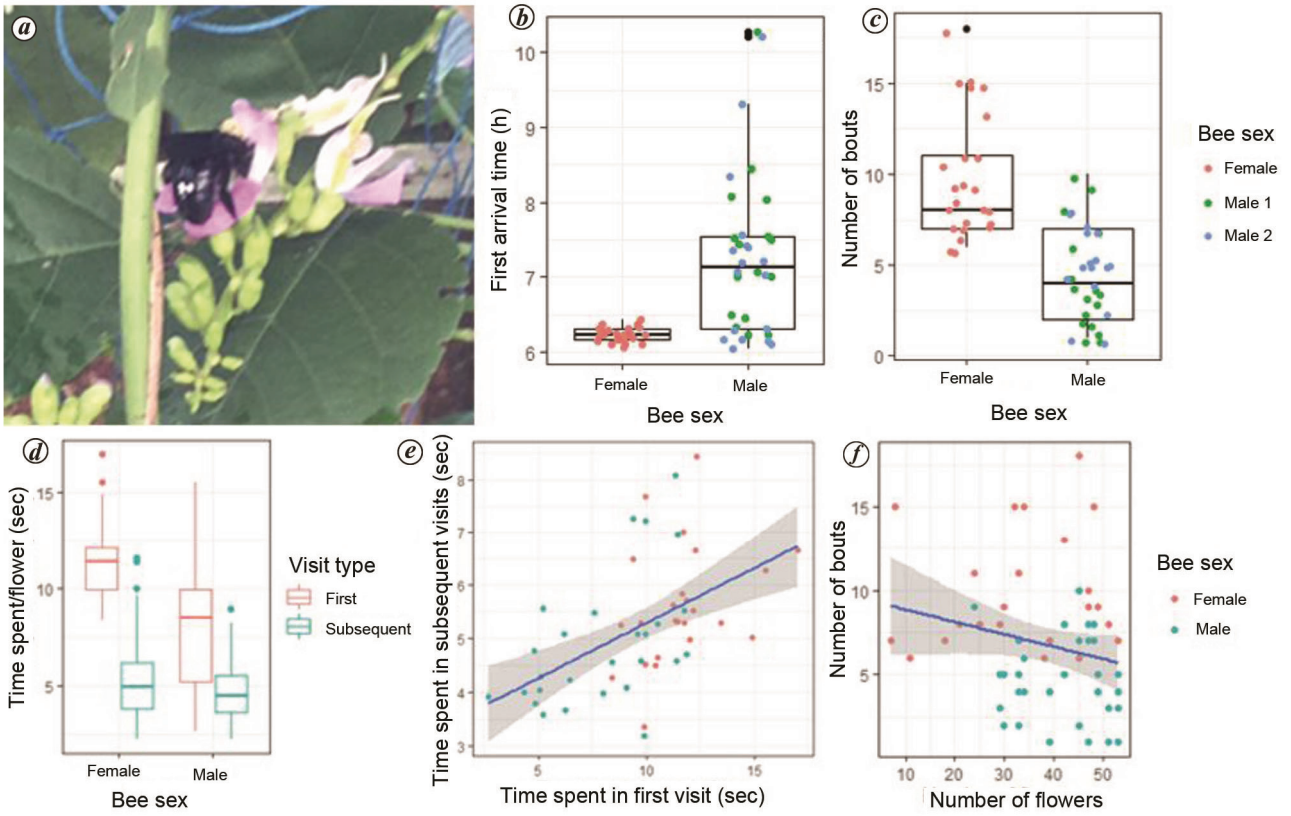

Figure 2. ***a***, The marked female carpenter bee foraging on a flower of sword bean. ***b***, First arrival time of the female bee was earlier and more consistent than the male bees. ***c***, The female bee made more number of bouts than male bees. ***d***, The first visit to the flowers was longer than the subsequent visits for both female and male bees. ***e***, The time that the bees spent per flower on subsequent visits was positively related to the time they spent on their first visit. ***f***, The number of bouts of the bees decreased with the number of flowers on the plant.

different. We used a linear model with Gaussian distribution as the error type to study whether the first arrival time of the female and male bees was different. Another linear model was constructed with the average time that the bees spent on the flowers during subsequent visits as the response variable and the time that they spent on their first visit as the predictor variable to examine the effect of the latter on the former. Another generalized linear model was employed using the number of visitation bouts as the response variable and the number of flowers across days as the predictor to study the effect of the latter on the former. In the latter two models, the pooled visitation characteristics of all the three bees were used to improve the sample size. The subsequent visits were calculated by averaging out all the subsequent visits of a day.

A total of 862 flowers bloomed during the study period, which received a total of 5213 visits; 95.13% of this was made by *X. latipes*. The median first arrival time of the female bee was 06:22 h (mean = 06:23:12 h, SE = 00:01:56 h; range = 06:05–06:44 h; Figure 2). The median first arrival time of the two male bees was 07:24 h ($N = 17$ days) and 07:14 h ($N = 16$ days) respectively. For two days, the first visit of all the three bees coincided at 06:22 h. Moreover, the time of the first visit of the female bee was more consistent than the male bees across the days (Figure 2). The difference in the arrival time of the first bout for the male and female bees was significant (LM: 1.03 ± 0.21, $t = 4.72$, $P = 0.00001$).

The female bee did more visitation bouts (9.68 ± 3.5 mean ± SD) than the male bees (4.5 ± 2.6 mean ± SD; GLM: -0.76 ± 0.10, $Z = -7.3$, $P < 0.00005$), but the two male bees did similar number of visits to the plant across the days (GLM: 0.18 ± 0.16, $Z = 1.11$, $P = 0.2$) (Figure 2). Though the visitation bouts decreased with the number of flowers for all the bees (GLM: -0.01 ± 0.004, $Z = -2.5$, $P = 0.01$), the female bee was unaffected (GLM: 0.001 ± 0.004, $Z = 0.31$, $P = 0.75$) (Figure 2). The time that the bees spent on the flowers during subsequent visits increased with the time that they spent on the flowers during their first visit (LM: 0.21 ± 0.04, $t = 4.35$, $P = 0.00006$). The first visit of both the female (LM: -6.25 ± 0.39, $t = -16.07$, $P < 0.00005$) and the male bees (LM: -3.31 ± 0.37, $t = -8.8$, $P < 0.00005$) to the flowers was longer than the subsequent visits (Figure 2).

Although site and plant species fidelity are reported in bees, it has been studied mostly in social bees[2,10,15–19]. Cecala and Rankin[3] demonstrated that solitary bees also return to the same site and same plant for foraging over

days. Our results, in conjunction with the above-mentioned studies, show that bees not only maintain high site fidelity, but also keep time on their first visit and maintain a consistent number of visits to the plant. While the female bee's visitation pattern is more consistent over days, the male bees' foraging pattern is not.

The bees, after their maiden visit and assessment of the crop size, might decide the pattern of their subsequent visits to the plant[7,20,21]. Although there were only a few flowers on some days, the bees, and in particular the female, maintained their visits to the plant in a consistent fashion. The time that the bees spent per flower on their subsequent visits was correlated to the time that they spent on their first bout. It is likely that the focal plant could be in the trapline of the bees and frequenting the same might help them maintain their territory[9,11,22]. The floral resources of the sword bean are foraged predominantly by the carpenter bees. This might limit the competition from other visitor species. The male bees, despite visiting most of the days, were late and inconsistent on the number of bouts across the days. We have no clue on the nest site of these bees, or whether all the three bees belonged to the same communal nesting place. We are also not aware of the other food plants of these three individuals to comment on whether any extrinsic factors explain the foraging pattern of the males, as their visitation pattern was unpredictable compared to the female bee.

The present study on three marked bees under typical field conditions provides some evidence for a carpenter bee species' consistency in flower visitation pattern. The female bee visited the plant all the 25 days of observation, maintained time for its maiden visit, and made similar number of bouts across the days. Although successful observations could be made only on three bees (the only individuals from *X. latipes*), we monitored the bees for a considerable amount of time during the peak flowering phase of the plant, which gave consistent and reliable results.

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