2004 BELTWIDE COTTON CONFERENCES, SAN ANTONIO, TX – JANUARY 5-9

WHITEFLY RESISTANCE TO INSECTICIDES IN ARIZONA: 2002 AND 2003 RESULTS

Timothy J. Dennehy, Benjamin A. DeGain, Virginia S. Harpold, and Sarah A. Brink
University of Arizona
Tucson, AZ
Robert L. Nichols
Cotton Incorporated
Cary, NC

Abstract

Whiteflies resistance to insecticides is a constant threat to successful management of sticky cotton resulting from inadequate control of *Bemisia* whiteflies. A three-stage resistance management program was implemented in Arizona cotton following a severe whitefly resistance crisis in 1995. This program has been highly successful for seven years. Success has been fostered by intensive investments into improved whitefly sampling and treatment decisions, coupled with conservation of natural enemies. This latter component has hinged on limited, strategic use of two insect growth regulators in cotton, use of the neonicotinoid insecticide, imidacloprid, in vegetables and melons, and tactical deployment of non-pyrethroid and pyrethroid chemicals. Statewide monitoring of whitefly resistance to insecticides in cotton, melons and greenhouse crops has permitted annual assessments of the status of whitefly resistance management in Arizona. In this paper we summarize susceptibility of whitefly collecions made in cotton in the 2002 and 2003 seasons and discuss longer term trends in resistance development. No major problems regarding field performance of insecticides against whiteflies were observed or reported in 2002 or 2003. However, monitoring confirmed the early stages of evolution of resistance to pyriproxyfen (Knack®) and showed that whiteflies possessing this resistance could be detected in all cotton-producing areas of the state. Susceptibility to buprofezin (Applaud®/Courier®) has not changed significantly since 1997. Mean susceptibility to synergized pyrethroids (e.g., Danitol® + Orthene®) has increased strikingly on a statewide basis since 1995. However, 50 and 25% of cotton fields sampled in 2002 and 2003, respectively, had resistance levels expected to result in inadequate performance of synergized pyrethroid treatments. Whiteflies from throughout Arizona were highly susceptible to imidacloprid (Admire®/Provado®) and two other neonicotinoid insecticides, acetamiprid (Intruder®) and thiamethoxam (Actara®/Centric®/Platinum®).

Introduction

The neonicotinoid insecticide, imidacloprid (Admire®/Provado®), and the growth-regulating insecticides (IGRs), buprofezin (Courier®/Applaud®) and pyriproxyfen (Knack®), serve critical roles in controlling whiteflies (*Bemisia tabaci*, a.k.a. *Bemisia argentifolii*) in the Arizona's low desert agricultural ecosystems (Dennehy and Williams 1997, Kerns and Palumbo 1995), as well as in other arid regions of the world (Denholm et al. 1998). Imidacloprid has provided successful season-long whitefly control in Arizona vegetables and melons since 1993, and has been used on a high proportion of these crops since its introduction (Palumbo 2003). The IGRs, buprofezin and pyriproxyfen, were introduced to Arizona cotton in 1996, after resistance to synthetic pyrethroids and other conventional insecticides reached crisis proportions in 1995 (Dennehy et al. 1996). Buprofezin and pyriproxyfen have provided the foundation for a successful resistance management strategy, their use against whiteflies in cotton being limited to once per season for each. Since 1995, insecticide treatments in Arizona cotton have declined to averages of less than two treatments per year (Agnew and Baker 2001, Shanley and Baker 2002, 2003). This represents a dramatic change from 1995 when producers were making 6 to12 insecticide treatments per acre of cotton. Thus, intensive investments into improved monitoring and management of whiteflies (Ellsworth et al. 1996, Ellsworth and Martinez-Carillo 2001), coupled with availability of highly effective, selective insecticides have greatly reduced the costs of controlling whiteflies in cotton. Sustaining successful whitefly management in Arizona will hinge foremost on avoiding whitefly resistance to neonicotinoid insecticides used in melons and vegetables and to insect growth regulators used in cotton.

Whiteflies have been shown to be capable of developing resistance to imidacloprid, pyriproxyfen, and buprofezin under both laboratory and field exposure conditions. An up-to 82-fold resistance to imidacloprid was selected by Prabhaker et al. (1997) under laboratory conditions. Control failures with whiteflies have been reported in greenhouses in Spain to imidacloprid (Denholm et al. 1998). Whitefly resistance has been documented to buprofezin and pyriproxyfen in Israel (Horowitz and Ishaaya 1994, Horowitz et al. 1994, 1999, 2002). Whitefly resistance is monitored yearly in Arizona in order to evaluate the appropriateness of resistance management recommendations and to identify resistance problems and potential solutions before they result in severe economic losses to growers. In this paper we report the results of monitoring of whitefly resistance conducted throughout Arizona cotton in the 2002 and 2003 seasons.

Materials and Methods

More than 80 cotton fields, 30 melon fields and 30 retail nurseries were sampled for whiteflies during 2002 and 2003. Herein, we report only on results of whiteflies collected from cotton. Our objective was to obtain a minimum of 1000 individuals from each collection. Low whitefly densities, field treatments with insecticides, and predation/parasitism prevented successful rearing of some collections. Whitefly cultures were successfully established (Table 1a) from 12 Arizona cotton sites in 2002 and from 17 Arizona cotton sites and one California cotton site in 2003 (Table 1b).

Adult whiteflies were collected in modified plastic vials by vacuuming plant foliage with a Makita® Cordless Vacuum (Model 4071D). Samples were chilled and transported to the laboratory in Tucson within eight hours. Samples were released into cages containing several cotton plants, *Gossypium hirsutum* L. (var. DPL-50), at the five to seven true-leaf stages. Adult whiteflies were assayed approximately 12-36 hours after field collection. Most samples from greenhouse plants were collected as nymphs on leaves. In such cases, infested leaves were transported back to the laboratory in Tucson and placed in cages. Bioassays were conducted on emerging adults. A reference population, Somerton'93, was maintained since its collection in Arizona in 1993 on cotton plants in laboratory cages, without insecticide exposure. Somerton'93 was tested repeatedly each year to provide an internal control of bioassay methodology.

Bioassays

Bioassays were conducted with six insecticides on each culture, when numbers of whiteflies in cultures permitted (Table 1b). Bioassay methods for pyriproxyfen and buprofezin were described by Li et al. (2000, 2003). The residual leaf-disk bioassay used for fenpropathrin + acephate mixtures was described by Dennehy and William (1997). All three neonicotinoid insecticides, imidacloprid, thiamethoxam, and acetamiprid, were testing using leaf disk bioassays (Li et al. 2000) and conditions noted in Table 1c.

Data Analyses

Mean mortality observed with all concentrations of the six insecticides evaluated was corrected for control mortality using Abbott's correction (Abbott 1925). Statistical differences in population responses within and between years were evaluated by analysis of variance (ANOVA, Tukey-Kramer HSD test) and non-parametric tests using the JMP-IN statistical analysis program (SAS Institute 2000). Mortality data were subjected to arcsine transformation before analysis. When appropriate, probit analyses of the concentration-dependent mortality were undertaken using POLO-PC (LeOra Software, 1987) to generate lethal concentration statistics.

Results and Discussion

Pyriproxyfen (Knack®)

Statewide Averages 1996 to 2003. During the first three years pyriproxyfen was used in Arizona, 1996-98, statewide averages of mortality in discriminating concentration bioassays of 0.1 µg/ml pyriproxyfen were ≥ 99.6% (Figure 1a). Approximately 5.5% of whiteflies collected from cotton survived these treatments in 2002; the grand mean of corrected mortality was 94.5% (Figure 1a). In 2003; 15% of whiteflies survived treatments of 0.1 µg/ml pyriproxyfen; the grand mean of corrected mortality was 85.3% (Figure 1a). Changes in mortality in bioassays of 0.01 µg pyriproxyfen/ml were even more dramatic over this same period. Grand mean mortality was > 80% from 1996 to 1998. This fell to < 40% in 2003 (Figure 1a).

Resistance Levels at Individual Field Sites. To contrast the frequency of pyriproxyfen-resistant whiteflies at individual sites tested, we have identified 2.0% survivors of 0.1 µg/ml pyriproxyfen bioassays as a critical frequency. None of the 48 cultures evaluated from 1996 to 1998 had ≥ 2.0% whiteflies surviving 0.1 µg/ml pyriproxyfen bioassays (Figure 1a). Indeed, as detailed above, survivors of 0.1 µg/ml pyriproxyfen bioassays were very rare for the first three years that pyriproxyfen was used, and constituted ≤ 0.4% of whiteflies tested each year.

Eight of the 12 cotton sites tested in 2002 (67%) had >2.0% (corrected) survivorship of 0.1 µg/ml pyriproxyfen (Figure 1b). In 2003, 14 of the 18 sites evaluated (78%) had >2.0% (corrected) survivorship of 0.1 µg/ml pyriproxyfen (Figure 1b). One collection made in 2002 and three made in 2003 had greater than 20% corrected survival of 0.1 µg/ml pyriproxyfen. The most resistant collection both years came from the Maricopa Agricultural Center. In 1996, a whitefly collection from the Maricopa Agricultural Center was shown to have an LC50 of 0.0033 µg/ml pyriproxyfen (Simmons et al. 1997). Probit analysis of responses of 2002 and 2003 collections from this same location yielded LC50 estimates of 0.045 and 0.16, respectively (Figure 1c). On this basis, the Maricopa Agricultural Center whiteflies were 13-fold less susceptible in 2002 and 48-fold less susceptible in 2003 than in 1996.

Selection for a Highly Pyriproxyfen-Resistant Laboratory Strain. We have intensively selected Arizona whiteflies for resistance to pyriproxyfen in the laboratory each year since 1996. We were unsuccessful at isolating resistant strains until 2002. In that year a collection from Queen Creek (Figure 1b, Table 1a) had approximately 10% survivors of 0.1 µg/ml pyriproxyfen when bioassayed directly from the field. Over the subsequent six months we exposed a sub-strain twice to treatments of 0.1 µg/ml pyriproxyfen. Both selected and non-selected Queen Creek strains were reared and tested simultaneously. The outcome of two exposures to pyriproxyfen in the laboratory was a > 1000-fold increase in resistance to pyriproxyfen (Figure 1d). In April of 2003 the selected strain had < 30% mortality in bioassays of 0.1 µg/ml pyriproxyfen and < 90% mortality in bioassays of 10 µg/ml pyriproxyfen. We have not detected field populations expressing this high a level of resistance.

*Conclusion Regarding Resistance to Pyriproxyfen of Whiteflies from Arizona Cotton***.** The Arizona Whitefly Resistance Working Group continues to recommend the use of either pyriproxyfen (Knack®) or buprofezin (Courier/Applaud®) as the first treatments against whiteflies in cotton. Monitoring of this situation throughout the state will be continued in 2004. It is clear from our findings that whiteflies in some areas of Arizona are substantially less susceptible to this insecticide than they were previously. However, this does not mean that Knack has failed or will fail imminently. As already stated, we know of no reports of field failures in Arizona cotton. Additionally, we cannot predict the future with accuracy. It is possible that the increases in resistance that we documented during the past three years (Figure 1a) may be reversed in the coming years. We will continue to work closely with the Arizona Cotton Growers Association, the Arizona Cotton Research and Protection Council, The Arizona Whitefly Working Group, and Valent, to provide Arizona cotton growers with the best information possible on this situation.

Typically agricultural producers have to experience expensive field failures of insecticides to determine that they have resistance problems. Once products fail in the field there are often lengthy delays before new insecticides become available and new research is completed to formulate control recommendations. This outcome typically has had negative financial implications for producers. This is especially true with stickiness of cotton resulting from whiteflies. Multiple years of discounted prices can result from a single year in which buyers experience stickiness in a region's cotton. By monitoring resistance proactively, i.e., prior to the onset of field problems, we strive to minimize resistance-related costs to producers. Thus, our reason for reporting the early stages of resistance to pyriproxyfen at this time is to increase producer awareness so that they will be most likely to assist us in identifying future problems. The sooner that we are able to detect new resistance problems in the field, the more likely we will be to have the needed time to isolate and manage the problem.

Buprofezin (Applaud®/Courier®)

Mean susceptibility of Arizona whiteflies to buprofezin in 2002 and 2003 is illustrated in Figure 2. We previously reported a small but statistically significant reduction in mortality observed with monitoring concentrations evaluated from 1996 to 1998 (Dennehy et al. 1999). Contrasts of 2002 and 2003 means with those from 1996, 1997, and 2000 (Figure 2) revealed no further decreases in susceptibility. Current levels of susceptibility of Arizona whiteflies to buprofezin are within the range observed since 1997.

Fenpropathrin + Acephate (Danitol® + Orthene®)

Statewide levels of resistance to synergized pyrethroid insecticides of whiteflies from Arizona cotton have declined dramatically since 1995. This is demonstrated by strikingly higher grand mean mortality observed in bioassays of fenpropathrin + acephate mixtures (Figure 3). However, the yearly percentage of individual cotton fields with ≥ 20% resistant whiteflies has oscillated widely from as high as 60% to as low as 10% of locations tested (Figure 3). 10 ug/ml fenpropathrin mixed with 1000 ug/ml acephate was previously shown to discriminate between whiteflies susceptible and resistant to this mixture (Dennehy and Williams 1997). Sivasupramaniam et al. (1997) subsequently demonstrated that susceptibility to fenpropathrin + acephate mixtures reflected susceptibility to all synergized pyrethroid mixtures being used against whiteflies in Arizona. Field trials (Simmons and Dennehy 1996) indicated that performance of synergized pyrethroid mixtures was acceptable at locations with a frequency of < 20% resistant whiteflies.

Sixty percent of cotton fields monitored in 2002 and 25% of cotton fields monitored in 2003 had frequencies of resistance exceeding the critical frequency (Figure 4). Thus, we conclude that some producers obtained inadequate control of whiteflies from expenditures on synergized pyrethroid treatments. However, our whitefly collections were made late in the season and some undoubtedly reflected susceptibility of populations after they had been treated with synergized pyrethroids. Synergized pyrethroids mixtures are used for controlling a number of pests of Arizona cotton, in addition to whiteflies. All such treatments, irrespective of the intended target pest, result in increased frequencies of resistance in treated whiteflies.

Synergized pyrethroid treatments against whiteflies can be highly effective and economical and they constitute an important element of our whitefly resistance management strategy. However, if used too frequently or used too early in the season they can be detrimental to whitefly management and, therein, increase production costs. It is for these reasons that the 1996 whitefly resistance management program for Arizona cotton recommended that synergized pyrethroids be used against whiteflies in cotton only late in the season and be limited to a maximum of two per season (Dennehy et al. 1996). The relatively low cost of synergized pyrethroid treatments of whiteflies provides an incentive to overuse them and/or to use them against whiteflies at times other than the late season. Without appropriate restraint, cotton producers could slip back into the trap that resulted in the pyrethroid resistance-related control problems experienced in 1994 and 1995. Thus, in extension education programs during the coming year producers will be reminded of the importance of delaying use of pyrethroids and other broadly-toxic insecticides until late in the season, as well as the value of limiting pyrethoids to no more than 2 applications per season.

Imidacloprid (Admire®/Provado®)

Whiteflies from cotton throughout Arizona were extremely susceptible to the neonicotinoid insecticide, imidacloprid, in 2002 and 2003, despite the fact that this insecticide has been used extensively on vegetable and melon crops since 1993 (Figure 5).

Susceptibility to imidacloprid dropped strikingly in Arizona whiteflies from 1995 to 1998 (Figure 5). Bioassays of collection made in 1998 commonly had 20 to 50% survivors of 100 and 1000 µg imidacloprid/ml treatments. We now occasionally find such resistant populations in greenhouse-grown ornamentals from Arizona. However, current levels of susceptibility of field populations from throughout Arizona are so high that we rarely observe greater than 10% survivors of assays of 10 µg imidacloprid/ml. Moreover, yearly testing of whiteflies from poinsettias and other ornamentals has yielded no indications of problems with performance of neonicotionids against whiteflies in greenhouses (data not shown). As with imidacloprid, all Arizona whitefly collections evaluated in 2002 and 2003 were highly susceptible (data not shown) to acetamiprid (Intruder®) and thiamethoxam (Actara®/Centric®/Platinum®).

Conclusions

No major problems regarding field performance of insecticides against whiteflies were observed or reported in 2002 or 2003 in Arizona. However, monitoring confirmed the early stages of evolution of resistance to pyriproxyfen (Knack®) and showed that whiteflies possessing this resistance could be detected in all cotton-producing areas of the state. Susceptibility to buprofezin (Applaud®/Courier®) has not changed significantly since 1997. Mean susceptibility to synergized pyrethroids (e.g., Danitol® + Orthene®) has increased strikingly on a statewide basis since 1995. However, 50 and 25% of cotton fields sampled in 2002 and 2003, respectively, had resistance levels expected to result in inadequate performance of synergized pyrethroid treatments. Whiteflies from throughout Arizona were highly susceptible to imidacloprid (Admire®) and two other neonicotinoid insecticides, acetamiprid and thiamethoxam.

Acknowledgments

We thank the Arizona Cotton Growers Association and Cotton Incorporated for supporting these studies. Facilities of the Extension Arthropod Resistance Management Laboratory are provided by the University of Arizona. We thank Peter Else and the staff of the University of Arizona Campus Agricultural Center for assistance in maintaining laboratory and greenhouse spaces. Peter Ellsworth and John Palumbo provided critical leadership of the Cross-Commodity Coordating Committee and cotton and vegetable IPM programs.

References

Abbott, W.J. 1925. A method of computing the effectiveness of an insecticide. J. Econ. Entomol. 18: 265-267.

Agnew, G.K. and P.B. Baker. 2001. Pest and pesticide usage patterns in Arizona cotton. Proc. 2001 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *pp. 1046-1054.*

Denholm, I., M. Cahill, T. J. Dennehy and A. R. Horowitz. 1998. Challenges with managing insecticide resistance in agricultural pests exemplified by the whitefly *Bemisia tabaci.* Phil. Trans. R. Soc. (Lond. B) 353(1376): 1757-1767.

Dennehy, T.J., Wigert, M., Li, X., and Williams, L., III. 1999. Arizona whitefly susceptibility to insect growth regulators and chloronicotinyl insecticides: 1998 season summary. 1999. University of Arizona Cotton Report. University of Arizona Cooperative Extension, *pp. 376-391.*

Dennehy, T.J. and Livy Williams, III. 1997. Management of resistance in *Bemisia* in Arizona cotton. Pestic. Sci. 51: 398-406.

Dennehy, T.J., P.C. Ellsworth and R.L. Nichols. 1996. The 1996 whitefly resistance management program for Arizona cotton. Univ. of Arizona IPM Series No. 8. *16 pp.*

Ellsworth, P.C. and J.L. Martinez-Carrillo. 2001. IPM for *Bemisia tabaci*: a case study from North America. *In* S.E. Naranjo and P.C. Ellsworth [eds]. Special Issue: Challenges and Opportunities for Pest Management in *Bemisia tabaci* in the New Century. Crop Protection 20:853-869.

Ellsworth, P.C., T.J. Dennehy and R.L. Nichols. 1996. Whitefly management in Arizona cotton—1996. IPM Series No. 3. Cooperative Extension Publication #196004, College of Agriculture and Life Sciences, University of Arizona, Tucson, AZ. 2 pp. URL: *http://cals.arizona.edu/crops/cotton/insects/wf/cibroch.html*

Horowitz, A.R., S. Kontsedalov, I. Denholm and I. Ishaaya. 2002. Dynamics of insecticide resistance in *Bemisia tabaci*: a case study with the insect growth regulator pyriproxyfen. Pest Management Sci. 58:1096-1100.

Horowitz, A.R., Z. Mendelson, M. Cahill, I. Denholm, and I. Ishaaya. 1999. Managing resistance to the insect growth regulator, pyriproxyfen, in *Bemisia tabaci*. Pesti. Sci. 55: 272-276.

Horowotz, A.R., G. Forer, and I. Ishaaya. 1994. Managing resistance in *Bemisia tabaci* in Israel with emphasis on cotton. Pesti. Sci. 42: 113-122.

Kerns, D.L. and J.C. Palumbo. 1995. Using Admire™ on desert vegetable crops. IPM Series No. 5. Cooperative Extension Publication #195017, College of Agriculture and Life Sciences, University of Arizona, Tucson, AZ. 2 pp. URL: *http://cals.arizona.edu/crops/vegetables/insects/wf/admire.html*

LeOra Software. 1987. POLO-PC: a user's guide to probit or logit analysis. LeOra Software, Berkeley, CA.

Li, A.Y., T.J. Dennehy, and R.L. Nichols. 2003. Baseline susceptibility and development of resistance to pyriproxyfen in *Bemisia argentifolii* (Homoptera: Aleyrodidae) in Arizona. J. Econ. Entomol. 96: 1307-1314.

Li, Y., T.J. Dennehy, X. Li, and M. E. Wigert. 2000. Susceptibility of Arizona whiteflies to chloronicotinyl insecticides and IGRs: new developments in the 1999 season. Proc. 2000 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *pp. 1325-1332*.

Palumbo, J. C., P.C. Ellsworth, T.J. Dennehy, and R. L. Nichols. 2003. Cross-commodity guidelines for neonicotinoid insecticides in Arizona. IPM Series No. 17, Pub. AZ1319. Cooperative Extension, College of Agriculture and Life Sciences, University of Arizona, Perring, T.M., A.D. Cooper, R.J. Rodriguez, C.A. Farrar, and T.S. Bellows. Tucson, AZ. 4 pp. http://cals.arizona.edu/pubs/insects/az1319.pdf

Prabhaker, N, N.C. Toscano, S.J. Castle, and T.J. Henneberry. 1997. Selection for imidacloprid resistance in silverleaf whiteflies from the Imperial Valley and development of a hydroponic bioassay for resistance monitoring. Pesti Sci. 51: 419-428.

Palumbo, J. C., A.R. Horowitz, and N. Prabhaker. 2001. Insecticidal control and resistance management of *Bemisa tabaci*. *In* S.E. Naranjo and P.C. Ellsworth eds. Special Issue: Challenges and Opportunities for Pest Management of *Bemisia tabaci* in the New Century. Crop Protection 20(9): 739-765.

SAS Institute 2000. JMP statistics and graphic guide. JMP version 4. SAS Institute, Cary, NC.

Shanley, E.H. and P. B. Baker. 2003. Pesticide update in Arizona cotton for 2002. Proc. 2003 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *12 pp.*

Shanley, E.H. and P. B. Baker. 2002. 2001 update on pesticide use in Arizona Cotton. Proc. 2002 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *11 pp.*

Simmons, A. and T. J. Dennehy. 1996. Contrasts of three insecticide resistance monitoring methods for whitefly. Proc. 1996 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *pp. 748-752*.

Simmons, A.L., L. Williams, III, T.J. Dennehy, L. Antilla, L.E. Jech, and S. Husman. 1997. Investigations of two insect growth regulators against Arizona whitefly populations. Proc. 1997 Beltwide Cotton Conferences. *pp. 1248-1251.*

Sivasupramaniam, S., T. J. Dennehy, and L. Williams, III. 1997. Management of pyrethroid-resistant whiteflies in Arizona cotton: selection, cross-resistance, and dynamics. Proc. 1997 Beltwide Cotton Conferences. National Cotton Council, Memphis, TN. *pp. 1252-1258.*

Table 1a. Locations from which whiteflies were successfully collected in 2002 and brought to the EARML facilities in Tucson for rearing and testing.

Sample	ID	Location	Host	Date
02-	15	Eloy, AZ	Cotton	27-Jul
02-	18	Campus Ag Ctr, Tucson, AZ	Cotton	6-Aug
02-	25	N. Gila Valley, AZ	Cotton	19-Aug
02-	40	Casa Grande, AZ	Cotton	16-Sep
02-	41	Maricopa Ag. Ctr., AZ, #2	Cotton	16-Sep
02-	43	Parker Valley, AZ	Cotton	25-Sep
02-	47	Paloma, AZ	Cotton	25-Sep
02-	48	Stanfield, AZ	Cotton	2-Oct
02-	49	Coolidge, AZ	Cotton	2-Oct
02-	100	Gilbert, AZ	Cotton	15-Oct
02-	101	Queen Creek, AZ	Cotton	15-Oct
02-	103	Vicksburg, AZ	Cotton	24-Oct
02-	01	S. Gila Valley, AZ	Melons	19-May
02-	02	Yuma Valley Ag. Ctr., AZ, #1	Melons	19-May
02-	05	Yuma, AZ #1	Melons	12-Jun
02-	06	Yuma, AZ #2	Melons	12-Jun
02-	07	Somerton, AZ	Melons	12-Jun
02-	08	Maricopa Ag. Ctr., AZ, #1	Melons	10-Jul
02-	09	Goodyear, AZ	Melons	10-Jul
02-	13	Yuma Valley Ag. Ctr., AZ. #2	Melons	23-Jul
02-	28	Calexico, CA	Melons	1-Sep
02-	102	Harquahala Valley, AZ	Melons	24-Oct
02-	108	Tucson Retail Nursery #5	Poinsettia	16-Dec

Table 1b. Locations from which whiteflies were successfully collected in 2003 and brought to the EARML facilities in Tucson for rearing and testing.

Sample	ID	Location	Host	Date
03-	10	Holtville, CA	cotton	20-Aug
03-	11	Chandler, AZ	cotton	25-Aug
03-	12	Palo Verde, AZ	cotton	25-Aug
03-	16	Tacna, AZ	cotton	31-Aug
03-	18	Avondale, AZ	cotton	11-Sep
03-	19	Coolidge, AZ	cotton	11-Sep
03-	24	Picacho, AZ	cotton	21-Sep
03-	30	Buckeye, AZ, #1	cotton	24-Sep
03-	31	Maricopa Ag. Center, AZ	cotton	21-Sep
03-	107	Harquahala Valley, AZ	cotton	8-Jul
03-	112	Parker Valley, AZ #2	cotton	21-Jul
03-	113	Buckeye, AZ, #2	cotton	23-Jul
03-	114	Eloy, AZ	cotton	3-Sep
03-	115	Stanfield, AZ	cotton	3-Oct
03-	17	Litchfield Park, AZ, #1	cabbage	8-Sep
03-	05	Parker Valley, AZ, #3	melons	10-Aug
03-	100	Yuma, AZ, #2	melons	19-May
03-	101	Goodyear, AZ	melons	16-Jun
03-	103	Litchfield Park, AZ, #2	melons	26-Jun
03-	104	Mohawk Valley, AZ	melons	29-Jun
03-	105	Yuma Ag. Center, AZ,	melons	29-Jun
03-	106	Eloy, AZ	melons	7-Jul
03-	109	Gadsen, AZ	melons	14-Jul
03-	111	Stanfield, AZ	melons	16-Jul
03-	102	Tucson Retail Nursery #1	hibiscus	18-Jun
03-	116	Tucson Retail Nursery #1	lantana	19-Dec

Table 1c. Summary of bioassay methods employed for each insecticide tested against whiteflies in 2002 and 2003.

	Pyriproxyfen	Imidacloprid	Fenpropathrin + Acephate	Buprofezin	Thiameth-oxam	Acetamiprid
Concentrations	control, 0.01, 0.1, 1.0	control, 1, 10, 100, 1000	control, 10, 100 (+1000)	control, 8, 100, 1000	control, 1, 10, 100, 1000	control, 1, 10, 100, 1000
Replications	6 plant replicates/>20 eggs/leaf	10 vial reps, 25 ad/vial	6 vial reps, 25 ad/vial	6 plant reps, >20 nymphs/plt	6 vial reps, 25 ad/vial	6 vial reps, 25 ad/vial
Method	seedling in vial	Residual leaf-disc on agar	Residual leaf-disc on agar	seedling in vial	Residual leaf-disc on agar	Residual leaf-disc on agar
Stage treated	egg	adult	adult	N1 stage	adult	adult
Treatment Method	leaf-dip, 20s	24h systemic uptake	leaf-dip, 10s	leaf-dip 20s	leaf-dip 10s	leaf-dip 10s
Duration	7 days exposure	48h exposure	48h exposure	9 days exposure	48h exposure	48h exposure
Notes	24h ovip period, followed by 20s leaf dip, read 7 days after dipping.	Small seedling (2-4 true leaf stage), cut stem above root line. Put into imda soln for 24h.	Small seedling (2-4 true leaf stage), cut leaf discs and dip for 10s into soln.	24h ovip period, followed by 8 days to de-velop to N1, 20s leaf dip, read 9 days after dipping.	Small seedling (2-4 true leaf stage), cut leaf discs and dip for 10s into soln.	Small seedling (2-4 true leaf stage), cut leaf discs and dip for 10s into soln.

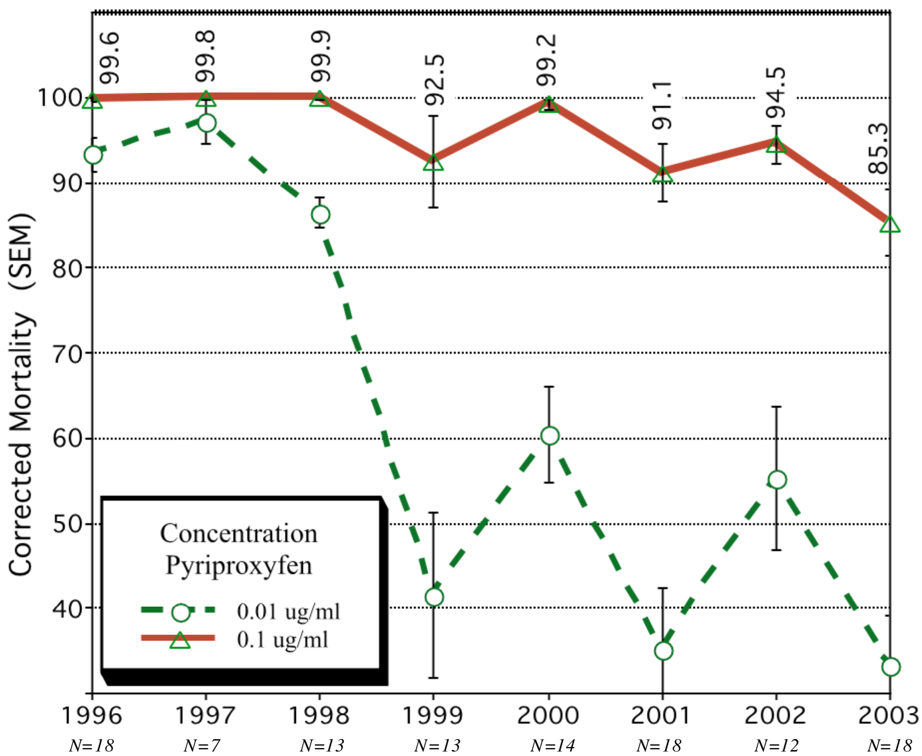

Figure 1a. Average susceptibility to pyriproxyfen (Knack®) of whiteflies from Arizona cotton, 1996-2003, as depicted by survivorship in bioassays of 0.01 and 0.1 µg pyriproxyfen/ml. Note that very few whiteflies survived 0.1 ug/ml bioassays during the first three years that pyriproxyfen was used in Arizona: 1996, 1997 and 1998. The number of collections tested is specified for each year.

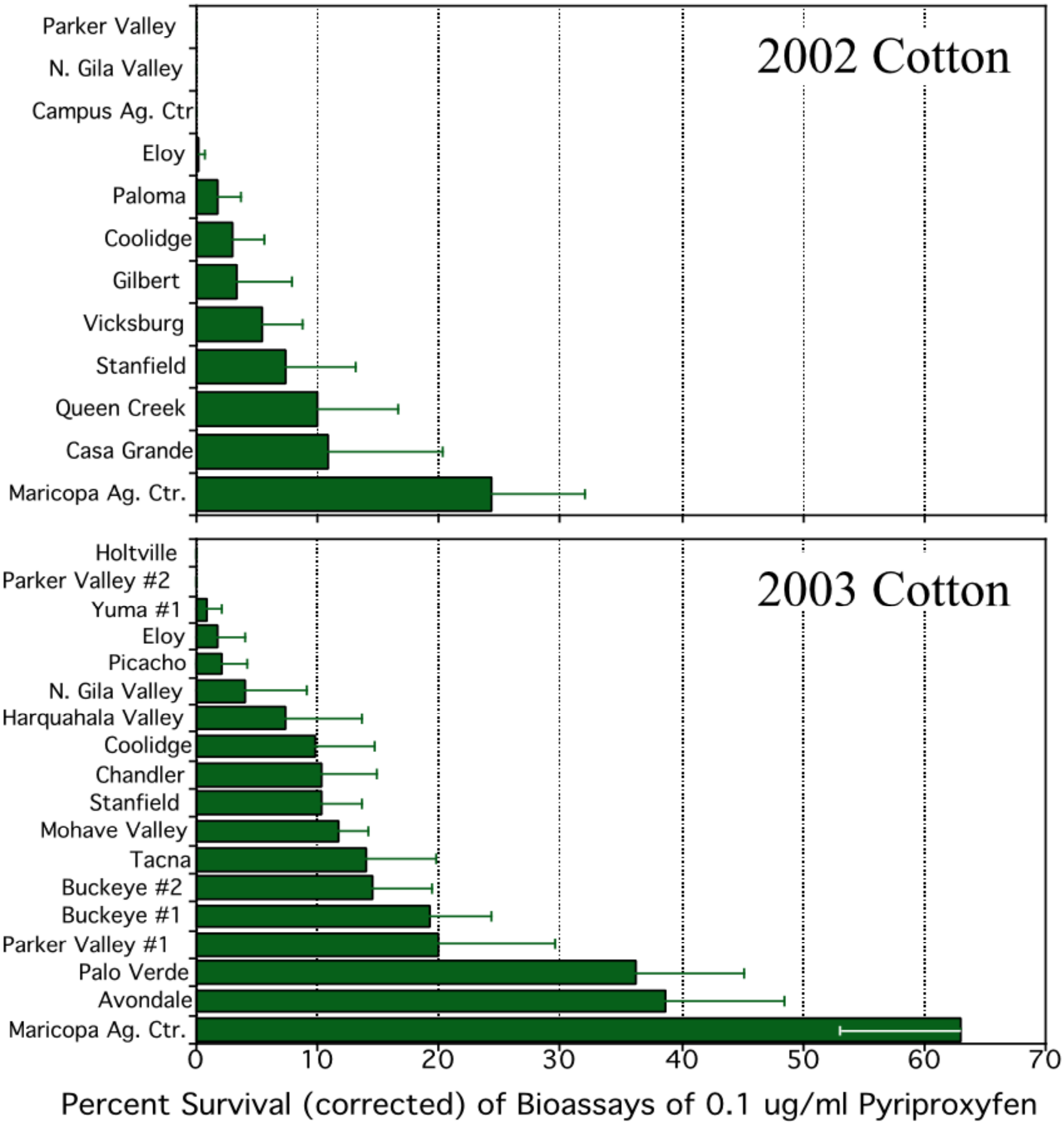

Figure 1b. Difference between field collections of Arizona whiteflies in susceptibility to pyriproxyfen (Knack®) in 2002 and 2003. Shown are the proportions of whiteflies surviving discriminating concentration bioassays of 0.1 ug pyriproxyfen/ml. Resistance of the 2002 Queen Creek population was subsequently increased in the laboratory through exposure to pyriproxyfen.

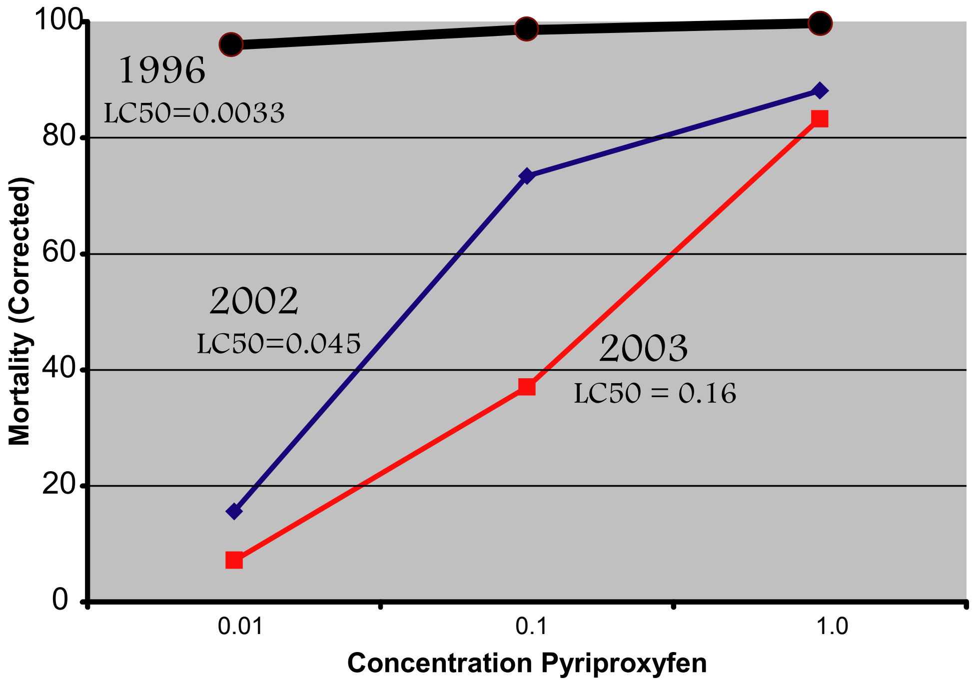

Figure 1c. Whiteflies least susceptible to pyriproxyfen in 2002 and 2003 were collected from cotton at the Maricopa Agricultural Center. Relative to 1996, the 2002 and 2003 collections were 13-fold and 48-fold less susceptible to pyriproxyfen. Some data points used to derive probit line for 1996 collection are not shown.

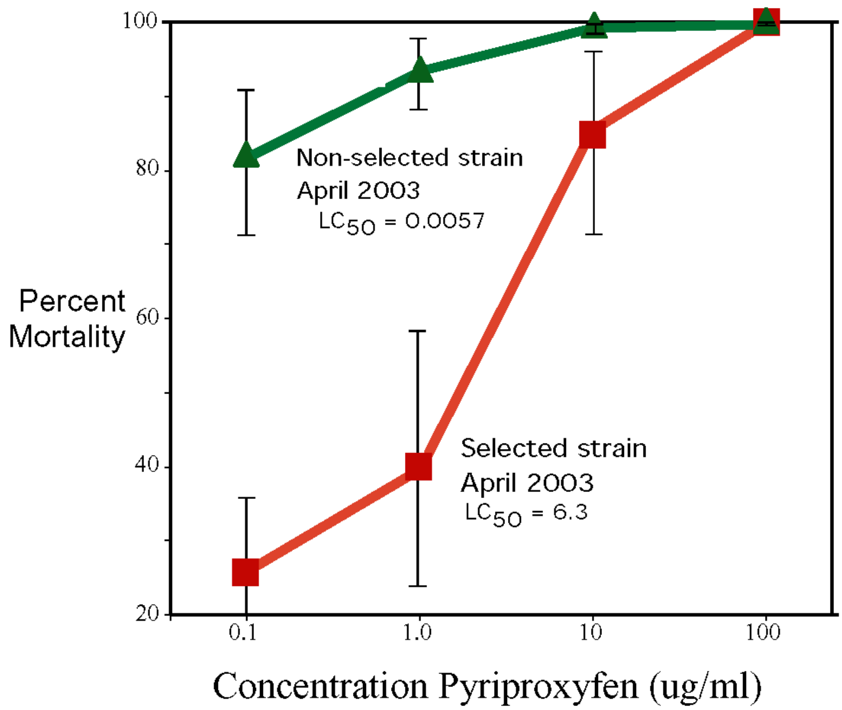

Figure 1d. Laboratory selection of the 2002 Queen Creek, Arizona, population of *Bemisia tabaci*. Two exposures to pyriproxyfen in the laboratory increased resistance levels in this strain by over 1000-fold. LC50 data for the non-selected strain were generated from full response lines (data not shown).

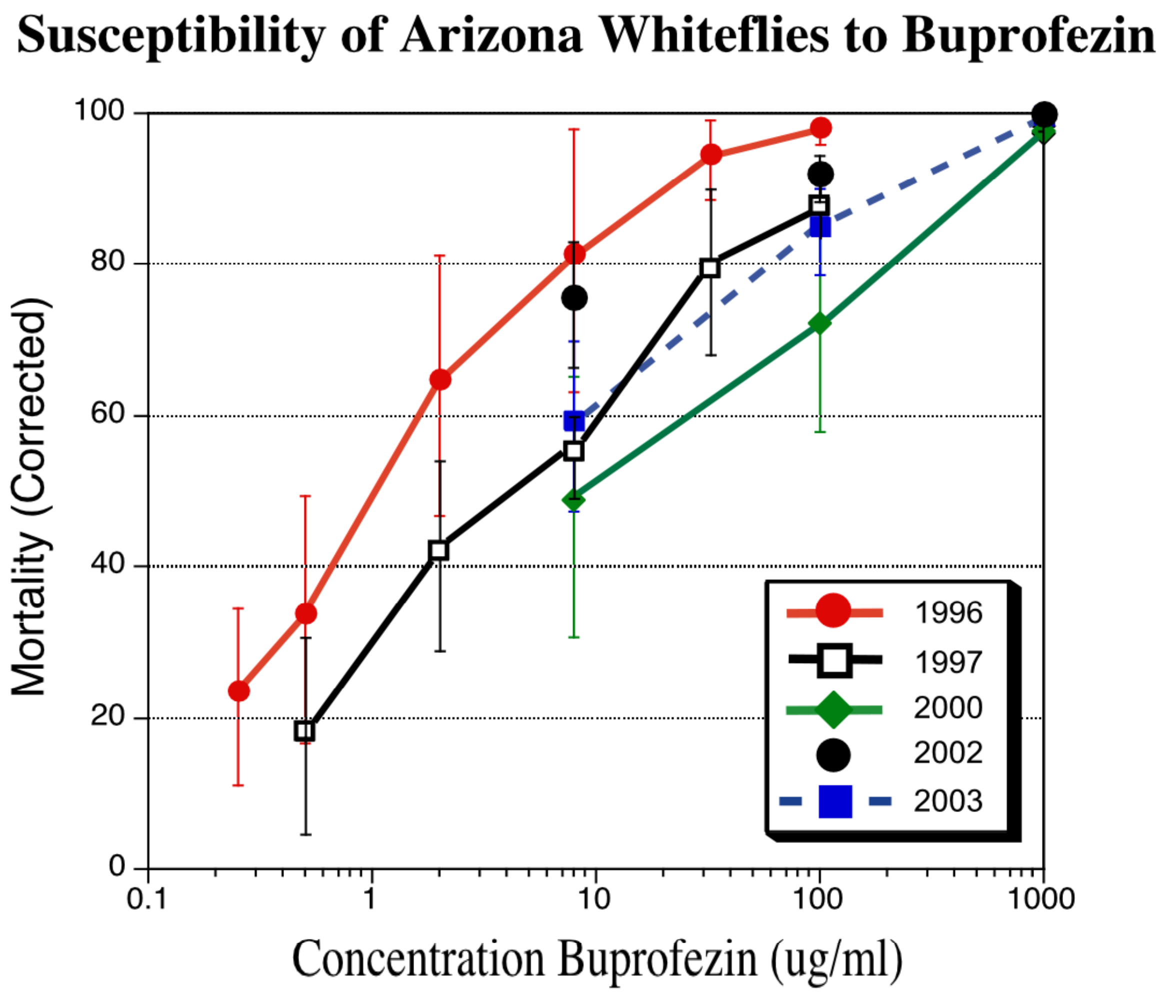

Figure 2. Grand mean corrected mortality (± stdev.) of whiteflies collected from Arizona cotton from 1996 through 2003 and bioassayed with buprofezin (Courier®/Applaud®). Susceptibility declined moderately from 1996 to 2000 but 2002 and 2003 results were intermediate to this range. Numbers of collections evaluated per year were: 1996, *N*=9; 1997, *N*=7; 2000, *N*=14; 2002, *N*=12; 2003, *N*=15.

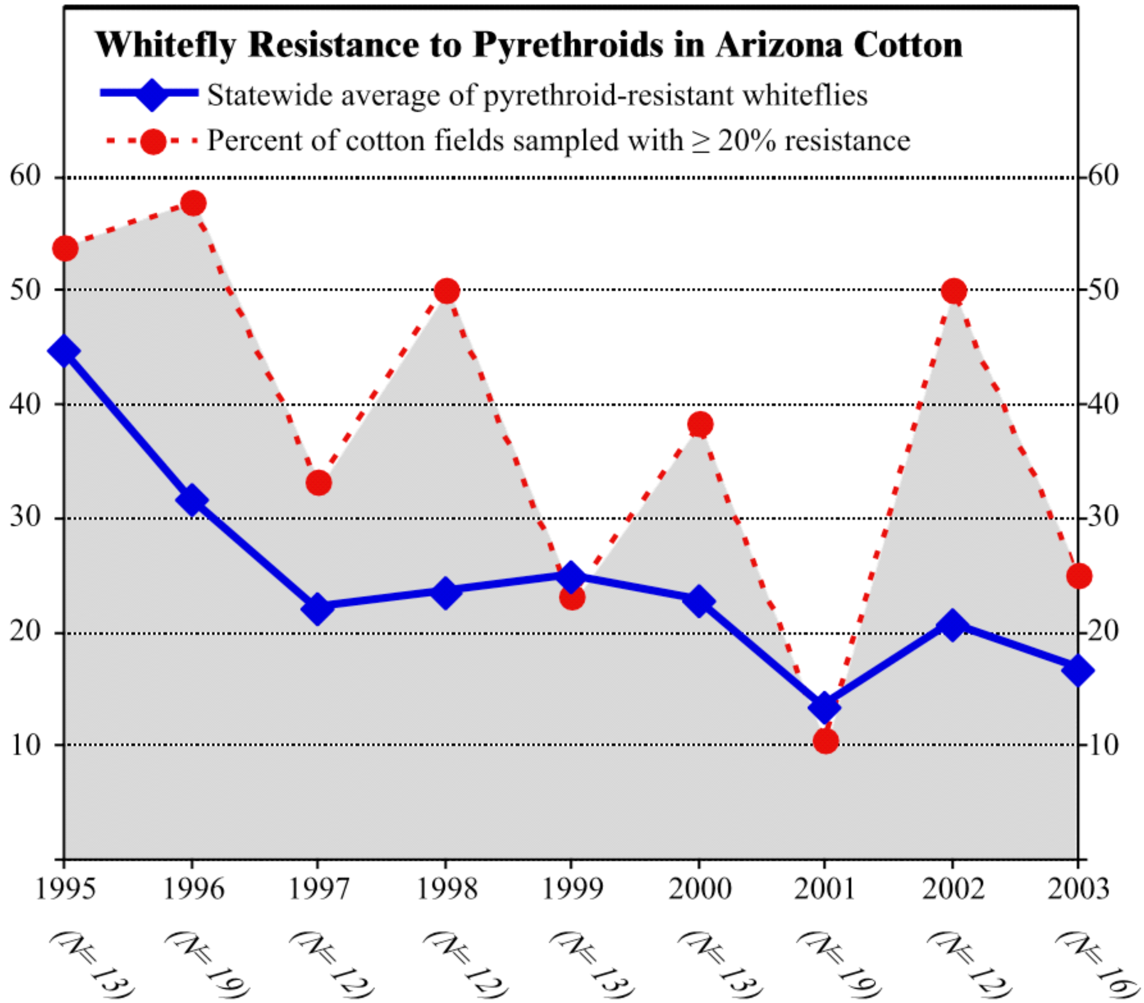

Figure 3. Resistance of whiteflies from cotton to synergized pyrethroids from 1995 to 2003, as reflected by changes in susceptibility to mixtures of fenpropathrin (Danitol®) + acephate (Orthene®). Yearly averages of the whiteflies surviving discriminating concentration bioassays (10 ug/ml fenpropathrin + 1000 ug/ml acephate) show overall declining levels of resistance. However, in some years as many as half of Arizona fields evaluated had resistance levels that were still too high to obtain adequate efficacy from synergized pyrethroid mixtures.

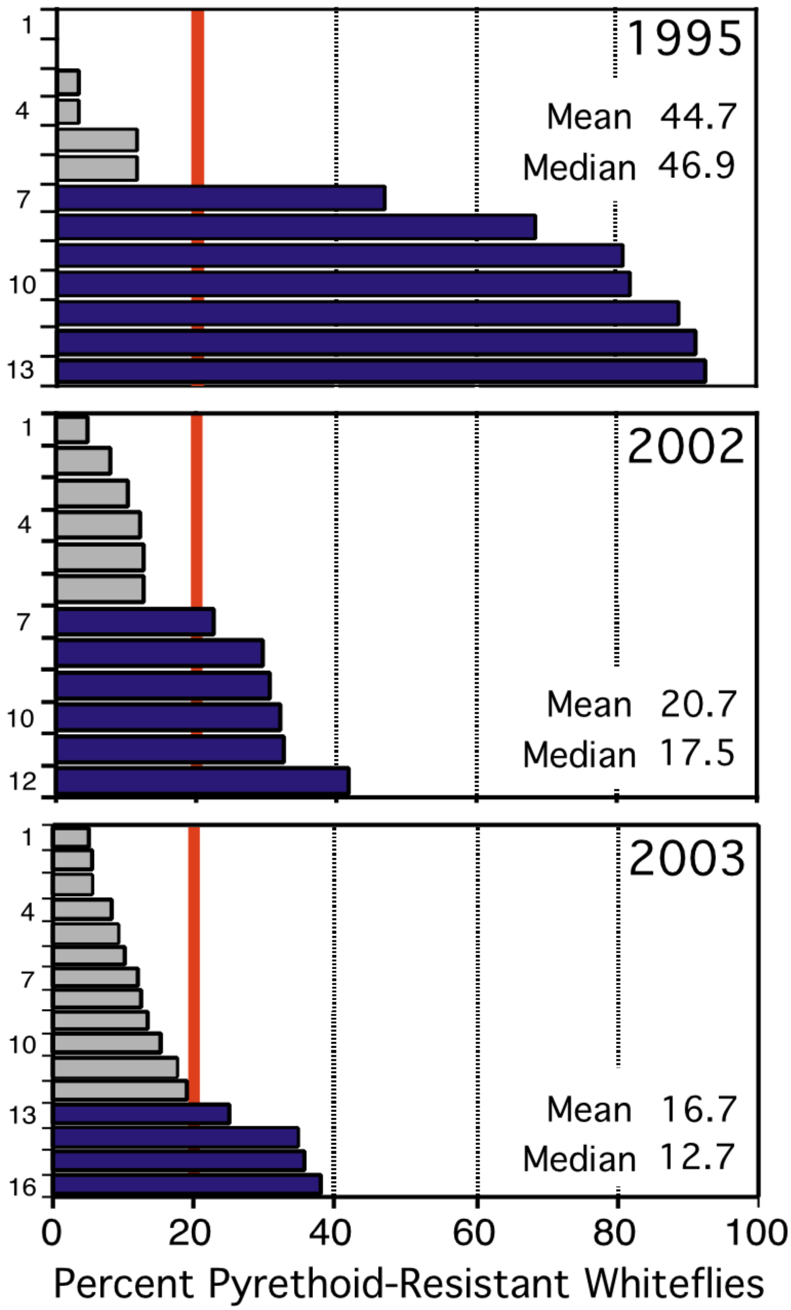

Figure 4. Susceptibility of *Bemisia* collected from cotton to synergized pyrethroid insecticides in 2002 (12 collections) and 2003 (16 collections), relative to 1995 (13 collections). Shown is the percentage of whiteflies from each sample surviving a discriminating concentration of 10 ug/ml fenpropathrin + 1000 ug/ml acephate. This concentration has been shown to kill susceptible whiteflies. The vertical line at 20% indicates the critical frequency above which resistance demonstrably impairs field performance. Synergized pyrethroids should not be used at locations with resistance frequencies ≥ this level. In 2003 only 4 of 16 whitefly populations collected from cotton exceeded the critical frequency for resistance. Synergized pyrethroid insecticides continue to perform very satisfactorily at locations with < 20% resistance, but their use should be limited to late in the season and to no more than two treatments per year.

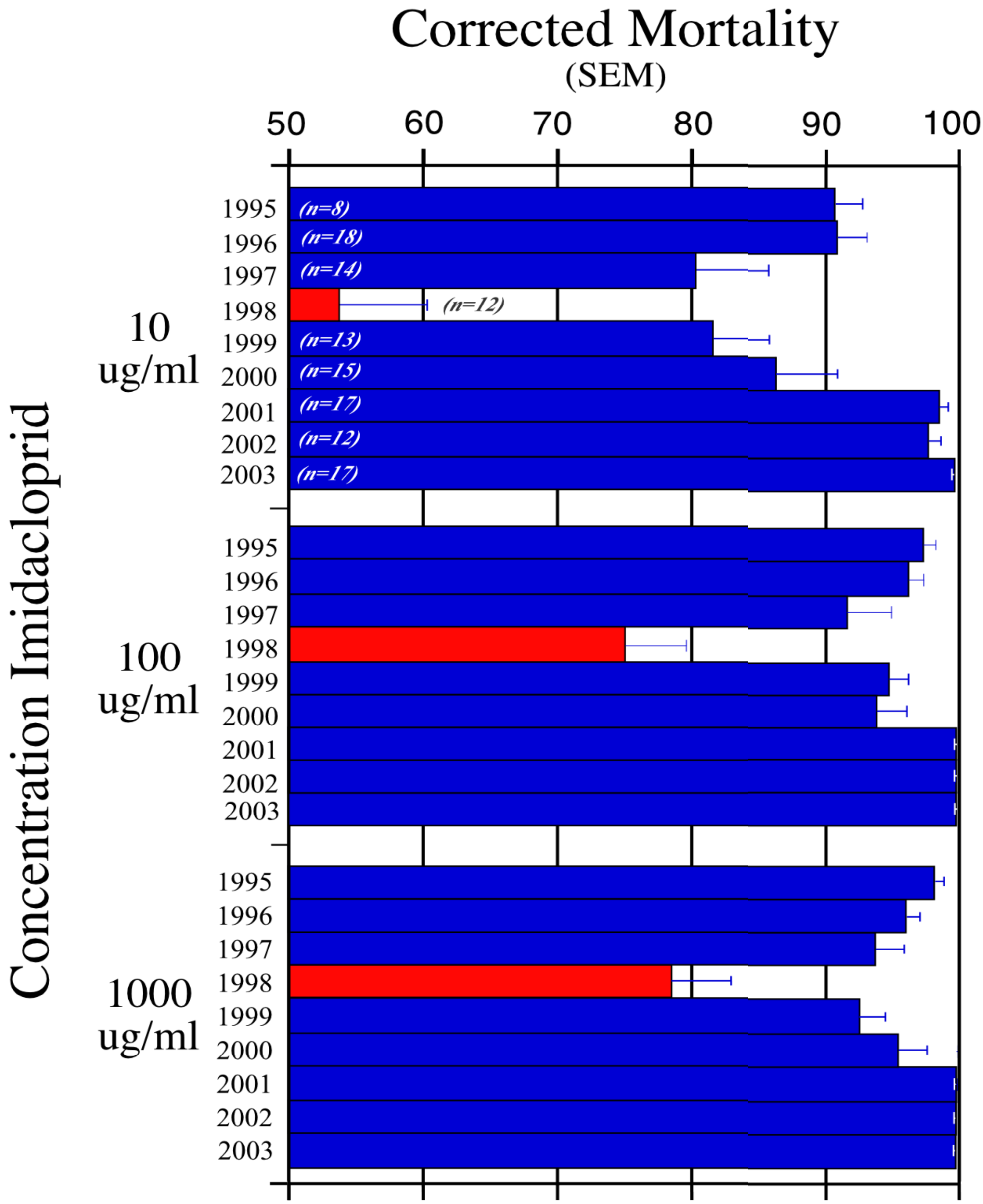

Figure 5. Susceptibility to imidacloprid (Admire®) of Arizona whiteflies collected from cotton, 1995-2002. Susceptibility declined sharply from 1995 to 1998 but was fully regained in 2001-2003.