7th International Integrated Pest Management (IPM) Symposium held in Memphis, Tennessee on March 27-29, 2012

Session R 20 Report

Introduction

Among the objectives of the Multi-Regional Work Group, WERA 60 “Management of Pesticide Resistance”, are: to facilitate exchange of information among pest management disciplines on the evolution of resistance in pests, to elucidate factors that influence the rate of resistance evolution, and to formulate strategies and tactics that may be utilized to delay resistance. A specific means to facilitate information exchange is to organize and deliver scientific symposia on pesticide resistance management. To provide such a forum, Dr. David Mota-Sanchez of Michigan State University (MSU), assisted by Drs. Mark E. Whalon, Andrew Wyenandt, and Robert L. Nichols of MSU, Rutgers University, and Cotton Incorporated, respectively, organized, moderated, and/or presented papers at session R 20 of the 7th International Integrated Pest Management (IPM) Symposium held in Memphis, Tennessee on March 27-29, 2012. We estimate that 120 individuals attended the symposium. A summary and abstracts representing the session as a whole and each of the individual presentations follows.

Summary Report

The session featured two presentations each on entomology, plant pathology, and weed science (total of six). The first paper presented for each discipline was an overview of resistance history, reporting procedures, and management strategies within the discipline. The second presentation for each of the respective disciplines covered an emerging resistance issue, current research findings concerning the resistance, and/or recommendations for its management. In addition, there were active discussions following several of the papers, and a general discussion of controversial issues at the conclusion of the session.

<u>Recent Issue in Entomology:</u> Whereas high-dose strategies for maintaining the efficacy of transgenic *Bacillus thurigiensis* (Bt) derived Cry proteins remain successful for managing European corn borer (*Ostrinia nubilalis*), Bt doses (Cry3Bb1) deployed against Western corn rootworm (*Diabrotica virgifera virgifera*) are not high enough to be fatal to heterozygotes, and resistance has emerged in Nebraska (Gassman et al. 2011 Plos1 6(7): e22629). Since the resistance has been confirmed in controlled and replicated bioassays following three years of reported field failures, there was a spirited discussion concerning when regulatory action would require deployment of remediation strategies. A representative of the Environmental Protection Agency suggested that the rights of the proprietors’ must be respected, and that the review process would likely take a year.Alternative effective treatments are in-furrow applications of the insecticides ethoprop, phoratre, or terbufos,

Recent Issue in Plant Pathology: Because of increases in prices for grain crops and aggressive marketing of foliar fungicides in corn (*Zea mays*) and soybean (*Glycine max*), there has been a large increase of the use of fungicides in agronomic crops in the Mid-Western region. This recent increase in fungicide sales is chronologically coincident with the emergence of resistance in *Cercospora sojina*, the fungus causing Frogeye leafspot of soybean to the QoI mechanism of action of the strobilurin fungicides. The fungicides flutriafol and thiophanate-methyl remain effective.
Recent Issue Weed Science: Although glyphosate was considered an herbicide at low risk for resistance development, the massive exposure of its mechanism of action frequently as a solo product for weed management in soybean; in multiple annual applications, with and sometime without other herbicides, in cotton (*Gossypium hirsutum*); and its more recent utilization in corn as a complement to the herbicide atrazine; has resulted in resistance in several driver weed species in agronomic crops including horseweed (*Conyza canadensis*), the dioecious amanranths, (*Amaranthus tuberculatus* and *A. palmeri*), and annual ryegrass (*Lolium perenne* var. *multiforum*). Weed management in agronomic crops in the United States (U. S.) is particularly at risk, because no new mechanisms of herbicide action have been registered in the U. S. since the mid-1990s. Following two years of active investigation, the Weed Science Society of America, in conjunction with the National Academy of Sciences, will offer recommendations for weed resistance management at a 'Resistance Management Summit' in Washington, D. C. on May 10, 2012. An abstract of the session as a whole and of the individual presentations follow.

Session Abstract

Pesticide resistance in arthropods, plant pathogens, and weeds: A growing threat to IPM and U. S. agriculture

Organizers: David Mota-Sanchez, motasanc@msu.edu, Michigan State University, East Lansing, MI; Andy Wyenandt,wyenandt@aesop.rutgers.edu, Rutgers University, Bridgeton, NY; Robert L. Nichols, bnichols@cottoninc.com, Cotton Incorporated, Cary, NC; Mark E. Whalon, whalon@msu.edu, Michigan State University, East Lansing, MI

Integrated Pest Management (IPM) and Resistance Management are inseparable. Resistance Management begins with IPM to minimize the number of pesticide applications to those that are absolutely essential. However, due to a failure to minimize pesticide applications, rotate mechanisms of action, or lack of effective alternatives, many arthropod pests, plant pathogens and weeds have developed resistance to pesticides. Most pest management scientists, in the public sector, the pesticide industry, and in government regulatory agencies, agree that pesticide resistance is making pest control increasingly difficult in human health, agriculture, animal production systems, and structural and urban pest management. An early estimate of the economic impact of pesticide resistance on crop protection in the U.S. exceeds $4 billion annually. Due to resistance and reduced chemical arsenal used against pests, it is essential to better manage those that are available and to

encourage development and registration of new alternatives. Current information on pesticide resistance and resistance management must be readily available to managers at the local, national and international levels. To help address this need, we will hold a mini-symposium describing current issues in pesticide resistance and development of global resistance to xenobiotics by arthropod pests, plant pathogens and weeds.

Global arthropod pesticide resistance

Mark E. Whalon, whalon@msu.edu, Michigan State University, East Lansing, MI; David Mota-Sanchez; Robert M. Hollingworth

Abstract

The occurrence of pesticide resistance frequently leads to the increased use, overuse, and even misuse of pesticides resulting in a risk to the environment, market access, and public health. Arthropods have been evolving for millions of years to defeat natural toxins, and now 574 species and 10,000 cases of pesticide resistance have been counted, most of which have been recorded over the last 65 years of intensive pesticide use. Development of global arthropod resistance to xenobiotics occurring in agriculture, medical, veterinary, and forest areas will be discussed, as well as resistance cases by insecticide mode of action and taxonomic group.

GMO's and instances of insect resistance development

Blair D Siegfried, bsiegfried1@unl.edu, University of Nebraska-Lincoln, Lincoln, NE

Abstract

Transgenic crops producing *Bacillus thuringiensis* (Bt) toxins for insect pest control have been successful in managing a variety of pest insects. However, widespread adoption of this technology is thought to impose considerable selection pressure on target pests and the risk of resistance evolution is perceived to be high. Successful management of resistance to Bt crops has been achieved in a number of instances. However, the list of pest species that have evolved resistance to Bt crops conditions is growing. Identifying the factors that contribute to both the successful and unsuccessful management of resistance is important to future resistance management recommendations.

Fungicide resistance: Current situation and management challenges

Margaret T. McGrath, mtm3@cornell.edu, Long Island Horticultural Research and Extension Center, Cornell University, Riverhead, NY

Abstract

Managing resistance is an important component of IPM programs because most fungicides have medium to high risk of resistance development, many important pathogens have demonstrated ability to develop resistance, and with a goal of delaying development, rather than managing resistant strains, implementation is always needed. Targeted activity of modern fungicides imparts low potential non-target impacts, but also resistance risk. These fungicides have resistance risk because of single-site mode of action. Challenges include predicting risk (for pathogen and fungicide), identifying best anti-resistance strategies (especially fungicide mixtures versus alternations), lack of tools (other fungicides, resistant varieties), detecting resistance, and increased management costs.

Strobilurin fungicide use in field crops: The road to resistance?

Carl A. Bradley, carlbrad@illinois.edu, University of Illinois, Urbana, IL; Venkat Chapara; Dianne Pedersen; Guirong Zhang

Abstract

Strobilurin foliar fungicide use in field crops has increased dramatically recently. Factors that have driven this increase include favorable commodity prices, new fungicide products, and marketing of fungicides for yield and plant health enhancement. Results of a survey of extension meeting attendees indicated that one of the most important criteria used in making fungicide application decisions was the potential for higher yields without considering disease risk or scouting observations. The impact of the increasing use of strobilurin fungicides on fungicide resistance will be discussed with emphasis on the current situation of strobilurin resistance in the soybean pathogen *Cercospora sojina*.

How the interaction of plant factors, crop management, and herbicide chemistry affect the development of herbicide resistance

W.K. Vencill, wvencill@uga.edu, University of Georgia, Athens, GA; R.L. Nichols; T.M. Webster; I. Heap

Abstract

The apparent rate of evolution of resistance of weeds to herbicides has increased substantially over the past decade. Data suggest that phenotypic expression of herbicide resistant is plants is affected by the mechanism of action of the herbicide, the taxonomy of the weed, the extent and frequency of selection, and the agronomic context of herbicide. The ability to identify weed and herbicide combinations that are most likely to develop herbicide resistance can aid in education and development of management systems to delay herbicide resistance.

Reducing the risks of herbicide resistance: Best management practices and recommendations

David Shaw, DShaw@research.msstate.edu, Mississippi State University, Mississippi State, MS; Jason Norsworthy; Sarah Ward; Rick Llewellyn; Robert Nichols; Ted Webster; Kevin Bradley; George Frisvold; Steve Powles; Nilda Burgos; Bill Witt; Michael Barrett
(presented by Dr. Nichols for Dr. Shaw)

Abstract
Herbicide resistance in plants has become a pressing issue in agriculture and has come to the fore with the development of glyphosate-resistant weeds. Federal agencies, industry, non-governmental organizations, commodity groups, and academia have begun a dialog at an unprecedented level on how to best preserve invaluable herbicide technologies. The Weed Science Society of America (WSSA) has been working to develop educational tools that promote sustainable weed management practices. These include training modules, special reports, and a jointly hosted National Resistance Management Summit with the National Academy of Science. WSSA has worked closely with stakeholders to disseminate this information widely.

WERA-060 Annual Report for Arizona

Peter C. Ellsworth, Al Fournier, Bruce Tabashnik, Xianchun Li, John Palumbo
Arizona Pest Management Center & Department of Entomology
& William B. McCloskey, School of Plant Sciences, University of Arizona

Stabilizing Cross-commodity Whitefly Management and Completing Transition to Novel Reduced Risk Chemistries

This project was funded through a Pest Management Alternatives Program (PMAP) grant (Li, Palumbo, Ellsworth & Fournier), heavily leveraged through other resources (Arizona Cotton Growers Association, Cotton Incorporated and industry support). The project includes evaluation of baseline susceptibility and resistance risk to whiteflies for new novel chemistries, including cross-resistance potential with current management tools. We are also evaluating and comparing field efficacy, non-target effects and economic effectiveness of the new chemistries with standards in cotton, melon and vegetable crops against whiteflies. Based on this research we are in the process of developing a new, sustainable stakeholder-driven cross-commodity whitefly management program and will transfer this technology to growers and PCAs through a comprehensive outreach plan incorporating field demonstrations, print and online publications, face-to-face trainings and peer network dissemination. We are in the third year of this two-year project.

Update: Assays of field-collected whiteflies conducted in Li's lab have shown a significant drop in mortality rates for acetamiprid-treated whiteflies over the past two years, ca. 60% median mortality in 2010 versus just 30% in 2011. Dr. Peter Ellsworth solicited feedback from pest control advisors at Extension meetings in late 2011 on their observations of field performance of acetamiprid, and got mixed responses, but most agreed that it isn't working as well as when it was introduced. Since 2005, performance for imidacloprid against whiteflies on vegetables has also declined, based on data from Dr. John Palumbo. We have examined the use patterns of available AIs across crops and have developed a draft concept that will be put up for discussion with industry reps and PCAs at an upcoming meeting.

Impact: *The anticipated impact is promotion of statewide adoption of cross-commodity pesticide use practices that will help sustain important chemical tools for whitefly management across key crops in Arizona.*

Statewide Whitefly (*Bemisia tabaci*) Resistance Monitoring Program

Statewide monitoring of whitefly resistance to pyriproxyfen, buprofezin, neonicotinoids, spiromesifen and synergized pyrethroids has been conducted in Arizona for over a decade. Work previously done in Dr. Tim Dennehy's lab is now being carried on by Dr. Xianchun Li's lab.

Findings: Field populations of B biotype whitefly are still susceptible to buprofezin and spiromesifen, but have developed moderate levels of resistance to pyriproxyfen and synergised pyrethroids for several years. Both cytochrome P450 monooxygenases (P450) and glutathione S-transferases (GST) are involved in whitefly resistance to pyriproxyfen. In 2011, field populations of B biotype whitefly have also developed low to medium levels of resistance to neonicotinoids tested (imidacloprid and acetamiprid). Consistent with our lab bioassay results, complaints on the field efficacy of neonicotinoids have increased this year. Lab bioassays also show that such field-evolved neonicotinoid resistance decrease significantly after 2-3 generations' lab rearing without exposure to neonicotinoids. Synergism experiments suggest that cytochrome P450 monooxygenases (P450) are involved in field-evolved neonicotinoid resistance. All these resistant populations are susceptible to novel chemistries including rynaxypyr, cyazypyr, spirotetramat, and pyrifluquinazon, based on current research. We have established the baseline susceptibilities of B biotype whiteflies to these novel insecticides.

We have surveyed the distribution of Q biotype whiteflies in Arizona, a biotype of worldwide significance and often with severe resistances to a wide array of chemistry. As of this year, Q biotype whiteflies in AZ are still limited to greenhouse plants and ornamentals. We have detected two subclades of Q biotype, designated as Q1 and Q2, respectively. We have developed a PCR-RFLP technique to differentiate Q1, Q2, and B biotype whiteflies. We have also monitored the resistance of Q biotype whitefly populations collected from ornamentals. All Q populations we have tested are resistant to the insecticides currently used for control of the B biotype whiteflies. All of the Q populations we have tested so far are susceptible to cyazypyr and rynaxypyr. But we have 1-2 Q populations that are resistant to the other two novel insecticides, namely, spirotetramat and pyrifluquinazon.

Large-Scale, Spatially-Explicit Test of the Refuge Strategy for Delaying Insecticide Resistance

Work in this area was published in PNAS this year:
Carrière, Y., Ellers-Kirk, C., Harthfield, K., Larocque, G., Degain, B., Dutilleul, P., Dennehy, T.J., Marsh, S.E., Crowder, D.W., Li, X., Ellsworth, P.C., Naranjo, S.E., Palumbo, J.C., Fournier, A., Antilla, L., Tabashnik, B.E. 2011. Large-Scale, Spatially-Explicit Test of the Refuge Strategy for Delaying Insecticide Resistance. Proceedings of the National Academy of Sciences DOI: 10.1073.
http://www.pnas.org/cgi/doi/10.1073/pnas.1117851109

Abstract: The refuge strategy is used worldwide to delay the evolution of pest resistance to insecticides that are either sprayed or produced by transgenic *Bacillus thuringiensis* (Bt) crops. This strategy is based on the idea that refuges of host plants where pests are not exposed to an insecticide promote survival of susceptible pests. Despite widespread adoption of this approach, large-scale tests of the refuge strategy have been problematic. Here we tested the refuge strategy with 8 years of data on

refuges and resistance to the insecticide pyriproxyfen in 84 populations of the sweetpotato whitefly (*Bemisia tabaci*) from cotton fields in central Arizona. We found that spatial variation in resistance to pyriproxyfen within each year was not affected by refuges of melons or alfalfa near cotton fields. However, resistance was negatively associated with the area of cotton refuges and positively associated with the area of cotton treated with pyriproxyfen. A statistical model based on the first 4 years of data, incorporating the spatial distribution of cotton treated and not treated with pyriproxyfen, adequately predicted the spatial variation in resistance observed in the last 4 years of the study, confirming that cotton refuges delayed resistance and treated cotton fields accelerated resistance. By providing a systematic assessment of the effectiveness of refuges and the scale of their effects, the spatially explicit approach applied here could be useful for testing and improving the refuge strategy in other crop-pest systems.

No Herbicide Resistance Detected in Arizona

Dr. William B. McCloskey investigates any claim of herbicide resistant weed populations in Arizona by collecting seed from suspected resistant populations and conducting herbicide trials side by side with known susceptible populations in the greenhouse. To date, there have been no confirmed instances of herbicide resistant weed populations in Arizona, including any resistance to glyphosate despite the presence of resistant weed populations in surrounding states.

Tools for Evaluating Resistance Management Practices in Arizona

We continue to develop data, tools and resources to support evaluation of IPM adoption, resistance management, and other pest management practices. This includes development of the Arizona Pest Management Center Pesticide Use Database in partnership with the Arizona Department of Agriculture. The database contains over 20 years of historical pesticide use reports, integrated with other useful resources. This effort has received a funding boost through three successful Arizona Department of Agriculture Specialty Crop Block Grants that will partially support a database specialist position for the next 2 years. We have integrated IRAC, HRAC and FRAC mode of action tables into the database that will help facilitate resistance-related data queries. ***Impact:*** *These data are used to infer resistance risk for cross-commodity pest management, and help guide our recommendations to growers. Data were also used in part of the analysis for a study recently published in PNAS (Carrière et al. 2011).*

Education and Outreach

Vegetable IPM Updates. Since January 2010, the Vegetable Crops IPM Leadership Team (Peña, Palumbo, Tickes, Matheron and Nolte) has published Veg IPM Updates on a biweekly basis. These updates deliver timely information to end-users via web, email and smart phone. Delivered 26 biweekly updates in 2011 and 7 in 2012 on insect, disease and weed management, often including resistance-related topics. These reached over 450 Arizona and California stakeholders by email list, and at least 300 stakeholders via the Arizona Crop Information Site (http://ag.arizona.edu/crops/vegetables/advisories/advisories.html). In addition, the same team has produced and posted 35 vegetable IPM videos to date (11 on insects, 15 on weed control, 3 on diseases and 6 "Question of the week" videos) and created video archive webpage at http://ag.arizona.edu/crops/vegetables/videos.html. Stakeholders have responded with enthusiasm about the quality and timeliness of these updates. We have seen a steady increase in attendance at educational meetings and a >2-fold increase in listserv membership for Veg IPM updates. Western Farm Press and Western Agri-Radio Network distributed these updates to over 20,000 readers.

Field Crops IPM Shorts. The Field Crops IPM Leadership Team (Brown, Ellsworth, Ottman, Norton, McCloskey, Mostafa and Fournier) in summer 2011 began producing short, timely advisory pieces on field crops pest management and getting these out to the broadest audience possible. "Field Crops IPM Shorts" are one-page articles on timely topics of interest that include photos, data and/or graphics. We have produced 18 shorts so far. Topics so far have included natural enemies of cotton pests, selective insecticides, cotton pest thresholds, and a guide to glyphosate products for weed control and others. Some of these outputs touch on resistance topics, including one piece on Round-up Ready alfalfa. The pieces go out to at least 360 stakeholders via agent email lists, and have also been picked up each week and redistributed by Western Farm Press while some pieces have been distributed by the National Cotton Council and Southwestern Farm Press, reaching many tens of thousands of readers. The pieces are archived on the ACIS site at http://ag.arizona.edu/crops/cotton/agronomic_ipm.html.

Arizona Crop Information Website. The ACIS website (http://ag.arizona.edu/crops/) hosts current information and publications for clientele on crop production and pest management, including resistance issues, and is a primary outlet for Extension outputs. The site also provides clientele with information about upcoming meetings and pesticide regulatory updates. Our ACIS email list includes about 300 participants, and is used to send updates to clientele on new extension publications, emerging pest or pesticide issues and upcoming events.

Presentations, Outreach and Continuing Education. The Ag Team organized and delivered 28 extension meetings in 2011, including 6 Crop Pest Losses workshops, indoor meetings, "tent talks" and other field-based meetings. In addition, several faculty (including Ellsworth, Palumbo, Tickes and Matheron) delivered presentations at state and regional conferences including the Desert Agriculture Conference and the Southwest Agriculture Summit. At least 94 Arizona Dept. of Agriculture CEUs, 56.5 California Dept. of Pesticide Regulation CEUs and 19 Certified Crop Advisor CEUs were delivered. Attendees are very conservatively estimated at over 1,600 people. The Southwest Ag Summit held in Yuma in March 2011 attracted 760 participants including 131 students, and delivered 12 AZ, 12 CA and 12 CCA CEUs in the breakout sessions alone. Nearly every Extension presentation related to cotton or vegetable pest management in 2011 included information about resistance of key pests to insecticides and strategies for retaining efficacy of important management tools. So far in calendar year 2012, we have held 7 Extension meetings and one farmer field day conferring about 15 Arizona CEUs.

References and Recent Publications

Brévault, T., Nibouche, S., Achaleke, J. and Y. Carrière. 2011. Assessing the role of non-cotton refuges in delaying *Helicoverpa armigera* resistance to Bt cotton in West Africa. Evolutionary Applications, *in press*.

Carrière, Y., C.Ellers-Kirk, K. Hartfield, G. Larocque, B. Degain, P. Dutilleul, T. J. Dennehy, S. E. March, D. W. Crowder, X. Li, P. C. Ellsworth, S. E. Naranjo, J. C. Palumbo, **A. Fournier**, L. Antilla & B. E. Tabashnik. 2012. Large-scale, spatially explicit test of the refuge strategy for delaying insecticide resistance. Proc. Nat. Acad. Sci. (USA) 109: 775-780.

Chu, D., Hu, X., Gao, C., Zhao, H., Nichols, R.L., and Li, X. 2011. Use of mtCOI PCR-RFLP for Identifying Subclades of Bemisia tabaci Mediterranean Group. *J. Eco. Entomol*. (in press)

Crowder, D. W., Horowitz, A. R., Bresulauer, H., Rippa, M., Kontsedalov, S., Ghanim, M., and Y. Carrière. 2011. Niche partitioning and stochastic processes shape community structure following whitefly invasions. Basic and Applied Ecology. 12:685-694.

Dennehy, T.J., Degain, B.A., Harpold, V.S., Zaborac, M., Morin, S., Fabrick, J.A., Nichols, R. L., Brown, J.K., Byrne, F.J., & Li, X. 2010. Extraordinary Resistance to Insecticides Reveals Exotic Q Biotype of *Bemisia tabaci* (Gennadius) in the New World. Journal of Economic Entomology Dec 2010 : Vol. 103, Issue 6, pg(s) 2174-2186 doi: 10.1603/EC10239

Ellsworth, P.C. 2010. Lygus in Cotton No. 4: Chemical Control Termination Guidelines (Draft). University of Arizona Cooperative Extension Circular (peer reviewed), 2 pp. http://ag.arizona.edu/crops/presentations/DRAFT_LT_guide2-pg.pdf

Ellsworth, P.C. 2011. Cotton IPM: A Quiet Revolution Reduces Costs, Losses and Risks for Arizona's Cotton Growers. University of Arizona College of Agriculture and Life Sciences Impact Report. http://ag.arizona.edu/apmc/docs/CottonIPM2011_Impacts.pdf

Ellsworth, P., L. Brown, A. Fournier, X. Li, J. Palumbo & S. Naranjo. 2011. Keeping Cotton Green. Field Crops IPM Short. University of Arizona Cooperative Extension. http://ag.arizona.edu/crops/cotton/files/SelectiveChemicalControlsvF.pdf. July 2011

Ellsworth, P., L. Brown, A. Fournier & S. Naranjo. 2011. $1-plus Cotton: New Insect Thresholds? Field Crops IPM Short. University of Arizona Cooperative Extension. http://ag.arizona.edu/crops/cotton/files/NewThresholdsVF.pdf. June 2011

Ellsworth, P. C., A. Mostafa, L. Brown & S. Naranjo. 2011. Soft-bodied *Collops* likes soft bodies. Field Crops IPM Short. University of Arizona Cooperative Extension. http://ag.arizona.edu/crops/cotton/files/CollopsVFlo.pdf. July 2011

Fabrick, J. A., L. G. Mathew, B. E. Tabashnik and X. Li. 2011. Insertion of an intact CR1 retrotransposon in a cadherin gene linked with Bt resistance in the pink bollworm, *Pectinophora gossypiella.* Insect Mol. Biol. 20: 651-665.

Fernández-Luna, M. T., B. E. Tabashnik, H. Lanz-Mendoza, A. Bravo, M. Soberón, J. Miranda-Ríos. 2010. Single concentration tests show synergism among *Bacillus thuringiensis* subsp. *israelensis* toxins against the malaria vector mosquito *Anopheles albimanus.* J. Invert. Pathol. 104: 231-233.

Heuberger, S., D. W. Crowder, T. Brévault, B. E. Tabashnik and Y. Carrière. 2011. Modeling the effects of plant-to-plant gene flow, larval behavior, and refuge size on pest resistance to Bt cotton. Environ. Entomol. 40: 484-495.

Heuberger, S., C. Ellers-Kirk, B. E. Tabashnik and Y. Carrière. 2010. Pollen- and seed-mediated transgene flow in commercial cotton seed production fields. PLoS ONE 5(11): e14128. doi:10.1371/journal.pone.0014128.

Heuberger, S., C. Ellers-Kirk, B. E. Tabashnik and Y. Carrière. 2011. A spatially-explicit analysis of crop-to-crop gene flow in cotton. Information Systems for Biotechnology News Report, March 2011: 5-8.

Hu, X., Dennehy, T.J., Ni, X., Zhao, H., Nichols, R.L., and Li, X. 2011. Potential adaptation of a Q biotype whitefly strain from poinsettia to field crops. Insect Science 18 (6): 719-728

Li, X., B.A. Degain, V.S. Harpold, P.G. Marcon, R.L. Nichols, A.J. Fournier, S.E. Naranjo, J.C. Palumbo and P.C. Ellsworth. 2012. Baseline susceptibilities of B- and Q-biotype Bemisia tabaci to anthranilic diamides in Arizona. Pest Management Science 2012, 68: 83–91. DOI 10.1002/ps.2227.

McCloskey, W. & L. Brown. 2011. Considering Roundup Ready$_{TM}$ Alfalfa. Field Crops IPM Short. University of Arizona Cooperative Extension. http://ag.arizona.edu/crops/cotton/files/RR-alfalfaShortF.pdf

Naranjo, S. E. 2010. Impacts of *Bt* transgenic cotton on integrated pest management. J. Agric. Food Chem. 59(11): 5842-51. (DOI:10.1021/jf102939c)

Naranjo, S.E. and P. C. Ellsworth. 2010. Fourteen years of *Bt* cotton advances IPM in Arizona. Southwest. Entomol. 35: 437-444.

Tabashnik, B. E. 2010. Communal benefits of transgenic corn. Science 330: 189-190.

Tabashnik, B. E. 2011. Pest control with Bt cotton and sterile insect releases. Information Systems for Biotechnology News Report, February 2011: 4-6.

Tabashnik, B. E. and Y. Carrière. 2011. Resistance to transgenic crops and pest outbreaks. In: Insect Outbreaks Revisited, eds. P. Barbosa, D. Letourneau and A. Agrawal: in press.

Tabashnik, B. E, F. Huang, M. N. Ghimire, B. R. Leonard, B. D. Siegfried, M. Rangasamy, Y. Yang, Y. Wu, L. J. Gahan, D. G. Heckel, A. Bravo and M. Soberón. 2011. Efficacy of genetically modified Bt toxins against insects with different mechanisms of resistance. Nature Biotechnology 29: 1128-1131.

Tabashnik, B. E., M. S. Sisterson, P. C. Ellsworth, T. J. Dennehy, L. Antilla, L. Liesner, M. Whitlow, R. T Staten, J. A. Fabrick, G. C. Unnithan, A. J. Yelich, C. Ellers-Kirk, V. S. Harpold, X. Li and Y. Carrière. 2010. Suppressing resistance to Bt cotton with sterile insect releases. Nature Biotechnology 28: 1304-1307.

Wan, P., Y. Huang, H. Wu, M. Huang, S. Cong, B. E. Tabashnik and K. Wu. 2011. Increased frequency of pink bollworm resistance to Bt toxin Cry1Ac. PLoS ONE: in press.

Williams, J. L., C. Ellers-Kirk, R. G. Orth, A. J. Gassmann, G. Head, B. E. Tabashnik and Y. Carrière. 2011. Fitness cost of resistance to Bt cotton linked with increased gossypol content in pink bollworm larvae. PLoS ONE 6 (6): e2183. doi: 10.1371/journalpone.0021863.

Zhang, H., W. Yin, J. Zhao, Y. Yang, S. Wu, B. E. Tabashnik and Y. Wu. 2011. Early warning of cotton bollworm resistance associated with intensive planting of Bt cotton in China. PLoS ONE 6(8): e22874. doi: 10.1371/journal.pone.0022874.

WERA-060 Annual Report for Colorado
Phil Westra and Scott Nissan
Department of Bioagricultural Sciences and Pest Management
Colorado State University

2012 saw significant research and outreach progress on glyphosate resistant kochia which was reported over a much wider geographic range including KS, CO, NE, SD, ND, and Alberta, Canada. Molecular research by Andrew Wiersma, a CSU MS graduate student, showed that in all cases, glyphosate resistant plants from many accessions over this geographic range, had increased copy number of the EPSPS gene – usually in the range of 3-9 copies which appears sufficient to confer resistance to a field labeled rate of glyphosate (.75 lb ae/acre). With increased EPSPS copy number came increased transcript abundance and increased detection of higher levels of EPSPS enzyme with an antibody. Andrew will pursue additional kochia transcriptome sequencing and bioinformatics at Michigan State University in the program of Dr. Robin Buell. We continue to work closely with KSU weed scientists on the glyphosate resistant kochia problem in the Central Great Plains. We have become a center for molecular kochia research for all parties dealing with glyphosate resistant kochia.

We collaborated with several other scientists on a publication of gene amplification cross-generational stability in Palmer amaranth from North Carolina. Work has been initiated on the rapid necrosis response in glyphosate resistant giant ragweed in multiple populations from North America.

Dr. Fernando Adegas, visiting scientist from Brazil, worked with Dr. Scott Nissen and the CSU weed science team on molecular aspects of glyphosate resistant sourgrass and horseweed. His research showed that glyphosate resistance in sourgrass is not due to glyphosate metabolism nor to a gene mutation nor to increased EPSPS protein expression. Key personnel on our Colorado resistant weed team include Drs. Scott Nissen, Dale Shaner (ARS), Chris Preston, Jan Leach, ASN Reddy, and Todd Gaines (U. of Western Australia).

Publications

Aman Chandi, Susana R. Milla-Lewis, Darci Giacomini, Philip Westra, Christopher Preston, David L. Jordan, Alan C. York, James D. Burton, and Jared R. Whitaker. 2012. Inheritance of Evolved Glyphosate Resistance in a North Carolina Palmer Amaranth (Amaranthus palmeri) Biotype. International Journal of Agronomy - Volume 2012, Article ID 176108, 7 pages doi:10.1155/2012/176108

Gaines, Todd A, Ward, Sarah M, Bukun, Bekir, Preston, Christopher, Leach, Jan E, Westra, Philip. 2012. Interspecific hybridization transfers a previously unknown glyphosate resistance mechanism in Amaranthus specie. Evolutionary Applications. ISSN: 1752-4571

WERA-060 Annual Report for Georgia

Katherine L. Stevenson
Department of Plant Pathology
University of Georgia

Research on Fungicide Resistance in the Gummy Stem Blight Pathogen of Watermelon

Didymella bryoniae, which causes gummy stem blight (GSB) of watermelon, has a history of developing resistance to fungicides, most recently the succinate-dehydrogenase-inhibiting (SDHI) fungicide boscalid (FRAC Group 7). Pristine, a formulated mixture of boscalid and the quinone (outside) inhibiting (QoI) fungicide pyraclostrobin (FRAC Group 11) worked well against *D. bryoniae* until resistance to boscalid was observed in the southeastern U.S. in the late 2000s. In laboratory assays, out of 103 field isolates of this fungus, 82 and seven were found to be very highly resistant (B^{VHR}) and highly resistant (B^{HR}) to boscalid respectively. Cross-resistance studies with the new SDHI penthiopyrad showed that the BVHR isolates were only highly resistant to penthiopyrad (B^{VHR}-P^{HR}), while the B^{HR} isolates appeared sensitive to penthiopyrad (B^{HR}-P^{S}). Research was conducted to investigate the molecular mechanism of resistance in these two phenotypes (B^{VHR}-P^{HR} and B^{HR}-P^{S}) and to assess their sensitivity to the new SDHI fluopyram. A 456-bp cDNA amplified fragment of the succinate dehydrogenase iron sulfur gene (DbSDHB) was initially cloned and sequenced from two sensitive (B^{S}-P^{S}), two B^{VHR}-P^{HR} and one B^{HR}-P^{S} isolate of *D. bryoniae*. Comparative analysis of the DbSDHB protein revealed that a highly conserved histidine residue involved in the binding of SDHIs and present in wild-type isolates was replaced by tyrosine (H277Y) or arginine (H277R) in the B^{VHR}-P^{HR} and B^{HR}-P^{S} variants respectively. Further examination of the role and extent of these alterations showed that the H/Y and H/R substitutions were present in the remaining B^{VHR}-P^{HR} and B^{HR}-P^{S} variants respectively. Analysis of the sensitivity to fluopyram of representative isolates showed that both SDHB mutants were as sensitive to this fungicide as the wild-type isolates. The genotype-specific cross-resistance relationships between the SDHIs boscalid and penthiopyrad and the lack of observed cross-resistance between these fungicides and fluopyram should be taken into account when selecting SDHIs for gummy stem blight management.

LIST OF PUBLICATIONS

Avenot, H., Thomas, A., Gitaitis, R. D., Langston, D. B. Jr., and Stevenson, K. L. 2012. Molecular characterization of boscalid- and penthiopyrad-resistant isolates of *Didymella bryoniae* and assessment of their sensitivity to fluopyram. Pest Management Science 68:645–651.

Stevenson, K. L., Keinath, A. P., Thomas, A., Langston, D. B., Roberts, P. D., Hochmuth, R. C., and Thornton, A. C. 2011. Boscalid insensitivity documented in *Didymella bryoniae* isolated from watermelon in Florida and North Carolina. Plant Health Progress doi:10.1094/PHP-2012-0518-01-BR.

Thomas, A., Langston, D. B. Jr., and Stevenson, K. L. 2012. Baseline sensitivity and cross-resistance within succinate-dehydrogenase-inhibiting fungicides and demethylation-inhibiting fungicides in *Didymella bryoniae*. Plant Dis. 96:979-984.
Thomas, A., Langston, D. B. Jr., Sanders, H. F., and Stevenson, K. L. 2012. Relationship between fungicide sensitivity and control of gummy stem blight of watermelon under field conditions. Plant Disease (in press).

Report of the MSU Arthropod Pesticide Resistance Database and Resistance Pest Management Newsletter

Mark E. Whalon, David Mota-Sanchez, Brittany Harrison and Rebeca Gutierrez. Department of Entomology. Michigan State University, East Lansing, MI48864

MSU Arthropod Pesticide Resistance Database

1) Accomplishments. The occurrence of pesticide resistance frequently leads to the increased use, overuse, and even misuse of pesticides that pose a risk to the environment, phytosanitation, market access, global trade, and public health. It can also result in serious economic loss and social disruption. The economic impact of pesticide resistance in the US has been estimated at $1.4 billion to over $4 billion annually (Pimentel et al 1991, 1993). Arthropods have been evolving for millions of years to defeat natural toxins. Since the first written report of insecticide resistance was published in 1914 by Melander, 574 species, 338 compounds, and 10,357 cases of pesticide resistance have been counted (Figure 1), most of which have been recorded over the last 60 years of intensive pesticide use. Most of the cases were found in agricultural, forest and ornamental plants (65.9%). Another 30.6% occurred in medical, veterinary and urban pests. Only 3.1% of the cases reported described the development of resistance in natural enemies such as predators and parasitoids, 0.4% in other species such as pollinators, and non-target insects. Conventional insecticides (organochlorines, organophosphates, carbamates and pyrethroids) make up about 85.2% of the total resistance cases. We have observed that there is an increase in the number of resistance cases in groups of compounds with novel chemistries and modes of action such as insect growth regulators, avermectins, neonicotinoids, IGRs, bacterial agents (Bts) and spynosins, among others.

In addition, the Insecticide Resistance Action Committee (IRAC) has reported resistance grouped by *insecticide mode of action*. These reports are hosted in our MSU arthropod pesticide resistance database at: http://www.pesticideresistance.org/irac/1/. The IRAC database content reflects the current working knowledge of a wide range of experts from industry, academia, and state and local cooperative extension, with IRAC making the ultimate decision on rankings of resistance status. IRAC makes no claim of completeness or accuracy because situations can change quickly due to many factors.

2) Impacts. Our database is visited frequently; recording about 500,000 visits to our web site (www.pesticideresistance.org) per year, and is perhaps one of the most complete databases in resistance of organisms to xenobiotics. It is our intention that this effort in reporting arthropod pesticide resistance should contribute to the design of better alternatives for resistance pest management; and in the end contribute to the world's effort to reduce hunger, and improve human and animal health and food security.

3) Publications:

Whalon, M.E., Mota-Sanchez, D. and Robert M. Hollingworth. 2012. Arthropod Pesticide Resistance Database 2012. On-line at: www.pesticideresistance.org

This effort in reporting resistance was supported through a partnership between the Insecticide Resistance Action Committee (IRAC), USDA/CSREES/IPM, WERA 60, USDA and Michigan State University.

Resistant Pest Management (RPM) Newsletter

Accomplishments and impacts.

The Resistant Pest Management (RPM) Newsletter was developed to spread knowledge of resistance around the world. The goal of the RPM Newsletter is to inform researchers, industry workers, pesticide policy and field personnel worldwide of ongoing changes and advances in pesticide resistance management, provide an archival resource to national and international policy leaders, and enhance communication of ideas among resistance managers worldwide. Since its 1989 inception, the Newsletter has published over 680 articles, including 19 articles in 2011. The Bi-annual publication has over 1,150 electronic subscribers (mostly in government, industry and academia), and hard copies are now part of 58 libraries serial listings worldwide. Example countries with serial listings include the United States, Germany, Italy, the United Kingdom, India, Japan, Taiwan, Egypt, Kenya, Costa Rica, Australia, Malaysia, Pakistan and New Zealand. The newsletter has received 21,879 visitors since May 2012.

Publications:

Resistant Pest Management Newsletter. 2011. A Biannual Newsletter of the Center for Integrated Plant Systems (CIPS) in Cooperation with the Insecticide Resistance Action Committee (IRAC) and the Western Regional Coordinating Committee (WRCC-60) Vol. 21, No. 1 (Fall 2011). On-line at: **http://whalonlab.msu.edu/Newsletter/pdf/21_1.pdf**

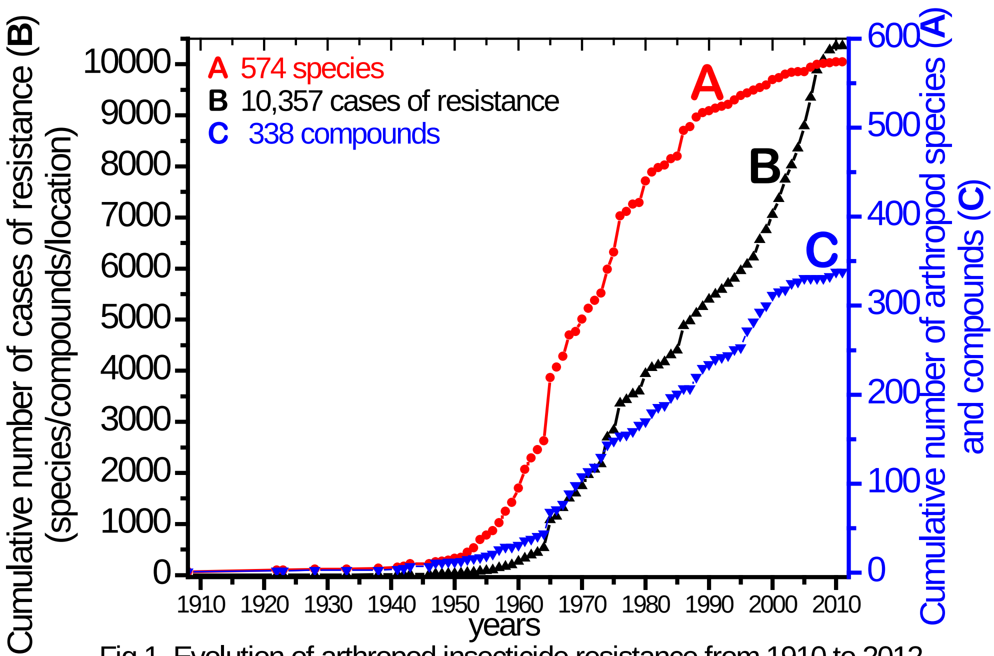

Fig 1. Evolution of arthropod insecticide resistance from 1910 to 2012. (species, compounds and total number of cases).

Source:

Whalon, M.E., Mota-Sanchez, D. and Robert M. Hollingworth. 2012. Arthropod Pesticide Resistance Database 2012. On-line at: www.pesticideresistance.org

WERA-060 Annual Report for Nebraska

Blair Siegfried
Department of Entomology
University of Nebraska

Summary: Resistance monitoring techniques developed at the University of Nebraska for detecting Bt resistance in the European corn borer are currently used in support of an annual resistance monitoring program. This effort provides a means for early detection of Bt resistance and is an essential component of Bt resistance management programs. Additional testing of new Bt toxins was initiated in 2009 development of diagnostic bioassays was initiated in 2011. Efforts to characterize Bt resistance have continued and have resulted in research results that will be important to future resistance management efforts. The availability of one of these strains has provided valuable information regarding the development of modified B t toxins that overcome a variety of resistance mechanisms. We continue to develop techniques for identification of Bt receptors in the gut of pest insects and potential modifications that may result from resistance development using next generation sequencing of the midgut transcriptome. We have also continued research to characterize field evolved resistance to Bt toxins in Puerto Rican populations of the fall army worm which represents one the first instances of control failures with Bt transgenic corn and have documented the existence of resistance alleles in North Amercian populations of FAW.

Impact: Planting of Bt corn has increased dramatically since its introduction in 1996. Widespread adoption of the technology has caused increased selection pressures and place increased priority on development of sound resistance management practices. The identification of resistant strains and characterization of resistance among field populations will provide critical information to federal agencies that regulate the use of this technology and help ensure that the technology is used a sustainable manner. Bt resistance monitoring information provided by our lab is currently utilized by most of the major seed and biotechnology companies to support registrations of transgenic corn for both European corn borer.

This project represents a number of collaborations. Specifically, scientists from USDA-ARS including Dr. Richard Hellmich and Dr. Brad Coates participated in a number of joint publications associated with this research. In addition, a number of graduate students including E. Pereira, C. Gaspers, A. Crespo, and S. Tan participated in this project and contributed research that formed part of their Ph.D. dissertations.

Publications:

Peira, E.J.G., N.P. Storer, and B.D. Siegfried. 2011. Fitness Costs of Cry1F Resistance in Laboratory-Selected European Corn Borer (Lepidoptera: Crambidae). J. Appl. Entomol. 135: 1-6.

Gaspers, C., B.D. Siegfried, T. Spencer, A.P. Alves, N.P. Storer, I. Schuphan, and S. Eber. 2011. Susceptibility of European and North American populations of the European corn borer to the Cry1F insecticidal protein. J. Appl. Entomol. 135: 7-16.

Crespo, A.L.B., A. Rodrigo-Simón, H.A.A. Siqueira, E.J.G. Pereira, J. Ferre, and B.D. Siegfried. 2011. Cross-resistance and mechanism of resistance to Cry1Ab toxin from *Bacillus thuringiensis* in a field-derived strain of European corn borer, *Ostrinia nubilalis.* J. Invert. Pathol. 107: 185-192.

Tan, S.Y., B.F. Cayabyab, E.P. Alcantara, Y.B. Ibrahim, F. Huang, E.E. Blankenship and B.D. Siegfried. Comparative Susceptibility of *Ostrinia furnacalis*, *Ostrinia nubilalis* and *Diatraea saccharalis* (Lepidoptera: Crambidae) to *Bacillus thuringiensis* Cry1 Toxins. Crop Prot. 30: 1184-1189.

Coates, B.S., D.V. Sumerford, H. Wang, C.A. Abel, R.L. Hellmich, and B.D. Siegfried. A single major QTL controls expression of larval Cry1F resistance trait in *Ostrinia nubilalis* (Lepidoptera: Crambidae). Genetica 139(8):961-72

Khajuria, C., L.L. Buschman, M. Chen, B.D. Siegfried, and K.Y. Zhu. Identification of a novel aminopeptidase P-like gene (OnAPP) possibly involved in Bt toxicity and resistance in a major corn pest (*Ostrinia nubilalis*). PLoSONE 6(8):e23983

B. E. Tabashnik, F. Huang, N. Mukti, B. Ghimire, B.R. Leonard, B.D. Siegfried, M. Rangasamy, Y. Yang, Y. Wu, L.J. Gahan, D.G. Heckel, A. Bravo and M. Soberón. Efficacy of genetically modified Bt Toxins against insects with different mechanisms of resistance. Nature Biotech. doi: 10.1038/nbt.

WERA-060 Annual Report for New Jersey
Andy Wyenandt
Extension Specialist in Vegetable Pathology
Department of Plant Biology and Pathology
Rutgers University

Fungicide resistance management in vegetable crop production continues to be a major focus in New Jersey as well as the rest of the mid-Atlantic region (PA, DE, MD, and VA). The 6th edition of the Fungicide Resistance Management Guidelines for Vegetable Crop Production in the mid-Atlantic Region will be published in 2012. Since 2007, over 10,000 of these guides have been distributed to growers, extension agents and specialists, crop consultants, and industry representatives throughout the region representing to our best estimates between 75,000 to 100,000 A of commercial vegetable production.

Publications:

Wyenandt, A. and N.L. Maxwell. 2011. Evaluating vegetable fungicide recommendations in the United States: Should more be done to limit the risks of fungicide resistance development? Online. Journal of Extension. June 2011. <http://www.joe.org/joe/2011june/a8.php>

WERA-060 Annual Report for New York
Margaret Tuttle McGrath
Cornell University

FUNGICIDE RESISTANCE IN CUCURBIT POWDERY MILDEW

Activities pertaining to fungicide resistance in cucurbit powdery mildew being conducted in New York are monitoring of resistance in production fields, evaluating fungicides at-risk for resistance, and determining baseline sensitivity for new fungicides. Fungicides are an important tool for managing cucurbit powdery mildew to avoid losses in quantity and/or fruit quality. This is the most common disease of cucurbit crops, which include pumpkin, squash and melon. Effective control necessitates products able to move to the lower leaf surface, where this disease develops best. Unfortunately these mobile products are prone to resistance development because of their single-site mode of action. Only 3 of the 5 fungicide chemical groups labeled for cucurbit powdery mildew in the US currently are recommended: FRAC Codes 3, 7, and 13. Resistance to FRAC Code 1 and 11 fungicides has been shown to be generally common through previous research conducted in NY. Spores of this pathogen (*Podosphaera xanthii*) can be dispersed by wind long distances enabling widespread dispersal of resistant strains.

Research conducted since the last report has focused on determining fungicide sensitivity of pathogen isolates (individuals) obtained at the end of the growing season in 2011 from commercial pumpkin crops, research fields, and non-fungicide-treated garden squash. Sensitivity is being determined using a leaf disk bioassay for the 55 isolates from 12 populations. Leaves of pumpkin at the cotyledon stage are sprayed with a fungicide, then one day later disks are cut, put on water agar in a sectioned Petri dish (six disks per section), and inoculated by transferring spores to the center of each disk. Three fungicide doses are tested and compared to a non-treated control in each bioassay. Pathogen growth is assessed after 7-14 days. A few more bioassays are planned to complete this work.

Results from 14 bioassays conducted so far are as follows. Based on bioassays conducted with Rally, a DMI (FRAC code 3) fungicide containing myclobutanil as the active ingredient, 20% of the isolates were able to grow on leaf disks treated with 40 ppm, 85% of the isolates tolerated 10 ppm, and 15% of the isolates were sensitive to 10 ppm. Bioassays conducted with Quintec (FRAC code 13) revealed that 24% of the isolates were able to grow on leaf disks treated with 40 ppm quinoxyfen (active ingredient), 78% of the isolates tolerated 10 ppm, and 22% of the isolates were sensitive to 10 ppm. Only 4% of isolates tolerated 500 ppm boscalid, an active ingredient in Pristine. Isolates tolerant of this concentration are considered resistant. Most isolates (61%) were sensitive to 100 ppm boscalid.

Doses used in bioassays cannot be directly compared to rates applied by growers treating their crops because the dose is prepared as a concentration and applied to coverage while the rate growers use is based on acreage treated. The concentration in a spray tank varies with the gallonage used, which varies a lot. When the fungicides used in the bioassay are applied at the highest labeled rate at 50 gallon/acre, the dose of active ingredient in the spray tank is 300 ppm of myclobutanil for Rally, 212 ppm of quinoxyfen for Quintec, and 700 ppm of boscalid for Pristine.

2011 Publications

McGrath, M. T.   2011. Challenge of fungicide resistance in managing vegetable diseases in United States and anti-resistance strategies. Chapter 16. Pages 191-207. *In* Fungicide Resistance in Crop Protection: Threat and Management. Thind, T. S. (Ed.). CABI International.

McGrath, M. T., and Hunsberger, L. K. 2011. Efficacy of fungicides for managing cucurbit powdery mildew and pathogen sensitivity to fungicides, 2010. Plant Disease Management Reports 5:V104.

McGrath, M. T. and Hunsberger, L. K. 2011. Effectiveness for cucurbit powdery mildew of fungicides prone to resistance development. Phytopathology 100:S (abstract for presentation at NED-APS annual meeting).

McGrath, M. T., Rivara, K. L., and Hunsberger, L. K. 2011. Sensitivity of the cucurbit powdery mildew pathogen to fungicides prone to resistance development. Phytopathology 100:S (abstract for presentation at NED-APS annual meeting).

McGrath, M. T. and Hunsberger, L. K. 2011. Fungicide sensitivity of Podosphaera xanthii and efficacy of fungicides with resistance risk for cucurbit powdery mildew in New York in 2010. Phytopathology (abstract for presentation at APS annual meeting).