Extension Education Methods

Getting Mixed-Up: Are Greenhouse Producers Adopting Appropriate Pesticide Mixtures to Manage Arthropod Pests?

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ADDITIONAL INDEX WORDS. insecticides, miticides, pest management, floriculture, survey

SUMMARY. Pesticide mixtures are commonly used by greenhouse producers to deal with the array of arthropod (insect and mite) pests encountered in greenhouses. Greenhouse producers tank mix pesticides due to convenience because it is less time consuming, costly, and labor intensive to mix together two or more pesticides into a single spray solution and then perform one spray application compared with making multiple applications. Pesticide mixtures may also result in improved arthropod pest control. However, there has been no quantitative assessment to determine what pesticide mixtures (two-, three-, and four-way combinations) are being adopted by greenhouse producers and why. As such, a survey was conducted by distributing evaluation forms in conjunction with three sessions at two greenhouse producer conferences (two in 2007 and one in 2008) to obtain data on the types of pesticide mixtures used by greenhouse producers and determine if there are any problems associated with these pesticide mixtures. The evaluation form requested that participants provide information on the four most common pesticide mixtures (insecticides and/or miticides) used and for what specific arthropod pests. The response rate of the evaluation forms was 22.5% (45/200). The two-way pesticide mixture that was cited most often ($n = 8$) was the abamectin (Avid) and bifenthrin (Talstar) combination. The two pesticides typically included in a majority of the two-way and three-way mixtures were spinosad (Conserve) and abamectin. Spinosad was a component of 17 two-way and 7 three-way combinations, while abamectin was cited in 15 two-way and 9 three-way combinations. Both products are labeled for control of the western flower thrips (*Frankliniella occidentalis*), which is one of the most important insect pests in greenhouses. One pesticide mixture that was difficult to interpret involved the fungicides, thiophanate-methyl (Cleary's 3336) and metalaxyl (Subdue). This mixture was cited twice, and the arthropod pest listed was thrips (Thysanoptera). However, both fungicides have no insecticidal activity. Two of the mixtures listed in the survey used pesticides with similar modes of action: acephate (Orthene) + methiocarb (Mesurol), and pyrethrins (Pyreth-It) + bifenthrin (Talstar). A number of the pesticide mixtures listed for spider mites (Tetranychidae) were questionable due to similar life stage activity of the a.i. as indicated on the label including fenpyroximate (Akari) + clofentezine (Ovation), abamectin + chlorfenapyr (Pylon), and bifenazate (Floramite) + etoxazole (TetraSan). In fact, 38% of pesticide mixtures cited for twospotted spider mite (*Tetranychus urticae*) control should have been avoided due to analogous life stage activity. The data obtained from the survey clearly demonstrates that greenhouse producers implement a wide-range of pesticide mixtures to deal with the multitude of arthropod pests in greenhouses. However, the basis by which greenhouse producers decide the types of pesticides to mix together is not known. As such, the survey data can be used to direct future multistate or multiregional extension (outreach) efforts in developing programs specifically designed to educate greenhouse producers on which pesticides should and should not be mixed together.

Pesticides, in this case, insecticides and miticides, are the primary means of controlling arthropod (insect and mite) pests encountered in greenhouse production systems, including greenhouse whitefly (*Trialeurodes vaporariorum*), sweetpotato whitefly B-biotype (*Bemisia tabaci*), green peach aphid (*Myzus persicae*), twospotted spider mite, western flower thrips, american serpentine leafminer (*Liriomyza trifolii*), and citrus mealybug (*Planococcus citri*) (Brodsgaard and Albajes, 1999; Hudson et al., 1996; Parrella, 1999). However, federal rules and regulations such as the Food Quality Protection Act (FQPA) and manufacturers' voluntary withdrawal or cancellations have resulted in the continual loss or registration changes associated with "older" or conventional, broad-spectrum pesticides, particularly in the organophosphate and carbamate chemical classes (Sray, 1997). This has led to an increase in the development and availability of alternative pesticides that are more selective in that they control a narrow-spectrum of arthropod pests compared with conventional pesticides. Examples of alternative pesticide groupings include insect growth regulators, insecticidal soaps, horticultural oils, selective feeding inhibitors, and microbial agents, including entomogenous bacteria and fungi, and related microorganisms (Cloyd, 2006; Parrella, 1999). In addition to their selectivity, many of these alternative pesticides are less toxic to humans, leave minimal residues, are short-lived in the environment, and have minimal direct and/or indirect impact on natural enemies, including parasitoids and predators (Cloyd, 2006; Croft, 1990; Lowery and Isman, 1995; Parrella et al., 1983; Thompson et al., 2000).

Although the availability of pesticides that demonstrate selectivity may be desirable, this creates a dilemma when dealing with multiple arthropod pest populations in greenhouses. To regulate or control the myriad of arthropod pests such as thrips, aphid (Homoptera), fungus gnat (*Bradysia* spp.), leafminer (Agromyzidae), whitefly (Homoptera), mealybug (Pseudococcidae), and spider mite that feed on ornamental crops, greenhouse producers will commonly mix together or tank mix two or more pesticides, including

conventional and alternative insecticides and/or miticides into a single spray solution to expand the activity of the application (Cloyd, 2001). As such, it may be necessary to tank mix two or more insecticides and/or miticides to obtain the same spectrum of control for multiple arthropod pests that a single broad-spectrum pesticide might provide (Warnock and Cloyd, 2005). To further complicate matters, fungicides are sometimes added to tank mixtures to help manage plant diseases.

There is relatively minimal information currently available on the effect of pesticide mixtures in controlling arthropod pests typically encountered in greenhouses (Cloyd et al., 2007; Warnock and Cloyd, 2005). Furthermore, there is no data or assessment pertaining to the types of pesticide mixtures (two-, three-, and four-way combinations) that greenhouse producers' use and why to control arthropod pests. In response to this lack of information, the objective of this study was to determine the types of pesticide mixtures employed so as to assess if greenhouse producers are selecting appropriate pesticides to mix together when dealing with the multitude of arthropod pests and if there are problems associated with the pesticide mixtures currently being used by greenhouse producers.

Materials and methods

Pesticide mixture evaluation forms were distributed during three sessions at two conferences in 2007 [Ohio Florists' Association Short Course in Columbus, OH (14 July 2007) and the GrowerTalks Greenhouse Experience Conference in Cleveland (10 Sept. 2007)] and one in 2008 [Society of American Florists 24th Annual Conference on Pest and Disease Management in Ornamentals in Atlanta (1 Mar. 2008)] where greenhouse producers were

participating in seminars on the fundamentals of tank mixing.

The evaluation forms were provided before initiation of each session, and the following information was requested from each participant: "What are the four most common pesticide mixtures (insecticides and/or miticides) you use and for what specific insect or mite pests?" The authors' address was also provided in the event that the participants completed the evaluation forms later and mailed them. There were ≈ 200 participants in attendance for all three sessions. Evaluation forms were returned the same day following each session or were received by the author via mail several days after the sessions had concluded. Although not all the participants in the three sessions were greenhouse producers, the overall majority ($>80\%$) were (R.A. Cloyd, unpublished data). After receiving the evaluation forms and collating the information, the data were then assorted into two categories: "response number" or number of times each pesticide mixture was cited in the survey, and chemical class or classification of pesticides used in the pesticide mixtures.

Because the raw data were presented as "response number" or the number of times each pesticide mixture was cited, there was no random variable and no way to determine if the data followed a binominal distribution (Moore and McCabe 1989). As such, it was not conducive or appropriate to subject the data to an analysis of variance or nonparametric statistics. Raw numbers were organized based on the specific pesticide mixtures listed and were pooled according to chemical class or classification.

Results and discussion

The results of the survey are summarized in Table 1 and represent the first quantitative data or assessment to determine the pesticide mixtures (two-, three-, and four-way combinations) used by greenhouse producers. A total of 45 fully

completed evaluation forms were assessed, and although a number of the evaluation forms ($n = 12$) did not contain the arthropod pests targeted for the specific pesticide mixtures, they were still included in Table 1 and used to assess the data. The response rate of the evaluation forms was 22.5% (45/200), which is in the range of 22% to 66% typical for most surveys (Feldman-Summers and Pope, 1994).

The two-way tank mixture that was cited most often ($n = 8$) was the combination of abamectin (Avid[®]; Syngenta Professional Products, Greensboro, NC) and bifenthrin (Talstar[®]; FMC, Philadelphia, PA) for control of mite, whitefly, mealybug, and aphid. The two-way tank mixtures cited six times by the survey respondents included abamectin and spinosad (Conserve[®]; Dow AgroSciences, Indianapolis, IN); abamectin and azadirachtin [Azatin[®] (OHP, Mainland, PA) and Ornazin[®] (SePro, Carmel, IN)]; and acephate (Orthene[®]; Valent U.S.A., Walnut Creek, CA) and fenpropathrin (Tame[®]; Valent U.S.A.). The two-way tank mixtures of spinosad and pymetrozine (Endeavor[®]; Syngenta Professional Products), and spinosad and novaluron (Pedestal[®]; OHP) were cited five and four times, respectively, by the survey respondents.

Abamectin and spinosad were used in 26 and 23 of the pesticide mixtures, respectively. They were the pesticides most often included in two-way (abamectin = 15 and spinosad = 17) and three-way (abamectin = 9 and spinosad = 7) mixtures. These pesticides are derived from the naturally occurring microorganisms *Streptomyces avermitilis* (abamectin) and *Saccharopolyspora spinosa* (spinosad), respectively (Lasota and Dybas, 1991; Sparks et al., 1998). Abamectin, which has been available since 1980, is commonly used by greenhouse producers for control of the twospotted spider mite, a major arthropod pest of greenhouses (Jeppson et al., 1975; Lasota and Dybas, 1991; van de Vrie, 1985). In fact, abamectin was included in 15 mixtures for mite.

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4536	lb	kg	2.2046
28.3495	oz	g	0.0353

Table 1. Results of pesticide mixture survey distributed at two conferences^z indicating the two-, three-, and four-way pesticide combinations cited by the participants (response number) for control of insect and mite pests in greenhouses.

Pesticide mixtures ^y	Active ingredients	Pest(s) ^x	Responses (no.) ^w
Two-way mixtures			
Avid + Talstar	Abamectin + bifenthrin	Mite, whitefly, mealybug, aphid	8
Avid + Conserve	Abamectin + spinosad	Thrips, aphid, spider mite	6
Avid + Azatin/Ornazin	Abamectin + azadirachtin	Thrips, spider mite, aphid, whitefly	6
Orthene + Tame	Acaphate + fenpropathrin	Thrips, caterpillar, whitefly, aphid	6
Conserve + Endeavor	Spinosad + pymetrozine	Aphid, thrips, caterpillar	5
Conserve + Pedestal	Spinosad + novaluron	Thrips	4
Avid + Endeavor	Shamectin + pymetrozine	Aphid, mite	3
Conserve + Floramite	Spinosad + bifentazate	Thrips, mite	3
Avid + Flagship	Abamectin + thiamethoxam	Aphid, mite, whitefly	2
Avid + Floramite	Abamectin + bifentazate	Thrips, mite	2
Avid + Marathon	Abamectin + imidacloprid		2
Avid + Mavrik	Abamectin + fluvalinate	Aphid, mite	2
Avid + TetraSan	Abamectin + etoxazole	Spider mite	2
Avid + Ultra-Fine Oil	Abamectin + paraffinic oil	Spider mite	2
Cleary's 3336 + Subdue	Thiophanate-methyl + metalaxyl	Pythium, thrips	2
Conserve + Flagship	Spinosad + thiamethoxam	Aphid, whitefly, thrips	2
Conserve + Marathon II	Spinosad + imidacloprid		2
Enstar II + Mavrik	Kinoprene + fluvalinate	Mite, aphid	2
Hexygon + Pylon	Hexythiazox + chlorfenapyr	Spider mite	2
Azatin/Ornazin + Talstar	Azadirachtin + bifenthrin	Fungus gnat, shore fly, whitefly	2
Talstar + Ultra-Fine Oil	Bifenthrin + paraffinic oil	Aphid, whitefly	2
Akari + Ovation	Fenpyroximate + clofentezine	Mite	1
Akari + TetraSan	Fenpyroximate + etoxazole	Mite	1
Astro + Azatin	Permethrin + azadirachtin	Whitefly, aphid, caterpillar	1
Astro + Floramite	Permethrin + bifentazate	Aphid, mite	1
Avid + Citation	Abamectin + cyromazine	Leafminer	1
Avid + Ovation	Abamectin + clofentezine	Spider mite	1
Avid + Orthene	Abamectin + acephate	Thrips, spider mite	1
Avid + Pylon	Abamectin + chlorfenapyr	Spider mite, thrips	1
Avid + Triact	Abamectin + neem oil ^v	Broad mite ^s	1
Aza-Direct + Ultra-Fine Oil	Azadirachtin + paraffinic oil	Mealybug, aphid	1
Azatin + BotaniGard	Azadirachtin + <i>Beauveria bassiana</i>	Aphid, thrips, whitefly	1
Azatin + Conserve	Azadirachtin + spinosad	Thrips, spider mite	1
BotaniGard + Conserve	<i>Beauveria bassiana</i> + spinosad	Thrips	1
BotaniGard + Dipel	<i>Beauveria bassiana</i> + Btk ^u	Whitefly, caterpillar	1
BotaniGard + DuraGuard	<i>Beauveria bassiana</i> + chlorpyrifos	Whitefly, caterpillar, aphid	1
BotaniGard + TriStar	<i>Beauveria bassiana</i> + acetamiprid	Whitefly, aphid, thrips	1
Citation + Daconil	Cyromazine + chlorothalonil		1
Citation + Floramite	Cyromazine + bifentazate		1

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Table 1. (*Continued*) Results of pesticide mixture survey distributed at two conferences^z indicating the two-, three-, and four-way pesticide combinations cited by the participants (response number) for control of insect and mite pests in greenhouses.

Pesticide mixtures ^y	Active ingredients	Pest(s) ^x	Responses (no.) ^w
Closure + Precision	Bendiocarb + fenoxycarb	Thrips	1
Conserve + Daconil	Spinosad + chlorothalonil		1
Conserve + Decathlon	Spinosad + cyfluthrin	Thrips, fungus gnat (adults)	1
Conserve + Enstar II	Spinosad + kinoprene	Thrips	1
Conserve + Distance	Spinosad + pyriproxyfen	Fungus gnat, thrips, whitefly	1
Conserve + Orthene	Spinosad + acephate		1
Conserve + Safari	Spinosad + dinotefuran	Thrips, whitefly	1
Conserve + Sanmite	Spinosad + pyridaben	Whitefly	1
Conserve + Talstar	Spinosad + bifenthrin	Thrips, aphid, whitefly	1
Conserve + TriStar	Spinosad + acetamiprid		1
Daconil + Pylon	Chlorothalonil + chlorfenapyr	Mite, botrytis	1
Daconil + Talstar	Chlorothalonil + bifenthrin		1
Distance + Endeavor	Pyriproxyfen + pymetrozine	Aphid, whitefly	1
Distance + TriStar	Pyriproxyfen + acetamiprid	Scale	1
Endeavor + Flagship	Pymetrozine + thiamethoxam		1
Endeavor + Ornazin	Pymetrozine + azadirachtin		1
Endeavor + Pyreth-It	Pymetrozine + pyrethrins	Whitefly, aphid	1
Endeavor + Talstar	Pymetrozine + bifenthrin	Whitefly	1
Enstar II + Tame	Kinoprene + fenpropathrin	Whitefly, mite	1
Enstar II + Triact	Kinoprene + neem oil	Mealybug, whitefly	1
Floramite + M-Pede	Bifenazate + potassium salts of fatty acids	Mite	1
Floramite + TetraSan	Bifenazate + etoxazole	Spider mite	1
Hexygon + Judo	Hexythiazox + spiromesifen	Mite	1
Hexygon + M-Pede	Hexythiazox + potassium salts of fatty acids	Mite	1
Horticultural Oil + Orthene	Paraffinic oil + acephate	Whitefly	1
Insecticidal Soap + Mesurol	Potassium salts of fatty acids + methiocarb	Slug, aphid	1
Judo + Marathon II	Spiromesifen + imidacloprid	Whitefly	1
Marathon II + Pylon	Imidacloprid + chlorfenapyr	Aphid, mite	1
Marathon II + Pyreth-It	Imidacloprid + pyrethrins	Aphid	1
Marathon II + Talstar	Imidacloprid + bifenthrin	Whitefly	1
Mesurol + Orthene	Methiocarb + acephate	Thrips	1
Orthene + Pylon	Acephate + chlorfenapyr		1
Orthene + Talstar	Acephate + bifenthrin		1
Ovation + Sanmite	Clofentezine + pyridaben	Mite	1
Pedestal + Talstar	Novaluron + bifenthrin		1
Pylon + TriStar	Chlorfenapyr + acetamiprid	Whitefly, mealybug, mite	1
Pyreth-It + Talstar	Pyrethrins + bifenthrin		1
Talstar + Triact	Bifenthrin + neem oil	Whitefly	1
Thiodan + Marathon II	Endosulfan + imidacloprid		1
Thiodan + Scimitar	Endosulfan + lambda-cyhalothrin	Thrips, spider mite	1

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Table 1. (*Continued*) Results of pesticide mixture survey distributed at two conferences^z indicating the two-, three-, and four-way pesticide combinations cited by the participants (response number) for control of insect and mite pests in greenhouses.

Pesticide mixtures ^y	Active ingredients	Pest(s) ^x	Responses (no.) ^w
Three-way mixtures			
Avid + Azatin + Pipron	Abamectin + azadirachtin + piperalrin		1
Avid + Conserve + Decathlon	Abamectin + spinosad + cyfluthrin	Thrips, mite, aphid	1
Avid + Conserve + Milstop/Compass	Abamectin + spinosad + potassium bicarbonate/trifloxystrobin		1
Avid + Daconil + Marathon II	Abamectin + chlorothalonil + imidacloprid		1
Avid + Decathlon + Dithane	Abamectin + cyfluthrin + mancozeb		1
Avid + Decathlon + Orthene	Abamectin + cyfluthrin + acephate		1
Avid + Lure + Mesurol	Abamectin + lure ^t + methiocarb	Thrips, aphid, mite	1
Avid + Milstop/Compass + TriStar	Abamectin + potassium bicarbonate/trifloxystrobin + acetamiprid		1
Avid + Orthene + Tame	Abamectin + acephate + fenpropathrin		1
Azatin + Daconil + TriStar	Azadirachtin + chlorothalonil + acetamiprid		1
Azatin + Decathlon + Talstar	Azadirachtin + cyfluthrin + bifenthrin	Mealybug	1
Azatin + Decree + TriStar	Azadirachtin + fenhexamid + acetamiprid		1
Bravo + Insecticidal Soap + Malathion	Chlorothalonil + potassium salts of fatty acids + malathion	Tomato blight, aphid	1
Capsil + Decathlon + Merit	Adjuvant ^z + cyfluthrin + imidacloprid	Aphid, caterpillar, whitefly, mealybug	1
Capsil + Merit + Orthene	Adjuvant + imidacloprid + acephate	Thrips, aphid, whitefly, mealybug	1
Compass + Floramite + Marathon	Trifloxystrobin + bifenthrin + imidacloprid	Aphid, mite, leaf spots	1
Compass + Floramite + TetraSan	Trifloxystrobin + bifenthrin + etoxazole	Twospotted spider mite, leaf spots	1
Conserve + Daconil + Orthene	Spinosad + chlorothalonil + acephate		1
Conserve + Enstar II + Orthene	Spinosad + kinoprene + acephate	Thrips, mealybug, whitefly	1
Conserve + Enstar II + TriStar	Spinosad + kinoprene + acetamiprid		1
Conserve + Floramite + Marathon II	Spinosad + bifenthrin + imidacloprid	Aphid, mite, thrips	1
Endeavor + Compass + Conserve	Pymetrozine + trifloxystrobin + spinosad		1
Floramite + Insecticidal Soap + TriStar	Bifenazate + potassium salts of fatty acids + acetamiprid	Whitefly, mealybug, twospotted spider mite	1
Floramite + Marathon + Sanmite	Bifenazate + imidacloprid + pyridaben	Aphid, whitefly, mite	1
Floramite + Sanmite + TetraSan	Bifenazate + pyridaben + etoxazole	Mite	1
Insecticidal Soap + Talus + TriStar	Potassium salts of fatty acids + buprofezin + acetamiprid	Whitefly, mealybug	1
Orthene + Azatin + Tame	Acephate + azadirachtin + fenpropathrin		1
Four-way mixtures			
Avid + Conserve + Floramite + Eagle	Abamectin + spinosad + bifenthrin + myclobutanil	Mite, aphid, thrips, powdery mildew	1
Avid + Daconil/Chipco + Marathon + Talstar	Abamectin + chlorothalonil + imidacloprid + bifenthrin		1

^zEvaluation forms were distributed at two conferences in 2007 [Ohio Florists' Association Short Course in Columbus, OH (14 July 2007) and GrowerTalks Greenhouse Experience Conference in Cleveland (10 Sept. 2007)] and one in 2008 [Society of American Florists 24th Annual Conference on Pest and Disease Management in Ornamentals in Atlanta (1 Mar. 2008)]. The total number of completed surveys returned was 45 (22.5% response rate).

^xAkari, Decree, Ornazin, Pipron, Talus (SePRO, Carmel, IN); Astro, Talstar (FMC, Philadelphia); Avid, Bravo, Citation, Daconil, Endeavor, Flagship, Scimitar, Subdue (Syngenta Professional Products, Greensboro, NC); Aza-Direct, Hexagon, Mesurol, Sanmite (Gowan, Yuma, AZ); Azatin, Compass, Decathlon, Floramite, Insecticidal Soap, Judo, Marathon, Marathion II, Pedestal, Pylon, Triact (OHP, Mainland, PA); BotaniGard, Milstop (BioWorks, Victor, NY); Capsil (Aquatrols, Paulsboro, NJ); Cleary's 3336, TriStar (Cleary Chemical, Dayton, NJ); Closure, Ovation (Scotts-Sierra, Marysville, OH); Conserve, Dithane, Eagle, M-Pede (Dow AgroSciences, IN); Dipel, Distance, Orthene, Saldan, Tame, TetraSan (Valent U.S.A., Walnut Creek, CA); DuraGuard, Horticultural Oil, Precision, Pyreth-It, Ultra-Fine Oil (Whitmire Micro-Gen Research Laboratories, St. Louis); Enstar II, Mavrik (Wellmark, Schaumburg, IL); Lure (many companies); Malathion (Control Solutions, Pasadena, TX); Merit, Thiodan (Bayer Environmental Science; Research Triangle, NC).

^yMite (Tetranychidae), whitefly (Homoptera), mealybug (Homoptera), aphid (Homoptera), thrips (Thysanoptera), spider mite (Tetranychidae), caterpillar (Lepidoptera), pythium (*Pythium* spp.), shore fly (*Scatella* spp.), leafminer (Agromyzidae), broad mite (*Polyplagiotarsonemus latus*), fungus gnat (*Bradysia* spp.), borer (*Botrytis cinerea*), scale (Homoptera), slug (Mollusk), blight [early blight (*Alternaria solani*), late blight (*Phytophthora infestans*)], leaf spots (many organisms), twospotted spider mite (*Tetranychus urticae*), powdery mildew (*Erysiphe* spp.).

^wResponse no. = number of times each pesticide mixture was cited by the survey participants.

^xNeem oil = clarified hydrophobic extract of neem oil.

^yBtk = *Bacillus thuringiensis* spp. *kurstaki*.

^zLure = attractant.

^xAdjuvant (spray) with the a.i.: blend of polyether-polymethylsiloxane-copolymer and nonionic surfactant.

Abamectin and spinosad are labeled for control of the western flower thrips—one of the most important insect pests of greenhouses (Daugherty et al., 1997; Jensen, 2000; Lewis, 1998). Spinosad was involved in 16 mixtures associated with thrips. After commercialization in 1998, spinosad has been the primary pesticide used by greenhouse producers to control western flower thrips (Loughner et al., 2005) due to its effectiveness against this insect pest (Cloyd and Sadof, 2000; Eger et al., 1998). Several of the two-way mixtures with spinosad including spinosad + abamectin, spinosad + bifenazate (Floramite®; OHP), and spinosad + imidacloprid (Marathon II®; OHP) have been demonstrated to not affect control of western flower thrips (Warnock and Cloyd, 2005).

Spinosad and abamectin were used extensively by greenhouse producers in pesticide mixtures. However, the sole use of one pesticide, even in a mixture, for a specific arthropod pest, is a concern because continual reliance on a single pesticide or mode action may lead to resistance (Yu, 2008). For example, in Aug. 2008, Dow AgroSciences voluntarily suspended the sale and use of all spinosad-related insecticides in two counties in Florida (Broward and Palm Beach counties) due to positive identification that western flower

thrip populations had developed resistance to insecticides containing spinosad as the a.i. (MeisterMedia WorldWide, 2008). Furthermore, the exchange of plant material nationally and globally among greenhouse producers may result in spreading arthropod pests with resistance genes (Denholm and Jespersen 1998).

The chlorfenapyr (Pylon®; OHP) and acetamiprid (TriStar®; Cleary Chemical, Dayton, NJ) two-way mixture that was cited once in the survey has been shown to provide 86% mortality of sweetpotato whitefly B-biotype nymphs 14 d after application (Cloyd et al., 2007). Although the evaluation form specifically stated only pesticide mixtures involving insecticides and miticides, sixteen of the pesticide mixtures involved combinations of a fungicide with an insecticide or miticide, or both. In fact, the fungicide chlorothalonil was cited in eight of the pesticide mixtures. Chlorothalonil is one of the “older,” broad-spectrum, foliar-applied protectant fungicides (Ware and Whitacre, 2004) and is commonly less expensive than the newer fungicides. It was interesting to note that the imidacloprid product Merit® (Bayer Environmental Science, Research Triangle Park, NC) was cited twice in pesticide mixtures. However, Merit® is registered for use in landscapes and nurseries, not greenhouses. The

reason why Merit® may have been selected as opposed to the greenhouse product Marathon® may be associated with convenience (product was available at the nursery) and costs. For example, a 4 × 1.6-oz container of Merit 75WSP costs \$167.00, whereas a 5 × 20-g pack of Marathon 60WP costs \$325.00 (Hummert International™, 2008). This is a difference of \$158.00.

Most of the mixtures cited in the survey involved pesticides classified as pyrethroids, neonicotinoids, or insect growth regulators (Table 2). The most widely cited neonicotinoid-based insecticide was Marathon® (n = 12), which is not surprising because this was the first neonicotinoid-based insecticide registered for use in greenhouses, and has been available since 1992 (Ware and Whitacre, 2004). The organophosphate insecticide cited most often in the pesticide mixtures by the survey respondents was acephate (Orthene). Acephate is a water-soluble, systemic insecticide that is active against a broad-range of insects feeding on ornamental plants (Cresswell et al., 1994) and is typically less expensive than many of the newer insecticides. For example, a 3 × 1/3-lb bag of Orthene costs \$15.30 (Hummert International™, 2008). The insect growth regulator most often cited by the participants was azadirachtin, which is naturally

Table 2. Chemical classifications and the pesticides trade names associated with each classification based on responses from the survey distributed at two conferences* indicating the two-, three-, and four-way pesticide combinations cited by the participants for control of insect and mite pests in greenhouses. The number in parentheses represents the frequency that each pesticide was cited by the survey participants.

OP	Chemical classification ^z						
	CARB	PY	NEO	IGR	SFB	OIL	SOAP
Trade name ^y							
DuraGuard (1)	Mesurool (2)	Astro (2)	Flagship (3)	Azatin/	Endeavor (8)	Ultra-Fine	Insecticidal
Malathion (1)		Decathlon (6)	Marathon (12)	Ornazin (10)		Oil (4)	Soap (4)
Orthene (13)		Mavrik (2)	Merit (2)	Citation (3)		Triact (3)	M-Pede (2)
		Pyreth-It (3)	Safari (1)	Distance (3)			
		Scimitar (1)	TriStar (10)	Enstar II (6)			
		Talstar (13)		Pedestal (2)			
		Tame (4)		Precision (1)			
				Talus (1)			
				TetraSan (5)			

^zOP = organophosphates, CARB = carbamates, PY = pyrethroids, NEO = neonicotinoids, IGR = insect growth regulators, SFB = selective feeding blockers, OIL = horticultural oils, SOAP = insecticidal soaps (potassium salts of fatty acids).

^yAstro, Talstar (FMC, Philadelphia); Azatin, Decathlon, Insecticidal Soap, Marathon, Pedestal, Triact (OHP, Mainland, PA); Citation, Endeavor, Flagship, Scimitar (Syngenta Professional Products, Greensboro, NC); Distance, Orthene, Safari, Tame, TetraSan (Valent U.S.A., Walnut Creek, CA); DuraGuard, Precision, Pyreth-It, Ultra-Fine Oil (Whitmire Micro-Gen Research Laboratories, St. Louis); Enstar II, Mavrik (Wellmark, Schaumburg, IL); M-Pede (Dow AgroSciences, INpolis); Malathion (Control Solutions, Pasadena, TX); Merit (Bayer Environmental Science; Research Triangle, NC); Mesurool (Gowan, Yuma, AZ); Ornazin, Talus (SePRO, Carmel, IN); TriStar (Cleary Chemical, Dayton, NJ).

^{*}Evaluation forms were distributed at two conferences in 2007 [Ohio Florists' Association Short Course in Columbus, OH (14 July 2007) and GrowerTalks Greenhouse Experience Conference in Cleveland (10 Sept. 2007)] and one in 2008 [Society of American Florists 24th Annual Conference on Pest and Disease Management in Ornamentals in Atlanta (1 Mar. 2008)]. The total number of completed surveys returned was 45 (22.5% response rate).

derived from the neem tree (*Azadirachta indica*) (Schmutterer 1990) and is commercially available as Azatin® or Ornazin®. It has been hypothesized that azadirachtin may actually “stress” insects, thus enhancing the efficacy of certain products such as those containing entomogenous or insect-killing fungi. For example, during the summer months, insect pests such as thrips and aphid molt or shed their skins (cuticle) so rapidly that entomogenous fungi are unable to penetrate the insect. The insect sheds off the spore forming conidia along with the old skin (James et al., 1998). However, tank-mixing azadirachtin with products containing the entomogenous fungus *Beauveria bassiana* as the a.i. [BotaniGard® (BioWorks, Victor, NY) and Naturalis O® (OHP)] may result in synergism or enhanced efficacy because azadirachtin, which is an insect growth regulator (Beckage, 1998), may slow down the molting process, thus allowing the insect-killing fungus to penetrate the target insect pest and initiate an infection.

Nearly all of the pesticide mixtures included arthropod pests that are on the label of at least one of the products. All the commercially available miticides labeled for use in greenhouses and the twospotted spider mite life stages (egg, larva, nymph, and adult) they are most active on are presented in Table 3. The miticide most often cited (n = 12) by the survey respondents was

bifenazate (Floramite®), which has been commercially available since the late 1990s (Thomson, 2001). A number of the miticide tank mixtures listed in Table 1 were legitimate based on the life stage activity of the a.i.: abamectin + etoxazole (TetraSan®; Valent U.S.A.), hexythiazox (Hexygon®; Gowan, Yuma, AZ) + chlorfenapyr, and abamectin + clofentezine (Ovation®; Scotts-Sierra, Marysville, OH) (Table 3). However, the following miticide tank mixtures listed in Table 1 were questionable due to similar life stage activity of the a.i.: fenpyroximate (Akari®; SePro) + clofentezine, fenpyroximate + etoxazole, abamectin + chlorfenapyr, bifenazate + etoxazole, and hexythiazox + spiromesifen (Judo®; OHP) (Table 3). Overall, ≈38% of the survey respondents used pesticide mixtures for control of twospotted spider mite that should have been avoided due to similar life stage activity.

One pesticide mixture that was difficult to interpret was the thiophanate-methyl (Cleary's 3336™) and metalaxyl (Subdue®; Syngenta Professional Products) mixture for control of thrips, which was cited twice in pesticide mixtures. Both pesticides are fungicides with no insecticidal activity. The four-way pesticide mixture of abamectin + spinosad + bifenazate + myclobutanil (Eagle™; Dow AgroSciences) was listed for control of mite, aphid, thrips, and powdery mildew (*Erysiphe* spp.). However, spinosad is not active on aphids or mites

(Bret et al., 1997; Thompson et al., 2000) and abamectin is only labeled for aphid suppression (Vance Publishing, 2006). A pesticide specifically labeled for and with demonstrated efficacy on aphids should have been included in the mixture.

Studies have been conducted to evaluate the effect of tank mixing pesticides on efficacy against western flower thrips, twospotted spider mite, and sweetpotato whitefly B-biotype. One study demonstrated that mixing the insecticide spinosad with other insecticides and miticides (imidacloprid, abamectin, and bifenazate) in two-, three-, and four-way combinations did not negatively affect the ability of spinosad to control western flower thrips (Warnock and Cloyd, 2005). Another study evaluated the effect of tank mixing the insecticides and miticides buprofezin (Talus®; SePro), acetamiprid, chlorfenapyr, and bifenazate in two-, three-, and four-way combinations on the control of twospotted spider mite and sweetpotato whitefly B-biotype (Cloyd et al., 2007). Based on the results, most of the tank mixtures did not affect control of either arthropod pest. However, the buprofezin + chlorfenapyr, and acetamiprid + chlorfenapyr + bifenazate tank mixtures resulted in a lower percentage of sweetpotato whitefly B-biotype nymphal mortality (<38%) than the other tank mixtures (Cloyd et al., 2007).

Based on the survey results, it is apparent that greenhouse producers mix together a diverse group of pesticides. However, it is not known where or how greenhouse producers get the idea to use specific products in pesticide mixtures. Tank mixing pesticides is popular because of the potential, in most instances, for improved pest control. However, although there are benefits to tank mixing, there are several issues, including antagonism, incompatibility, and phytotoxicity, that need to be considered before mixing any pesticides together (Marer, 1988). In addition, it is essential to consider why certain pesticides are being mixed together. Greenhouse producers need to develop tank mixtures that are based on the developmental life stage(s) of the target arthropod pest(s) that each pesticide is most active on. For example, tank mixing two products that have miticidal

Table 3. Activity of commercially available miticides for use in greenhouses and the life stages of twospotted spider mite on which the miticides are most effective.

Active ingredient	Miticide Trade name ^z	Activity type ^y	Life stage of twospotted spider mite			
			Eggs	Larvae	Nymphs	Adults
Abamectin	Avid	T and C		X ^x	X	X
Acequinocyl	Shuttle	C	X	X	X	X
Bifenazate	Floramite	C	X	X	X	X
Chlorfenapyr	Pylon	T and C		X	X	X
Clofentezine	Ovation	C	X	X	X	
Etoxazole	TetraSan	T and C	X	X	X	
Fenbutatin-Oxide	ProMite	C		X	X	X
Fenpyroximate	Akari	C	X	X	X	X
Hexythiazox	Hexygon	C	X	X	X	
Pyridaben	Sanmite	C	X	X	X	X
Spiromesifen	Judo	T and C	X	X	X	

^zAkari, ProMite (SePRO, Carmel, IN); Avid (Syngenta Professional Products, Greensboro, NC); Floramite, Judo, Pylon, Shuttle (OHP, Mainland, PA); Hexygon, Sanmite (Gowan, Yuma, AZ); Ovation (Scotts-Sierra, Marysville, OH); TetraSan (Valent U.S.A., Walnut Creek, CA).

^yC = contact, T = translaminar.

^xX = life stages on which each miticide is most active.

properties such as abamectin and bifenazate is not recommended because both are active on twospotted spider mite adults (Table 3). However, tank-mixing abamectin with clofentezine or etoxazole is appropriate because abamectin is primarily active on adults, whereas clofentezine or etoxazole are active on the eggs, larvae, and nymphs (Table 3). These tank mixtures target all life stages of the twospotted spider mite.

In two instances, pesticides with the same mode of action were mixed together. In the first one, acephate and methiocarb (Mesurrol®; Gowan) were tank mixed; however, despite being in different chemical classes (organophosphates and carbamates), both have identical modes of activity. The a.i. blocks the action of acetylcholinesterase (AChE), an enzyme that deactivates acetylcholine (ACh), which is responsible for activating ACh receptors, thus allowing nerve signals to travel through the central nervous system. The a.i. in both pesticides inhibit or block the action of AChE by attaching to the enzyme (Ware and Whitacre, 2004; Yu, 2008). Therefore, tank mixing these pesticides should be avoided because this exposes the insect pest population to the same mode of action, which may result in the population developing resistance to similar modes of action. This situation is referred to as cross-resistance (Brattsten et al., 1986). The second instance was the mixture of pyrethrins (Pyreth-It™; Whitmire Micro-Gen Research Laboratories, St. Louis, MO) and bifenthrin. Both are pyrethroid-based insecticides responsible for keeping the sodium channels in the neuronal membranes open (Ware and Whitacre, 2004; Yu, 2008). Again, these two products should not have been mixed together.

In conclusion, it is apparent from the survey results that greenhouse producers use many different pesticide mixtures. Although greenhouse producers commonly mix together a diverse group of pesticides to reduce labor costs associated with spray applications and to potentially improve control of arthropod pests (synergism), they need to be cautious when tank mixing so as to avoid problems associated with antagonism, incompatibility, and phytotoxicity. Although pesticide labels often state whether

certain pesticides can be mixed, not all combinations can be evaluated. Based on the results from the survey, 19% of the time, the respondents (primarily greenhouse producers) employed pesticide mixtures that should have been avoided, including using pesticides for nonlabeled arthropod pests, using pesticides with similar modes of action, and mixing together miticides that are active on the same life stages of twospotted spider mite on which they are most effective. Because tank mixing will likely continue to increase, it is important to develop multistate and multiregional extension-related programs specifically designed to educate greenhouse producers so they do not make the mistakes as indicated in the survey.

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