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Flowers promote aphid suppression in apple orchards

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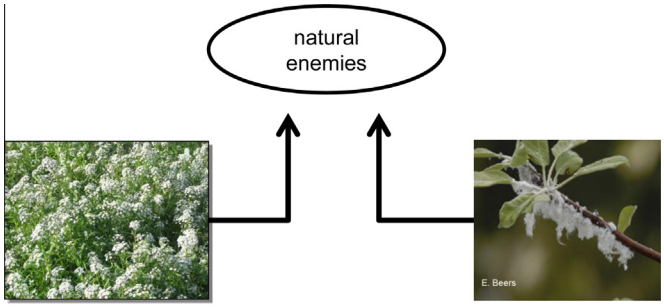
HIGHLIGHTS

- Sweet alyssum flowers had the highest attractiveness to syrphids.
- Faster suppression of woolly apple aphid occurred on trees closer to alyssum flowers.
- Higher densities of natural enemies were observed near sweet alyssum plantings.
- Natural enemies were found to move between sweet alyssum and adjacent apple trees.

GRAPHICAL ABSTRACT



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ABSTRACT

Predators and parasitoids often benefit from feeding on nectar and/or pollen, such that the addition of flowering plants should bolster natural enemies and improve biological control. Nonetheless, this conceptually-simple approach often fails to reduce pest numbers. We examined whether flowering annual plants drew more natural enemies to apples (*Malus domestica*) in Washington State, USA, and in turn whether this improved suppression of woolly apple aphids (*Eriosoma lanigerum*) on nearby trees. Initial screening of candidate flowers indicated that syrphid flies (Diptera: Syrphidae), thought to be important aphid predators, were particularly attracted to sweet alyssum flowers (*Lobularia maritima*). Therefore, in two subsequent field experiments we compared aphid densities on trees placed adjacent to, or relatively far from, flowering sweet alyssum. The results were striking: after one week aphid densities were significantly lower on trees adjacent to flowers than on those on control plots, and these differences were maintained for several weeks. It was unlikely that aphid decline was primarily due to syrphid predation, because lower aphid densities were observed despite few syrphid larvae being present. Rather, a diverse group of generalist-predator spiders and bugs increased significantly near sweet alyssum plantings, and may have been responsible for much of the aphid suppression that we observed. Immunomarking revealed that natural enemies regularly moved from sweet alyssum to the surrounding orchard. In summary, the floral resources that sweet alyssum plants provided attracted natural enemies and indirectly suppressed densities of woolly apple aphids, suggesting an effective means for apple growers to enhance biological control.

1. Introduction

Predators and parasitoids of herbivorous pests often benefit from the presence of flowering plants, when the natural enemies can use pollen or nectar as supplemental food (Landis et al., 2000). For example, lady beetles inhabiting alfalfa fields have been observed to use pollen as alternative food source, which may help bolster predator numbers and their impacts on aphid and beetle pests (Davidson and Evans, 2010). Likewise, adult female parasitoids can dramatically increase their lifespan, and thus net fecundity, when provided with access to nectar from flowers (Winkler et al., 2006). The addition of these "floral resource" to

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agroecosystems could be one obvious means to enhance biological control of agricultural pests, by planting annual or perennial flowering plants at field edges (Hickman and Wratten, 1996). In several cases this approach has been notably successful. For example, Tylianakis et al., (2004) observed a significant increase in aphid parasitism in wheat plots closer to floral-resource patches.

Nonetheless, there are surprisingly few published case-studies where the addition of flowering plants has both enhanced natural enemy populations and improved pest suppression (Heimpel and Jervis, 2005). There are many reasons why adding flowering plants might fail to improve biological control. First, the flowers must add novel resources not already provided elsewhere in the environment by aphid honeydew or other sugar sources. For example, the addition of new floral resource may not reliably improve parasitoid performance when sugars from aphid honeydew are already available (Lee et al., 2006). Second, flowers must be carefully chosen to provide resources easily accessed by natural enemies but not by moths or other pests that also use nectar or pollen (Baggen and Gurr, 1998; Baggen et al., 1999; Géneau et al., 2012), or by intraguild predators or parasitoids of the natural enemy species that one is seeking to conserve (Araj et al., 2006; Prasad and Snyder, 2006; Jonsson et al., 2009). Third, natural enemies must readily move back and forth between flowers and the crop which one is seeking to protect, and not simply aggregate and arrest in the flowers (Landis et al., 2000). These obvious limitations have led some authors to question how often the provisioning of floral resources is likely to enhance, rather than disrupt (or simply fail to alter), overall biological control (Heimpel and Jervis, 2005).

We examined the potential for annual flowering plants to attract natural enemies that attack woolly apple aphids (*Eriosoma lanigerum*) in Washington State, USA, apple (*Malus domestica*) orchards. In our region the aphids typically reach high densities soon after bud-break, and then again later in the growing season starting in July; peak aphid densities are often seen between July and October (Beers et al., 2010). The relationship between aphid density and yield reduction is not known, such that growers usually reach spray decisions in the absence of rigorously-documented action thresholds (Beers et al., 2010). There have been increasingly severe woolly apple aphid outbreaks in our region in recent years (Beers et al., 2010). It is likely, that in the past aphids were indirectly killed by sprays of organophosphate and other broad spectrum insecticides targeting codling moth (*Cydia pomonella*). In addition, mating disruption and reduced-risk alternative management programs for the primary pest have been associated with higher aphid densities.

Woolly apple aphids are attacked by the specialist parasitoid *Aphelinus mali*, and also preyed upon by syrphid larvae whose adult females are known to benefit from nectar and pollen (Telenga, 1958; Haslett, 1989). Unfortunately, apple orchard floors are generally maintained with a mown grass sod and strips of bare ground beneath the trees, providing few or no floral resources for resident predators (Horton et al., 2003). Thus, the addition of flowers might greatly enhance resource availability for woolly apple aphid natural enemies, perhaps increasing their numbers and improving biological control. Compared to annual crops, fruit orchards are particularly amenable to natural enemy conservation using flowers because of their semi-permanent features and relatively high levels of structural complexity (Simon et al., 2010). The main objectives of this study were to: (1) identify an annual flowering plant highly attractive to natural enemies of aphids; (2) determine whether providing these flowers bolsters enemy densities and improves aphid suppression; and (3) verify that natural enemies readily move from flowers to surrounding apple trees.

2. Materials and methods

2.1. Screening of flowering plants

Several factors focused our search for flowering plants that would be most useful in our study system. First, the literature reports several flowering plants known to be attractive to adult syrphid flies, which have been reported to be important natural enemies of aphids in the northwestern USA (and elsewhere) that are responsive to the addition of floral resources (e.g., Hogg et al., 2011). Second, we focused on flowering annual plants. This was for purely pragmatic reasons, as in our experience apple growers are more receptive to short-term plantings that can be periodically tilled-under and replanted to avoid becoming weedy (E.H. Beers, personal communication). A literature search led us to the following six plants that met our selection criteria: marigold, *Calendula officinalis*; buckwheat, *Fagopyrum esculentum*; cosmos, *Cosmos sulphureus*; mustard, *Brassica juncea*; zinnia, *Zinnia hybrida*; and sweet alyssum, *Lobularia maritima* (Kloen and Altieri, 1990; Lovei et al., 1993; Ambrosino et al., 2006; Sadeghi, 2008). Plots of these flowers were established in a field area near tree-fruit orchards, and we then monitored flower visitation by adult syrphids, as described below.

Our screening of annual flowering plants was conducted in a field at Washington State University's Tree Fruit Research & Extension Center in Wenatchee, WA, USA. This site was surrounded by apple orchards to the north and west, a cherry (*Prunus avium*) orchard to the south, and buildings to the east; a large tract of unmanaged ground with native shrub-steppe plants (primarily *Artemisia tridentata*, *Purshia tridentata*, *Erigonum* spp., and *Agropyron spicatum*) adjoined the apple orchard on the west. Flowering plants were grown from seed in a greenhouse (25 ± 2 °C, R.H. 65 ± 5%) in 0.25 m pulp pots filled with potting soil (Miracle-Gro Promixing soil, Marysville, OH) and watered as needed. Ten days after germination, plants were transported to the field site, on 12 August 2008. We established four replicate plots of each of the six flower species, arranged within a completely randomized design. Each plot consisted of 30 pots of that plants species, arranged in three rows of 10 pots, covering roughly 1 × 3 m of ground. Plots were 10.5 m (east–west) or 15 m (north–south) apart, and the existing in-ground irrigation system (impact sprinklers on 0.60 m risers) was used to provide water to the potted plants, which were irrigated twice per week.

Flower attractiveness was measured by recording the flower-visit frequency of adult syrphids during a 2 min observation period per replicate plot, with observations made between 10:00 am and 12:00 pm, on 1, 6, 13, 20 and 27 September 2008. After the 2 min observation period in each plot, we captured adult syrphids using an aerial net; these adults were killed and pinned for later species identification. The temperature for those time slots varied from 23 to 28 °C, and the conditions were sunny for the first, third, and fourth sample dates, and partly cloudy for the second and fifth sample dates.

2.2. Effect of sweet alyssum on woolly apple aphid suppression

Having identified sweet alyssum as the most attractive annual flowering plant in objective 1 (see above; Fig. 1), our second goal was to determine whether these flowers significantly increased natural enemy densities and improved woolly apple aphid suppression. Our experimental design included just two treatments: (1) sweet alyssum flowers planted nearby to focal apple trees infested with woolly apple aphid, and (2) mowed grass but no flowers provided near aphid-infested apple trees. The experiment was conducted twice, first in September 2010 and again in October