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The contribution of floral resources and honeydew to the performance of predatory hoverflies (Diptera: Syrphidae)

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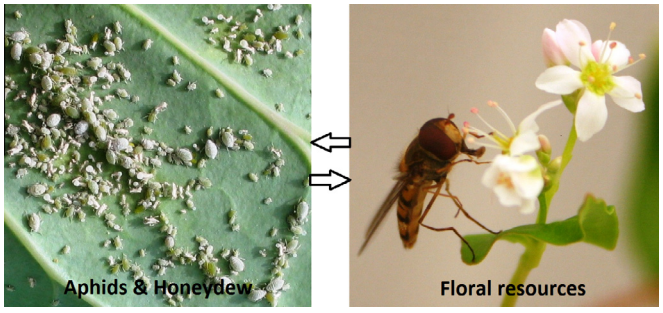
HIGHLIGHTS

- Aphid honeydew enhances adult hoverfly longevity.
- When pollen and nectar are available, honeydew still generates additional survival.
- Feeding on floral resources for only one week is sufficient for female reproduction.
- This implies a reduced need to commute between feeding sites and oviposition sites.
- Hoverfly larvae are able to suppress aphid colony growth.

GRAPHICAL ABSTRACT



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ABSTRACT

Hoverflies with predatory larval stages are important natural enemies of aphids and other pests in field crops. Many adult hoverflies are actively visiting and feeding on flowers, indicating that pollen and nectar are important resources for them. The scarcity of suitable flowers in intensified agriculture is therefore likely to limit their effectiveness as biological control agents. In this study on *Episyrphus balteatus* we quantify how permanent and temporal availability of pollen and nectar affects adult survival and reproduction, and assess to what extent aphid honeydew can substitute floral resources.

Our results show that honeydew of cabbage aphids (*Brevicoryne brassicae*) strongly enhances hoverfly survival in the absence of floral resources. Less to be expected, when floral resources are available, honeydew supplementation still generates additional survival.

A sucrose solution (as mimic for nectar) strongly increases adult longevity relative to water only, similar to honeydew. Flowers of buckwheat (*Fagopyrum esculentum*), permanently providing both nectar and pollen, further increases adult longevity and also supports egg production.

Feeding on flowers of buckwheat during a 6 days pre-ovipositional period allows adult females to produce eggs for a week thereafter, and to survive for another 2 weeks, indicating that they can store and benefit from these nutritional resources for a substantial time. This suggests that the hoverflies only occasionally need to commute between aphid patches for oviposition (e.g., in the crop) and floral patches for feeding (e.g., at the border of the field). Honeydew, when locally at sufficiently high levels, may be used by the hoverflies to restore their energy demands, thereby postponing the need to search for floral resources.

Cage experiments show that when suitable flowers are present the hoverflies can strongly suppress the growth of cabbage aphid colonies on Brussels sprouts.

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1. Introduction

Many insect predators and parasitoids that play a role in the suppression of pests, require non-prey food such as nectar or pollen during their adult life stage (Wäckers and Van Rijn, 2012). The scarcity of flowering plants in modern agricultural fields may prohibit an effective performance of these beneficial insects (Winkler et al., 2006; Olson and Wäckers, 2007; Tscharntke et al., 2007; Meyer et al., 2009). Providing these floral resources in the agricultural landscape may therefore be an effective tool to improve natural pest control (White et al., 1995; Heimpel and Jervis, 2005; Van Rijn and Sabelis, 2005). In many European countries programs have been developed promoting the use of flowering strips in the margins of arable and vegetable fields that provide these floral resources for the natural enemies of pests (www.ELN-FAB.eu, www.ecostac.co.uk). In the Netherlands, the Functional Agrobiodiversity (FAB) project (Van Rijn et al., 2008) initiated the study of plant species and plant mixtures most suitable for this purpose.

In arable crops, such as potato and wheat, aphids are among the most important pests. Extensive sampling in such arable fields (Van Rijn et al., 2008) indicated that hoverflies, together with lacewings and parasitoids, are likely the most important groups of natural control agents. Hoverflies with predatory (or 'aphidophagous') larvae (Diptera: Syrphidae: Syrphinae) are probably highly dependent on floral resources during their adult life stage. It has been shown for some species that the protein-rich pollen is needed for sexual maturation (Haslett, 1989; Laubertie et al., 2012). The sugar-rich nectar is an important energy source, needed for the energy-demanding hovering flight and for survival (Haslett, 1989; Gilbert, 1985). Adult hoverflies are widely studied with respect to their flower visiting behavior (e.g. Sutherland et al., 1999; Colley and Luna, 2000; Tooker et al., 2006) and are commonly recognised as important pollinators (Biesmeijer et al., 2006; Meyer et al., 2009). However, very few studies addressed the effect of floral and other food sources on the survival and fecundity of adult hoverflies (Haslett, 1989; Branquart and Hemptinne, 2000; Laubertie et al., 2012). In those species for which flowers are an essential source of nutrients, mature females need to alternate searching for flowers with searching for oviposition sites, i.e. aphid colonies. For parasitoids, which are confronted with the same problem, it has been shown that in many species feeding is required every 1–2 days in order to survive (Wäckers and Swaans, 1993; Lee and Heimpel, 2008). Such feeding intervals clearly put limits to the spatial separation of the two resources, flowers and aphids (Vollhardt et al., 2010). For hoverflies it is still unknown how frequently they need to feed on floral resources to realize their full reproduction capacity.

Honeydew, the sugar-rich secretion product of aphids, is also reported to be used by hoverflies for feeding (Ssymank and Gilbert, 1993; Hogervorst et al., 2007). Moreover, it has been shown to be a searching cue and an oviposition stimulus for aphidophagous hoverflies (Budenberg and Powell, 1992; Almohamad et al., 2009). However, its effect on adult survival and fecundity had not yet been studied. This knowledge is essential for understanding the role of floral resources for the conservation of this species rich group of insects, and for indicating what measures at landscape and farm level could improve natural pest control.

In this study we focus on the marmalade fly, *Episyrphus balteatus* (L.), one the most common predatory hoverfly species around agricultural fields (Reemer et al., 2009), and which is commercially available as an aphid biocontrol agent. We use three separate experiments to study the impact of the various food resources on hoverfly fitness parameters and on biological control.

(1) As a rich source of sugars honeydew is expected to affect primarily longevity. In a full factorial experiment the contribution of honeydew to adult longevity is studied at various levels of floral resource availability.
(2) We hypothesis that during their pre-ovipositional period (Branquart and Hemptinne, 2000) hoverflies can concentrate on feeding only. However, as soon the first eggs have matured they will start searching for oviposition sites (i.e. aphid colonies). To learn how soon they need to revisit floral feeding sites we gave female hoverflies access to flowers during their pre-oviposition period only, and studied their subsequent survival and fecundity relative to hoverflies that either had no, or permanent access to flowers.
(3) To quantify the potential impact of a reproducing hoverfly on aphid colony growth, we studied the population development of hoverfly larvae and cabbage aphids in cages with and without flowers.

2. Materials and methods

For each experiment fresh pupae from the hoverfly *E. balteatus* were obtained from Koppert B.V. (Berkel and Rodenrijs, NL). To assess the survival and reproduction of the hoverflies under various conditions and to investigate their interaction with cabbage aphids, in 2005 and 2007 experiments were performed in gauze cages (L × W × H = 40 × 48 × 68 cm) placed in illuminated climate chambers (23 °C, 80% RH). Each cage was provided with one newly emerged (<24 h) female, as well as one or two newly emerged males. As main source of floral nectar and pollen we used plants of buckwheat, *F. esculentum* Moench. The flowers of this plant are known to provide accessible food of high nutritional value to several natural enemies including hoverflies (Bowie et al., 1995; Wäckers and Van Rijn, 2012). The plants were grown from seed in 1 l pots in a greenhouse (D:L = 16:8 h, min. 18 °C), and used when flowering c. 5 weeks later. As a substrate and stimulus for oviposition we provided each cage with one or two small plants of Brussels sprouts (*Brassica oleracea* L. var. *gemmifera* DC) also grown from seed and infested with cabbage aphids (*B. brassicae* (L.)) a few days before the experiment.

2.1. Impact of aphid honeydew and floral resources on hoverfly survival and reproduction

To study the impact of aphid honeydew, the level and period of cabbage aphid infestation was varied among treatments. In the aphid/low honeydew treatment the plants were infested with 50 aphids one day before the experiment. In the aphid/high honeydew treatment the plants were infested 3 days before the experiment and adjusted to c. 250 aphids one day before the experiment. In the first treatment plants had accumulated virtually no honeydew at the start of the experiment, while in the second treatment honeydew was clearly present on the surface of the leaves. The aphids were not removed from the plants to ascertain continues supply of fresh honeydew. As a control treatment the plants were not infested with aphids, and did not contain any honeydew. These three aphid/honeydew treatments (i.e. zero, low and high) were combined in a full factorial design with three levels of floral food availability. At the highest level both nectar and pollen was provided by means of flowering buckwheat plants. At a lower food level the hoverflies were provided with a 1 M sucrose solution (34.2 g/100 ml), as mimic for nectar. This 'nectar' was offered in a small vial with a yellow lid featuring a 1 cm round hole, and the solution was replenished daily. At the lowest level no food source was provided. In all treatments, water was provided by soaked cotton wool