GREENHOUSE TRIALS OF *APHIDIUS COLEMANI* (HYMENOPTERA: BRACONIDAE) BANKER PLANTS FOR CONTROL OF APHIDS (HEMIPTERA: APHIDIDAE) IN GREENHOUSE SPRING FLORAL CROPS

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Abstract

Banker plants with *Aphidius colemani* Viereck were tested in greenhouses in Massachusetts and New York for control of cotton aphid *Aphis gossypii* Glover, and green peach aphid *Myzus persicae* (Sulzer) on 2 spring flower crops, pansies (*Viola tricolor hortensis*) and Marguerite daisies (*Argyranthemum* hybrid). Banker plants consisted of pots of barley plants infested with the bird cherry-oat aphid *Rhopalosiphum padi* (L.), inoculated at the start of the crop with adults of *A. colemani* purchased from a commercial insectary. Initial trials were conducted in University of Massachusetts greenhouses containing flats of the crop plants. Sentinel plants in flats were infested uniformly with aphids, and particular greenhouses were subjected to the presence of banker plants or left as controls. Prior to University trials, a survey was conducted in commercial greenhouses in Massachusetts and New York to determine the frequency and species of aphid infestation in spring flower crops. After University trials, the efficacy of banker plants was tested in commercial greenhouses in both states. In surveys of commercial greenhouses, *M. persicae* was the most frequently detected species, accounting for 53% of all infestations. In University greenhouse trials, in absence of parasitism, *A. gossypii* increased fastest on daisy, followed by *M. persicae* on daisy, *M. persicae* on pansy, and *A. gossypii* on pansy. Parasitoid suppression of population increase was strongest for *A. gossypii* on daisy and poorest for *M. persicae* on pansy. The presence of 2 aphid species in the same greenhouse did not alter the level of biological control in our trial. In commercial greenhouses, banker plants failed to control *M. persicae* deployed on infested pansies as sentinel hosts. In the laboratory, a 12-h exposure to dried residues of pyriproxyfen or pymetrozine, insecticides commonly used to control aphids, reduced survival of *A. colemani* adults, compared to a water control (82% survival), to 71% and 53%, respectively. Adult parasitoid emergence from pesticide-treated aphid mummies was reduced from 68% for the controls to 56% for pyriproxyfen and 62% for pymetrozine.

Key Words: *Aphidius colemani*, *Myzus persicae*, *Aphis gossypii*, banker plants, biological control, greenhouse flower crops

Resumen

Plantas banqueras con *Aphidius colemani* Viereck fueron probadas en invernaderos en los estados de Massachusetts y Nueva York para el control del áfido del algodón, *Aphis gossypii* Glover, y el áfido verde del durazno, *Myzus persicae* (Sulzer) sobre 2 cultivos de flores de la primavera, violetas (*Viola tricolor hortensis*) y margaritas (hibrido de *Argyranthemum*). Las plantas banqueras consistieron de plantas de cebada sembradas en macetas infestadas con el áfido, *Rhopalosiphum padi* (L.), inoculadas al principio con adultos de *A. colemani* comprados en un insectario comercial. Se realizaron las pruebas iniciales en plantas del cultivo puestas en bandejas en los invernaderos de la Universidad de Massachusetts. Las plantas centinelas puestas en las bandejas fueron infestadas de una manera uniforme con áfidos, y ciertos invernaderos fueron sujetos a la presencia de plantas banqueras o dejados como un control. Antes de las pruebas en la Universidad, se realizaron sondeos de los invernaderos comerciales en Massachusetts y Nueva York para determinar la frecuencia y las especies de los áfidos infestando los cultivos de flores de primavera. En los sondeos de invernaderos comerciales, *M. persicae* fue la especie mas frecuentemente detectada, representando 53% de todas las infestaciones. En las pruebas del invernadero de la Universidad, en la ausencia de parasitismo, la población de *A. gossypii* aumento más rápido sobre las margaritas, seguida por *M. persicae* sobre las margaritas, *M. persicae* sobre las violetas y *A. gossypii* sobre las violetas. La supresión de la población de áfidos debida a los parasitoides fue mas fuerte para *A. gossypii* sobre las violetas y mas débil en *M. persicae* sobre las violetas. La presencia de 2 especies de áfidos en el mismo invernadero no cambio el nivel de control biológico en nuestra prueba. En los invernaderos comerciales, las plantas banqueras fallaron en controlar *M. per-*

sicae puestos sobre las violetas infestadas como hospederos centinelas. En el laboratorio, la exposición de 12 horas a residuos secos de piriproxifen o pimetrozin, insecticidas comúnmente usados para controlar áfidos, reducieron la sobrevivencia de adultos de *A. colemani*, en comparación al control con solo agua (82% sobrevivencia), a 71% y 53%, respectivamente. La emergencia de los adultos de parasitoides de las momias de áfidos tratadas con pesticida fue reducida 68% en el control a 56% para piriproxifen y 62% para pimetrozin.

Aphids are a common problem on a wide variety of greenhouse crops. In a survey of Massachusetts flower growers in 1996, growers reported applying an average of 3 pesticide applications per crop for aphids, second only to thrips (Smith, 1998). Use of pesticides for control of aphids, however, can disrupt biological control of other pests. Current use of aphid biological control in flower crops has an inadequate research base, and has largely been guided by insectary recommendations. On a per capita basis, parasitoids have greater potential for suppressing aphid populations in greenhouses than predators because of their higher intrinsic rates of increase. But even for parasitoids, price can be an obstacle to use. The cost of the most commonly used aphid parasitoid, *Aphidius colemani* Viereck, is 7 cents per adult (at US $22.50 per 500 parasitoid pupae, Koppert Inc., at Koppert.com, allowing for shipping cost and non-emergence of some adults). Vásquez et al. (2006) found that direct releases of *A. colemani* provided excellent control of *Aphis gossypii* Glover in small, within-greenhouse netted enclosures (2.1 × 6.1 m; = ca 108 sq. ft.) when released at 5 mixed-sex adults/m^2 in each of the first 3 weeks of a 5-week trial. However, at this release rate, biological control was 4.7 times more expensive than the pesticide standard (imidacloprid). The limitation of noncompetitive price is most important in smaller greenhouses producing short-term crops such as flowers because time for parasitoid reproduction during the crop is limited.

A potential solution to the high cost of repeated mass releases of parasitoids for aphid control in short duration crops is to place breeding colonies of parasitoids (called "banker plant systems" or "open rearing systems") in greenhouses at planting time, before aphids appear. This approach can be quite effective against some aphid species in some crops (e.g., Conte 1998). Banker plant systems begin with of a colony of a monocot-feeding aphid such as *Rhopalosiphum padi* (L.), the bird cherry-oat aphid, reproducing on a mildew-resistant variety of a monocot such as rye, grown in pots. Parasitized aphids (mummies) or adult parasitoids, purchased from commercial insectaries, are then placed on such pots at the start of the crop and pots are changed as needed when plants deteriorate. This system reduces cost because only enough parasitoids need be purchased to establish the initial breeding colonies and time is gained for 1 or more parasitoid generations to occur on the alternative non-pest aphid before pest aphids invade the crop. Banker plant systems for two *Aphidius* species (*A. colemani* and *Aphidius ervi* Haliday) are available for use in the United States.

Three potential problems exist with use of the *A. colemani* banker plant system in spring flower crops. First, this parasitoid does not parasitize all aphid species that might become important in some crops, such as the potato aphid, *Macrosiphum euphorbiae* (Thomas), and the foxglove aphid, *Aulacorthum solani* (Kaltenbach), requiring spot applications of pesticides to plants infested with these species. To conserve the efficacy of banker plant systems when such species are among the aphids present, pesticides compatible with key parasitoids are needed. Second, banker plants require watering and possibly fertilization, can die from plant diseases like mildew, or may cease to produce parasitoids if all the aphids on the plant are killed by the parasitoid or other natural enemies. These problems can be managed by use of mildew-resistant rye and periodic transfer of aphids to new rye plants. Third, aphid suppression is poor if greenhouse temperatures exceed 28°C because such temperatures are favorable to aphids and unfavorable to *A. colemani* (Goh et al. 2001; Kim & Kim 2003).

Our goal was to better understand the potential for effective use of *A. colemani* banker plants for aphid control in spring flower crops in the northeastern US. Our specific objectives were, as follows: (1) to survey aphids in commercial greenhouses in Massachusetts and New York to determine if the aphids found most frequently in the region's spring flowers were species susceptible to *A. colemani*; (2) to measure aphid control provided by *A. colemani*-banker plants in University greenhouses filled with various combinations of *M. persicae* and *A. gossypii* on pansy and Marguerite daisy; (3) to assess the efficacy of *A. colemani* banker plants in commercial greenhouses in Massachusetts and New York; and (4) to determine if 2 widely used insecticides might be compatible with *A. colemani*.

Materials and Methods

Aphid Surveys in Greenhouse Floral Crops

In 2004, to determine what species of aphids occurred in greenhouses during the spring flower crop and the relative frequency of their infestations, we visited 41 greenhouses, 20 in New York (from 26

May to 10 Jun) and 21 in Massachusetts (from 15 Apr to 25 May). At each greenhouse, 30 plants of each of the 3 most prevalent flower species were examined for aphids. In greenhouses in which there were more than 3 plant species in significant numbers, the 90 scouted plants were divided equally among the most common plants. In Massachusetts, but not New York, if no aphids were found during initial scouting of the dominant crops, we checked additional species known to be especially susceptible to aphid infestations (ivy geranium, petunia, and fuchsia) or that were reported by the grower to be infested, examining 30 plants per species. Samples of aphids detected were preserved for later identification. Identifications were made by Suzanne Lyon (MA) or K. C. Bennett (NY), following their training by Susan Halbert of the Florida Department of Agriculture. We then calculated the relative frequency of infestations by aphid species.

Efficacy of *A. colemani*-banker Plants in University Greenhouses

Sources of Aphids and Plants. For this trial, we infested plants with one or both species of *A. gossypii* and *Myzus persicae* (Sulzer), which were 2 of the 3 most commonly encountered species in our survey (the third, *Aulacorthum solani* (Kalten bach) is not attacked *by A. colemani*, and so could not be considered for inclusion in this test). Colonies of both of the pest aphids were provided by Dan Gilrein of Cornell Cooperative Extension in Riverhead, New York. Aphids were reared in cages at University of Massachusetts on pansies (*Viola tricolor hortensis,* Delta Blotch Mix) and Marguerite daisies (*Argyranthemum* hybrid), which were the plant species subsequently used in our trials. Choice of plant species was coordinated with choice of aphid species and strain so that both aphids used were able to feed and reproduce on both species of plants. Insecticide-free plants used in experiments were grown on contract for us by a local greenhouse operator (Five Acre Farms, Northfield, Massachusetts).

Source, Management, and Number of Banker-Plants. The monocot-feeding bird cherry-oat aphid (*R. padi*), a species not able to infest dicot flower crops, was used as the aphid on the banker plants. These aphids were obtained from Melanie Filotas at Cornell University, Ithaca, New York. Banker plants consisted of mildew-resistant barley (*Hordeum vulgare,* McGregor barley, of Agri-Culver seeds, Trumansburg, New York) grown in pots (20 cm diam.). Plants were infested with aphids when 15-20 cm tall. Aphids periodically were moved to new barley plants as old ones declined in vigor due to aphid feeding. The number of banker plants per greenhouse and the number of parasitoids released per banker plant in our trials at the University of Massachusetts were chosen to be low in cost and therefore potentially acceptable to growers. For each 4 x 8 m plastic hoop greenhouse (ca 350 sq ft., ca 50% filled), we used 1 banker plant, onto which we released 25 mixed-sex parasitoids once at the start of the trials. Wasps were purchased from Koppert Biological Inc. at a cost of $22.50/ 500 mummies (parasitoid pupae in host aphids), which came to 7 cents per emerged wasp when emergence rate (65%) and shipping were considered. Given this cost and the fill rate of the greenhouse, the price for this treatment was $0.11/m^2(= $10 per 1000 sq ft) of protected crop.

Experimental Design and Description of Sampling. Four trials were run, 2 each in 2005 and 2006. All trials were run in 4 identical plastic hoop greenhouses (4 × 8 m) at the University of Massachusetts. The purpose was to measure the effect of *A. colemani*-banker plants on suppression of aphid densities. We examined 2 aphid species (*M. persicae* and *A. gossypii*) on 2 plant species (pansy and Marguerite daisy) because of the high plant diversity in spring flower crops. We structured trials to measure if the presence of a second aphid host species in the same greenhouse affected the degree of control. Trial dates corresponded to a slightly early and slightly late spring flower crop period in each year (trial one, 23 Mar-11 May, 2005; trial two, 15 Jun- 7 Jul, 2005; trial three, 16 Feb- 3 Apr, 2006; and trial four, 26 Apr-2 Jun, 2006). Only 2 trials were retained for analysis because delay caused the 15 Jun- 7 Jul, 2005 trial to occur mostly after the normal spring flower production period and as a consequence this trial experienced hot weather, not typical of the crop and unfavorable to this parasitoid (Zamani et al., 2007). We excluded the 26 Apr- 2 Jun, 2006 trial because parasitoids invaded the control greenhouse and suppressed aphids.

There were 4 greenhouses in each trial. These were partially filled with plants purchased as plugs from a commercial grower (grown without pesticide use), potted in 10 cm dia pots, grouped 8 per flat (25 × 50 cm), and placed on greenhouse benches. Each greenhouse contained 30 flats of pansies and 30 of Marguerite daisies. One banker plant was placed on a bench beside the crop plants in each of 3 of the 4 greenhouses, and the fourth was kept as an untreated control where parasitoids were not released. The 3 greenhouses containing banker plants were inoculated with either (1) *A. gossypii* only, (2) *M. persicae* only, or (3) both aphid species. The control greenhouse, without parasitoids, contained both species of aphids. In the single-aphid greenhouses, aphids of the indicated species were taken from our laboratory colony and 5 aphids were placed on 1 flagged sentinel plant in the middle of each flat (30 of each plant species) at the start of the trial. In the mixed aphid greenhouses (the control greenhouse and 1 with a banker plant), there were 15 plants of each of the 4 aphid species x plant species combinations. In all greenhouses, plants were grouped by species, not

interspersed. Data collected consisted of a total count of all aphids on each sentinel plant, weekly for 7 weeks. At the end of each trial, 1 additional sample was taken by counting all aphids on each of 30 randomly selected plants of each plant species (exclusive of the inoculated sentinel plants) in single-aphid greenhouses or 15 plants for each aphid x plant combination in greenhouses with 2 aphid species present.

Efficacy of Banker Plants in Commercial Greenhouses

In 2006, concurrent with the second year of the trials at the University of Massachusetts, we conducted a modified trial of banker plants at 7 commercial greenhouses growing spring flower crops, 3 in Massachusetts and 4 in New York. Based on data from our 2004 survey of aphid occurrence in regional greenhouse spring flower crops, which showed *M. persicae* to be much more common than *A. gossypii* (Table 1), we focused on control of *M. persicae* to evaluate banker plants. Furthermore, because the same survey showed aphids to be spotty in their occurrence in greenhouses, we decided to evaluate the efficacy of banker plants in greenhouses based on population increase of aphids deliberately added to test plants in greenhouses, rather than waiting for infestations to develop naturally. At each test greenhouse, we introduced 4 flats (25 × 50 cm), each with 10 pots (11.2 cm dia) of pansies. Two flats were placed in a 60 × 60 × 60 cm "Bug Dorm" cage (from BioQuip Inc., Rancho Dominguez, CA), while 2 uncaged flats were placed next to the cage on the same greenhouse bench. Five plants in each flat were inoculated with 2 *M. persicae* individuals from our colonies at the start of the experiment. In each greenhouse, we placed 1 banker plant (as in the University of MA trial) per 38 m^2 (400 square feet). Each banker plant, previously infested with bird cherry-oat aphids, was inoculated with 25 mixed-sex parasitoid adults or aphid mummies.

TABLE 1. SPECIES OF APHIDS FOUND IN A SURVEY OF 41 GREENHOUSES WITH SPRING FLOWER CROPS IN 2004 IN MASSACHUSETTS AND NEW YORK.

Aphid species	No. infestations detected (% of total)
Mysus persicae (Sulzer)	27 (52.9)
Aulacorthum solani (Kaltenbach)	14 (27.5)
Aphis gossypii (Glover)	3 (5.9)
Aphis sp.	2 (3.9)
Macrosiphum euphorbiae (Thomas)	2 (3.9)
Ovatus crataegarius (Walker)	1 (2.0%)
Macrosiphum sp.	1 (2.0%)
Aphis spiraecola Patch	1 (2.0%)
Total	51 (100%)

Whole plant counts of aphids were made weekly on each of the 20 inoculated plants (5 per flat). First aphid counts were made either on 21 or 27 of Mar in Massachusetts and continued either until 26 Apr or 2 May, depending on location. Sampling in New York greenhouses began either on 4 or 7 Apr and continued until 12 or 21 May.

Compatibility of *A. colemani* with Insecticides

The goal of this experiment was to determine if 2 common pesticide products used to control aphids, formulations of pymetrozine and pyriproxyfen, were compatible with *A. colemani* adults (via contact with freshly dried residues) or mummies (via direct sprays). If compatible, such materials might be used to control species not parasitized by *A. colemani*.

Pesticide Rates. Pymetrozine (Endeavor 50WG, manufactured by Novartis) was applied at the label-recommended rate for aphid suppression (2.5 oz per 100 gallons, = 0.177g product/473 mL, = 0.000374 g ai/mL spray). Pyriproxyfen (Distance IGR, manufactured by Valent) was used at the high end of the labeled range for aphids (8 fl. oz per 100 gallons, = 0.3 mL product/473 mL spray, = 0.0000653 g ai/mL spray). Pesticide solutions were applied with small, hand pumped, spray bottles. Water was applied as a control.

Wasp Source. All *A. colemani* used in these experiments were purchased from IPM Laboratories in Locke, New York (sourced originally from Koppert, Inc.). Wasps were shipped as aphid mummies, and typically adult wasps were just beginning to emerge on the day the shipment arrived.

Exposure of Adult A. colemani to Pesticide Residues. Adult wasps were exposed to freshly dried residues in glass shell vials (3.7 ml, 15 × 45 mm, Fisher Scientific) in groups of 10. Vials were treated individually with 3 pumps from a spray bottle containing either an insecticide solution or water, until vial walls were coated to run off. After 1 h, vials were inverted to allow excess liquid to drain out. Two h after application, vial surfaces were dry, and 10 adult wasps (unsexed) were aspirated into each vial (= 1 replicate). For ventilation, a 10-mm dia hole was cut in each vial top and fine-meshed polyester screening then secured over the mouth of the vial by the remainder of the lid. Wasps were collected with aspirators from emergence containers and allowed to walk from the aspirator into the test vials. Vials with wasps were held in a growth chamber at 22° C, 75% RH, and constant light. After 2 and 12 h, vials were examined under a dissecting microscope and the number of dead wasps counted. Each treatment was replicated 30 times.

Exposure of A. colemani Pupae to Pesticide Sprays. Groups of aphid mummies from which wasps had not yet emerged were placed on blotting paper on plastic dishes with a fine paintbrush. Each group was sprayed directly with one of the

test solutions as described above and allowed to dry. Each replicate consisted of 10 treated mummies, which were held in a clean vial (3.7 mL, 15 × 45 mm, Fisher Scientific) secured with fine mesh polyester fabric in place of a lid. Mummies were held in a growth chamber at 22° C, 75% RH, 16:8 L:D photoperiod for 72 h, and then the number of emerged wasps were counted. Each treatment was replicated 40 times (total, 400 treated mummies).

Statistical Analyses

For the trial at the University of Massachusetts, the response (aphid numbers per plant on initially inoculated plants only) was recorded each week for 7 weeks on each sentinel plant in each greenhouse. Each greenhouse contained a unique combination of aphid species, plant types, and banker plants. These treatment combinations were randomly assigned to greenhouses in each trial. We accounted for these treatment combinations as fixed effects in the analysis, and included plants in each trial, and trials as nested random effects. Thus, we represented the study by a randomized block design with repeated measures made on each sentinel plant nested in each block (i.e., trial). We considered the blocks and plants to be random, and accounted for the repeated measures that were nested on sentinel plants in each greenhouse using a mixed model for SAS PROC Mixed. Plots of the number of aphids per week were constructed for each plant and aphid species for each treatment combination in each block, along with average profiles. The plots indicated exponential growth over time for aphids in non-banker plant blocks. We took the natural log of the aphid count (after adding 1 to avoid zero counts) to linearize the response pattern over time, and summarized the linear trend for each plant by the linear trend for a first order orthogonal polynomial (using 7 equally spaced time points) for each plant (Kirk, 1995). A mixed model with plants nested in blocks as random blocks was fit to evaluate differences between conditions (aphid species, plant species, and banker plant effects) on the linear trend in aphid growth. We examined homogeneity of variance between trials and between plants for different conditions prior to conducting statistical tests. The statistical analysis focused on comparisons between linear trends equivalent to growth slopes for simple population growth curve models between conditions. Slopes of the resulting regressions have biological meaning because they reflect the population increase of the pest aphids over time in greenhouses either with or without the treatment being tested (= parasitoids on banker plants). If parasitism restrains aphid population growth rate, data from greenhouses with this treatment will give regression lines with lower slopes. After calculating average slopes associated with each treatment, we compared slopes against the null hypothesis that slopes were zero (no increase over time) and among each other. Data on aphid density on non-inoculated plants in the various treatments at the end of the trial were analyzed by similar models. The response corresponded to the natural logarithm of the number of aphids (plus 1) per plant. For analysis of the data on wasp survival after exposure to pesticides, we fit a mixed model accounting for the repeated measure using vials as random effects to compare response between conditions (water, pyriproxyfen, and pymetrozine) and response (number of live wasps) over time. A one-way analysis of variance model was used to test for differences in wasp emergence rates at 72 h comparing treatments by water, pyriproxyfen, and pymetrozine.

Results

Aphid Surveys in Greenhouse Floral Crops

In Massachusetts, aphids were detected in 5 of the 21 commercial greenhouses surveyed during the initial sampling period. The most frequently infested plants were fuchsia (*Fuchsia* hybrids), million bells cultivars (*Calibrachoa* hybrids), and ivy geranium (*Pelargonium peltatum*). At 4 greenhouses in which aphids were not initially detected, aphids were later found on ivy geranium, *Petunia* sp., *Gerbera jamesonii*, or *Helichrysum* hybrids. In New York, aphids were found at 12 of 20 commercial greenhouses, mostly frequently on fuchsia, petunia, or *Impatiens* sp. Of 51 detected aphid infestations (both states), the 3 most common aphids were *Myzus persicae* (52.9% of infestations), *Aulacorthum solani* (27.5%), and *Aphis gossypii* (5.9%) (Table 1).

Efficacy of *A. colemani*-Banker Plants in University Greenhouses

Plant Effects. From highest to lowest, average growth rates were (1) *A. gossypii* on daisy (2) *M. persicae* on daisy (3) *M. persicae* on pansy, and (4) *A. gossypii* on pansy (Fig. 1). However, population

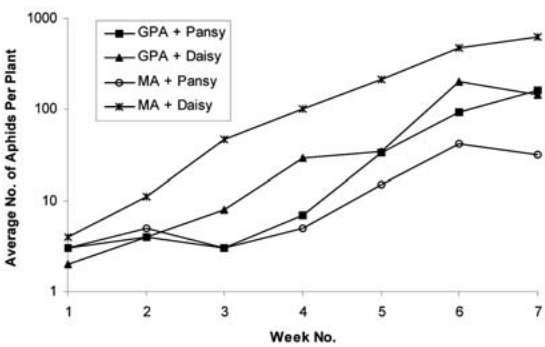

Fig. 1. Effect of plant species on growth of *A. gossypii* and *M. persicae* populations in the absence of *Aphidius colemani*. (Data are geometric means of exponentiated values of the log transformed values used in analysis).

growth rates of *M. persicae* and *A. gossypii* colonies (estimated as the slope of the regression of aphid density vs sample date) developing on either pansy or Marguerite daisy in University greenhouses were not different by either aphid (F = 0.13, df = 1, 4, P < 0.7366) or plant species (F = 1.09, df = 1, 4, P < 0.3559), nor was the interaction of aphid by plant species significant (F = 0.71, df = 1, 4, P < 0.4461). Variances between trials and between plants within a trial were not equal for the 4 aphid-plant combinations, but this inequality was accounted for in the analysis.

Parasitoid Suppression of Aphid Population Growth. Again, variances between trials and between plants within a trial were not equal for the 4 aphid-plant combinations, but this inequality was accounted for in the analysis. The presence of banker plants in greenhouses had a significant effect on the growth of aphid populations (F = 212.62, df = 1, 351, P < 0.0001). There was a statistically significant interaction between the effect of banker plants and plant species (F = 10.41, df = 1, 351, P < 0.0014). In contrast, the interaction of aphid species and the effect of banker plants was not significant (F = 3.29, df = 1, 351, P < 0.0707). The three way interaction of plant species, aphid species and banker plants was significant, suggesting that parasitoids respond to both aphids and the plant on which they must forage for aphids (F = 13.05, df = 1, 351, P < 0.0003).

In all greenhouses where banker plants were used, no slopes of lines for aphids vs time were significantly different from zero (that is, no populations showed a statistically significant increase in aphid numbers over time). Results of hypothesis tests of zero slope were GPA/daisy (t = 1.28, df = 8, P < 0.2367); MA/daisy (t = -0.73, df = 8, P < 0.4887); GPA/pansy (t = 0.71, df = 8, P < 0.4983) and MA/pansy (t = 0.45, df = 8, P < 0.6651). In contrast, in greenhouses without banker plants, slopes did differ significantly from zero, suggesting real increase in aphid numbers for 3 aphid-plant combinations (GPA/daisy, t = 5.15, df = 8, P < 0.0009; MA/daisy, t = 4.03, df = 8, P < 0.0038, and GPA/pansy, t = 22.73, df = 8, P < 0.0001), but not for *A. gossypii* on pansy (t = 2.17, df =8, P = 0.0621).

When slopes of aphid numbers vs time from greenhouses without banker plants (controls) were directly compared to slopes of populations in greenhouses with banker plants (Fig. 2), differ-

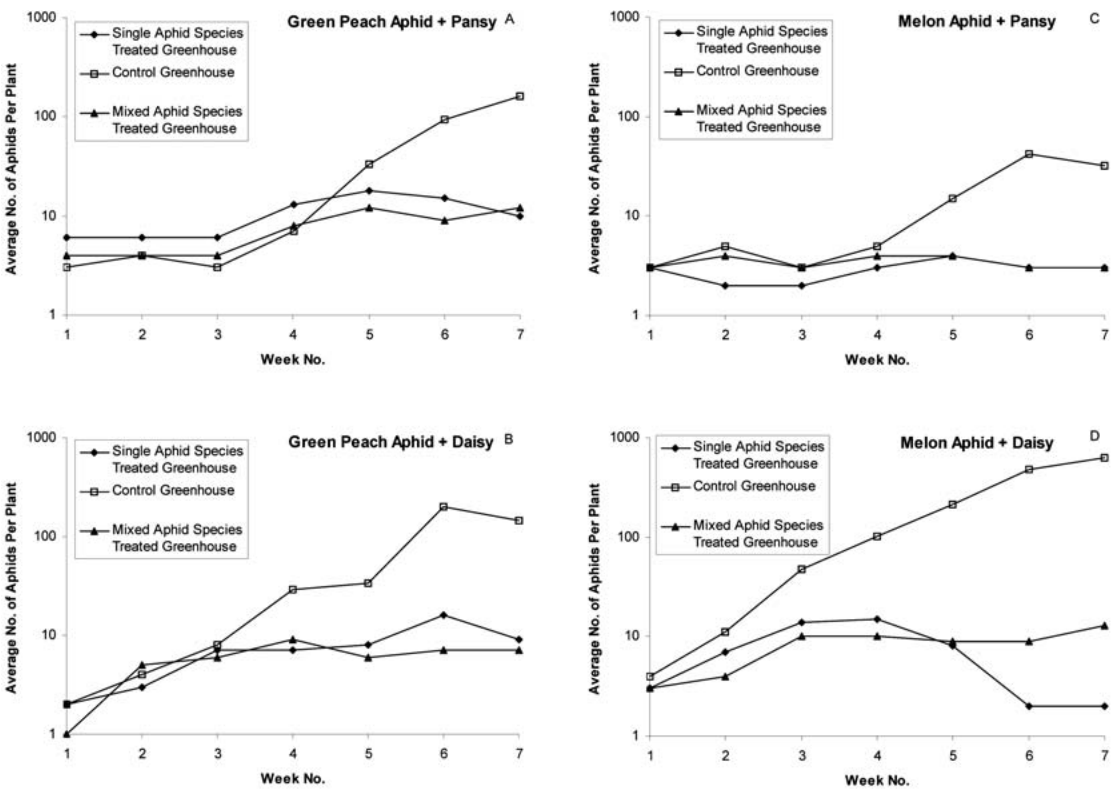

Fig. 2. Effect of the presence of the braconid parasitoid *Aphidius colemani* on population growth of *A. gossypii* or *M. persicae* on 2 host plants in single-aphid or mixed-aphid greenhouses. (Data are geometric means of exponentiated values of the log transformed values used in analysis).

ences were found for *A. gossypii* on daisy (t = 3.78, df =8, P = 0.0054) and *M. persicae* on pansy (t = 2.40, df =8, P = 0.0434), but not for *A. gossypii* on pansy (t = 1.90, df =8, P = 0.0938) or *M. persicae* on daisy (t = 2.17, df =8, P = 0.0616).

Effect of 1 versus 2 Aphid Species. The presence of a second host species (here, a second aphid species), which in some systems can enhance biological control, had no significant effects in this case. Rates of increase per aphid species were not significantly different between banker plant greenhouses with 1 aphid species vs banker plant greenhouses with both aphid species present (Fig. 2a,b,c,d). No pairwise comparisons between one-aphid species and two-aphid species greenhouses, both with banker plants, were significant (GPA-D, t = 0.29, df =8, P = 0.7760) (MA-D, t = -1.42, df =8, P = 0.1942) (GPA-P, t = -0.09, df =8, P = 0.9335) (MA-P, t = 0.18, df =8, P = 0.8639).

Final Aphid Densities in the Crop as a Whole. On non-inoculated plants, the use of banker plants suppressed aphids from 73 to 90% relative to the controls, depending on aphid and plant species (Table 2). Comparison of aphid densities among treatments showed a significant effect of banker plants (F = 6.56, df = 8, P < 0.0336). However, no individual pairwise comparisons were significant between final aphid densities on non-inoculated plants between greenhouses with and without banker plants, for any aphid x plant combination.

Efficacy of Banker Plants in Commercial Greenhouses

In commercial greenhouses, use of banker plants at the rate tested did not provide adequate suppression of *M. persicae* (the only species tested). Population growth on sentinel pansies, inoculated at the start of the trial, was suppressed successfully in only 4 of 7 greenhouses. Moreover, of these 4, control was due at least in large part in 2 instances to larvae of syrphid flies that spontaneously invaded the greenhouses (Table 3). In only 1 of 7 cases did the banker plants prevent aphids from increasing in number.

Compatibility of *A. colemani* with 2 Insecticides

At 2 h, adult survival of *A. colemani* in the water control (98%), was different from survival in vials treated with Distance (pyriproxyfen) or Endeavor 50WG (pymetrozine) (both, 89%) (F = 3.21, df = 2, 88, P=0.0452). By the end of the experiment at 12 h, there were larger differences in wasp survival among treatments in a one-way

TABLE 2. SUPPRESSION LEVEL AND FINAL APHID DENSITY (#/PLANT, MEAN, STANDARD DEVIATION) IN (A) CONTROL GREENHOUSES, (B) PARASITOID-TREATED GREENHOUSES WITH 1 APHID SPECIES, AND (C) PARASITOID-TREATED GREENHOUSES WITH 2 APHID SPECIES IN A TRIAL AT THE UNIVERSITY OF MASSACHUSETTS IN 2005 AND 2006.

	(A) Final aphid density (#/plant) in control greenhouses			
Trial	*M. persicae* (in mixed aphid greenhouses)		*A. gossypii* (in mixed aphid greenhouses)	
	Daisy	Pansy	Daisy	Pansy
1	532.9 ± 562.7	115.2 ± 23.1	3214.4 ± 2750.1	145.6 ± 29.4
2	4.9 ± 6.4	271.6 ± 225.9	2.2 ± 1.5	9.2 ± 14.6
	(B) Final aphid density (#/plant) in parasitoid-treated greenhouses with one aphid species (and % reduction compared to control)			
Trial	*M. persicae*		*A. gossypii*	
	Daisy	Pansy	Daisy	Pansy
1	4.4 ± 2.7 (99%)	3.1 ± 3.9 (97%)	0.4 ± 1.3 (100%)	0.3 ± 0.6 (100%)
2	2.5 ± 3.2 (49%)	54.6 ± 56.8(80%)	0.6 ± 1.3 (73%)	1.8 ± 3,3 (80%)
Ave. suppression	74%	89%	87%	90%
	(C) Final aphid density (#/plant) in parasitoid-treated greenhouses with two aphid species (and % reduction compared to control)			
Trial	*M. persicae*		*A. gossypii*	
	Daisy	Pansy	Daisy	Pansy
1	23.5 ± 12.2 (96%)	0.6 ± 1.3 (100%)	16.5 ±11.4(100%)	1.1 ± 1,6 (99%)
2	2.5 ± 2.9 (49%)	68.9 ± 73.5 (75%)	1.4 ± 2.1 (36%)	2.9 ± 3.9 (70%)
Ave. suppression	73%	88%	68%	85%

TABLE 3. LEVEL OF INCREASE IN DENSITY (AS RATIO OF FINAL OR PEAK DENSITY/DENSITY ON FIRST SAMPLE DATE) OF *MYZUS PERSICAE* (SULZER) DURING SPRING FLOWER CROPS IN 7 COMMERCIAL GREENHOUSES IN THE NORTHEASTERN UNITED STATES, COMPARED TO DENSITIES INSIDE EXCLUSION CAGES, IN THE PRESENCE OF BANKER PLANTS WITH THE PARASITOID *APHIDIUS COLEMANI*.

		Caged controls		Uncaged treatment (accessible to parasitoids from banker plants)		BC Success/ Failure? (S, F)
Site	Wks in trial	Final (or peak[1]) density	#-fold increase (last/first sample date)	Final Density	#-fold increase (last/first sample date)	
MA						
1	4	10.6	17.7	57.3	47.8	F
2	7	563.6	234.8	6.0	3.0	"S"[2]
3	6	157.5	29.2	2.7	2.1	S
(Ave.)			(93.9)		(17.6)	
NY						
4	3/6[3]	177.6	66.0	0.6	0.5	S
5	7	415.4	33.5	134.6	41.4	F
6	7	236.4	19.3	3.3	1.0	"S"[2]
7	7	500.0	57.5	206.3	75.0	F
Ave.			(44.1)		(29.5)	
All			65.4		24.4	

[1]For caged controls, if aphid densities peaked in middle of trial and then collapsed due to effects on plant quality, increase is calculated using the peak value rather than the final value, to correct for loss of plant quality

[2]Outcomes at growers #2 and #6 were mostly due to syrphids that naturally invaded the greenhouse. Numerous syrphid eggs and larvae were found on the uncaged test plants.

[3]Caged control plants collapsed after 3 weeks due to high aphid numbers. Observations on uncaged plants, on which aphid growth was very low, were made for 6 weeks.

ANOVA (F = 18.54, df = 2, 88, P < 0.0001). Survival on pymetrozine-treated surfaces was 53% versus 71% for pyriproxyfen and 82% for the water control, with both being different from survival in the controls (pyriproxyfen, t = 2.21, df = 88, P < 0.0296; pymetrozine, t = 6.01, df = 88, P < 0.0001).

The emergence of adult parasitoids from pesticide-treated aphid mummies was affected by exposure to pesticides (one-way Anova, F= 5.2, df = 2, P < 0.0069). In pairwise comparisons, pyriproxfen's effect (56%) was different from the water control (68%) (F = 10.39, df = 1, P < 0.0016) but pymetrozine's (65%) was not (F = 2.6, df = 1, P < 0.1098).

DISCUSSION

The presence of banker plants in greenhouses had a significant effect on the growth of aphid populations. *Aphidius colemani* banker plants placed in 4- × 8-m plastic hoop greenhouses at the University of Massachusetts significantly suppressed aphids in 2 of the 4 aphid x plant combinations tested (*M. persicae* on pansy and *A. gossypii* on daisy), while the other 2 combinations showed levels of suppression that might have been significant with greater replication. Least impact occurred on *A. gossypii* on pansy. The presence of a second species of aphid in the greenhouse did not have any important effect on the level of suppression by *A. colemani* versus greenhouses with only 1 aphid species.

Little control was achieved by banker plants against *M. persicae* in commercial greenhouses. This may have been caused by neglect of banker plants by some growers (failure to adequately water plants, which occurred in New York), too few aphids on banker plants at the start of the crop (due to late placement in greenhouses), or use of too few banker plants per unit area in view of crop density. The banker plant rate (#/m^2 of greenhouse floor) used in this research was the same as our University trials, whose greenhouses were only partially filled with plants. This banker plant rate may have been insufficient in commercial greenhouses, which were completely filled with larger, more densely packed plants. Greater foliage volume would have increased the area for parasitoids to search, reducing their efficiency.

In addition to using more banker plants per m^2, control might be improved through better management of the banker plants to ensure larger, healthier populations of grain aphids, or use a different monocot-feeding aphid more suitable as a host for *A. colemani*, since *R. padi* is not

a high quality host for this parasitoid (Ode et al., 2005). However, the commonness of foxglove aphids in the northeastern US flower crops could compromise the use of *A. colemani* because this aphid's presence would require spot applications of pesticides (which could harm parasitoids) or use of some other natural enemy.

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REFERENCES CITED

CONTE, L. 1998. New prospects for the biological control of *Aphis gossypii* on protected crops. Informatore Fitopatologico 48: 25-30.

GOH, H., J. KIM, AND M. HAN. 2001. Application of *Aphidius colemani* Viereck for control of the aphid in the greenhouse. J. Asia-Pacific Entomol. 4(2): 171-174.

KIM, Y., AND J. KIM. 2003. Biological control of aphids on cucumber in plastic greenhouses using banker plants. Korean J. Appl. Entomol. 42: 81-84.

KIRK, R. E. 1995. Experimental Design. Procedures for the Behavioral Sciences. Brooks/Cole Publishing Company, New York.

ODE, P. J., K. R. HOPPER, AND M. COLL. 2005. Oviposition vs. offspring fitness in *Aphidius colemani* parasitizing different aphid species. Entomol. Exp. Appl. 115: 303-310.

SMITH, T. 1998. Survey of integrated pest management for bedding plants: Part II. Floral Notes 10 (5): 4-5 (March-April issue); see also http://www.umass.edu/umext/programs/agro/ipm/Reports/plantina.htm

VÁSQUEZ, G. M., D. B. ORR, AND J. R. BAKER. 2006. Efficacy assessment of *Aphidius colemani* (Hymenoptera: Bracondiae) for suppression of *Aphis gossypii* (Homoptera: Aphididae) in greenhouse-grown chrysanthemum. J. Econ. Entomol. 99: 1104-1111.

ZAMANI, A. A., A. TALEBI, Y. FATHIPOUR, AND V. BANIAMERI. 2007. Effect of temperature on life history of *Aphidius colemani* and *Aphidius matricariae* (Hymenoptera: Braconidae), two parasitoids of *Aphis gossypii* and *Myzus persicae*. Environ. Entomol. 36: 263-271.