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Research Article
Foraging Behavior of an Aphidophagous Hoverfly, *Sphaerophoria macrogaster* (Thomson) on Insectary Plants

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Abstract

Background and Objective: Flower resources are prerequisites for survival and reproduction of aphidophagous hoverflies adults. It is, therefore, necessary to evaluate their foraging behavior with regards to different flowering species in order to utilize hoverflies to enhance conservation biological control (CBC) of aphids. **Materials and Methods:** The foraging behavior of the female hoverfly, *Sphaerophoria macrogaster* (Thomson) was observed in coriander (*Coriandrum sativum* Linnaeus) and blue salvia (*Salvia farinacea* Bentham) flower patches using a focal sampling method combined with continuous recording. The sequences and durations of all foraging bouts were recorded during the residence of observed *S. macrogaster* in each flower patch. **Results:** Significantly more transitions from searching to assessment of flowers were noted in coriander than in blue salvia flower patches ($\chi^2 = 4.55$, $p<0.05$). However, approaching to probing transitions were significantly more frequent in blue salvia than in coriander flower patches ($\chi^2 = 9.59$, $p<0.05$). Foragers showed significantly prolonged inter plant movement but shorter probing durations in coriander flower patches. Of interest, total duration of time spent in patches by *S. macrogaster* did not differ significantly between coriander and blue salvia. **Conclusion:** Results from the present study illustrated that both flowering plant species were apparently attractive to *Sphaerophoria macrogaster* females but these foragers preferred coriander flowers. This finding may form the basis of flower selection in and around the crop fields for enhancement of this aphidophagous natural enemy to maximize the biological control of aphids.

Key words: Blue salvia (*Salvia farinacea* Bentham), coriander (*Coriandrum sativum* Linnaeus), conservation biological control, foraging behavior, *Sphaerophoria macrogaster* (Thomson)

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Insectary plants or floral resources have become an important tool for conservation biological control (CBC) to enhance natural enemies role against agricultural pests[1,2]. The CBC based integrated pest management (IPM) has been proposed for open-field eggplants[3,4] focusing on the conservation of *Orius* spp., promising natural enemies of *Thrips palmi*. As insectary plants for *Orius* spp., blue salvia has been considered important[5]. However, as far as we know, there has been no insectary plant to enhance natural enemies attacking aphids. In this study, the foraging behavior of *Sphaerophoria macrogaster* was examined on blue salvia. To compare its effectiveness, such behavior was also examined on coriander, which has been proved as useful insectary plants for hoverflies[1].

Aphidophagous hoverflies play a vital role in the control of aphids[6,7], serious pests of agricultural crops. A study at Kyoto in Japan revealed that among the aphidophagous hoverflies, *Sphaerophoria macrogaster* (Thomson) was the dominant species[8]. Mizuno *et al*.[9] found that the larva of *Sphaerophoria* sp. was an oligophagous aphid predator and it fed on at least four aphid species in Japan. However, the adult hoverflies depend on flower resources for their survival and reproduction. The scarcity of flowering plants in the modern agricultural lands often does not allocate adequate provisions to these natural enemies that are heavily relying on the floral resources for their reproduction and survival[10,11,12].

The aphidophagous female hoverflies require to forage for flowers while searching for aphid colonies to lay eggs. Therefore, they must forage effectively for flowers. According to Kevan and Baker[13], flower structures and attractants (cues) coevolved with pollinator anatomy, preferences, behavior and learning ability to enhance visitation and pollination activity. Foraging costs such as time and energy are also affected by flower structure[14], flower corolla depth[15], color of corolla and anther[16], along with olfactory cues from different floral organs; these are associated with rewards that have been shown to influence flower selection by honey bees[17,18] and bumble bees[19,20]. Therefore, it is crucial to investigate how to select a flowering plant species for effective foraging by an aphidophagous hoverfly which will maximize the energetic gains such as reward (nectar and pollen) and minimize foraging costs such as time and energy.

In the present study, an investigation was conducted on the foraging behavior of *Sphaerophoria macrogaster* in two flowering plant species, coriander (*Coriandrum sativum* Linnaeus) and blue salvia (*Salvia farinacea* Bentham), each of which consists of small flowers with relatively shallow corollae. According to Branquart and Hemptinne[21], the *Sphaerophoria* sp. and *S. scripta,* a hoverfly of small size with a long, narrow proboscis found in open and anthropogenic habitats, was able to access inflorescences with small and narrow corollae. Hence, both flowering species were considered good candidates for foraging by small-sized hoverflies with long, narrow proboscis such as *S. macrogaster*. Coriander has been already tested and found to be an efficient insectary plant with regards to the proportion of females laying eggs[22]. Blue salvia is a flowering plant belonging to the family *Lamilaceae*. It possesses nectar guides, a blue corolla and yellow anthers, effective floral cues for any flower visitor; flowers with similarly colored corolla and anthers were found to be effective floral cues for bumble bees[16]. Short-tongued flower visitors such as *Bombus terrestris* demonstrated suitability for foraging on blue salvia flowers[23], suggesting that *S. macrogaster* may also be able to forage on blue salvia.

Structure and flower color are key parameters for attracting hoverflies[24,25]; these morphological traits have been found to strongly influence the foraging behavior of other hoverflies such as *Episyrphus balteatus* in laboratory settings[26]. Thus far, laboratory and field assessments of flowering plant attractiveness to hoverflies have focused on indicators such as visitor longevity, reproductive parameters and the abundance on the flowering plant species[10,22,27]. However, there is no sufficient research on the detailed foraging patterns of an aphidophagous hoverfly like *S. macrogaster* on flowering plants of different structures and cues.

In the present study, details of the foraging patterns of *S. macrogaster* females were investigated in two different types of flowering plants. Based on the findings, the effective foraging by *S. macrogaster* in the two flowering plants and the sound basis for finding out the suitable flowering plants as insectary plants which are likely to contribute to biological control of aphids were discussed.

MATERIALS AND METHODS

Study site, hoverfly and insectary plant: The study of foraging behavior of *Sphaerophoria macrogaster* (Thomson) was conducted in an experimental field of 10×10 m^2 at the University of Miyazaki (36°14'N and 59°40'E) from May- June, 2014. Insectary plants, coriander (*Coriandrum sativum* Linnaeus) and blue salvia (*Salvia farinacea* Bentham) were planted in 6 plots in the field directing from south to north edge of the field on April, 2014. The area of each plot was 9 m^2 (3×3 m^2) and plots were spaced 0.63 m apart. Each plot consisted of 7 rows with 4 flowering plants in each row. Rows were separated by 28 cm and plants by 40 cm. Each of the plots was termed as 'patch' in the present study. During the experiment, mean temperature was 20.0°C and mean relative humidity was 70.6%. Both temperature and relative humidity were recorded by the thermo recorder RTR-53 during the study.

Foraging bouts of *S. macrogaster* in coriander and blue salvia flower patches: The foraging behavior of *S. macrogaster* was observed in both coriander and blue salvia flower patches by a focal sampling method with continuous recording as described by Martin and Bateson[28]. The observation was conducted from 7 am until 12 pm under clear sunny sky using a voice recorder and stopwatch. The foraging behavior of each individual was observed from once it enters the patch until it leaves the patch. The behavior was divided into foraging bouts classified by time spent performing each of a different type of foraging activity, listed below. Whether any of the observed *S. macrogaster* females re-entered in any of the coriander and blue salvia patch could not be considered in the present investigation as it was not possible to distinguish between individuals. The foraging bouts observed in coriander and blue salvia flower patches were as follows:

- **Interplant movement (including hovering):** It was a slightly motioned flight. *Sphaerophoria macrogaster* moved from one flowering plant to another in coriander and blue salvia flower patches
- **Approaching a flower:** Approaching occurred when they came <4 cm around the flowering plant. Sometimes they touched the corolla briefly. This bout also included hovering
- **Probing:** The feeding on pollen and nectar from flowers after landing on them
- **Landing on the flower:** *Sphaerophoria macrogaster* landed on the flower without probing it
- **Landing on leaf:** A stationary activity
- **Grooming:** Cleaning mouthparts or antennae
- **Fly out:** Leaving the patch

The sequence and duration of each bout was recorded. Transition frequency was calculated from each foraging bout sequences. The number of flowers probed during each visit into each patch by *S. macrogaster* were also recorded.

Flowering patterns of the two flowering plant species: The flowering patterns of coriander and blue salvia were estimated every 5-6 days during the study. The number of open flowers and inflorescences bearing open flowers from coriander and open flowers from blue salvia were counted from each patch.

Patch residence duration: In the present study, patch residence duration was calculated as the time between entering and leaving the patch (i.e., cumulative duration of all the foraging bouts).

Statistical analysis: The normality of the data was assayed using the Kolmogorov-Smirnov test. Statistically significant differences among the proportion of the dominant transitions among the main foraging bouts were evaluated by Chi-square test. As the normality assumption was not met, the Mann-Whitney U-test was used to compare the durations of interplant movement, approaching and probing between coriander and blue salvia flower patches. Linear regression analysis was performed to assess the relationships between patch residence durations of *S. macrogaster* and open flower resources of coriander and blue salvia patches. All statistical analyses were performed with SPSS software, version 19.

RESULTS

Foraging bouts of *S. macrogaster* in coriander and blue salvia flower patches: In this study, more than 70% of the transition sequences of the foraging bouts were interplant movement to approaching, approaching to probing and probing to approaching, in both flowering plant patches with transition frequencies ranging from 52-89%. Therefore, these transition sequences, as well as the foraging bouts included, were considered as predominant. The flow diagrams of the three main foraging bouts along with the terminal bout (fly out) in coriander and blue salvia flower patches were presented in Fig. 1 and 2, respectively. Incase of coriander, transitions from interplant movement to all other bouts occurred in total 183 occasions, out of which majority of the transitions from interplant movement was observed towards approaching (117/183) and 73/140 for blue salvia. Approaching transited to probing occurred in major occasions (300/378 in coriander and 186/208 in blue salvia). Probing led to approaching in major occasions (204/232 in coriander and 131/172 in blue salvia). The probabilities among these dominant transitions among these three main foraging bouts are presented in Fig. 3. The transitions from interplant movement to approaching were significantly more in coriander than in blue salvia flower patches ($\chi^2 = 4.55$, $p<0.05$). However, occurrences of approaching to probing transitions were significantly more frequent in blue salvia than in coriander flower patches ($\chi^2 = 9.59$, $p<0.05$). Transitions from probing to approaching were found to be significantly more frequent in coriander than in blue salvia flower patches ($\chi^2 = 9.66$, $p<0.05$).

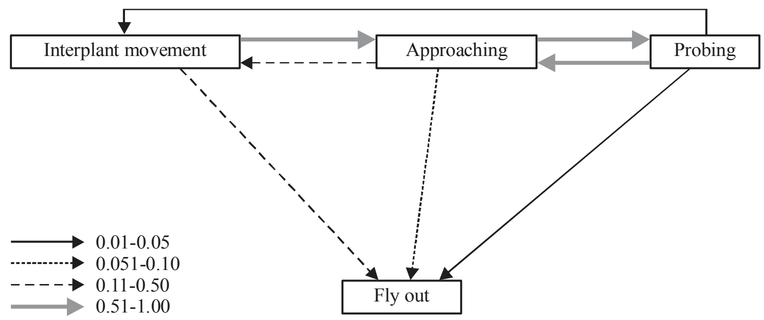

Fig. 1: Flow diagram of *Sphaerophoria macrogaster*'s foraging bouts in coriander flower patches based on 816 bouts from observed 83 hoverfly individuals. Arrows represent transition frequencies between four define foraging bouts

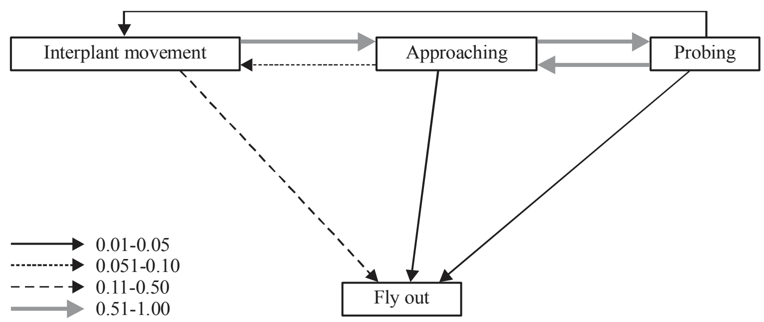

Fig. 2: Flow diagram of *Sphaerophoria macrogaster*'s foraging bouts in blue salvia flower patches based on 553 bouts from observed 76 hoverfly individuals. Arrows represent transition frequencies between four define foraging bouts

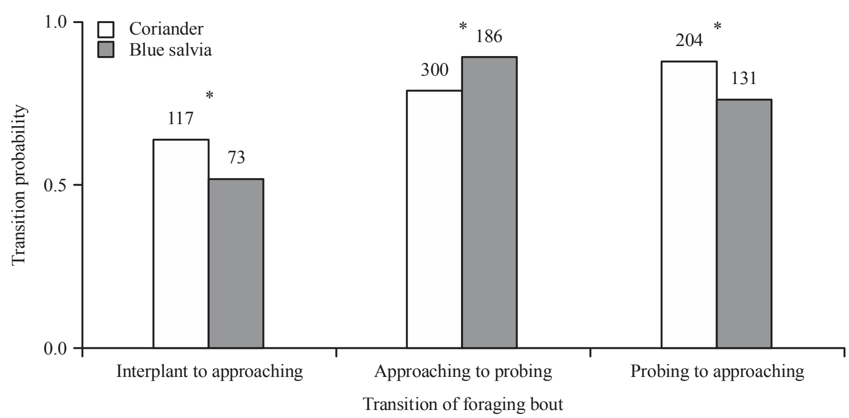

Fig. 3: Probabilities among the dominant transitions among the three dominant foraging bouts of *S. macrogaster* in coriander and blue salvia flower patches. The number in each bar are the sample sizes. *Significant difference (Chi-square test, $p<0.05$)

Longer interplant movement bouts, averaging 36.87 sec were observed in coriander than in blue salvia flower patches (30.22 sec) (Mann-Whitney U-test, $p<0.05$, Fig. 4). Approaching duration did not differ significantly in both the flowering plant patches (Mann-Whitney U-test, $p>0.05$). Approaching of 2.79 sec was recorded in coriander and it was 2.80 sec for blue salvia. A remarkable probing pattern of *Sphaerophoria macrogaster* is illustrated in Fig. 5. Longer probing was observed in blue salvia (34.86 sec) than coriander (7.47 sec) and this probing duration differed significantly between the two flowering plant species (Mann-Whitney U-test, $p<0.05$; Fig. 5).

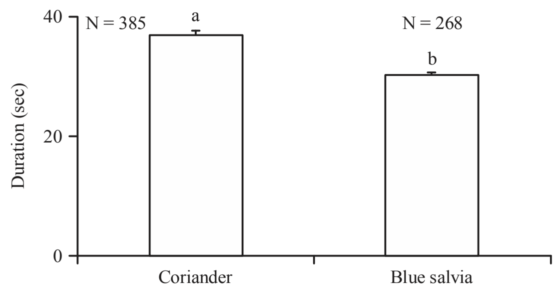

Fig. 4: Interplant movement duration (Mean±SE) of *S. macrogaster* for coriander and blue salvia flowering plant patches respectively

Different letters above bars are significantly different (p<0.05, Mann-Whitney U-test)

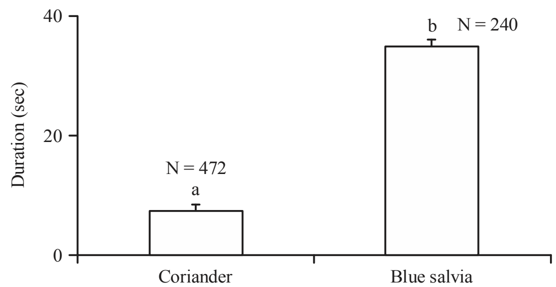

Fig. 5: Probing duration (mean±SE) of *S. macrogaster* for coriander and blue salvia flowering plant patches respectively

Different letters above bars are significantly different (p<0.05, Mann-Whitney U-test)

Flowering pattern of the two flowering plant species: On average, the number of open flowers per plant was 109.53 for coriander and 27.00 for blue salvia.

Patch residence duration: The patch residence of *SSphaerophoria macrogaster* was significantly positively correlated with the number of open inflorescences per patch of coriander (r = 0.720, p<0.05; Fig. 6a). *Sphaerophoria macrogaster* also showed a positive response to the number of open flowers per patch of blue salvia (r = 0.752, p<0.05; Fig. 6b).

DISCUSSION

The present study showed that both the flower species were apparently attractive to *Sphaerophoria macrogaster* as the patch residence duration of *S. macrogaster* responded to open floral resources of both coriander and blue salvia (Fig. 6). However, this study clearly demonstrated certain differences in the foraging behavior of *S. macrogaster* females between coriander and blue salvia flower patches. *Sphaerophoria macrogaster* females probed for nectar for longer periods in blue salvia (Fig. 5) which have deep and complex structured bilabiate flowers and shorter periods in coriander flowers (Fig. 5) which are arranged as compact and flat umbels with exposed nectaries. Gilbert[15] defined handling time during nectar probing by hoverflies as the time taken to insert the proboscis, suck up the nectar and withdraw the proboscis. Therefore, it is possible that the different flower structures

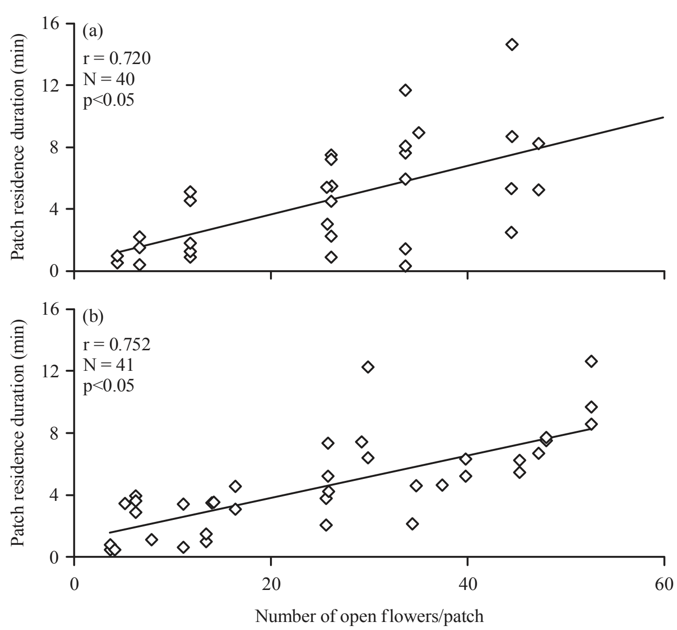

Fig. 6(a-b): Relationship between *S. macrogaster* patch residence duration and number of open floral resources per patch, (a) Coriander and (b) Blue salvia caused the differences in the flower handling times of *S. macrogaster* during nectar probing. This is in line with additional findings by Gilbert[15] demonstrated that flower handling time of hoverflies increased with increasing corolla depth.

Coriander flowers have short corolla which facilitated nectar availability to hoverfly species such as *Episyrphus balteatus* and *Syrphus rebesii*[15]. The corolla depth of coriander (*C. sativum*) has been measured at 0 mm[29], while the corolla depth of blue salvia (*S. farinacea*) has been found to be about 6 mm[23]. It is also possible, however, that the longer probing duration of *S. macrogaster* in blue salvia could be the result of greater nectar production in the deeper nectaries rather than longer handling time for accessing to the nectar of these flowers, as the depth of the flower corolla is found to be positively correlated with nectar production[14,30]. Nonetheless, *S. macrogaster* females analyzed in this study foraged more in coriander than in blue salvia flower patches. This is evident by longer interplant movement durations, suggesting more intensive searching, in coriander compared to blue salvia flower patches (Fig. 4). In addition, the foragers more frequently transited from searching to closer inspection (approaching) of coriander flowers and from feeding on nectar and pollen (probing) to closer inspection (approaching) of coriander flowers during foraging (Fig. 3). This is aligned with the findings of Lovei *et al*.[25] in that hoverflies were attractive to the white colored flowers of coriander over other flower species of blue color. However, less frequent transitions from approaching to probing were observed in coriander flower patches (Fig. 3). This could indicate that the amount of pollen and nectar probed from each of the coriander flowers was greater and resulted in less probing of coriander flower patches compared to blue salvia flower patches. Therefore, *S. macrogaster* foraged effectively in shorter handing time and open flowers of coriander than blue salvia.

Flower structure of coriander could be a strong indicator as to the effective foraging thereof by *S. macrogaster* in the present study. This statement is aligned with results by Koul *et al*.[31] demonstrated that the pattern of inflorescence of coriander provided suitable landing space to a relatively large number of visitors. The attractiveness of coriander flowers to many hoverfly species including *Sphaerophoria rueppellii*, *Sphaerophoria scripta* and *Sphaerophoria sulphuripes* has been detailed in many reports[1,27,32]. This study revealed that *S. macrogaster* preferred coriander over blue salvia while foraging.

CONCLUSION

Results from the present study demonstrated that foraging interest of hoverfly in specific flowering plant species could be crucial to successful implementation of CBC of aphids with aphidophagous hoverflies. It revealed that flowering plant species should be selected based on not only attractive floral properties but also rewarding values with low handling costs. This will lead to effective foraging of hoverflies such as *Sphaerophoria macrogaster* and enhancement of this aphidophagous natural enemy for effective CBC of aphids.

SIGNIFICANCE STATEMENT

The present study showed that *Sphaerophoria macrogaster* foraged differently in two different flower species. The foragers transited more frequently from searching for flowers to assessment in coriander than that of in blue salvia flower patches. Moreover, the foragers showed significantly shorter probing in coriander flower patches. It might be due to the shorter handling time which led to effective foraging by the foragers. However, the residence duration of *S. macrogaster* did not differ significantly between coriander and blue salvia flower patches. All the findings of this study indicated that *S. macrogaster* females foraged on both the flowering species but they foraged on coriander flowers more effectively. For proper selection of flowering plants, these findings are very important and have great implication for successful CBC of aphids using hoverflies.

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