Importance of early arrival of adult *Harmonia axyridis* for control of *Aphis spiraecola* on apple

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Abstract The biological control of aphid populations may only be possible when natural enemies arrive soon after aphid colonization. This study was done to identify how quickly adult *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae) need to arrive at newly established spirea aphid [*Aphis spiraecola* Patch (Homoptera: Aphididae)] colonies on apple (*Malus domestica* Borkh.) to provide population control. A total of 100 newly established spirea aphid colonies were caged in an experimental apple orchard in West Virginia, USA. A single adult *H. axyridis* was added to each of ten caged colonies at day 0, 5, 10, 15 and 20 days after caging. An additional ten caged colonies were opened for exposure to natural levels of predation at each of the treatment intervals as a control. The single *H. axyridis* eliminated the aphid colonies significantly more quickly than natural predation for up to ten days after colony establishment. The probability of an aphid colony producing alates was significantly lower in the presence of a single *H. axyridis* adult than when exposed to natural predation for the first ten days. Adult *H. axyridis* beetles are capable of completely controlling individual spirea aphid colonies on apple only if they are abundant enough to find colonies within one week of colony establishment.

Introduction

Coccinellids are widely acknowledged to be voracious predators with a high searching capacity for aphids and other small arthropods (Hodek and Hoňek 1996). However, their capacity to control aphid populations is often considered to be limited (Frazer 1988; Dixon 2000; Obrycki et al. 2009; Latham and Mills 2010). Out of 155 attempts at classical biological control using coccinellids against aphids, none were completely successful and only one was deemed substantially successful (Dixon 2000). The lack of aphid control by coccinellids has been attributed to their inability to respond rapidly to aphid population growth (Frazer 1988), their broad host range (Dixon 2000) and relatively long generation time compared with aphids (Kindlmann and Dixon 1999, 2001). However, there have been a number of systems where coccinellids have been shown to be a key predator in aphid control (Kring et al. 1985; Bugg et al. 1991; Michaud 1999; Conway et al. 2006). Coccinellids can also be an integral part of the predator guild

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providing early season control of pests (Völkl et al. 2007). Early arrival of any predator is a critical prerequisite for control of aphid populations (Smith 1966; Chiverton 1986; van der Werf et al. 1992; Landis and van der Werf 1997; Harwood et al. 2004).

In the apple agroecosystem of eastern North America, the spirea aphid, *Aphis spiraecola* Patch (Homoptera: Aphididae), has been the most abundant aphid since 1986 (Pfeiffer et al. 1989). Although the spirea aphid can use apple as a primary (overwintering) host, populations on apple do not begin expanding until alate migrants (foundresses) arrive on apple in early May from other primary hosts (Pfeiffer et al. 1989; Brown et al. 1995). The coccinellid, *Harmonia axyridis* (Pallas) (Coleoptera: Coccinellidae), is the key predator providing biological control of spirea aphid in eastern North America (Brown 2004). Since the arrival of *H. axyridis* in northeastern U.S. orchards in 1994, it has controlled populations of spirea aphid to levels below action thresholds (Brown and Miller 1998). Adult beetles, not larvae, provide control of aphid populations in this system. Adult *H. axyridis* have the ability to consume an average of 20 spirea aphid colonies (less than 30 aphids per colony) within one day in the laboratory (Brown 2004).

This study was designed to evaluate the importance of early arrival of adult *H. axyridis* to control of spirea aphid colonies on apple. A second objective was to quantify how soon adult *H. axyridis* need to arrive after colony establishment to be capable of providing adequate control.

Materials and methods

In May to early June of 2008 and 2009, a total of 100 *A. spiraecola* colonies on apple were selected for observations. Eighty colonies were sampled in 2008, 20 in 2009. There was at least one colony sampled in 2009 in each treatment and control group. There were no differences in colony response variables between the 2008 and 2009 samples. Therefore, data from both years were combined for analysis. All colonies were in experimental orchards located at the Appalachian Fruit Research Station, Kearneysville, WV, USA. These orchards were not treated with insecticides for the duration of the study. Selection of aphid colonies was based on the criterion that they were recently established; that is, that there were only a

few young nymphs, with or without a foundress (from 3 to 16 total aphids). Upon selection, each colony was caged in a 60 cm long, 25 cm diameter polyester mesh bag with 22 by 11 threads cm^{-1} (Quest Outfitters, Sarasota, FL, USA). This type of mesh cage has been used in previous studies and did not affect microclimate within the cage (Brown 2004). Prior to caging, each apple branch was examined and all predators and other arthropods were removed.

Ten aphid colonies were randomly assigned into each of five experimental treatments with another ten colonies randomly assigned into each of five control groups to match the treatments. Adult *H. axyridis* used for this study were from a laboratory colony begun with overwintering adults and starved, with access to water, for 24 h prior to use. Sex and age of the beetles were not determined. The first treatment had an adult *H. axyridis* placed on the apple branch at the time of caging. The matching control colonies were left uncaged for exposure to natural levels of predation. The second treatment had one adult *H. axyridis* placed into the cage five days after initial caging and the matching control was uncaged. The third treatment had one adult *H. axyridis* added to the cage on day 10, day 15 for treatment 4 and day 20 for treatment 5, with matching controls for each treatment uncaged on the same day as beetle introduction. Colonies were monitored daily except on weekends, during no-reentry periods for fungicides or herbicides, or during inclement weather. The number of aphids, presence of alate adults or nymphs with wing pads and fate of the introduced *H. axyridis* in the treatment cages were recorded at each observation. For control colonies the number of aphids, presence of alate adults or nymphs with wing pads and presence of any predators was recorded.

Two response variables were used for analysis. Colony longevity, measured by the number of days from introduction of the adult *H. axyridis* until all aphids were dead, was compared between treatment and the matched control using a two-sample *t* test (Steel and Torrie 1960). The colony longevity data fit the assumptions of normality without transformation. Proportion of successful colonies, defined as the production of alate aphids; and therefore able to produce additional colonies on apple or other hosts; was compared between treatment and the matched control with a binomial test (Conover 1971) using presence or absence of wings or wing pads within the

colony as the independent variable. A total exclusion control for aphid colony longevity, using similar mesh bags to exclude all predators and parasitoids, was from an earlier experiment in the same orchards (Brown 2004).

Results

There were significant differences in colony longevity between colonies exposed to predation by a single adult *H. axyridis* and the controls that were exposed to natural levels of predation within ten days of colony initiation (Fig. 1). All ten colonies that had an adult *H. axyridis* introduced on the 1st day of observation were completely consumed within one day (Fig. 1). Two of the ten colonies exposed to natural levels of predation were also completely consumed in the 1st day. At five days after colony initiation, those exposed to a single *H. axyridis* survived less than colonies exposed to natural predation. Ten days after colony initiation, a single *H. axyridis* was still effective in reducing colony longevity compared with colonies with natural predation. At 15 and 20 days after colony initiation there were no differences between the treatment and control colony longevity. As anticipated, the number
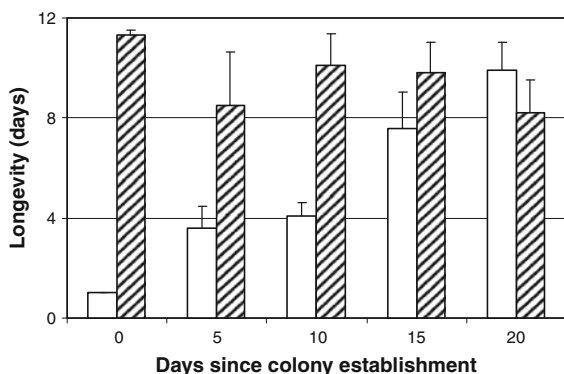
Fig. 1 Average (+SE) number of days until death of spirea aphid colony on apple after addition of a single adult *H. axyridis* (open bars) or a matched control exposed to natural levels of predation (shaded bars). Statistical details: day 0, $t = 3.160$, df = 18, $P = 0.005$; day 5, $t = 4.716$, df = 16, $P < 0.001$; day 10, $t = 5.025$, df = 18, $P < 0.001$; day 15, $t = 1.249$, df = 17, $P = 0.229$; day 20, $t = 1.022$, df = 17, $P = 0.321$. Note: SE was 0 in the first treatment exposed to an adult *H. axyridis* because all colonies were consumed at the first observation
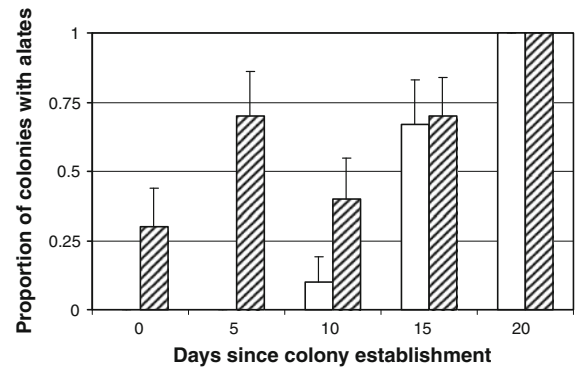
Fig. 2 Probability (+SE) or a spirea colony producing alates in the presence of a single adult *H. axyridis* (open bars) or a matched control exposed to natural levels of predation (shaded bars). Statistical details: day 0, df = 9, $P = 0.028$; day 5, df = 7, $P = 0.002$; day 10, df = 8, $P = 0.0464$; day 15, df = 8, $P = 0.715$; day 20, df = 8, $P = 1.000$. Note: SE was 0 at probabilities of 0 and 1.0 due to no variation in data

of aphids present at the beginning of each treatment increased with the number of days following colony initiation.

The probability of a colony producing alates was significantly lower for colonies exposed to a single adult *H. axyridis* than to natural predation through ten days past colony initiation (Fig. 2). Only with exposure to *H. axyridis* at ten days past colony exposure did any colony exposed to *H. axyridis* (1 compared with 4 in the control) produce alate aphids. At 15 and 20 days beyond colony initiation there were an equal proportion of colonies producing alates in colonies exposed to *H. axyridis* as exposed to natural predation. At 15 and 20 days after colony establishment nymphs with wing pads were present in treatment and control colonies at the time of exposure to predators.

Discussion

A single *H. axyridis* adult is capable of consuming a spirea aphid colony on apple when it arrives within ten days of colony establishment (Fig. 1). Exposure to the natural guild of predators, which at this early time of colony development is comprised largely of adult *H. axyridis* (Brown 1999), resulted in only 20% of the colonies being consumed. The control colonies exposed to the guild of aphid predators in this study survived about ten days after being exposed to predation (Fig. 1), which was the same longevity

found in the earlier study of spirea aphid predation on apple (Brown 2004). *H. axyridis* adults are part of this guild of predators, indicating that at least in 2008 and 2009 there were not sufficient numbers in the experimental apple orchards to provide population control of spirea aphid. In the previous control study (Brown 2004), spirea aphid colonies that were caged to exclude all predators survived more than 20 days.

H. axyridis adults are the keystone predator of spirea aphid on apple in the mid-Atlantic states of the eastern US (Brown 2004). They are also important in providing early control of rosy apple aphids, *Dysaphis plantaginea* (Passerini) (Homoptera: Aphididae), in the eastern U.S. (Brown and Mathews 2007). This study showed that adult *H. axyridis* must find spirea aphid colonies within ten days of colony establishment to provide control. By 15 days after establishment aphid colonies become too big and continue to grow in spite of the presence of a single adult *H. axyridis*. By ten days after colony establishment some spirea aphid colonies were capable of producing alatae, thus continuing aphid population growth on apple or other hosts. A caged predator is expected to feed on more prey than a predator able to freely disperse, thus these data on caged predators should be considered a maximum estimate of the effect of the predator on colony fitness.

The success of *H. axyridis* in providing control of aphid populations on apple depends on numerous factors. The abundance of overwintering adults (Brown 2004), its ability to consume entire small newly established colonies (Fig. 1), the lack of alternative prey early in the spring, abundance of immigrating spirea aphids and various weather factors will all influence the interaction between aphid and coccinellid. Adult *H. axyridis* can provide control of spirea aphid in West Virginia in some years (Brown and Miller 1998; Brown 2004) but they are not present in large enough numbers relative to the number of migrant spirea aphids to provide reliable, consistent control. Only when sufficient populations of *H. axyridis* arrive within ten days of spirea aphid colony establishment can successful biological control be possible. Where Spring-time aphids are a problem, such as in apple production, it may be useful to provide overwintering shelters near orchards or to collect adult *H. axyridis* from known aggregation sites to ensure adequate numbers to provide biological control.

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