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Banker Plants for Aphid Biological Control in Greenhouses

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Abstract

Banker plants are mobile habitats that provide alternative hosts, prey, or food for commercially available natural enemies. As a biological control strategy, banker plants offer a novel nonchemical approach to managing commonly encountered pests in the greenhouse. Most banker plants that target aphids consist of a graminaceous plant, a nonpest cereal grain aphid, and a parasitoid that attacks both the nonpest and pest aphids occurring on crop plants. The use of banker plants may provide more effective, long-term pest control than pesticide applications, but both may be combined effectively. The following paper is a brief review of the history of biological control in enclosed environments, pesticides compatible with natural enemies, the use of various species of banker plants, and specifically the *Aphidius colemani* (Viereck) (Hymenoptera: Braconidae)–*Rhopalosiphum padi* (L.) (Hemiptera: Aphididae) system to manage aphid pests.

Key words: *Aphidius colemani*, *Myzus persicae*, *Rhopalosiphum padi*, horticultural entomology

Banker plants (a.k.a., open-rearing systems, biocontrol plants) offer sustained management of common arthropod pests and are often incorporated into greenhouse crop production (Kuo-Sell 1987, Van der Linden 1992, Jacobson and Croft 1998, Schoen et al. 2000). Banker plant systems consist of arthropod natural enemies (i.e., predators or parasitoids), alternative prey or hosts for the natural enemies, and banker plants that support the alternative prey or hosts (Huang et al. 2011). Banker plants are placed throughout the greenhouse and provide reliable, long-term reproduction (Stacey 1977, Huang et al. 2011) and dispersal of natural enemies released for control of target pests (van Lenteren et al. 1997, Pratt and Croft 2000). Banker plants are considered a combination of augmentative and conservation biological control strategies (Parella et al. 1992, Frank 2010, Huang et al. 2011) as they provide an optimal habitat for natural enemies but do not require their frequent release. Specifically, natural enemies are released into the crop, and banker plants promote their survival, longevity, and reproduction by providing them with essential resources such as food or shelter (Arnó et al. 2000, Gurr et al. 2000, Huang et al. 2011). Ideally, banker plants are compact and mobile; thus, they do not need extensive production space and easily conform to current growing practices. Additionally, banker plants can be moved closer to problem areas or removed from the greenhouse when pesticide sprays or other maintenance is necessary. Banker plants are replaced every few weeks or few months depending on the species (Frank 2010).

Biological Control in Greenhouses

The first documented, successful use of biological control in greenhouses was in 1927 targeting greenhouse whitefly, *Trialeurodes vaporariorum* (Westwood) (Hemiptera: Aleyrodidae), with augmentative releases of *Encarsia* species (Hymenoptera: Aphelinidae) (Speyer 1927). However, the development and adoption of synthetic pesticides in the late 1940s led to a decline in the use of biological control until pesticide resistance occurred in the 1960s and 1970s (van Lenteren 2007, Huang et al. 2011). In response to resistance management concerns, integrated pest management (IPM) strategies were considered, including biological, cultural, and mechanical controls. This ecologically based approach minimizes the risk of resistance development as pesticides are used less frequently and replaced with preventative strategies and biologically based methods. Still, the adoption of IPM in greenhouses may lag for several reasons, including the availability of effective insecticides, fear of exporting pests, and reduced marketability of plants with visible damage (van Lenteren 2000).

The use of banker plants in greenhouses is a fairly new concept in IPM, first described in the late 1970s in tomatoes using *Encarsia formosa* (Gahan) (Hymenoptera: Aphelinidae) and the pest-in-first strategy (see description below) with *T. vaporariorum* (Stacey 1977). As with other biological control strategies, banker plants can be used in the field but are ideal in controlled environments where higher profits can be generated per square foot of production space

(van Lenteren 2000, Huang et al. 2011). Biological control may be easier in greenhouses compared with field-grown crops as many pests are excluded by the structure, fewer insects pests are encountered in greenhouses, and pest and natural enemy development is more predictable in known temperature ranges (van Lenteren 2000). Also, pests and natural enemies are readily monitored in enclosed environments, which helps mitigate damage from costly pests (van Lenteren et al. 1997, van Lenteren 2000). Variations in banker plant systems can be used to control pests such as thrips (Ramakers and Voet 1995), whiteflies (Stacey 1977, Lambert et al. 2005), aphids (Hofsvang and Hågvar 1979, Wick 1992, Andorno and López 2014), spider mites (Van Rijn and Tanigoshi 1999, Pratt and Croft 2000), and leafminers (van Lenteren and Woets 1988). Banker plants and other IPM methods are frequently used in vegetables, but are being adapted for use in the production of potted plants and cut flowers (Blumel and Hausdorf 1996, van Lenteren 2000, Vásquez et al. 2006, Van Driesche et al. 2008, Abraham et al. 2013). Banker plants may provide a food source such as pollen to conserve or attract natural enemies. Other banker plant systems may involve the use of previously parasitized alternative hosts, an initial augmentative release of beneficial insects, or the pest-in-first approach. In the latter, the target pest is deliberately introduced prior to an infestation and acts as alternative prey for the natural enemy (Huang et al. 2011). The pest-in-first strategy can be successful when using parasitoids to control whiteflies in vegetables (Stacey 1977, Lambert et al. 2005) but may not be adopted by growers for fear of pest outbreaks. Stacey (1977) documented control of *T. vaporariorum* in greenhouse tomatoes using pest-in-first tomato banker plants with whiteflies parasitized by *E. formosa*. In this study, no sooty mold was found in occurrence with the whitefly, and 8,000 parasitoids were produced over a 9-wk period to suppress *T. vaporariorum*. In addition, Lambert (2005) successfully suppressed *T. vaporariorum* over 5 mo in winter greenhouse tomatoes using *Dicyphus hesperus* (Knight) (Hemiptera: Miridae) on mullein banker plants with supplemental *Ephestia* (Lepidoptera: Pyralidae) egg releases. Worldwide, an estimated 32,000 ha of greenhouse and interiorscapes are managed with biological control using 150 species of natural enemies (van Lenteren 2006, 2012). Traditionally, greenhouse growers have depended on pesticides and have not embraced biological control in their operations due to a zero-tolerance mentality for pests and associated damage in ornamentals and vegetables (van Lenteren and Woets 1988, van Lenteren 2000). However, biological control may be more readily adopted as the use of pesticides has lost favor because of lack of available chemistries (van Lenteren and Woets 1988), resistance management concerns (van Lenteren 2000, Desneux et al. 2007), required employee training and use of personal protective equipment (Kühne 1998), phytotoxicity or abscission in sensitive plants (van Lenteren and Woets 1988), potential health risks (van Lenteren and Woets 1988), mandatory re-entry and post-harvest intervals (van Lenteren and Woets 1988), and consumer demand for products with low pesticide residues and decreased environmental impacts (Kühne 1998, van Lenteren 2000). Consumer backlash over the use of neonicotinoids and their negative effects on pollinator health has put pressure on greenhouse growers to label plants treated with neonicotinoids or use alternative pest management strategies in flowering ornamental plants (Rihn and Khachatryan 2016). Biological control is an option for those greenhouse growers interested in low-impact pest management.

Banker plants provide an effective first step in pest management with little or no negative environmental impacts and may be combined with other biological control agents or pesticides to solve many pest issues (Gentz et al. 2010, Prado et al. 2015). Biological control reduces the number of pesticide applications, decreases or eliminates the likelihood of pest resistance (Hågvar and Hofsvang 1994, van Lenteren et al. 1997, van Lenteren 2000, Goh et al. 2001, Heinz et al. 2004, Parker and Popenoe 2008), and is conducive to the survival and reproduction of beneficial insects (Gandhi et al. 2005, Desneux et al. 2007, Krischik et al. 2007, Rogers et al. 2007). Banker plant systems may provide cost savings to greenhouse growers (van Lenteren et al. 1997, van Lenteren 2000, Matteoni 2003, Van Driesche et al. 2008, Huang et al. 2011) as they may be less expensive than multiple releases of natural enemies and easier and less time consuming than pesticide applications (van Lenteren et al. 1997, Conte et al. 2000). Accounting for inflation, initial costs *of T. vaporariorum* control in greenhouse tomatoes using *D. hesperus* banker plants and supplemental *Ephestia* eggs costs US\$0.99 per m^2 per yr and drop to US\$0.60 per m^2 per year after establishment of predators, while augmentative *E. formosa* controls without *D. hesperus* cost US\$1.08 per m^2 per yr (Lambert et al. 2005). In addition, preliminary cost analyses show that implementing banker plants provides the greatest return on investment and costs approximately five times less per year than augmentative releases (Payton Miller, unpublished data). Due to decreased effectiveness against common pests, repetitive insecticide applications can lead to increased treatment costs (van Lenteren et al. 1997, Foster et al. 2003, Davis and Radcliffe 2008, Frank 2010). Many chemical formulations may be ineffective against a pest, limiting options for growers to rotate pesticides (van Lenteren et al. 1997). Greenhouse growers who combine multiple IPM practices successfully should only need pesticides during pest outbreaks (van Lenteren 2000, Rebek et al. 2012). IPM programs can be tailored to fit specific greenhouse operations, target pests, and crops (van Lenteren 2000). In a survey of Oklahoma greenhouse producers, 56% did not use any biological control agents, but other IPM practices were embraced such as mechanical controls and pest monitoring with sticky traps (P. Miller, unpublished data).

Major greenhouse pests such as aphids can be difficult to manage in a controlled environment as they can be unresponsive to diapause (van Lenteren 2000) and go unnoticed until population densities are high (Rabasse and Van Steenis 1999, Goh et al. 2001). Aphids are prevalent in temperate areas, cause issues in greenhouses globally, and serve as vectors for many plant viruses (van Lenteren et al. 1997). Van Driesche et al. (2008) showed aphids are the pest in most need of control in greenhouses, requiring a minimum of three insecticide treatments for suppression during a single crop cycle. Rabasse and Van Steenis (1999) illustrated that aphid populations increase quickly, making augmentative biological control tricky. Some pests must be present for releases of biological control agents, but if populations grow too fast, natural enemies are not able to maintain pest levels below treatment thresholds. In contrast, banker plants allow natural enemies to be introduced when pest population densities are low (Hofsvang and Hågvar 1979), maintaining the pest below treatment levels (Wick 1992, Conte et al. 2000, van Lenteren 2000, Kim and Kim 2004). Overall, banker plants reduce environmental concerns and provide the grower an opportunity to advertise earth-friendly, low-impact pest management with their customers (van Lenteren et al. 1997, van Lenteren 2000).

The Banker Plant Method

Banker plant systems are an innovative way to apply biological control in the field (Freuler et al. 2003) and greenhouse (Hågvar and Hofsvang 1994, Goh 1999, Kim and Kim 2004, Frank 2010, Andorno and López 2014). They are easily replaced when plant vigor is lost (7–14 d with winter wheat banker plants) and only a

few plants may be needed in moderately sized greenhouses. Banker plants require some additional maintenance in sowing seed and maintaining alternative host colonies. However, they do not usually require additional time to water as they are easily incorporated with the growing crop (Jacobson and Croft 1998). Protocols for commercially available banker plants advise as little as one, 15–25 cm pot of wheat (*Triticum aestivum* (L.) (Poales: Poaceae)), barley (*Hordeum vulgare* (L.) (Poales: Poaceae)), rye (*Secale cereale* (L.) (Poales: Poaceae)), or oat (*Avena sativa* (L.) (Poales: Poaceae)) banker plants infested with *Rhopalosiphum padi* (L.) (Hemiptera: Aphididae) to provide parasitoids for 600–1,500 m^2 of greenhouse space (IPM Laboratories, Inc. 2013). The number of banker plants can be increased by grower preference or by timing with the crop and adding additional plants per week until crop sale or shipment. Efficacy of banker plant systems are difficult to quantify but tend to be measured in the number of natural enemies present or a result of effective control in the crop (Huang et al. 2011).

Calendar-based augmentative releases of parasitoids may not be necessary when using banker plants (Hofsvang and Hågvar 1979, van Lenteren et al. 1997). However, augmentative release may allow more flexibility on targeting of pests in certain systems. This reduces costs to implement biological control and trades the effect of immediate releases for long-term pest control provided by several generations of predator or parasitoid progeny (Huang et al. 2011). Vásquez et al. (2006) showed continuous augmentative releases alone were almost five times more expensive than applying imidacloprid. In contrast, Stacey (1977) reported that only one augmentative release of *E. formosa* with a banker plant was needed to control greenhouse whitefly, *T. vaporariorum*, on greenhouse tomatoes. Despite the benefits, one obstacle to adoption of banker plant systems is the lack of knowledge concerning their function and incorporation into current greenhouse production systems (Parker and Popenoe 2008). Employment of banker plants in greenhouses may be effective on a case-by-case basis (P. Miller, unpublished data)

Aphidius colemani (Viereck) (Hymenoptera: Braconidae) and *R. padi* Banker Plant System

Parasitoids in the hymenopteran family, Aphelinidae, have been used since the 1920s for greenhouse biological control of whiteflies, armored scales, soft scales, and aphids (van Lenteren et al. 1997). *A. colemani* is a koinobiont endoparasitoid (Boivin et al. 2012) with four larval instars that attacks over 41 different aphid species (Stary 1975, Prado et al. 2015). This small (2–4 mm), solitary, brown wasp (Fig. 1) has a short life span and high reproductive capacity (Ode et al. 2005, Stara et al. 2010). *A. colemani* is native to northern India, but can be found in the Americas, Australia, areas of Europe, and Hawaii (Stary 1975, Benelli et al. 2014). *A. colemani* mates within minutes of emergence and may sting aphids to ingest their hemolymph (van Lenteren et al. 1997). Parasitoid performance is optimum at temperatures between 20 and 27°C, with development time from egg to adult occurring in 11–13 d (van Lenteren et al. 1997, Ahmad et al. 2016).

A. colemani has been used successfully for decades as a biological control agent in controlled environments (Fernández and Nentwig 1997, Goh et al. 2001, Matteoni 2003, Van Driesche et al. 2008, Frank 2010, Prado et al. 2015), including greenhouse operations in Canada (Matteoni 2003), Germany (Kühne 1998), Japan (Nagasaka et al. 2010), Korea (Goh et al. 2001), the Netherlands (Van Lenteren and Woets 1988), Norway, the United Kingdom, Czech Republic (Benelli et al. 2014), and the United States (Van Driesche et al. 2008).

The majority of natural enemies are purchased from commercial rearing companies (Van Lenteren 2000), with quality standards

Fig. 1. *Aphidius colemani* parasitoid. (Photo: David Cappaert, Bugwood.org)

set by the International Organization of Biological Control West Palaearctic Regional Section (IOBC/WPRS) (van Lenteren and Woets 1988). *A. colemani* quality may vary by source and season, with unpredictable emergence rates, decreased parasitism efficiency, male-biased sex ratios, reduced longevity, a shortage in shipped quantities of parasitoids as to what is advertised, differing affinity to aphid species based on rearing material, and mixed parasitoid species or hyperparasitoid presence (Fernández and Nentwig 1997, Van Lenteren 2000, Benelli et al. 2014). Parasitoid progeny reared on banker plants may be female biased and more effective for biological control over time (Prado and Frank 2014). Because traits of commercially produced parasitoids can be unreliable, banker plant systems help recoup some cost in low-quality shipments (Van Lenteren 2000). However, aphid colonies and banker plants should be regularly inspected for the presence of hyperparasitoids which can decrease the efficacy of the system (Fernández and Nentwig 1997).

A common, commercially available banker plant system targets pest aphids in controlled environments using the bird cherry oat aphid, *R. padi*, as an alternative host for *A. colemani* (Goh 1999, Jandricic et al. 2014). *R. padi* is a cereal grain pest maintained on wheat, rye, barley, oats, or other species in the Poaceae family (Fig. 2) (Conte et al. 2000, Pineda and Marcos-García 2008, Jandricic et al. 2014). The use of *R. padi* in banker plants is similar to the pest-in-first strategy in biological control (Huang et al. 2011). However, this species only feeds on monocots (Kieckhefer 1984), reducing the risk of an unintentional, secondary infestation in most ornamental and vegetable greenhouse operations.

R. padi is used with *A. colemani* parasitoids in banker plant systems targeting *Myzus persicae* (Sulzer) (Hemiptera: Aphididae) (Fig. 3) or *Aphis gossypii* (Glover) (Hemiptera: Aphididae) (Fig. 4), common agricultural pests (Grasswitz 1998). In choice tests, *A. colemani* prefers *M. persicae* over *R. padi* and yields larger offspring and greater offspring survival, increased offspring fecundity, and a female-biased population of parasitoids (Ode et al. 2005, Martinou and Wright 2007), especially when both aphids are present (Prado and Frank 2014). *A. colemani* is effective in banker plant systems as it has a high potential to move from less preferred to highly preferred aphid hosts and maintain them below treatment

Fig. 2. Bird cherry oat aphid, *Rhopalosiphum padi*, on winter wheat. (Photo: T.P. Miller)

Fig. 3. Green peach aphid, *Myzus persicae*, on ornamental pepper. (Photo: T.P. Miller)

thresholds ([Ode et al. 2005](#), [Zamani et al. 2006](#), [Van Driesche et al. 2008](#)). *R. padi* may be a less desirable host for *A. colemani*, but an innate preference for the pest aphid may be beneficial to encourage foraging away from banker plants, leading to a more effective system ([Prado and Frank 2014](#), [Prado et al. 2015](#)). However, *A. colemani* in the presence of both *R. padi* and *M. persicae* has shown better results than with just one aphid species present ([Prado and Frank 2014](#))

Fig. 4. Cotton melon aphid, *Aphis gossypii*, on ornamental pepper. (Photo: T.P. Miller)

A. colemani will not parasitize foxglove aphid (*Aulacorthum solani* (Kaltenbach) (Hemiptera: Aphididae)), chrysanthemum aphid (*Macrosiphoniella sanborni* (Gillette) (Hemiptera: Aphididae)), potato aphid (*Macrosiphum euphorbiae* (Thomas) (Hemiptera: Aphididae)), or banana aphid (*Pentalonia nigronervosa* (Coquerel) (Hemiptera: Aphididae)), potential pests in the field and greenhouse ([Van Driesche et al. 2008](#), [Benelli et al. 2014](#), [Prado et al. 2015](#)). However, other natural enemies may be available to target these pest aphids. For more information, visit the Association of National Biocontrol Producers' website at [www.anbp.org](#).

Banker plant systems have shown to be effective in several greenhouse productions systems. For example, barley banker plants with *R. padi* and *A. colemani* parasitoids offered 73–90% control of *A. gossypii* and *M. persicae* on Marguerite daisies (*Argyranthemum* hybrid (L.) (Asterales: Asteraceae)) and pansy (*Viola tricolor hortensis* (DC) (Malpighiales: Violaceae)) than untreated controls over 7 wk ([Van Driesche et al. 2008](#)). In addition, barley banker plants containing the greenbug (*Schizaphis graminum* (Rondani)) and *A. colemani* for *A. gossypii* management on melons resulted in good control, 0.2–5 aphids per leaf, after ~2 mo, when introduced early in the crop cycle ([Kim and Kim 2004](#)). Furthermore, parasitism was greater, and the number of live *A. gossypii* aphids was lower in red pepper (*Capsicum annuum* (L.) (Solanales: Solanaceae)) and watermelon (*Citrullus lanatus* (Thunb) (Cucurbitales: Cucurbitaceae)) greenhouses with *A. colemani*–*R. padi* barley banker plants (1.3–2.4 aphids per 10 leaves, 73–92% parasitism) than in those without treatment (1,711–2,349 aphids per 10 leaves, 2–17% parasitism) after 5 wk ([Goh et al. 2001](#)). For control of other pests besides aphids, alternative banker plant systems have been evaluated with various parasitoids and predators. Although some systems have alternative prey or beneficial insects that are not commercially available, they may be obtained through private sources, universities, or collected from the field. Consult plant protection and quarantine policies in your state or country prior to acquiring insects that could be invasive species or agricultural pests.

Green Peach Aphid, *M. persicae*

Green peach aphids feed on over 800 species of plants, including ornamental plants ([Van Driesche et al. 2008](#)), vegetables ([Hofsvang and Hågvar 1979](#), [Freuler et al. 2003](#)), fruits ([Kim and Kim 2004](#)),

and weeds but may also be found attacking barley, rye, and winter wheat before feeding on potato in northern climates (Davis and Radcliffe 2008). This aphid has a wide host range, so biotype development is unlikely (Davis and Radcliffe 2008). However, *M. persicae* is a major pest in commercial greenhouses (Wick 1992, Van Driesche et al. 2008) as it is resistant to many classes of conventional pesticides (Goh et al. 2001, Foster et al. 2003, Davis and Radcliffe 2008).

Depending on weather, this polyphagous aphid overwinters outdoors as an adult on one of many hosts, or as eggs on *Prunus* (Rosales: Rosaceae) species. Green peach aphid infestations may require multiple treatments, a rotation of chemical modes of action, or there may be a lack of aphicides to control an outbreak. A lack of reliable controls makes *M. persicae* an excellent candidate for biological control programs, specifically banker plant systems.

M. persicae was shown to be significantly controlled in Argentine arugula (*Eruca sativa* (Mill.) (Brassicales: Brassicaceae)) and sweet pepper greenhouses over a 2-mo period, using the *A. colemani*–*R. padi* system on oat (*A. sativa*) banker plants. In this experiment, banker plants provided the lowest pest aphid density, never reaching the critical spray threshold of 800 aphid nymphs per 16 leaves (Andorno and López 2014). In contrast, three of the four untreated controls exceeded the spray threshold (Andorno and López 2014).

It is important to keep in mind that a parasitized aphid may continue to have offspring. *A. colemani*, *Aphidius gifuensis* (Ashmead) (Hymenoptera: Braconidae), and *Diaeretiella rapae* (M'Intosh) (Hymenoptera: Braconidae) were evaluated to determine the reproductive capacity of *M. persicae* post-parasitism (Mitsunaga et al. 2016). Once any of the parasitoids reached the second larval instar, reproduction of the aphid ceased due to consumption of the reproductive organs. Healthy *M. persicae* averaged a lifetime birth rate of 61.43 nymphs per aphid, but when parasitized by *A. colemani*, *A. gifuensis*, and *D. rapae*, this number decreased to 3.96, 6.40, and 6.48, respectively. *A. colemani* may be slightly more effective than *D. rapae* or *A. gifuensis* during short-term applications, such as inoculative releases, and overall, may be a more effective parasitoid in control of green peach aphids (Mitsunaga et al. 2016).

Pesticide Compatibility with Banker Plants

Compatibility of compounds with natural enemies must be considered if biological control is to be implemented successfully, including banker plant systems. A comprehensive IPM program combines biological control with pesticide use and garners careful consideration of pesticide compatibility with natural enemies, including chemical modes of action, application rates and methods, timing of application, natural enemy life stage during application, and whether the biological control agent is a parasitoid or predator (Cloyd 2005, Rogers et al. 2007, Abraham et al. 2013, Prado et al. 2015). Commonly used greenhouse pesticides can have lethal and sub-lethal effects on predators and parasitoids (Rebek and Sadof 2003, Krischik et al. 2007, Rogers et al. 2007, Biondi et al. 2013, Joao Zotti et al. 2013, Thompson et al. 2014). Sub-lethal effects may include decreased host acceptance, reduced natural enemy longevity, altered sex ratios, unsuccessful food acquisition, reduced fecundity, decreased emergence rates, or increased development time (Cloyd 2005, Prado et al. 2015). The IOBC/WPRS may select active ingredients that work in concert with IPM programs based on mortality and sub-lethal effects to natural enemies (van Lenteren and Woets 1988, Abraham et al. 2013). Laboratory toxicity studies reveal maximum mortality when compared with field studies (Cloyd 2005), but even insecticides classified as low (<30% mortality in 48 h) or slightly harmful (30–79%

mortality in 48 h) by the IOBC/WPRS still cause significant losses to *A. colemani* adults and their offspring (Prado et al. 2015). Pesticide applications at varying label rates can also show injurious effects on natural enemies, while the target pest may survive and resurge. Alternatively, pesticides that kill too many hosts limit the food available for natural enemies to survive and reproduce effectively (Cloyd 2005). This can be unacceptable when implementing biological control, so it is important to screen new compounds used in greenhouses for toxicity (Stara et al. 2010, Prado et al. 2015). Active ingredients that cause high mortality in natural enemies (Rebek and Sadof 2003, Krischik et al. 2007, Rogers et al. 2007) will not be well-suited to biological control programs.

Compounds with high toxicity to *A. colemani* 24–48 h after exposure include abamectin, dimethoate, acetamiprid, spinosad, azadirachtin, and pyridaben (Bostanian and Akalach 2004, Cloyd 2005, Stara et al. 2010, Abraham et al. 2013). Van Driesche et al. (2008) showed a reduction in adult survival when pyriproxyfen and pymetrozine were used. Kim et al. (2006) demonstrated 97% or higher mortality in *A. colemani* 7 d post application with chlorpyrifos-methyl, diflubenzuron + chlorpyrifos, etofenprox + diazinone, and imidacloprid + chlorpyrifos, whereas insecticides to control thrips had no effect on mummy formation by the parasitoid (Kim et al. 2006).

Some biorational insecticides may cause sub-lethal effects on nontarget insects (Cloyd 2005, Biondi et al. 2013). Biorational, or reduced-risk, insecticides include horticultural oils, insecticidal soaps, insect growth regulators, or beneficial fungi, and could negatively affect a broader range of insects than some conventional insecticides (Cloyd 2005). Horticultural oil and insecticidal soap sprayed directly on natural enemies can be detrimental, especially to parasitoids (Cloyd 2005). Insecticidal soap caused 100% mortality in adult parasitoids 24 h after treatment, but no effect was observed on immature stages or egg capacity in females (Tremblay et al. 2008).

The use of imidacloprid has increased among growers for its systemic properties, low mammalian toxicity, long residual activity, and ease of application (Rogers et al. 2007, Scholer and Krischik 2014). Responses from a survey of Oklahoma greenhouse producers indicate that over one-third rely on imidacloprid to control phloem-feeding insect pests in controlled environments (P. Miller, unpublished data). The use of imidacloprid has gained attention as it can be translocated to the floral organs of angiosperms, affecting beneficial Hymenoptera (Desneux et al. 2007, Krischik et al. 2007, Lawrence and Sheppard 2013, Scholer and Krischik 2014). Adult hymenopteran parasitoids may be at risk in production systems where neonicotinoids are used as the wasps could use flowering crops as food resources (Fujinuma et al. 2010, Goulson 2013). *A. colemani* mortality increased when feeding on plants treated with imidacloprid via soil drenches, as the floral nectar exceeded the established LC50 for the parasitoid (Charles-Tollerup 2013). In addition, aphids may secrete systemic neonicotinoid products in their honeydew, potentially harming foraging parasitoids that feed on their excrement or hemolymph (Cloyd and Bethke 2011).

Foliar-applied fungicides may harm biological control agents in greenhouse operations (van Lenteren 2000). Five foliar fungicides screened against *Phytoseiulus persimilis* (Evans) (Acari: Phytoseiidae) showed no lethal or sub-lethal effects, except mancozeb, which negatively affected fecundity of the predator (Ditillo et al. 2016). In Korea, however, fungicides used for powdery mildew showed no harmful effects on mummy formation in *A. colemani* (Kim et al. 2006). Fungicides used in combination with biological control had no negative effects on the leafminer parasitoid, *Diglyphus isaea* (Walker) (Hymenoptera: Eulophidae) (Abraham et al. 2013).

Greenhouse Production and Variety Trials

Greenhouse growers maintain temperate environments all year, causing cool-season banker plant species to decline quickly. This is especially true in Oklahoma and other states in the southwestern United States, where temperatures commonly exceed 32°C (P. Miller, personal observation). While winter wheat and barley used for rearing *R. padi* currently provide the best banker plant material (Jandricic et al. 2014), these cool-season annual grasses must be replaced every 7 to 14 d, especially during summer months. Even mildew-resistant or other resistant grain varieties (Van Driesche et al. 2008) may not tolerate high summer temperatures. Other warm-season grasses may have potential as banker plants for *R. padi* in the southwestern United States. While *R. padi* prefers to feed and reproduce on barley, it can also reproduce on sand lovegrass (*Eragrostis trichodes* (Nutt.) (Poales: Poaceae)), sideoats grama (*Bouteloua curtipendula* (Michx.) (Poales: Poaceae)), buffalograss (*Buchloe dactyloides* (Nutt.) (Poales: Poaceae)), mature switchgrass (*Panicum virgatum* (L.) (Poales: Poaceae)), and mature indiangrass (*Sorgastrum nutans* (L.) (Poales: Poaceae)) (Kieckhefer 1984).

Jandricic et al. (2014) conducted multi-generational studies of host plant species on alternative prey on wheat, barley, rye, and oats in the *A. colemani*–*R. padi* system. Results showed varying effects on aphid traits and parasitoid development; specifically, rye and oats were less suitable banker plants for *R. padi* and barley and wheat were most suitable. In addition, varieties within a species showed no direct bottom-up effects, such as survival, mating, or fecundity, on *A. colemani* (Jandricic et al. 2014). Male parasitoids, and those female parasitoids reared on unsuitable hosts, are typically smaller in size than healthy female adults. Thus, mixtures of wheat, barley, rye, and oats may hold promise when using parasitoids of varying uniformity, specifically because of the change in visual and volatile cues attractive to *A. colemani*.

McClure and Frank (2015) evaluated mixtures and monocultures of cereal grains as banker plants to see whether species mixtures provided a greater diversity of *M. persicae* sizes and life stages for the diversified quality of parasitoids. Species mixtures grew taller than monocultures, but did not provide improved biological control of *M. persicae* in any treatment. Additionally, rye banker plants sustained more live *R. padi* than other monocultures but not as many aphid mummies as wheat monocultures (McClure and Frank 2015).

Herbivore-induced plant volatiles could factor into the success of host plants used in banker plant systems. Mixtures of plant species have been evaluated to see whether levels of diversity among and within species affect aphid size and used by parasitoids. In commercially reared *A. colemani* specimens, various sizes of female parasitoids may attack a variety of stages of alternative prey and pest aphids. Different species of banker plants have bottom-up effects on aphids (Jandricic et al. 2014) and may be a means for optimizing shipments of mass-reared parasitoids. Although monocultures are attractive to herbivores, diversity in plant mixtures may be attractive to foraging predators and parasitoids, having a dampening effect on fluctuating herbivore populations and a decreased incidence of disease.

Characteristics of plant leaves, stems, or flowers may positively or negatively influence predator survival and persistence in the greenhouse. Banker plants supply pollen as a food supplement for the predator, *Orius insidiosus* (Say) (Hemiptera: Anthocoridae), for biological control of western flower thrips, *Frankliniella occidentalis* (Pergande) (Thysanoptera: Thripidae) (Waite et al. 2014). *O. insidiosus* is commonly reared on 'Black Pearl' ornamental pepper (*C. annuum*); however, Waite et al. (2014) found that 'Purple Flash' ornamental pepper accounted for the greatest long-term population growth of the predator. Pollen-producing plants are also used as banker plants to rear predaceous mites such as *P. persimilis* and *Neoseiulus californicus* (McGregor) (Acari: Phytoseiidae) to control two-spotted spider mites (*Tetranychus urticae* (Koch) (Trombidiformes: Tetranychidae)). Bresch et al. (2015) screened eight banker plants, and only two plant species, *Viburnum tinus* (L.) (Dipsacales: Adoxaceae) and *Vitus riparia* (Michx.) (Vitales: Vitaceae), contained predatory mites and no pest mites.

Biological control has been used successfully for greenhouse pest control for almost a century. Using natural enemies with banker plants is a mobile and versatile way to manage aphids and other common greenhouse pests in lieu of conventional pesticides. However, compatible pesticides are also available for use with this IPM system. Banker plant systems can be tailored to fit a variety of crops and pests by using various alternative hosts and banker plant species. The benefits of using banker plants include: long-term suppression of pests, decreased insecticide resistance, reduced time required to implement compared with spraying, little training is necessary, no re-entry intervals, no pre- or post-harvest intervals, as well as no negative environmental impacts. This may give the grower a unique opportunity to market a conscious decision to use a natural method of pest control.

Acknowledgments

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