RESISTANT PEST MANAGEMENT

A Biannual Newsletter of the Pesticide Research Center (PRC) in Cooperation with the
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Thank you for your interest and commitment to sharing resistance information.

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Editorial

Insecticide Resistance and Genetic Myths: A Cautionary Tale

Resistance management programs are designed to retain efficacy of important insecticides by preventing or delaying development of resistance. If these ideals cannot be realized, we at least need to be aware of resistance changes in populations. Resistance gets its start at the level of the individual as one or a few genotypes conferring some level of resistance appear in a particular geographic area. However, development of resistance sufficient to cause control failures is a population genetic phenomenon: a change (increase) in the frequency of resistance genotypes in the area. Resistance genotypes increase in frequency because we supply the selective agent: insecticide applications. Thus, resistance management programs need to consider at least three general features of the insect/insecticide system: 1) genetic basis of resistance, 2) the ecological (population/ quantitative) genetics of resistance, and 3) the patterns of selection pressure applied by particular application schemes (acknowledging that not all application schemes are consistent with the grower's other constraints).

But while the genetic basis of resistance may be an important consideration, successful resistance management does not necessarily depend on an accurate description of the genetics of resistance. The crux of a resistance management program is to avoid strong selection for increased tolerance at times when the population has significant ability to respond to that selection. An accurate description of the genetic basis of resistance may or may not help with this problem. In fact, incorrect descriptions of the genetic basis of insecticide resistance can do more harm than good and exacerbate the problem by promoting further development of resistance.

In this article, I discuss problems associated with methods that have been used to examine the genetic basis of resistance, the ability of these methods to provide a clear description of the genetics of resistance, and problems that can be caused by using inaccurate genetic descriptions in a resistance management program.

It is widely believed that resistance to insecticides is a simple monogenic trait. Some resistance management programs rely on this assumption. For non-scientists, or scientists who don't work on the genetics of insecticide resistance, it is reasonable to conclude that resistance is a simple monogenic trait; most studies have indeed concluded that insecticide resistance results from the actions of a single or single major gene. However, when these studies are subjected to close scrutiny, a different picture emerges.

I recently reviewed a portion of the literature dealing with the genetic basis of insecticide resistance (Firko 1991). My review and three independent examinations of the analysis used most often to examine the genetic basis of insecticide resistance (backcross progeny analysis), led to the inescapable conclusion that published data do not support the widely held belief that insecticide resistance is a simple monogenic trait. This conclusion was based on two findings: 1) backcross progeny analysis is seldom capable of discriminating among genetic hypotheses, and 2) monogenic inheritance of insecticide resistance was rejected in most studies. Thus, the notion that insecticide resistance is a simple monogenic trait is a dictionary example of a myth: an unproved collective belief that is accepted uncritically.

Most (93%) recent examinations of the genetic basis of insecticide resistance relied on backcross progeny analysis. To perform the analysis, a susceptible strain is crossed with a resistant strain to produce an F_1 generation which is then backcrossed to the susceptible and/or the resistant parent strain. Susceptible, resistant, and F_1 insects are tested for response to various doses of the insecticide and the measured dose-response relationships are used to calculate mortalities in backcross progeny expected with specific genetic hypotheses. Responses of backcross insects to the insecticide are then used to test genetic hypotheses. Use of backcross progeny analysis requires two important assumptions concerning the genetics of resistance. First, it is assumed that there are only two possible forms (alleles) of each resistance gene: one allele for susceptibility (S), and one for resistance (R). Because individuals have two copies of each of their genes, possible genotypes at resistance gene loci are SS, SR, and RR (resistance level of SR would depend on dominance). The two-allele assumption has been proven false for a variety of insect traits; it is not uncommon to find three or more alleles at a particular gene locus. Currently, in the case of insecticide resistance, little can be done to test this assumption, it is simply taken on faith.

The second assumption is that no individuals from the susceptible population have alleles for resistance, and vice versa. The monogenic hypothesis is based on the assumption that all individuals from the resistant strain are RR, all from the susceptible are SS, which, when crossed would produce only SR individuals in the F_1. When the F_1 is backcrossed to the RR parent, if the system is monogenic, we expect a 50:50 ratio of RR and SR in backcross progeny. If the ratio is not 50:50 it could be because there is more than one gene for resistance or because there were some SR individuals in one or both of the parent colonies. Most investigators address this assumption by selecting for resistance to "weed out" alleles for susceptibility in the resistant strain. Unfortunately, it has never been possible to produce a strain of insects with all individuals having the same level of resistance, there is always variation.

If there are multiple alleles for a resistance gene or if there is allelic variation in either population, the observable effects of such genes are unpredictable ranging from being completely hidden to resembling the actions of multiple genes. If two populations are fixed for the same allele (e.g., a minor resistance gene that also affects other traits) the actions of that gene will be undetectable. While these assumptions are common in many types of genetic analyses, the bottom line is that the analysis loses precision to the extent that the assumptions are violated.

But even when these two assumptions are satisfied, there are other problems associated with using backcross progeny analysis to examine the genetics of insecticide resistance. The statistical procedures used with backcross analysis are imprecise. Tabashnik (1991 [abstracted in the February 1991 issue of this newsletter]) showed that backcross progeny analysis is subject to high error rates. Preisler *et al.* (1990) showed that the statistical methods used in backcross analysis lose precision because of a type of variation inherent in insecticide bioassay data.

But beyond these problems with statistical methods, a serious shortcoming of the analysis itself is its inability to distinguish sets of mortalities predicted by various genetic hypotheses. Tabashnik (1991) showed that choice of doses used to test backcross insects dramatically affects ability to distinguish between genetic models. I reached the same conclusion (Firko, in revision) by showing that mortalities predicted by different genetic models are typically so similar, especially at certain doses, that the analysis is incapable of distinguishing among genetic hypotheses.

Figure 1 shows backcross (F_1 X resistant) mortalities expected with genetic models incorporating the effects of 1, 2, 4, and 8 genes. Here, the resistant pest strain is 10,000 times more resistant than the susceptible strain (i.e., the resistance ratio [LD_{50} of the resistant strain / LD_{50} of the susceptible strain] = 10,000), and the slopes of the dose-response lines are 1. Because results of insecticide bioassay tests are notoriously variable, it would be almost impossible to "accept" one of these hypotheses while rejecting the others. Clearly, high levels of resistance by themselves can not provide the ability to distinguish genetic hypotheses. If there is less variation within each population (steeper slopes) it is easier to distinguish genetic hypotheses; the expected backcross mortalities shown in Figure 1 also apply to a system with 100 fold resistance (resistance ratio = 100) and slopes of 2. It only becomes possible to distinguish among genetic hypotheses if the F_1 and backcross parent strains have non-overlapping tolerance distributions (high resistance ratios and relatively steep slopes). Regardless of insect or insecticide, if slopes of the dose-response lines of the F_1 and parent strains are around 1, backcross analysis is incapable of distinguishing between genetic hypotheses. If the slopes are around 2, a resistance ratio of at least 1,000 is needed, with slopes around 4, a resistance ratio of only 30-40 is needed. Most insect/ insecticide research has resulted in resistance ratios under 1,000 and slopes in the range of 1-2.

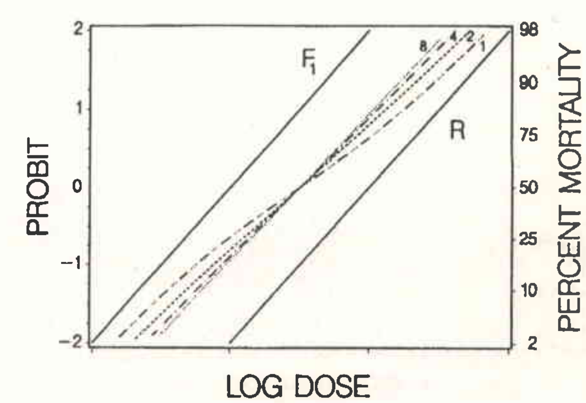

Figure 1. Dose-response lines of the F1 and R parent, and expected backcross mortalities with genetic models incorporating the effects of 1, 2, 4 and 8 codominant genes.

I also showed that expected mortalities are exactly the same for monogenic and some polygenic hypotheses. It is unfortunate that investigators have generally been concerned only with testing a monogenic hypothesis because while backcross mortality data that are consistent with a monogenic hypothesis are automatically also consistent with some polygenic hypotheses, it is likely that such data will also be consistent with sets of expected mortalities generated by other genetic hypotheses. Unless alternative genetic hypotheses are actually tested, and unless some genetic hypotheses are rejected while others are found to be consistent with the bioassay data, little information is obtained from a backcross progeny analysis (e.g., Firko & Wolfenbarger 1991).

These recent studies, and the original description of backcross progeny analysis for examinations of insecticide resistance (Tsukamoto 1963) make it clear that it is not possible to determine the genetic basis of an insect/insecticide resistance system with backcross analysis unless certain criteria are satisfied. When these criteria are satisfied, it may be possible to reject some genetic hypotheses while finding that other hypotheses are consistent with the bioassay data. To obtain this level of resolution, there must a high resistance ratio and essentially no overlap of tolerance distributions (probit lines). The unwelcome fact here is that these criteria are usually not satisfied. In most cases, backcross progeny analysis is simply incapable of providing useful information about the genetics of resistance.

While the above arguments are sufficient to cast serious doubt on the notion that insecticide resistance is a simple genetic trait, one straightforward and revealing result of the literature review is sufficient to dispel the myth. In 81% of the reported analyses, the authors formally rejected the monogenic hypothesis... the data supported monogenic inheritance of insecticide resistance only 19% of the time. Yet despite these results, alternative genetic hypotheses were seriously considered (tested) in only one study and the authors concluded that resistance was monogenic 79% of the time. Clearly, studies of the genetics of insecticide resistance have not been subjected to the level of scientific rigor that this important problem deserves. The unfortunate result has been firm establishment of the monogenic myth.

It can be dangerous to assume incorrectly that insecticide resistance is a monogenic trait. This assumption has been used to estimate the "gene frequency" of "the" resistance allele by applying monogenic models of population genetics (e.g., Campanhola & Plapp 1989) which assume that there is no selection for increased insecticide resistance in insect pest populations. Such an exercise will always lead to an underestimation of the frequency of resistance genotypes in a population, and will never provide estimates of the critical piece of information in a resistance management program: the ability of the population to become more tolerant. If an underestimate of the frequency of resistance genotypes is used to justify an insecticide application at a time when the population has significant ability to become more tolerant, resistance levels in the population may rise rapidly and lead to loss of efficacy and control failures.

But all is not lost concerning efforts to determine the genetic basis of insecticide resistance. Backcross analysis can provide useful information under certain conditions. Additionally, there are alternative methods for studying the genetics of insecticide resistance; new information is currently being obtained with cutting-edge techniques. Pioneering research by Dave Heckel and Tom Brown (see the February 1991 issue of this newsletter) is beginning to provide detailed information about the genetics of insecticide resistance in tobacco budworm.

Fortunately for current resistance management programs, understanding the genetic basis of resistance may be the least important consideration in a resistance management program. The key is to avoid strong selection for increased tolerance at critical times. This can be accomplished without knowing the genetic basis of resistance by considering the average and range of tolerance levels, and the ecological genetics of insecticide resistance in a geographic area. Methods for understanding the ecological genetics of resistance have been discussed by Tabashnik & Cushing (1989) and Firko & Hayes (1990, 1991). Resistance management programs would be well served if we could escape genetic myths and place more emphasis on the potential for increased resistance in populations.

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Feature

Resistance Management and Agricultural Policy

Remarks delivered at the American Association for the Advancement of Science, Symposium on Pest Resistance to Control Tactics, Washington, D. C., February 15, 1991.

Introduction

Pest resistance to control tactics has received greater attention in scientific circles in recent years. However, the issue has not yet attained a corresponding level of attention in policy discussions. With an intense policy debate surrounding pesticide use, sustainable agriculture, and environmental issues in agriculture generally, there is both a need and an opportunity to discuss pest resistance. Without consideration of pest resistance factors in these issues, there is the danger of inappropriate or counter productive government action being taken. At the same time, any policy or program designed to encourage integrated, knowledge-based agricultural production systems, such as integrated pest management (IPM), could help deal with pest resistance problems.

This situation urges the integration of pest resistance issues into broader policy decisions on pesticide use and regulation and programs to educate agricultural producers. To some degree this process has started to occur. Changes incorporated in the Food, Agriculture, Conservation, and Trade Act of 1990 (1990 Farm Bill - P.L. 101-624) address pest resistance detection and management. In addition, the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which authorizes the pesticide regulatory program at the Environmental Protection Agency (EPA) is to be reauthorized in 1991, providing another opportunity to address the issue.

It is recognized that increased research is needed on the genetic, biological, and ecological factors of resistance. (NAS, 1986) As important in dealing with pest resistance are the operational factors which involve pest control strategies, pesticide use, and programs to educate pesticide users. This paper will focus primarily on the operational factors since those are most influenced by the broader agricultural policy debates.

Dimensions of the Problem

Pest resistance to control measures, principally chemical pesticides, is expanding. From early discoveries of resistance in the 1940's, the list of pests which have developed resistance has grown to include nearly 450 species of insects, 150 species of plant pathogens, 55 species of weeds, and 5 species of rodents. (NAS, 1986) This resistance results in increased pesticide application, increased losses due to pests, or both.

At the same time, the rate at which new pesticides are being introduced is slowing. (Dover and Croft, 1984) Economic concentration in the pesticide industry, increasingly stringent regulatory standards, and the elimination of the "easy" discoveries in chemical pesticides have contributed to this slowing. While biotechnology holds promise for the future of pest control, widespread commercial availability of new biopesticides is not a current reality. And, with early work concentrating on a limited number of biopesticide opportunities, such as Bacillus thuringiensis (Bt) and its endotoxin, there may not be a broad range of these pest control options available in the near term.

Further complicating the situation is pressure upon existing pesticides due to recent regulatory changes. The 1988 Amendments to FIFRA require EPA to review and "reregister" all pesticides registered before November 1, 1984. (P.L. 100-532) This review process is causing some pesticide registrants to drop pesticide registrations, narrowing pest control options and making some pest-crop combinations more dependent upon fewer pesticides. This situation can lead to increased development of pest resistance. (NAS, 1987)

There is currently no national system for predicting, assessing, monitoring, and responding to pest resistance. Funding by the U.S. Department of Agriculture (USDA) for pest control strategies which can help minimize pest resistance, specifically IPM research and extension work, peaked in 1986 and has only in the last fiscal year seen any funding increases. (personal communication with USDA)

These factors taken together describe a situation which demands the attention of policy makers. With resistance increasing, with fewer pesticides on the market, and with no national system for dealing with the situation, there is the potential for growing environmental and economic damage.

Resistance and Agricultural Policy

Pest resistance should factor into a number of agriculturally-related policies and programs, especially those dealing with the regulation of pesticides and their use. However, until recently there has been no specific mention of pest resistance in these programs.

Pesticide Regulation

The modern FIFRA statute traces its origins to laws passed in 1910 and 1947 which were largely pesticide efficacy provisions, designed to prevent the marketing of ineffective pest control devices and compounds. Later versions of FIFRA emphasized the protection of health and the environment and in the 1980 FIFRA amendments, EPA was given authority to waive the requirements for efficacy data in registering or reviewing a pesticide. EPA has made extensive use of these waivers, expressing the view that the market place will eliminate those pesticides which do not work or are no longer effective. (Personal Communication with EPA staff)

With widespread efficacy waivers, EPA's major source of information regarding pest resistance is applications for emergency use permits under Section 18 of FIFRA, in cases where pest resistance necessitates the use of a new pesticide. However, this information, even when available, is not routinely compiled. And, for resistance episodes to create new markets they will have reached serious proportions, making any information collected through this route useless for early intervention.

FIFRA regulates pesticides on a risk-benefit basis. In this situation, unreasonable risks to man and the environment are balanced against the economic, social, and environmental costs and benefits of pesticide use. Under FIFRA, a registrant is required to report new information on risks from the pesticide, but is not currently required to report any changes in the benefit side of the risk-benefit equation. This means that a loss of benefits due to pest resistance would not be routinely reported.

Taken together, the efficacy waiver and the lack of attention to changes in benefits have effectively eliminated consideration of resistance from the FIFRA regulatory process.

There are concerns that the pesticide regulatory process may actually foster resistance problems. The pesticide regulatory process operates on a chemical-by-chemical basis, with little consideration of alternative pest control measures or the effects of cancellation upon overall pest control effectiveness. The primary weight given to alternatives is their increased cost or the increased crop loss if there are no alternatives available. Efficacy and the potential for pest resistance are not given much weight, other than the economic impact.

The best example of this process is occurring with the fungicides. With fungicides coming under close scrutiny following food safety concerns, chemical-by-chemical decisions may be leading to a resistance problem. As broad spectrum fungicides are cancelled due to human health concerns, fewer alternatives remain. This may result in more widespread use of certain fungicides with a greater potential for pest resistance as a result. (NAS, 1987)

Even when resistance is discovered, FIFRA does not provide an effective means of changing the use patterns of a pesticide. Under FIFRA, the pesticide label, which contains details about conditions of use, is the major enforcement tool. FIFRA penalties dealing with pesticide use under Section 12 are for uses in a "manner inconsistent with its labeling." With many pest resistance episodes local in nature or involving situationspecific decisions, a national label does not provide many options.

There are cases, however, where labeling has included resistance information, such as with Benlate (Dover and Croft, 1984). In addition, EPA policies to deal with ground water contamination and endangered species involve state "labels" for pesticides which will prescribe conditions for use within individual states. This trend to state-level use restrictions may help deal with pest resistance if these issues are factored into pesticide registration and education decisions.

Agriculture Programs

Outside of individual research and extension projects, pest resistance has not been a formal component of government agriculture programs. In response to the 1984 National Academy of Sciences conference on pesticide resistance (NAS, 1986) and a 1984 study by the World Resources Institute (Dover and Croft, 1984), Congress included a provision on pesticide resistance in the 1985 Farm Bill. (Section 1437, P.L. 99-198) This provision asked USDA to study pesticide resistance and plan a strategy for the establishment of a national pesticide resistance monitoring establishment of a national resistance monitoring program. (USDA, 1986) While this report was not the comprehensive effort expected by the author of the amendment requesting the study, it represented a significant official response by USDA to the pest resistance problem. (personal communication with author of amendment)

Under Section 11 of FIFRA, pesticide applicators using restricted use pesticides are to be trained and certified in the use of those pesticides. These programs are nearly always conducted by the states, usually through the Cooperative Extension Service. States may require training or certification in excess of the federal minimum and many states have opted to provide more comprehensive training.

While current law prohibits the federal government from requiring IPM training as a part of these programs, many states do provide IPM education. Given the compatibility of pest resistance management programs with many IPM programs, it would make sense to include resistance management as a part of applicator training programs.

Finally, as mentioned above, IPM has been an ongoing research and extension focus of USDA and the university system. IPM is a good match with an operational focus for pest resistance management and is usually included in IPM strategies. IPM adoption has been hampered by inadequate funding, as noted previously. An enhanced IPM education effort would also provide an avenue for pest resistance management education.

Private Sector Activities

Pesticide registrants represent a group as directly affected by pesticide resistance as are agricultural producers. The loss of product efficacy through resistance can shorten the useful life of a pesticide product, with negative economic consequences for the registrant. Registrants also can have a role in controlling resistance since they, directly and through pesticide dealers, can provide information at the point of sale about pesticide use.

Pesticide registrants monitor pest resistance and have in a number of cases responded individually and in groups to resistance problems. The Pyrethroid Efficacy Group in the pesticide industry was formed in response to synthetic pyrethroid resistance. Recent problems with the sulfonylurea herbicides has prompted registrants to engage in a high-profile program involving grower education and reduced use. In fact, just this week, Dupont announced the withdrawal of Glean from the northern plains area. And some of the companies engaged in Bt bioengineering have formed a working group to anticipate Bt resistance problems.

However, the private sector response is limited by a number of factors. A resistance management program can be expensive and may represent product sales which are foregone, if the strategy involves reduced use of a pesticide. For a pesticide to which resistance develops early in its market life, while it is still under patent protection, there is greater financial incentive for a resistance program than for a "generic" product, especially one manufactured by a number of companies. Also, in the latter case, any coordinated resistance management program may encounter problems with antitrust laws. In addition, information required for the support of a resistance management program may be sensitive business information, such as sales data, making coordinated efforts more difficult.

Any coordinated pest resistance management program must involve the private sector along with the public sector. Any proposals to address resistance management in FIFRA should be tempered by the willingness of the private sector to voluntarily cooperate in providing resources and information. But the terms of this cooperation need to be explored carefully. The potential conflict of proprietary and economic gain in one sector balanced against the need to protect against a common problem affecting another sector is difficult.

1990 Farm Bill

In the 1990 Farm Bill, a number of provisions were adopted which dealt directly and indirectly with pest resistance management. First, USDA was instructed to implement the national pest resistance monitoring program which they outlined in the 1985 Farm Bill report. (Section 1651, P.L. 102-624) Since the 1986 USDA study described the components of a national program but did not provide great detail about the establishment and operation of the program, USDA has sufficient flexibility to respond to changing conditions and new scientific findings in this field.

Second, the USDA is now required to compile a pest control data base to track available pest control measures and to provide this data, along with pest resistance data, to EPA on an annual basis. (Section 1495, P.L. 102-624) The annual reporting requirement was made to Section 28 of FIFRA, making it a regulatory requirement and not an optional activity. And the pesticide resistance data coming from the national system under Section 1651 was specifically cited as information to be included in the annual report by USDA. This information will also be available through the National Agricultural Library.

While this information will be of use to EPA, the major purpose of the data base was to help USDA prioritize its pest control research needs. It was hoped that pest resistance research would be included in this process , perhaps resulting in greater research on this topic.

Third, pesticide record keeping was required of anyone using restricted use pesticides. (Section 1491, P.L. 102-624) This is expected to provide a reliable, consistent data base with both national and local validity which can be used to monitor pesticide use.

Fourth, IPM research and extension efforts were given a higher priority with the specific authorization of an IPM program. The recently released budget proposal for Fiscal Year 1992 contained funding increases for IPM activities, which had received increases in FY 1991 as well.

1991 FIFRA Consideration

FIFRA was reauthorized in 1988 and this authorization will expire at the end of Fiscal Year 1991. A number of issues related to pest resistance could be raised during the Congressional debate on FIFRA.

One of the major points of controversy will be the process of cancellation of pesticides under Section 6 of FIFRA. Most of the debate has centered around the need to expedite the cancellation process and the need to involve USDA more closely in the cancellation process. If progress is made on developing a comprehensive pest control data base, as envisioned in the 1990 Farm Bill, it might be possible to include greater discussion of alternative pest control and resistance management in cancellation decisions. It might be timely to discuss the "cluster" approach raised by the 1987 NAS report, where health and environmental trade-offs are made on a group of pesticides, rather than taking a simple chemical-by-chemical approach.

Another point of controversy will be the use of a risk benefit process in registration and cancellation of pesticides. It is expected that the benefits calculation process will come under intense scrutiny and there may be attempts to move to a risk-only cancellation trigger. Part of the debate, and one way to bolster arguments for retention of benefits calculations, could be the requirement to report changes in benefits under Section 6(a)(2) of FIFRA, a provision currently used to require detection of additional risk. This information could become part of the resistance data base under Section 28 of FIFRA.

EPA is looking into a "safer pesticide" policy in which the relative health and safety of pesticides with similar use patterns would be considered. Included in this policy must be consideration of resistance, since some health-based decisions may result in a "safer" pesticide which is actually more disruptive of IPM systems and the management of pest ecosystems and pest resistance. This is not to suggest, however, that pest resistance issues should predominate human health and broad environmental concerns.

A related issue is the need to expedite the registration of biopesticides, especially pheremones. This issue is given passing treatment in the 1990 Farm Bill but needs to be stressed in FIFRA as well. EPA currently provides wide latitude for data waivers for these pesticides, but resource problems constrain progress in this area. Since these pesticides, as a group, have generally lower human toxicity, they represent the best nearterm hope for increasing pest control options.

There is great opportunity for dealing with pest resistance under the applicator training program mandated in Section 11 of FIFRA. At a minimum, the prohibition against federally-mandated IPM training should be struck from law and replaced with language encouraging IPM and pest resistance education as a part of pesticide training and certification efforts.

Section 28 of FIFRA is devoted primarily to EPA-USDA interactions. It is the section which now contains requirements for USDA to report annual to EPA on pest control availability and resistance detection. This Section can be the focus of a number of positive steps designed to better coordinate EPA-USDA activities.

It is expected that the reregistration program authorized in or the 1988 FIFRA amendments will come under review during this debate as well. It would be good to review a number of issues during this phase of the 1991 reauthorization debate including: the effect of the program on minor uses and resulting pest resistance potential in minor crops or with minor pests; reconsideration of the use of widespread efficacy waivers, especially with pesticides or pests for which resistance is a problem, and; an effort to better coordinate reregistration decisions with USDA. The last point will require USDA to take a more active role on pesticide issues than it has displayed to date.

Summary

Pest resistance is a growing problem which demands both a research and a policy response. The scientific response has been growing in recent years. However, the policy response has only recently been noted.

At the federal level, programs have been authorized at USDA to specifically deal with pest resistance detection and monitoring in the 1990 Farm Bill. There is also an increased emphasis on changing agricultural operations to deal with resistance, assuming that pest systems like IPM are compatible with pest resistance management goals.

Reauthorization of FIFRA in 1991 presents further opportunities to include pest resistance considerations in the regulatory process. This process also provides an opportunity to better integrate resistance research advances into regulatory decisions, through better coordination with USDA.

There has also been an increasingly constructive response to resistance problems by the private sector. This needs to be encouraged and a public-private partnership in this area is essential. During any policy discussions, the private sector needs to be involved and their willingness to voluntarily cooperate needs to be factored into any regulatory proposals.

Government programs are being authorized to deal with pest resistance. The success of these efforts, and their expansion, will depend upon the ability of researchers, registrants, and agricultural producers to convince USDA, EPA, and the Congress to make this issue a higher priority.

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The International Organization for Resistance Pest Management (IPRM)[1]

Progress Report by Dr. B. C. Smale Director of IRPM Executive Committee

During the past 18 months or so since the official formation of IRPM, we have made great strides toward our stated objectives of: providing an international forum (1) to promote the concept of resistant pest management within the context of IPM systems and (2) to identify and facilitate implementation of resistant pest management programs in industrial and developing nations and emerging democracies.

The U.S. Agency for International Development (AID); the Office of International Cooperative Development of the U.S. Department of Agriculture (OICD/USDA); the U.S. Environmental Protection Agency (EPA); the Agrichemical industry and industry associations; the academic community, non-governmental organi- zations, United Nations organizations, Government agricultural research extension, regulatory and overseas development agencies have through funding and/or participation been fully supportive and crucial to our success.

Leadership of the Technical Working Groups by Drs. Jackson and Frisbie (Insecticides/Acaracides); Drs. Lorenz and Northover (Pathogens); and Drs. Gressel and LeBaron (Weeds) has been outstanding. Their choices of working group members and approaches to program management provided the technical expertise, opportunity and incentive for sound project development.

The agrichemical industry and U.S. EPA contributed $135,000 to IRPM. U.S. AID provided $25,000 for development of the Mexican apple project with additional funds ($35,000) for the project forthcoming from the Organization of American States (OAS) and UNIFRUT, the apple growers group. Funding for the India (cotton) and Poland (apple) projects is provided through OICD/USDA under U.S. Public Law 480. The expanded project development meetings in-country with Indian (1 week) and Polish (2 weeks) specialists and government staff are, because of their duration, estimated to cost about $65,000 in PL 480 funds. Total receipts to date are approximately $260,000.

Disbursements of approximately $115,000 were required for travel and expenses of the 90 members of the three technical working groups (five meetings) and the Charter Working Group (two meetings). Administrative costs incurred by the Agriculture Research Institute total $15,000. Because of the common aims of WRCC-60 and IRPM, the executive committee has at the request of WRCC-60 become a supporting member and has provided $4,000 to aid in publication of the newsletter.

Report on Activities of the Technical Working Groups

Mexico: Resistance Management of Apple Insects and Fire Blight:

(Drs. Brian Croft and John Northhover. Funding provided by U.S.A.I.D., OAS and UNIFRUIT)

The Tree Fruit Task Group (TFTG)[2] and Pathogen Resistance Working Group (PRWG)[3] will jointly convene a working research/ education meeting in November of 1991 that will include repre- sentatives from several key groups concerned with management of resistant pests of tree fruits in Mexico. We will also involve other key leaders in this field of work from countries of Central and South America. The initial meeting group would include:

- Officials of the grower group UNIFRUT which has headquarters in Chihuahua City, and maintains a research station at Cuauhtemoc near the center of the fruit region. This group, as well as the Organization of American states, will provide resources to support the project now that U.S.A.I.D. support has been committed. This national organization is made up of a number of regional apple groups and is administered by elected presidents from each of 10-15 area councils. UNIFRUT has an annual budget which is raised by a 7 cent fee per box on all apples produced. From their facility at Cuauhtemoc, UNIFRUT provides pest monitoring, tree fruit nutrition analysis, several biological control agents for release and other related IPM services.

1 The new name of the organization as it appears here and in the WRCC-60 Masthead has been adopted by the IRPM executive committee.

2 of the Insecticides/Acaricides Steering Committee

3 of the Insecticides/Acaricides Steering Committee

- Representatives from the National Institute of Agriculture and Forestry Research (Instituti Nacional de Investigationes Forestales y Agropecuarias, INIFAP). Their group in Cuauhtemoc has eight scientists including two phyto- pathologists, a plant nutritionist, an entomologist, a clima- tologist, a sociologist, an economist and a soil scientist. Four of these people have Ph.d's, and the rest have Masters or agronomic engineering degrees (a specialized B.S.). These people are anxious to expand their ability to deliver technology to growers. They do have a field station in the nearby valley of Bachinivas that could be used for demonstration programs. They are qualified to handle the day-to-day operations of the project. Some of them would like to obtain graduate degrees at U.S. uni- versities during the longer-term project.
- One or two key leaders in this field from Central or South America will be invited to the meeting to establish liaisons with other international programs. A good example of such a person is Dr. Roberto Gonzales from Santiago University in Chile. He worked for many years as an international specialist in agricultural research at FAO in Rome and has been a leader in tree fruit pest control in South America for many years now. He would link the results of our Mexico initiative to other nearby countries where problems with resistant pests are severe (e.g., Ecuador, Peru, Bolivia, Uruguay, Argentina).
- A small team of IRPM scientists who represent specialists with expertise in the following areas of resistance pest management (these areas were identified as priorities in earlier discussions in Mexico): a) codling moth resistance monitoring and management, b) pesticide selectivity evaluation and releases of pesticide-resistant populations of the beneficial wasp, Trichogramma prateosum, c) resistance monitoring and management to acaricides in spider mites, d) pesticide selectivity and release of insecticide-resistant predatory mites, e) resistance monitoring and management to insecticides in the wooly apple aphid, Eriosoma lanigerum, and f) resistance monitoring to streptomycin and resistance management in fireblight disease.

In our meeting we will identify research/implementation teams, identify sites of work and design experiments and educational programs to implement programs of resistance management for the pest complex groups cited above. Meeting agenda development and coordination would be handled by Dr. Brian Croft, of Oregon University and Dr. Carlos Garcia, a Ph.D from INIFAP. Dr. Garcia will act as a liaison between the people from UNIFRUT and INIFAP organizations. At the meeting, small teams having representatives from both INIFAP and UNIFRUT would be identified who will carry out the proposed program.

Brazil: Resistance Management of Two Mite Pests and One Fungal Pathogen on Citrus.

(Dr. Tim Dennehy. Funding is being negotiated and will probably be available by the end of 1991.)

Objectives:

- IRPM, in cooperation with the established citrus IPM program in the State of Sao Paulo, plans to establish and implement a provisional resistance management strategy targeting two mite pests and one fungal pathogen. The resistance management strategy will involve rotations of different classes of acaricides and fungicides and will be implemented via a multi-tactic IPM program that uses chemicals only when economically justified and maximizes biological control ("soft" insecticides, conservation of *Hirsutella thompsoni*, monitoring key pests and use of reasonable thresholds.
- Within the large implementation project, to conduct large-plot, replicated evaluations of the benefit of the resistance management strategy (i.e., chemical rotations plus other integrated management techniques employed). Definitive evaluation of the benefit of the resistance management strategy will be made by bioassaying the changes in frequency of resistant pests. Evaluation trials will be conducted at a subset of the locations where the larger implementation program is being conducted.

Pests Targeted for Resistance Management:

*Citrus leprosis mite	Brevipalpus phoenicis
*Citrus rust mite	Phyllocoptruta oleivora
*Citrus scab	Elsinoe australis, E. Fawcitti

Institutions Involved(tentative):

University Cooperators

Dr. T.J. Dennehy, Spider Mite Resistance Laboratory, New York State Agric. Expt. Sta., Cornell University, Geneva, NY 14456

Dr. C.W. McCoy, Citrus Entomology Laboratory, University of Florida Citrus Research and Education Center, Lake Alfred, Florida

Dr. Santin Gravena, Centro de Manejo Integrado de Pragas (CeMIP), Universidade Estadual Paulista de Jaboticabal

Dr. Octavio Nakano, Department of Entomology, Universidade de Sao Paulo, Piracicaba

Dr. D.H. Thurston, International Professor of Plant Pathology, Cornell University, Ithaca, NY

Dr. G.B. White, Department of Agricultural Economics, Cornell University, Ithaca, NY

Industry Cooperators (tentative)

E. I. DuPont de Nemours & Company. Contact person: Dr. Steve Riley, Agricultural Products Department, Stine-Haskell Research Center, Newark, Delaware 19714

Rohm and Haas Company, Latin American Region. Contact person: Mr. Renato Mello, Rohm and Haas Brasil, Ltda., Alameda Purus, 105 Alphaville - C. Postal 39 CEP 06400, Barueri, SP, Brasil.

Uniroyal Chemical Company, Contact person: Dr. Richard Moore, Bethany, Connecticut.

Advantages of the Brazilian Citrus System for Implementation of Resistance Management

- Strong biological control component to citrus IPM program
- Strong incentives to use pesticides only when economically necessary
- Major industry (ca. 800,000 ha in Sao Paulo alone) so large potential impact
- Processed commodity so thresholds are relatively high
- Important pathology component to the implementation program
- Wide range of IPM tools (many acaricides, "soft insecticides," predators, pathogens) to work with
- Demonstrated strong interest by chemical industry in management of resistance to pesticides used in Brazilian citrus
- Much baseline work has already been completed on methods for monitoring resistance in this system

Plan of Work:

Implementation Program

The IPM program based at the UNESP Jaboticabal campus, the Centro de Manejo Integrado de Pragas (CeMIP), presently serves as an implementation vehicle for the large citrus industry in the State of Sao Paulo. This program could provide an excellent setting for accomplishing the goals set forth by IRPM, i.e., "to encourage and coordinate the implementation of local resistance management programs on an international scale." The CeMIP program currently employs scouts who monitor pest populations on farms located throughout the citrus region. Strong emphasis is already placed on maximizing biological control through use of "soft" insecticides and selective placement of insecticides. A beneficial insect rearing facility has recently been built at CeMIP and argumentative releases of specific predators is in the planning. We propose a joint effort with the CeMIP program and researchers located at key campuses in Sao Paulo (possibilities include individuals located on campuses at Jaboticabal, Piracicaba and Botucatu) to agree upon a single "best guess" resistance management program for implementation within the IPM program.

Evaluation Criteria:

Comparisons will be made between farms cooperating with the CeMIP implementation program and farms not cooperating with the program. A resistance management strategy will be deemed successful if it results in demonstrable reductions in the frequencies of resistant pests on cooperating farms relative to non-cooperating farms. Surveys of cooperating and non-cooperating farms will include the following:

- Grower evaluation of severity resistance problems
- Surveys of pesticide use at cooperating vs. non- cooperating farms
- Measures of frequency of resistant pests on cooperating vs. non-cooperating farms

Economic Evaluation:

Economic evaluation criteria will be determined in conjunction with the project agricultural economist, Dr. Gerald White. Surveys of participating and nonparticipating growers will focus on the cost of pest control under both regimes as well as potential impacts on crop yield and quality.

Education

The CeMIP program has a well developed record of disseminating information to growers via on-farm visits, training sessions, trade journal articles and technical bulletins. For example, a trade journal article on basic principles of resistance management was jointly written in 1990 by Gravena and Dennehy in cooperation with Rohm and Haas personnel. The citrus trade journals *Coopercitrus* and *Laranja* are ideally suited for such information dissemination. Participation of chemical industry field personnel in resistance management education efforts will be invited.

Poland: Resistance Management of Apple Insects and Diseases

(Drs. Gisela Lorenz and Davie Pree. Funding provided by Poland under the authority of U.S. Public Law 480, as managed by OICD/USDA)

The TFTG and PRWG will jointly convene a 2-3 week working research education meeting in Poland with key representatives of the government, academic, and grower communities.

The first phase of the September 23-27 visit of Drs. David Gyles, Gisela Lorenz, David Pree and Wayne Wilcox of IRPM with Drs. Kropcznynska, Bielenin and other Polish scientists and growers will entail 3-4 day field trip to various apple production areas to observe first-hand the insect and disease problems and select potential implementation sites. The second phase will involve development, by the IRPM and Polish scientists, of a detailed resistance implementation proposal.

The Vegetable Crops Task Group of the Insecticides/Acaricides Steering Committee[4]

(Drs. Keith Andrews, Janice Reed, Ronald Estrada and Jeff Waage. Project not funded.)

Insect pests and diseases threaten cabbage and broccoli production throughout the New World Tropics. Bombardment of these crops with pesticides menaces the health of consumers, contaminates the environment, and handicaps the incipient export industry in all Central American and Caribbean countries. Resistance is a major problem which further complicates the situation. Pilot extension programs have shown that several non-pesticide alternatives are highly cost-effective means to reduce insecticide use which exacerbates present high levels of resistance. Pesticide use in crucifers can be rationalized without jeopardizing production. Public concern, grower desperation, industry support, the political will, and technological capabilities all exist. A multination crucifer IPM outreach program aimed at mitigating resistance problems would have a high probability of success, and would create momentum for future regional IPM efforts in vegetables; farmers and technicians who learn pesticide resistance management procedures in crucifers will transfer them to other horticultural crops. Developed country consumers and importers will benefit from produce which is free of dangerous or illegal pesticide residues.

The program is conceived as a five-year long project with a ten-year horizon. A networking arrangement will link the isolated, underfunded implementation efforts underway in Central America and the Caribbean. Honduras will lead the effort with Guatemala, Jamaica and Trinidad-Tobago as key collaborating countries. These countries have all made progress in researching and implementing certain components of crucifer IPM and enjoy an adequate to excellent supportive legal context. None of them can independently mount this sort of programme.

Implementation efforts by public and private-sector agencies in all countries will have considerable grower participation. IPM training will empower farmers to make their own decisions and to understand the ecological principles underlying pesticide resistance management. Outreach will be backstopped by applied, responsive research programs which will address complications that arise as the IPM and pesticide resistance management tech- nologies are implemented; advisory boards consisting of farmers and PVO representatives will orient the research.

Resistance management programs will make use of different combinations of the following alternatives: reduced use of synthetic insecticides; rotations of synthetics, botanicals and microbials; mosaic spraying; use of synergists; use of comple- mentary biological and cultural controls. An internationally recognized specialist will monitor resistance levels in all implementation sites using appropriate techniques. The outreach programs will be living laboratories in which large numbers of technology transfer specialists from other Central American and Caribbean countries will receive in-service training and obtain validated training materials. After the program ends, other countries in the region can recruit project personnel to lead similar activities. South-south linkages among small countries will be enhanced.

The Cotton Working Group of the Insecticide/Acarcides Steering Committee:[5]

(Dr. Neil Forrester. Funding provide by India under the authority of U.S. Public Law 480, as managed by OICD/USDA)

A group meeting sponsored by the Indian Council of Agricultural Research (ICAR), International Organization of Resistance Pest Management (IRPM), and the Far Eastern Regional Research Office (FERRO) of United States Department of Agriculture will be held in Hyderabad from October 14-18, 1991.

Insecticide Resistance has become a major limiting factor to economic cotton production worldwide. Since synthetic organic insecticides were first used, insect pests attacking cotton have developed resistance to virtually all classes of insecticides. The development of pyrethroid resistance by *Heliothis* spp. has caused great concern and economic hardship in major cotton producing areas of Asia, Australia, Central America, USA and USSR. In addition to *Heliothis* spp., pink bollworm (*Pectinophora gossypiella*), white fly (*Bemisia* spp.), aphids, spider mites (*Tetranychus* spp.) and other insects have become resistant to a wide range of insecticides/acaricides.

In India, in the last few years, the outbreaks of *Heliothis* in Andhra Pradesh, Tamil Nadu and more recently in Punjab and Haryana have caused great alarm. A very high degree of resistance to pyrethroids has been found in *Heliothis* populations in all the major cotton growing areas

4 Central America-Caribbean Resistance Management of Diamond Back Moth on Crucifers

5 India: Resistance Management of *Heliothis* on Cotton

of the country. In addition resistance has also been reported in *Heliothis* on pigeonpea and chickpea. A sound resistance management strategy is needed to ensure the long term effectiveness of all classes of pesticides, especially synthetic pyrethroids.

The main objective of this meeting is to facilitate the development of a resistance management program for India. The meeting would address itself to the following:

- Determine the nature and extent of the resistance problems in India.
- Review cotton culture and existing methods of pest management within India.
- Identify existing technologies from around the world that may serve to guide resistance management research programs.
- Under the guidance of representatives from India, identify regions within the country where pilot research programs may be implemented.
- Develop research priorities and a timetable of activities for the pilot programs.
- Determine opportunities and constraints for the implementation of resistance management research results through a series of demon- strations.

Five members of the Working Group (Forrester, Matthews, LeRumeur, Frisbie, Thomas) and Bernie Smale (RPM Executive) were invited to attend a USDA sponsored meeting on resistance problems in Indian cotton last February (funded via the Office of International Cooperation & Development, Far Eastern Regional Research Office). However, the Gulf War intervened and this has now been postponed to 14-18th October 1991. It is proposed to hold a joint three day Workshop with Indian researchers at Hyderabad followed by a brief field visit to the cotton belt of Guntur/Prakasham districts in Andhra Pradesh. The main objective of the meeting is to facilitate the development of a resistance management program for India.

Two members of the Working Group (LeRumeur, Alcock) attended the ICAMA Resistance Meeting in Beijing in March. Members attending the "Resistance 91' Symposium to be held at Rothamsted Experimental Station, UK from 15-17 July, will meet informally with Geoff Jackson and Bernie Smale on the 18th July at ICI, Fernhurst.

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News/Review

Midwestern Climate Information System (MICIS)

Weather is an obviously important factor in crop and pest development. An assessment of the current status of development over large areas requires knowledge of weather conditions from the start of the growing season to the present. The Midwestern Climate Center, located within the Illinois State Water Survey on the campus of the University of Illinois, has recently developed a real-time computerized on-line system known as the Midwestern Climate Information System (MICIS). MICIS provides a large variety of climate information products for a nine-state region in the Midwest (Illinois, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Ohio, and Wisconsin).

The heart of MICIS is a large on-line data base. Data for many stations are obtained daily, providing a current assessment of conditions. Large historical data are also available, allowing an historical perspective on current conditions. Historical daily values of precipitation and maximum and minimum temperature are available for about 1500 stations, often dating back to 1948 or earlier; these data are updated monthly, usually 5-6 weeks after the end of the month. Daily updates are obtained for 200+ stations; these data are usually available by 9 A.M.

A large variety of products based on these data are available. These include displays of daily values and monthly averages/totals. Products which summarize data are available for arbitrary user-chosen time periods from days to years. Degree day (heat unit) accumulations are available for user-chosen base temperatures.

A common problem with near real-time operations is missing data, which can occur for a variety of reasons. For temperature, we address this problem by using objective analysis techniques to calculate (daily) gridded (0.5, latitude by 0.71 longitude) temperature values from all available data. Missing data for a particular station are then estimated by interpolation from the four nearest gridpoints. Products requiring complete data, such as degree day (heat unit) accumulations, can then be estimated for all available stations.

Model estimates of soil moisture are available for climate divisions (there are 75 divisions in the region). These estimates, updated daily, provide an up-to-date picture of regional conditions. Another innovative product utilizes two crop development models, CERES-Maize and SOYGRO, to make risk assessments of possible crop yield outcomes for corn and soybeans. This product provides a range of possible crop yields based on a range of future weather conditions which are derived from the historical climate data base. These assessments are updated weekly during the growing season.

Other types of data are also available including humidity, cloud cover, surface pressure, potential evaporation, and solar radiation. These are generally available for only some airport sites.

Access to this system is available by subscription. There are two options: "regular service" and "limited access service." The regular service fees are $35/month plus connect time charges ($0.20/min. daytime; $0.10/min. evening; $0.05/min. night) up to a maximum of $75/month total. Regular service allows access to all products. The limited access service does not carry a monthly charge; there is an initial $50 setup charge. Connect time charges ($0.25/min. daytime; $0.17/min. evening; $0.10/min. night) must be prepaid; an initial deposit of $25 is required in addition to the $50 setup charge. Limited access service allows access to raw data, but not certain derived products such as soil moisture and crop yield assessments.

MICIS can be accessed with a modem at either 1200 or 2400 BAUD. The system can also be accessed through Internet.

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An On -Farm Insecticide Resistance Test Kit for Colorado Potato Beetle

The Colorado potato beetle, *Leptinotarsa decemlineata* (Say), is the most destructive pest of potatoes in the U.S. and world-wide (Gauthier et al. 1981). Control problems stimulated the first large-scale use of insecticides on an agriculture crop (Casagrande 1987). In the U.S., Colorado potato beetle problems are the most severe in the northeastern production regions, although they are becoming much more common in the North central Region.

In Michigan, insecticide resistance is highly variable. Most populations in the northern part of the State are generally susceptible to insecticides, while moderate to severe resistance problems occur in central and southern parts of Michigan. In southern and central production regions, resistance is highly variable from farm to farm and even from field to field, especially where potatoes have been in continuous production for up to 60 years (Ioannidis et al. 1991). Resistance levels in Michigan are as high as 109, 900 and 1000 fold to pyrethroid, organophosphate and carbamate insecticides, respectively.

An on-farm insecticide resistance test kit was developed in 1988 for use by growers, Cooperative Extension Service agents, private crop consultants, and agrichemical dealers and representatives (Bishop and Grafius 1991). Discriminating concentrations were developed using a number of resistant and susceptible beetle populations (Ioannidis et al. 199 1). Each kit includes five 14 cm diameter petri dishes with filter paper treated with discriminating concentrations of phosmet (organophosphate), carbofuran (carbamate), endosulfan (organochlorine), esfenvalerate (pyrethroid), or esfenvalerate plus piperonyl butoxide (synergist).

Results were returned from tests of 260 populations during 1988 through 1990. Overall, results indicate an extremely rapid development of insecticide resistance over this period. For example, approximately 58% of the populations tested in 1988 were susceptible to carbofuran. This decreased to 47% in 1989 and 22% in 1990. Most populations were resistant to phosmet and endosulfan in 1988. By 1990, only 4% were susceptible to phosmet and 8% were susceptible to endosulfan. For esfenvalerate, only 5% of the populations were susceptible in 1988, but 56% were susceptible to esfenvalerate plus piperonyl butoxide synergist. Mortality with the synergist was higher than mortality with esfenvalerate alone in 95% of the populations in 1988. By 1990, only 10% were classified as susceptible to esfenvalerate plus piperonyl butoxide. Over 32% of the populations tested in 1990 were resistant to all of the materials in the test kit. For these situations, the only chemical control options were *Bacillus thuringiensis,* phosmet (or azinphosmethyl) plus piperonyl butoxide, or cryolite, when approved through emergency section 18 registration.

Test kit results generally correlated well with results of field sprays, greenhouse foliage sprays and laboratory topical applications. Use of the kit prior to insecticide application resulted in direct economic savings where an ineffective material might have been applied. Also, pretesting of beetles avoided delays in control. Timely control avoids excessive defoliation and also affects potato beetle population age structure and future control options. For example, timely control of adults reduces the numbers of egg masses, timely control of larvae reduces the number that enter the protected soil environment for pupation, etc. In addition to the above benefits, the test kit has been successfully used to diagnose the causes of control failures (insecticide resistance versus poor timing, spray coverage, etc.). Growers also can maintain historical records of resistance status on a field basis and better manage insecticide resistance.

Thanks to Phillipos Ioannidis, Mark Otto (Agri-Business Consultants, Inc.), Bob Hollingworth, and the Michigan Energy Conservation Program for their assistance and support.

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Cotton Resistance Management Conference, Beijing

The Cotton Resistance Management Conference sponsored by the Institute for the Control of Agrochemicals, Ministry of Agriculture was held from 25-27 March, 1991 in Beijing, China.

Seventy five participants attended the conference, including representatives from six provincial plant protection stations in China, pesticide managers from the Ministry of Agriculture, Chemical Industry, Commerce and State Farms as well as resistance experts from agricultural universities and institutions. Experts from nine foreign agrochemical companies were also invited and attended the conference.

Fourteen presentations were given at the meeting focussing on strategies for the management of cotton pest resistance problems both in China and other countries. Information and experiences with resistance monitoring techniques for cotton pests were exchanged. It was recommended that

- A National Committee on Management of Pest Resistance should be set up.
- A cooperative relationship with the relevant international organizations should be established.

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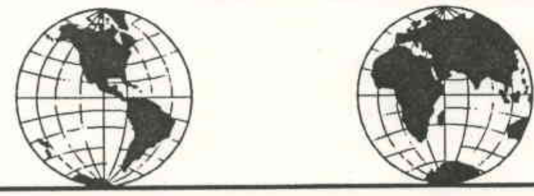
New Test Kit for Triazine Resistance

A new Agri-Screen test kit for checking Triazine resistance in weeds, produced by Neogen and marketed by ConAgra Technologies, has just become available. This Agri-Screen Triazine Resistance test can be used on weeds that survive pre-emergence application and weeds in late summer to select next year's herbicide. Weeds that can be tested for Triazine herbicides include atrazine, cyanazine, metribuzin, prometryne, propazine, simazine. For more information contact:

ConAgra Technologies
Goodfield, IL 61742
1-800-634-7571

Resistance Around the Globe



Helicoverpa Arimigera Resistance to Insecticides in India

Helicoverpa armigera has emerged as a dominant pest of chickpea, pigeonpea, cotton, a number of cereals and vegetable crops in India[1]. A survey of farmers fields show that the loss of the two major pulses, chickpea and pigeonpea, may exceed $300 million per year and losses in other legume corps, cotton, cereals, vegetables and others must add substantially to the total[2]. Although insecticide resistance in *Helicoverpa* to chlorinated hydrocarbons, organophosphates and to pyrethroids had been reported from Australia in 1984[3,4], apparently the pest was susceptible in India until recently. *Helicoverpa armigera* assumed notoriety in India in 1987-88 cotton season, when large scale cotton crop failures due to this pest were seen in districts of Prakasham, Guntur and Krishna in Andhra Pradesh leading to public uproar. This failure of pyrethroids to control *H. armigera* was traced to the development of high resistance to pyrethroids in populations occurring on cotton independently by two groups; one working at New Delhi[5] and the other at Reading University, U.K.[6]. Dhingra *et al*[5] reported 100 to 300-fold resistance at LC_{50} level, to cypermethrin in populations of *H. armigera* from Andhra Pradesh, taking the response of Delhi populations of this insect, as susceptible. When McCaffery *et al*[6] compared the response of *H. armigera* populations from Andhra Pradesh with those of Reading strains, resistance levels were between 287-fold to 700-fold at LD_{50} level. It was also noted by McCaffery *et al*[6] that the pest at Hyderabad in 1986 was not resistant to pyrethroids. In fact, it was more susceptible to cypermethrin than the Reading strain. Until 1988 the resistance in *Helicoverpa* was restricted to an area 75 km wide and 200 km long in Andhra Pradesh[7]. Populations in Northern India (Delhi, Hisar, Karnal) were still susceptible[7]. During the cotton crop season 1988-89 the resistance levels were drastically reduced in Andhra Pradesh. Similarly, reductions in resistance to synthetic pyrethroids were also observed by the Reading group (quoted from Armes *et al* 1989). In the cotton growing season 1989-90 there was an increased in resistance levels though not as high as those seen in 1987-88[7,8,9]. It may be mentioned here that resistance against DDT (70-fold) and endosulfan (12.5-fold) in *H. armigera* populations from Andhra Pradesh was observed when compared with the Reading strain as early as 1986. Little or no resistance was seen against monocrotophos[10]. Recent reports from Andhra Pradesh suggest that in Guntur region resistance to DDT (8.8-fold) and monocrotophos (7.5-fold) at LC_{50} level when compared with populations collected from Srikakulam, Andhra Pradesh. Similarly in the Kurnool region of Andhra Pradesh resistance to DDT was 4.8-fold, to monocrotophos 6.6-fold and to carbaryl 4.82-fold, when compared to Srikakulam populations11. As far as 1990-91 season is concerned in Delhi populations have the same response to cypermethrin as in the earlier years. There has been no change in the LC_{50} and slope. In Guntur and Colmbatore the degree of resistance is now nearly the same whereas at Hyderabad (ICRISAT) the resistance level to synthetic pyrethroids are higher (approx. 17-fold)12. The present distribution of pyrethroid resistance indicates that the area of pyrethroid resistance which was restricted to Prakasham, Guntur and Krishna districts has now extended to include Hyderabad (ICRISAT) also. Pyrethroid resistance has also reached Colmbatore also by 1989[9]. The pesticide resistance has also been encountered in Karnatka (Virokamuth personal communication 1991). This year (1990-91 cotton season) the pyrethroid resistance appears to have flared up in Punjab (B. Singh and A. S. Sidhu personal communication 1991). Biochemical studies suggest that both esterase and mixed function oxidases may be involved in this resistance. Studies are in progress to evaluate the relative importance of these two systems in imparting resistance to this insect.

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Mechanisms of Resistance to Pyrethroids in *Spodoptera Littoralis* (Boisduval)

Although new, more effective products are being used, the continued and sometimes unreasoned use of pyrethroids has increased levels of tolerance in many places. Some 40 arthropod species are now resistant to this category of insecticides.

One of the only problems of resistance encountered by IRCT in the field has been in northern Madagascar in *Spodoptera littoralis* following repeated and probably poorly controlled spraying of deltamethrin. Populations resistant to 1000 times the dosage were observed, and a research program is currently in progress in the IRCT Control of Sensitivity to Pesticides Laboratory in Montpellier to determine the mechanism(s) responsible for such high resistance.

Research on resistance combined with toxicity trials (LD_{50}) on various classes of chemical insecticides on deltamethrin-sensitive and resistant *Spodoptera littoralis* larvae showed that the resistance is caused mainly by an intensified metabolism mechanism.

Comparative study of the *in vitro* metabolism of deltamethrin was performed on the strains sensitive and resistant to the insecticide. The resistant strain of *S. littoralis* (R) displayed high oxidasic activity in comparison with the sensitive strain (S). Cytochrome P450 levels (a component of the oxidasic system) were similar in the two strains but cytochrome P450 activity was four times higher in the resistant strain. The microsomal fractions of the 5th stage of R and S contained 0.2 nmol of CytP450 per mg total protein. CytP450 activity was 2 ng of 7 OH formed per min per mg in strain R and 0.6 ng of 7 OH formed per min per mg in strain S. Hence although the amounts of microsomes are identical in the two strains, the activity of the microsomal fraction of strain R is three times as great as that of strain S.

These studies of the metabolization of deltamethrin revealed not only a hydroxylation mechanism but also hydrolysis of the ester bond. Indeed, the metabolites revealed in autoradiographs and by thin layer chromatography appear to show that esterase activity was greater in the resistant strain than in the sensitive strain.

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Recent Advances in Host Plant Resistance Studies with Whiteflies and Mealybugs on Cassava at CIAT

Cassava is a major source of calories throughout the tropical and subtropical regions of the world. That cassava is grown primarily by resource-limited small farmers, implies that plant resistance is a primary component of any IPM strategy.

Whiteflies and mealybugs can cause considerable yield reductions in American and African cassava-growing regions. The principle species of whiteflies attacking cassava in the Americas are *Aleurotrachelus socialis*, *Trialeurodes variabilis*, *Bemisia tuberculata*, and *Aleutrixua aepim*. Whitefly resistance studies were initiated in 1975 in Tolimai, Colombia where *A. socialis* is the dominant species. After several years of screening, five of 1000 clones tested were identified as resistant. M Bra 12, M Ecu 72, M Col 336, M Col 339, and M Pan 70. Crosses between these clones made by the CIAT Cassava Breeding, Program resulted in selection of four hybrids with whitefly resistance and good root yield and quality. Four hybrids from crosses between M Bra 12 and M Ecu 72, (CG 489-4), CG 489-23, CG 489-31, CG 489-34) will soon be released to farmers. Yield depression (pesticide vs no pesticide) was less than 10% in the hybrids compared to 33% in three susceptible cultivars. Resistance mechanism studies have been initiated.

The mealybug, *Phenacoccus herrenit* can cause yield losses as high as 88%. Field resistance studies with artificial infestions, initiated in 1985, have identified six tolerant or moderately resistant clones (CM 2177-2, SG 100-54, SG 250-3, CM 6068-3, CM 5263-1 , and SM 540-8). Yield depression for SG 250-3 and CM 2177-2 was 10.1 and 9.3% respectively, indicating good levels of resistance. High calcium content of cell walls and leaves may be associated with resistance and is being investigated further. Crosses are being made to incorporate this mode of resistance in agronomically acceptable hybrids.

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Hexythiazox Resistance in Twospotted Mite *Tetranychus urticae* Koch in Australia.

Hexythiazox is a relatively new ovicide which is used to control twospotted mite in a range of horticultural crops. Resistance to hexythiazox in twospotted mite was first documented in 1987 (Edge et al. 1987). This strain had been exposed to repeated applications of clofentezine on roses. Hexythiazox resistance was at an extremely high (1600OX). Resistance in strain QR has been maintained in the laboratory by regular pressuring with hexythiazox to produce QRPH.

Studies were conducted on this strain and a susceptible reference strain (S) which was collected from an unsprayed source in Sydney. To avoid complications due to host-plant preferences both strains were maintained on potted French bean plants for at least 6 months prior to the commencement of the study.

Mode of Inheritance of Hexythiazox resistance

The mode of inheritance of hexythiazox resistance was determined by a reciprocal-crossing technique in conjunction with log dose-probability (ld-p) assays using the L2 method outlined by Edge and James (1986). The responses of the reciprocal Fl female progeny were similar, indicating hexythiazox resistance in strain QRPH was not sex linked. A dominance factor of 0.21 (incomplete dominance) was calculated from the responses of the reciprocal Fl female progeny as compared with those of the S and QRPH strains. The responses of the reciprocal F2 haploid progeny indicate the resistance mechanism in strain QRPH is probably controlled by a single gene although high control mortality caused by strain incompatibility complicated their interpretation. This result will be verified by a repeated back-crossing technique in combination with mild hexythiazox selection. By doing this a strain essentially identical to S (SQRPH) but expressing the gene for hexythiazox resistance will be produced. This work is now underway.

The Relative Fitness of Hexythiazox Resistance

The fitness of strain S was compared to QRPH using methods similar to those of Flexner et al.(1989). Fitness parameters studied included total egg production, proportion of females produced, percentage survival (egg to adult), longevity and oviposition rate. The resistant strain was fitter (p) than the susceptible in all categories except proportion of females produced and percentage survival. There was no significant difference between strains S and QRPH in percentage survival, but the S strain produced significantly (p.T) more female offspring than QRPH. It is intended to repeat these experiments with the isogenic SQRPH stain in the near future. Additional studies will be undertaken to produce cohort life tables for strains S, SQRPH and QRPH enabling the calculation of the rm values (intrinsic rate of increase) for each strain.

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Mechanisms of Pyrethroid Resistance in Australian *Helicoverpa armigera* (Rubner).

A complex of pests attacks the Australian cotton crop. None is more important than the cotton bollworm, *Helicoverpa aimigera* (Hubner) and insecticides are considered essential for its control. *H. armigera* has a long history of insecticide resistance in Australia, to DDT in the early 1970's and more recently, in 1983, to the synthetic pyrethroids. Since 1983, *H. armigera* insecticide resistance has been the subject of an insecticide resistance management program in NSW and Queens land which has restricted the use of pyrethroids in cotton and other crops. A knowledge of resistance mechanisms was considered fundamental to this resistance management strategy, so management could be targeted at avoiding or counteracting the mechanisms.

In 1983, at the onset of pyrethroid resistance in Australian *Helicoverpa armigera,* three resistance mechanisms were identified. They were: a strong nerve insensitivity (Super - *Kdr)*, penetration resistance (Pen), and a factor which was overcome by piperonyl butoxide *(Pbo).* Nerve insensitivity was the major cause of pyrethroid resistance and conferred high order resistance - 100 times. From 1987 to 1990, to monitor accurately the effectivness of the Australian *Helicoverpa* insecticide resistance management strategy, we conducted a survey of resistance mechanism frequencies in field collected resistant *H. armigera* . The relative importance of the *Pen and Pbo* mechanisms in resistant *H. armigera* have increased, as *Kdr* has decreased in gene frequency and potency. *Pen and Pbo* confer only low order resistance.

Our studies show the precise impact of the *H. armigera* insecticide resistance management strategy on pyrethroid resistance. The importance of *Super-Kdr* as a resistance mechanism has decreased with a concomitant increase in the relative importance of the *Pen* and *Pbo* factors. These changes have coincided with an increasing resistance frequency, despite decreased pyrethroid use. The reasons for the selection of the *Pen and Pbo* resistance mechanisms are not clear. Cross resistance selection of *Pen and Pbo* by other insecticides is improbable.

It is possible that the removal of pyrethroid selection pressure has caused the loss of the *Super-Kdr* mechanism. *Super-Kdr* is normally an intractable mechanism that confers such high order resistance that resistants are difficult to control. *Pen and Pbo* confer only low order pyrethroid resistance which is less of a challenge to pyrethroid efficacy.

H.armigera resistance to pyrethroids is complex and clearly is sensitive to resistance management decisions. While the adjustment of pyrethroid selection pressure has ameliorated the danger of *Super-Kdr,* any increase in rates would undoubtedly exacerbate the situation. The overuse of pyrethroids, synergised by piperonyl butoxide, in the field should be avoided for similar reasons.

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Behavioral Aspects of Dicofol Resistance in the Twospotted Spider Mite *Tetranychus urticae*

Acaricide action has been investigated principally from the standpoint of toxicity to pests and natural enemies and has only infrequently incorporated observations of how chemicals alter animal behavior. Yet, it is recognized that behavioral responses, especially movement patterns may influence dramatically the encounter of arthropod with pesticide. For example, acaricides that elevate activity levels may increase, exposure to residues and reduce the chances of a pest residing on an untreated areas. Alternatively, an acaricide that is not excitatory but that can be perceived and avoided by arthropods might result in individuals reducing exposure by seeking out untreated areas,. Behavior of pests is of additional interest as it applies to questions of pest resistance to pesticides. In particular, little has been done to measure changes in behavior patterns of susceptible versus resistant pests to infer the possible role that behavior plays in the pest's ability to resist the toxic action of a chemical, Therefore, we have focused research on describing how spider mite resistance to acaricides and discontinuity of acaricide residue influence the behavior patterns of *Tetranychus urticae.* Our investigations have involved both microscopic observation and macrovideo observation of individual spider mites, to record the behavior of resistant or susceptible individuals on both continuous and discontinuous acaricide residues.

We found that dicofol resistant *T. urticae* have not developed behavioral patterns that reduce their contact with dicofol. On the contrary, homozygous resistant individuals were much more likely than near-isogenic homozygous susceptible individuals to remain in contact with treated areas on Leaves. At a more detailed level of resolution of spider mite behavior, we demonstrated that what appeared to be 'avoidance' of dicofol residues by susceptible spider mites was really feeding repellency caused by dicofol. Specifically, susceptible, spider mites demonstrated significantly shorter feeding bout durations on dicofol) residues of 100 ppm in both continuous or discontinuous residue treatments. Dicofol resistant spider mites demonstrated no such response to the acaricide. Using discontinuous residues, analysis of walking patterns on . and off of the dicofol treated areas revealed that what appeared to be repellency really wasn't, in the strictest sense. Dicofol susceptible spider mites walked on and off of dicofol treated areas with equivalent bout lengths. However, when susceptible spider mites initiated a feeding event on the dicofol residue it was likely to end significantly sooner than a feeding event off of the residue. Therefore, though there was really not repellency, per se, the relatively longer feeding bouts on residue-free areas resulted in accumulation of individuals in these areas, and the appearance of repellency by the acaricide.

In a subsequent study, we found that expression of this avoidance appeared to influenced by duration of undisturbed occupancy of individuals on leaves. Avoidance of dicofol treated areas by susceptible *T. urticae* began to be expressed within 3 hr of their placement on discontinuous residues of 100 ppm dicofol, if they remained undisturbed upon the residue, However, if the spider mites were disturbed during the first few hours on the treated leaf, by being lifted above the leaf and then placed back on it, their avoidance of dicofol-treated areas was not exhibited until 6 hr after initial placement on the treated leaf. If spider mites were periodically transferred to webbing-free, leaves, their avoidance of dicofol-treated areas was not observed until the 24 hr observation period, in all cases the avoidance of dicofol residues took place during nonlocomotory behavior (reduced feeding bout length and/or frequency), rather than during locomotory behavior.

Our current studies employ similar detailed behavioral analyses to measure how pyrethroid acaricides influence the behavior of bifenthrin-resistant and bifenthrin-susceptible spider mites in contrast with dicofol-resistant and dicofol-susceptible individuals. In addition to improving our understanding of the impact of specific acaricides and resistances on pest behavior, our objective is to relate how these behavior responses may affect the efficacy of different acaricides by increasing or decreasing the exposure of individuals residing on treated surfaces.

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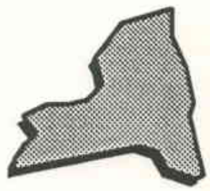

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Insecticide Resistance in the Cotton Aphids in the Mississippi Delta

Several states across the U. S. cotton belt have recorded difficulty in controlling the cotton aphid, *Aphis gossypii* Glover, in recent years. Field control failures in the midsouthern U. S. have been observed with all insecticides recommended for aphid control. In response to concerns about insecticide resistance, we initiated studies to quantify resistance levels to insecticides representative of four classes of insecticides recommended for control.

A laboratory colony established from collections of aphids from a field control failure in 1989 in Mississippi was compared with a known susceptible colony for insecticide resistance using a leaf dip bioassay (Grafton-Cardwell in press). Discriminating doses of insecticides used were 10 ppm bifenthrin (pyrethroid) , 300 ppm chlorpyrifos (organophosphate [OP]) , and 300 ppm endosulfan (organochlorine). Aphids were also bioassayed for resistance to the carbamate aldicarb using a greenhouse soil-incorporation method. Aphids were reared under insecticide-free conditions and were tested at 7 and 12 months after colony establishment, except aldicarb which was tested after 7 months only. Significant resistance was found for all compounds tested with the leaf-dip after 7 months in colony (P. 05) (Table 1). For compounds tested with the leaf dip at 12 months, both bifenthrin and endosulfan showed significantly lower levels of resistance while chlorpyrifos resistance apparently remained relatively stable (Table 1). Highly significant resistance was also found for tests with aldicarb, with approximately 20% survival of resistant aphids compared to less than 1% survival of susceptible aphids (Table 2).

Because OP resistance appeared stable through time, additional studies were conducted to investigate the level of OP resistance in monoclonal colonies of susceptible and resistant aphids. Dose-mortality lines were determined using formulated chlorpyrifos in the leaf dip assay described above. Resistant aphids showed a significant 4-fold level of resistance (based on non-overlap of 95% confidence intervals) compared to susceptible aphids, with

LC50 values of 62.3 (50.3-84.0) and 272 (198.0-424.7) ppm for susceptible and resistant aphids, respectively.

In summary, at least one population of the cotton aphid has developed resistance to compounds within all major classes of insecticides recommended for aphid control in the Mississippi Delta. Significant resistance to bifenthrin and endosulfan was not detected in aphids tested from collections made in 1988 (O'Brien et al., 1990). The loss of resistance at different rates for the compounds tested in this study would suggest, though not confirm, that multiple mechanisms may be involved in insecticide resistance in the cotton aphid. Finally, because the 4-fold resistance was relatively low for monoclonal aphid tests with chlorpyrifos, other biological factors such as high reproductive potential and short generation time may also partially explain the widespread and sometimes severe control problems seen in the field. Studies are underway to describe various biological variables of the cotton aphid so that resistance can be more effectively managed.

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Table 1. Percent mortality of susceptible and resistant cotton aphids exposed to three classes of insecticides.

		Months	
Insecticide	Colony	7	12
Bifenthrin (Pyrethroid)	Susceptible	91.3 a	95.7 a
	Resistant	21.7 b	78.4 b*
Chlorpyrifos (organophos.)	Susceptible	96.1 a	97.1 a
	Resistant	28.9 b	39.1 b
Endosulfan (Organochlor.)	Susceptible	92.0 a	98.5 a
	Resistant	32.7 b	48.3 b *

Column values within an insecticide followed by different letters are significantly different; row values within an insecticide followed by an asterisk are significantly different ($P \leq 0.05$).

Table 2. Mean percent survival of susceptible and resistant cotton aphids exposed to control and aldicarb solutions.

	Susceptible		Resistant	
Time (h)	No ald.	With ald.	No ald.	With ald.
0	455.1 a	846.8 a	423.6 a	545.4 a
48	794.5 b	0.3 b	827.1 b	103.0 b

Column values followed by different letters are significantly different ($P \leq 0.05$).

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Integrated Pest Management as an Essential Feature to Manage Resistance in Egyptian Cotton

The Egyptian cotton pest control program comprises several resistance management strategies such as less frequent applications which reduce the selection pressure over time, the use of pesticides of different classes and modes and sites of action in a rotational manner to control the same pest, local rather than area wide applications so that susceptible individuals move into previously treated areas and dilute the frequency of resistance, use of less persistent insecticides to slow the development of resistance due to reduced exposure, and using pesticides against the life stage of the target pest that is not likely to develop resistance.

Egyptian entomologists believe that resistance can be perfectly managed through the adoption of integrated pest management, hence the cotton control program takes also into account the ecology and biology of major pests, protection of natural enemies during their peaks in the field, treatments based on economic threshold, and physical and regulatory control.

Having all these components, the essence of the present control program from seed to harvest can be summarized in the following:

The Seedling Stage

The disease complex *Rhizoctonia solani, Pythium ultinum* and *Sclerothium rolfsii* is dealt with by good preparation of the seed bed, appropriate time of planting and seed dressing with effective insecticides. As for *Fusarium* the Egyptian varieties are genetically resistant to this fungus.

Nematodes are controlled by crop rotation, adequate plowing, and Temik which is rarely used and only when necessary.

Mole crickets and cutworms are satisfactorily controlled by adequate plowing, removal of previous crop residues and by exposing soil to solar radiation. If infestation is serious, only affected rows are treated with insecticidal baits. Adjacent rows are also treated as a preventive method to avoid further spreading of infestation. Insecticidal spray of infested seedlings is not allowed to preserve natural enemies.

The Vegetative Stage

The cotton aphid *Aphis gossypii* is the major pest affecting cotton at the early vegetative stage. Previous experience with aphid control revealed that successive treatments with insecticides usually develop high resistance and stimulate reproduction, a matter that necessitated the consideration of the pest behavior and ecology. Before cotton planting the pest normally reproduce on adjacent hosts. Among the alternate hosts are weeds grown on the canal banks, so destruction of weeds by flaming decreases initial infestation. When cotton reaches the early vegetative stage, the pest migrates to cotton borders and remains there for 4 or 5 generations to increase in number after which it attacks cotton in waves and in a manner difficult to control. Here inspection of the borders is important and upon reaching 20% infestation insecticidal spray with a highly selective insecticide is carried out. If a portion of the population succeeds to invade cotton in the depths, this usually occurs in spots and it is recommended that the spots should be sprayed at once and the rest of acreage is left without treatment to allow natural enemies to supplement the action of the chemical.

Infestation with aphids usually dominates jassids and thrips and chemical control directed to combat aphids is also effective against either pest. As for mites Kelthane or Kelthane S can do a perfect job and are only sprayed in infested areas.

Mid-season the cotton leafworm *Spodoptera littoralis* is the major pest and inflicts considerable damage. It is highly resistant to pyrethroids and to most OPs and carbamates but it is still responsive to chlorpyriphos and methomyl. The egg-masses are laid on the underneath of the leaves, thus, usually escape insecticide treatments.

Studies on the ecology of the pest revealed that after the end of the cotton season in October it migrates to clover fields and due to its polyphonous nature it continues to attack clover until December then diapauses in the soil waiting for better weather to complete its life cycle. In the spring the weather becomes more suitable and moths start to emerge from diapausing pupae and reattack clover during March, April and May. In June where cotton is in its vegetative stage, the pest migrates to cotton and starts its first generation.

As a function of the government there is a regulatory law that prevents migration of *Spodoptera* to cotton fields. The law prevents clover irrigation after May 10 so that the soil is deprived from moisture required for moth emergence from diapausing pupae. As a consequence the 1st generation of *Spodoptera* on cotton is much reduced. As a physical control, starting from mid May to the first of July, *Spodoptera* egg-masses are hand picked by small children then burned. If some egg-masses are left behind, hatched larvae of 1st to 3rd instars are taken care of with chlorpyriphos and methomyl in only affected areas. Bigger larvae of 4th to 6th instars are left without treatment because their resistance defence mechanisms become well established and ready to highly resist the action of chemicals. After 20 days from larval escape the children go again through the infested fields and collect the egg-masses of the second generation and burn them out.

Such types of localized spraying usually spare predators and parasites that are most common early and mid cotton season. The main predators in cotton fields in Egypt are *Coccinella undecimpunctata, Scymnus interruptus, Paederus alfierii. Chrysopa carnea. Orius albidipennis* and several species of spiders and ants.

The main indigenous parasites recorded on the cotton leafworm *Spodoptera littoralis* are *Trichogramma evanescens, Exorista larvarum, Strobliomyia aegyptia, Eulimnarium xanthostoma, Barylpa numeralis, Zelechlorophthalma* and *Conomorium eremita*.

The important parasite species on the greasy cutworm *Agrotis ypsilon* are *Apanteles ruficrus* and *Meteorus* sp.

The flowering stage

The pink bollworm *Pectinophora gossypiella* is the most severe on this stage of cotton. The first generation of the pest starts on cotton flowers during the first half of June. Sex pheromones alongside with flower inspection are used for population monitoring. Upon reaching 5% infestation, the first spray starts to protect the bolls that will form later.

In this respect it should be mentioned that the parasite species secured from the pink bollworm are *Exeristes roborator, Chelonus sulcatus, Bracon brevicornis* and *Pyemotes herfsi*.

The fruiting stage

The most abundant pests in this stage of plant growth are *Pectinophora gossypiella* and the whitefly *Bemisia tabaci*.

Before going through the control program directed to control the pest complex of this stage the following points are considered:

- If *Spodoptera littoralis* is not adequately controlled mid in the season, it continues to attack cotton alongside with *Pectinophora gossypiella* until the end of the season. Hand picking of *Spodoptera* egg-masses is no longer feasible due to the dense branching of cotton plants.

- Using sex pheromones as sex attractants or mating disturbance agents against *Pectiniphora* is only effective with low population densities,
- If aphids are adequately controlled at the early vegetative stage they rarely attack cotton late in the season.
- Infestation with mites late in the season is not important since it coincides with normal defoliation.
- Infestation with *Bemisia tabaci* is usually severe and it is naturally resistant to chemicals.

The chemical control program also considers the following resistance management points:

- The use of pesticides of different classes or modes and sites of action in rotation can reduce resistance allele frequencies, assuming that resistant genotypes have substantially lower fitness than the susceptibles, hence their frequency declines during generations between applications.
- The position of each insecticide in the sequence should be appropriate for effectively reducing the insect it is directed to control in the pest complex, and that all pesticidal applications are presumably sufficient to check all insects anticipated to infest the crop at this stage of its development.

Considering the above mentioned points the following chemical control program is applied:

1st spray: OP-urea derivative mixture to control *Pectinophora* and the left over from *Spodoptera* (cotton flowering stage).

2nd spray: Pyrethroids are essentially used against *Pectinophora* upon reaching 5% infestations in bolls

3rd spray: A carbamate that has high potency against *Pectinophora* and *Bemisia tabaci.*

4th spray: An OP that is potent against both pests.

In such chemical regime each insecticide is used only once per rotation to preserve the useful life of the chemicals.

Maturity stage (senescens)

After harvest, cotton stalks with the remaining bolls usually harbor a high population from *Pectinophora*, so the stalks are destroyed by burning. Moreover the seeds are followed to the ginneries and sanitized by heating at 60°C to get rid of diapausing larvae.

New developments in the present cotton control program

Although the present control program is quite satisfactory, cotton growers encounter in recent years severe infestation with aphids and whitefly. The honeydew excreted by both pests causes stickiness favoring the development of black sooty mold fungus on the leaves. The honeydew also causes complication in picking, ginning and spinning resulting in the reduction in the value of the produce.

In order to control aphids early and mid season without going through frequent spraying with insecticides, several experiments are now carried out with the new Bayer's chemical Gawsho (imidachloprid). The results showed that when this chemical is used as a seed dressing, good protection of cotton against aphids and sucking pests is revealed for at least 6 weeks after plantation. Temik when used as a seed dressing also protects cotton in a similar manner. This type of application was shown to preserve natural enemies because they are not in direct contact with the chemicals.

The results also showed that at the flowering stage Temik could be applied as side dressing to protect cotton from infestation with the whitefly for another 6 weeks.

Trials are underway to explore the potency of the new chemicals Polo, Applaud and Comfidor (imidachloprid) whether individually or combined with pyretroids against immature stages of the whitefly and the pink bollworm late in the season.

It is anticipated that the results derived from such field experiments will reshape the present cotton control program in the near future.

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A General View of the Resistance Problem of Cotton Pests in Egypt

So far, the control of cotton pests depends mainly on pesticides. More than 60% of the total annually applied pesticides (mostly insecticides) is utilized against cotton pests. Therefore, most resistance studies are dealing with such pests. Cotton is attacked by a number of pests throughout its growing season. At the seedling stage it may be attacked by mole crickets, cutworms, aphids, thrips, leafhoppers and mites. At later stages it may be attacked by the cotton leafworm (CLW), bollworms (BW), aphids, whiteflies (WF's) and leafhoppers. The latter three sucking insects were considered as secondary pests, but since a few years they became primary pests.

Among all these pests, only the CLW was subjected to intensive resistant studies. Chemical control of this pest with organic insecticides started in 1950 with DDT either alone or as a mixture with BHC and sulphur (called Cotton Dust). Since 1955 they were gradually replaced by the polychlorinated hydrocarbon, toxaphene, which became the major insecticide not only against the CLW but also against BW. Since then, the recommended dosage was raised from 2.25 L/acre in 1958 to 3.35L in 1959 and to 5L in 1961.

Thus, as a result of the misuse and overuse of this compound, the so called "toxaphene disaster" took place. A severe failure of control was evident, resulting in a dramatic loss of cotton yield.

Resistance ratios ranged from 1.5 to 13-folds only. Such low resistance levels were associated with complete failure of control. This can be attributed to (1) the insecticide was used almost solely and continuously throughout the season for a couple of years against both the CLW and BW; (2) the insect was subjected to continuos pressure of chlorinated insecticides for more than a decade; and (3) the LC_{50} values (in ppm) for standard strain (brought from the Oasis, where it was claimed that no insecticides were used) were 225 for toxaphene, less than 14 for endrin, and 130 for carbaryl, indicating the presence of natural tolerance to toxaphene, and thus resulting in erroneous low values for resistance ratios.

This historic case of the "toxaphene disaster" was a turning point in resistance studies in Egypt which started with the CLW. This insect is still an attractive model for such studies because its larvae are relatively large; experimentally manipulable and without diapause. Also it is easy to rear and has many generations in the laboratory (ca. 3 weeks generation).

At present, according to the control program recommended by the Ministry of Agriculture, cotton receives at least four sprays against both the CLW and BW. The insecticides are used alternatively and in each spray several ones are used. Insecticide mixtures (mostly OP's) with antimoulting compounds, pyrethroids, carbamates and/or organophosphates are used for the 4 successive sprays, respectively.

Resistance monitoring is carried out annually in several research laboratories, covering different parts of the country. The results obtained from the Central Pesticide Laboratory, Agriculture Research Center are summarized in Table (1). The first 4 Governments are located in Lower Egypt and the last two in Upper Egypt (see map), Although the data are fraught with irregularities, especially those concerning pyrethroids some conclusions can be drawn. The CLW was much more resistant to pyrethroids than to organophosphates and carbamates particularly in Lower Egypt.

In contrast, the frequency of resistance toward organophosphates and carbamates in both Lower and Upper Egypt was more or less stabilized at a lower magnitude and showed some degree of uniformity. Also, the levels of resistance were not significantly altered after the conclusions of the spray season.

The data obtained by the group working in the Faculty of Agriculture in Assiut are more uniform and regular (Table 2). The general pattern of those concerning organophosphates and carbamates is similar to that shown in Table (1) There are a number of discrepancies between the two reports, (1) A marked decline in resistance frequencies in the population of Upper Egypt toward all tested insecticides was evident and (2) , Contrary to the results of Table (1), the population of the CLW of Upper Egypt was more susceptible to pyrethroids than to organophosphates and carbamates, and also having a lower magnitude of resistance.

The contradictory results obtained with pyrethroids are surprising. Most likely, the population of the CLW in Lower Egypt was subjected to more intensive treatment of DDT and related compounds. Thus, though the sequence after DDT and related compounds has involved several years of organophosphate and carbamate use before the introduction of pyrethroids in the control program in the mid 70's high levels of resistance has evolved. Seemingly,

Table (1): Resistance ratios of the CLW against insecticides assessed before (B) and after (A) the spray season of 1988 and 1990.

	Insecticides	Menofia				Garbia				Behera				Dakahlia				El-Minia				Assiut			
		1988		1990		1988		1990		1988		1990		1988		1990		1988		1990		1988		1990	
		B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
Pyrethroids	Fenvalerate	14.2	9.2	180	244	26.7	37.1	—	361.9	16.3	11.4	116.3	384	3.0	16.7	840.0	253	1.5	0.0	108.7	8	1.7	1.1	81.3	—
	Deltamerthrin	40.5	11,0	639	-	162,3	244	—	339.7	74.8	15.3	827.9	294	44.5	177.5	396.5	3789	3.8	-	16.3	5	1.3	2.0	19.5	-
	Cypermethrin	12.4	2.4	22.4	35	14.0	7.7	-	191	6.3	9.7	109.2	70	10.4	5.4	31.2	108	4.2	0.2	5	4	3.6	0.8	13.0	-
OP-compounds	Profenofos	7.4	5.3	3.4	8	12.9	4.6	6.7	13	6.7	4.8	3.4	13	6.8	6.7	11.9	7	5.2	-	6.6	4	5.1	7.3	12.7	-
	Chlorpyrifos	4.1	9.5	2.4	2	9.7	11,3	-	8	6.5	7.3	2.4	9	4.1	7.5	6.7	13	4.0	2.2	1.4	5	3.2	6.7	9.1	-
	Methamidophos	9.2	6.9	6.3	7	14.8	4.4	6.4	4	7.7	6.7	1.9	6	5.9	7.2	4.1	2	19.3	9.0	3.3	4	7.2	0.8	5.2	-
Carbamates	Methomyl	6.7	15.4	9.1	20	22.9	20.2	7.2	37	5.2	11.5	11.0	28	4.6	11.4	8.7	17	10.6	5.3	6.6	6	15.0	7.7	12.6	-
	Thiodicarb	28.5	15	-	-	9.0	13.6	-	8	11.2	14.0	5.2	20	10.6	14.2	3.1	9	29.3	5.1	12.6	-	6.9	10.7	4.0	-

Data from the Centeral Pesticide Laboratory Agriculture Research Center.

this period was not sufficient to deplete the population of the semi-reccessive gene kdr which is involved in both DDT and pyrethroid resistance. The retaining of the kdr gene was further ensured by the use of some chlorinated hydrocarbons, e.g., endrin during that period.

Table (2): Resistance ratios of the CLW against insecticides assessed before (B) and after (A) the spray season of 1988 and 1990.

Insecticide	El-Minia strain			Assiut strain		Sohag strain			
	1988		1990	1988	1990		1988	1990	
	B		A	B	A	B	A		
Methomyl	9.01	6.52	6.96	12.71	4.62	4.78	7.88	3.7	3.7
Chloropyrifos	14.17	8.09	8.82	14.67	9.56	8.82	10.00	6.47	6.47
Sulprofos	14.7	6.33	6.33	18.64	6.83	7.33	10.0	3.83	4.00
Profenfos	13.79	5.05	5.26	14.14	4.12	4.74	7.24	4.4	4.32
Phosfolan	6.14	2.14	2.43	6.14	2.64	2.57	5.11	2.3	2.29
Cypeniethrin	4.29	1.79	2.0	4.86	3.0	3.67	3.92	2.3	2.14
Fenvalerate	6.02	3.08	3.38	7.36	1.15	1.54	2.86	2.5	2.62
Deltamthrin	2.22	2.0	2.16	3.67	1.58	1.68	1.56	1.58	1.42
Flucythrinate	3.73	1.8	2.2	4.78	1.5	1.4	2.67	1.68	1.5

Data from the Fac. of Agriculture, Assiut University.

The generally uniform pattern of resistance toward the organophosphates and carbamates, its low frequency and the marked decline observed in Upper Egypt, might be attributed to the following factors: (a) the implementation of supervised control measures which could successfully reduce the amounts of insecticides by about 40% (6) the alternative use of insecticides, and (c) changing the insecticide use practices so that treatments are only confined to infested areas and thus creating refugia for a considerable portion of the population.

We conclude by emphasizing that through the judicious use of insecticides the evolution of resistance of CLW toward insecticides would either be delayed or prevented or even reversed.

Bollworms:

The Bollworms which cause much more damage than the CLW received less consideration. Owing to rearing difficulties no susceptible strain could be reared and maintained in the laboratory. Also, most studies are carried out with last stage larvae collected from infested bolls late in the season. Such larvae are either in diapause or entering diapause.

Therefore, results obtained are fraught with uncertainties, and should be taken with much reservation.

Sucking Insects:

Unfortunately, resistance studies with sucking insects attacking cotton e.g., aphids, whiteflies and leafhoppers are scarce. However, since these insects became primary pests extensive studies are undertaken in many laboratories, but mostly dealing with problems other than resistance.

As these insect pests are under insecticidal pressure for longer periods and are characterized by rapid development and high reproduction, it is anticipated that high levels of resistance in the field are acquired.

In our laboratory, preliminary experiments with *Aphis gossypii* and *Myzus persicae* revealed that the cotton aphid was more resistant to several insecticides than the green peach aphid *M. persicae* particularly against dimethoate, a commonly used insecticide against aphids in Egypt, It is worth emphasizing that *A. gossypii* is subjected to more insecticidal pressure.

The poor control of the whitefly *Bemesia tabaci* (Gen.) infesting cotton fields in last years promote us to establish a resistance monitoring program covering eight Governorates. In these tests, the adults were collected from the field, selected for viability and exposed to cotton leaf-discs placed in petri dishes containing agar for 24 hrs, A susceptible strain reared in the laboratory for 10 years was used as the standard strain. Six organophosphates, 3 carbamates and 2 pyrethroids were tested for 2 successive years. To the best of our knowledge this is the first report including extensive studies on monitoring resistance of WF's in Egypt.

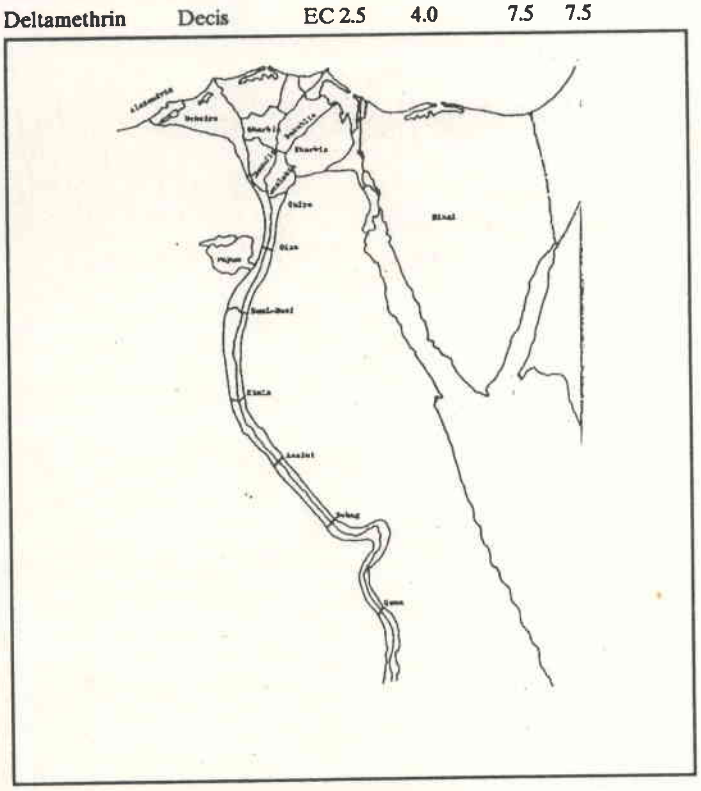
The results set out in Table (3) are obtained from Qualubia Governorate. They are striking. The WF developed resistance of various magnitudes to almost all tested organophosphates and carbamates. In 1989, higher levels of resistance were recorded for the organophosphates dimethoate, methamidophos and monocrotophos. They were extremely high with methamidophos and the carbamate furathiocarb. The four insecticides are extensively applied against some cotton pests which may account for this high resistance. Moderate levels were observed for chlorpyrifos and methomyl (ca, 1OxX). Just within one year a steep rise was evident and the insect acquired massive resistance. The increase was substantial with the above mentioned 4 insecticides. Unfortunately, rapid development of resistance took place with carbosulfan, which is the only recommended insecticide so far against whiteflies.

Resistance against methamidophos was so massive that no further development could be assessed. The level of resistance to chlorpyrifos and methomyl was negligible.

With pyrethroids, however, the frequency of resistance was low and relatively stable. This suggests that the time of application of these compounds within the spray program of cotton pests should be adjusted to coincide with the occurrence of higher WF populations.

Table (3): Level and rate of development of resistance of whitefly adults against insecticides in two successive years.

Insecticide	Trade name and formulation		(S) strain LC50 (ppm)	RR 1989	RR 1990
Organophosphates:					
Dimethoate	Diimthoate	EC 400	20.0	50	150
Methamidophos	Tarwron	EC 400	10.0	1000	1000
Monocrotophos	Nuvacron	SCW 400	12.0	29	208
Chlorpyrifos	Dursban	EC 480	11.0	9.09	10
Profenofos	Curacron	EC 500	10.0	-	6
Pirmiiphosmethyl	Actellic	EC 500	22.0	4.5	18.18
Carbamates:					
Carbosulfon	Marshal	W P25	18.0	5.5	33.3
Furathicarb	Deltanet	EC 400	1.5	100.0	466.0
Methonyl	Latinate	WP 25	30.0	10.0	13.3
Pyrethroids:					
Cypermethrin	Polytrim	EC 200	15.0	1.2	4.66
Deltamethrin	Decis	EC 2.5	4.0	7.5	7.5



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Insecticide Resistance and Management of Diamonback Moth and Imported Cabbage Worm in the People's Republic of China

Insecticides provide the main method for the control of the Diamonback moth (DBM), *Plutella xylostella* L., and the Imported cabbage worm (ICW), *Pieris rapae* L. in cruciferous vegetables in the People's Republic of China. DBM and ICW developed high levels of resistance in the late 1970s to trichlorphon, the most commonly used insecticide after stopping the use of BHC and DDT. Acephate (organophosphate) and pyrethroids have been commonly used since the late 1970s and the beginning of the 1980s. Pyrethroid resistance by DBM and ICW appeared in the middle 1980s (Wu & Gu, 1986, 1987). The insecticide resistance and it's management in DBM and ICW were studied in 1986-1990 under a national research project (IPM in vegetables). Satisfactory results have been obtained by the application of resistance management strategies and tactics in more than 10,000 ha. of crucifers, especially in the south of China where the resistant problems and the damage caused by DBM and ICW were severe.

Monitoring of resistance to pyrethroids and organophosphates of field populations of DBM and ICW was carried out from 1979 to 1989 in Shanghai in the south of China, where there are about 10 and 7-8 generations per year of DBM and ICW, respectively. The LC_{50} values for direct dip of DBM 4th instars of the field populations in 1979, when pyrethroids had not been commercially used and acephate use was just beginning, were used as standards for susceptible DBM for the calculation of resistance ratio (RR). DBM began to develop resistance to fenvalerate in 1984, the fourth year of commercial use of fenvalerate, with RRs of 10.3, 48.3, 435.2, and 359.5-fold in 1984, 1985, 1986, and 1989, respectively, (Table 1). The RRs for cross resistance of fenvalerate with flucythrinate and permethrin, which had not been commercially used, were 313.5 and 38.2-fold in 1986. The RRs of DBM larvae to acephate were 5.7, 9.3, 16.6, and 28.9-fold in 1983, 1985, 1987, and 1989, respectively. The RRs of ICW to fenvalerate, deltamethrin, and acephate were 31.4, 13.2, and 19.4-fold, respectively, in 1987-1988, about six years after the commercial use of the insecticides.

The strategy and tactics for insecticide resistance management were:

- The development and application of IPM tactics to control DBM and ICW in cruciferous vegetables, including cultural, biological and chemical control techniques. Natural control effects were encouraged by the change of cropping patterns of crucifers and by the research and usage of economic thresholds (ET) in insect pest control. The ET commonly used for the control of ICW in cabbage was one larva per plant in Beijing but subject to change according to the growth stages of cabbage. A remarkable example of the effects of cultural practices on insect pest was in Beijing, where the spring crop of cabbage matured earlier by means of early varieties and other practices and could be harvested before the peak of ICW. The areas of crucifers in summer were dramatically decreased, with decreased density and damage of ICW and DBM in autumn because of the lack of host plants in summer.

- Rotation of insecticides with different modes of action was used, including *Bacillus thuringiensis* (B.t.), IGRs (acylureas), organophosphates, cartap, and a product without a common name in English $(CH_3)_2$-N-CH-$(CH_2SSO_3Na)_2$. Use of pyrethroids has been stopped for the control of DBM because of high resistant levels, but they are still used in the north of China for the control of ICW.

- Carefully timed application of IGRs (acylureas), the most efficient insecticides for control of DBM and ICW at present and newly introduced in the People's Republic of China, in order to delay the development of resistance. The susceptibility of DBM and ICW to several IGRs tested before commercial use in Shanghai and Beijing is listed in Table 2. IGRs were restricted to use at low dosages and not more than 2-3 applications per year, and use only at peaks of occurrence and injury of DBM and ICW to reduce the population densities and damages. Monitoring in certain regions in Shanghai showed that the above restrictions for IGRs were valuable in the insecticide resistance management.

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Table 1. The sensitivity and resistance ratios (RR) of diamondback moth to fenvalerate and acephate in 1979-1989 in Shanghai

	Fenvalerate		Acephate	
Year Tested	LC_{50} (ppm)	RR	LC_{50} (ppm)	RR
1979	3.53	1	26.4	1
1981	3.78	1.1	46.6	1.8
1983	5.21	1.5	151.0	5.7
1984	36.39	10.3	-*	-*
1985	170.36	48.3	246.0	9.3
1986	1536.20	435.2	-*	-*
1987	-*	-*	438.9	16.6
1989	1269.10	359.5	763.8	28.9

*not tested

Table 2. The toxicity of four IGRs to diamondback moth (DBM) and imported cabbage worm (ICW) before commercial use in China.

Insecticide	Insect	LC50 (ppm) or LD50 (μg/g)[a]	95% C.L. and year	Site[b]
Chlorfluazuron	DBM	0.30 ppm	0.11-0.67	SH 1987
Flufenoxuron	DBM	0.10 ppm	0.05-0.19	SH 1987
	ICW	0.43 μg/g	0.33-0.55	BJ 1990
Hexafluron	DBM	0.38 ppm	0.09-0.64	SH 1987
Teflubenzuron	DBM	0.09 ppm	0.04-0.17	SH 1987
	ICW	0.76 μg/g	0.51-1.12	BJ 1990

[a]LC50 by direct dip and LD50 by topical application method, 5 days after treatment of 3rd instars at $25+1^{\circ}C$.

[b]SH = Shanghai; BJ = Beijing

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Resistance to triazines of *Capsella bursa-pastoris* (L.) Med. is located in chloroplast.

Van Oorschot (9189) listed the following methods of determination whether plants are resistant to herbicides; field treatments, whole plant studies, flotation of leaf discs, leaf photosynthesis, electron transport of isolated chloroplasts and chlorophyll fluorescence of intact larvae. Recently, the photoacoustic method has been developed (Havaux, 1989). In 1988 Lipecki (1988), using both field experiments and whole plant studies showed that the resistance to simazine occurred also in *Capsella bursa-pastoris* (L.) Med, plants. Individuals of the resistant biotype of this species survived the use of simazine in doses up to 10 kg ha^{-1} c.f. The nature of this resistance remained, however, unknown. LeBaron (1985) pointed out several mechanisms of plant resistance to herbicides, with resistance concerning triazines being located in chloroplast. In 1990 attempts were made to identify the reason of *Capsella bursa-pastoris* resistance to simazine, which is the most common triazine herbicide used in orchards, in comparison to two other species also showing such a resistance. One of the methods mentioned by Van Oorschot (1989) was used, based on the measurements of electron transport in isolated chloroplasts.

Chloroplasts were isolated from leaves (or from above-ground parts in case of *Sedum acre* L.) according to the method described by Sane *et al.* (1970) and resuspended in 50 mM potassium phosphate buffer (pH 7.4) containing 150 mM KCl. The chloroplasts activity was compared with water as the electron donor and 2.6 dichlorophenolindophenol (DCPIP) as electron acceptor. The reaction mixture for the electron transport determination contained following components (in 3 cm^3): 50mM Tricine-NaOH (pH 7.0), 5mM $MgCl_2$, 5mM NH_4CL, 0.06 mM DCPIP, chloroplasts equivalent to 40 μg of chlorophyll and simazine, as was illuminated with red light (300 E x m^{-2} x s^{-1}) at 22^{o}C.

Four concentrations of simazine were used: 0, 10^{-6} M, 10^{-5} and 10^{-4} M. Kockova *et al* (1988) consider the concentration of 10^{-5} M as being optimal for studying the resistance to atrazine.

Plants from three species were studied. Samples of *Capsella bursa-pastoris* plants were collected in two orchards treated for many years with simazine in the Lublin region and also in two other places never treated with herbicides (urban recreational area in Lublin and field of vegetables grown without herbicides). Two other species: *Galium aparine* L. and *Sedum acre* L. were sampled from the railroad areas treated also for many years with herbicide mixture containing atrazine. These tow plant species grew vigorously in railroad areas without any damage reaching much larger size than the plants of the same species growing under competition with other plants (without herbicides).

Table 1. Effect of simazine on the chloroplasts activity (μM of reduced DCPIP x mg^{-1} of chlorophyll x h^{-1})

Species and sampling place	Simazine (a.i.) concentration OM	10^{-6} M	10^{-5} M	10^{-4} M
Capsella bursa-pastoris (L.) Med				
a) vegetables no herbicides	170.8 c**	110.9 b	63.8 a	49.0 a
b) recreational area no herbicides	123.3 d	101.2 a	57.2 b	23.6 a
A) apple orchard 1 triazine used	171.9 a	164.1 a	162.0 a	154.8 a
B) apple orchard 2 triazine used	105.7 a	102.6 a	99.5 a	93.7 a
Galium aparine L				
railroad area triazine used	55.8 d	36.6 c	21.7 b	10.0 a
Sedum acre L.				
railroad area triazine used	98.0 d	69.9 c	42.1 b	10.5 a

*all measurements were repeated four times

**the same letter following averages for simazine concentrations mean no significant differences at 5% level of probability

The results presented in Table 1 pointed out that the chloroplasts isolated from *Capsella bursa-pastoris* plants resistant to simazine showed insignificant decrease in activity in the presence of simazine. In the case of plants of this species grown under non-herbicide conditions, a sharp decrease in chloroplasts activity was observed, related to the simazine concentrations. Similar reaction was observed in *Galium aparine* and *Sedum acre* plants. These results mean that the resistance of *Capsella bursa-pastoris* is located in the chloroplast, whereas that of the other two studied weeds is probably of different nature, perhaps enzymatic.

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Tobacco Budworm Pyrethroid Resistance in Northwest Louisiana

The first field control failures attributed to pyrethroid resistance in cotton occurred in the tobacco budworm in West Texas during 1985. These failures were later confirmed in the laboratory as being the result of a 16-fold decrease in susceptibility to permethrin. During 1986, field control failures resulting from a decreased pyrethroid susceptibility were observed in Arkansas, Louisiana, and Mississippi.

With the advent of the glass vial bioassay technique (Plapp *et al.*, 1987), or as it is more commonly called - the adult vial test (AVT), it became possible to rapidly and easily determine pyrethroid resistance levels within a field population. In August of 1986, monitoring of pyrethroid resistance levels using the AVT began at the Red River Research Station, Bossier City, LA. This resistance monitoring program has continued since that time. The program has been supported in part since 1989 by grants from PEG-US.

Data have also been collected concerning several other issues related to pyrethroid resistance including: 1) comparing AVT results with that obtained from a neonate larval leaf dip bioassay, 2) comparing the AVT responses to cypermethrin of male and female tobacco budworm adults, and 3) comparing the AVT responses of hand-collected moths to that of moths collected from pheromone-baited wire cone traps.

Pheromone-baited wire cone traps have been operated at the Red River Research Station since 1982 to monitor tobacco budworm and bollworm populations. These traps along with eight additional traps placed around a 5-acre field on the station were used to collect male tobacco budworm moths for resistance monitoring.

For the AVT, male moths were removed early in the morning and only those males that appeared to be healthy were used in these tests. Adults were placed in 20-ml glass scintillation vials that were coated with a residual film of cypermethrin. Vials were held on their sides at room temperature and after 24 h exposure, adults unable to fly more than a short distance (lm) were recorded as dead. Dosage levels ranged from 5 to 100 μg/vial. Three to five doses (10-30 moths/dose) were used to estimate each dose/mortality line.

Larvae used in the leaf dip bioassays were obtained from the LSU colony or from ovipositing females collected in or near the 5-acre field where the eight pheromone traps were located. Tobacco budworm females were hand collected at night with an aerial sweepnet and placed in 3.8 L cartons with a 10% sugar water solution. Cotton gauze was used to cover the cartons and served as an ovipositional substrate. Eggs were collected daily and allowed to hatch at room temperature. Only neonate larvae were used in the test. Formulated cypermethrin was used in the leaf dip bioassays. Untreated cotton leaves were dipped into a cypermethrin-distilled water solution for 20-30 seconds, removed and allowed to dry. A minimum of 6 doses (in ppm) and 3 replications were used to estimate each dose/mortality line. Neonate larvae were transferred to 1-oz plastic cups (5/cup) using a camel hair brush. A treated leaf was placed over the cup and covered with a piece of moistened cotton wadding. This was then sandwiched between the cup and a wax-coated paper lid. Cups were inverted and held at 26.7 degrees C, 65-70% RH, and a 14:10 (L:D) photoperiod. Mortality was determined 48 h posttreatment.

Average monthly responses of male tobacco budworm moths to a discriminating dose of 10 μg of cypermethrin per vial are shown in Figure 1. In 1987, the highest survival rate occurred in July. Since 1987, the highest survival rate at the 10 μg/vial dose has occurred in August each year. Although it is not shown by the monthly averages, it should also be noted that each year the largest jump in resistance level on a particular date as measured by the AVT occurred for the first reading taken after the first pyrethroid spray on the Red River Research Station. The trend indicates that despite the pyrethroid management plan adopted by Louisiana and several of its neighboring states, resistant levels continue to rise each year. This is not to say the resistance management plan has not helped since the situation might have looked much worse without the resistance management plan and the excellent cooperation of growers and consultants in Louisiana. Nevertheless, because of this trend, the pyrethroid window has been narrowed over the last several years.

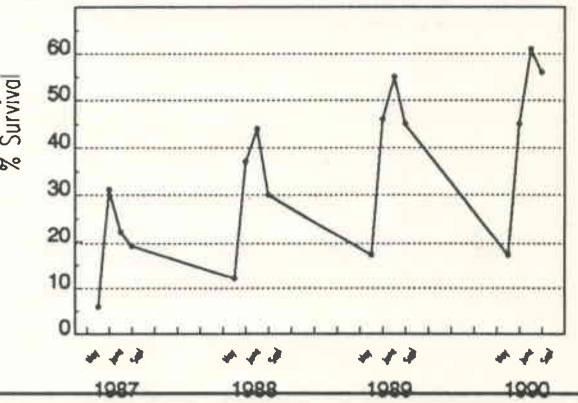

Figure 1. Percent survival of tobacco budworm male moths as 10 g of cypermethrin per vial per vial at the Red River Research Station, 1987-1990.

Despite the increase in resistant genotypes in the population over the last several years, no serious field control problems attributed to pyrethroid resistance have occurred in the Red River Valley area of northwest Louisiana since 1987. This is most likely due to a declining tobacco budworm population over the last several years as observed in pheromone trap catches (Figure 2). Both July and August total pheromone trap catches have declined since 1987. This decline is greatest for the August generation. Tobacco budworm numbers in August of 1988 were approximately half of that caught the same month in 1987. It should, however, be noted that serious control problems occurred during 1990 in portions of the cotton growing area of northeast Louisiana. The control problems were attributed to tremendous tobacco budworm population pressure. Resistance levels as measured by the AVT in northeast Louisiana were not significantly higher than those obtained at the Red River Research Station. This demonstrates that both resistance levels and population pressure work together to determine the probability that field control problems will occur.

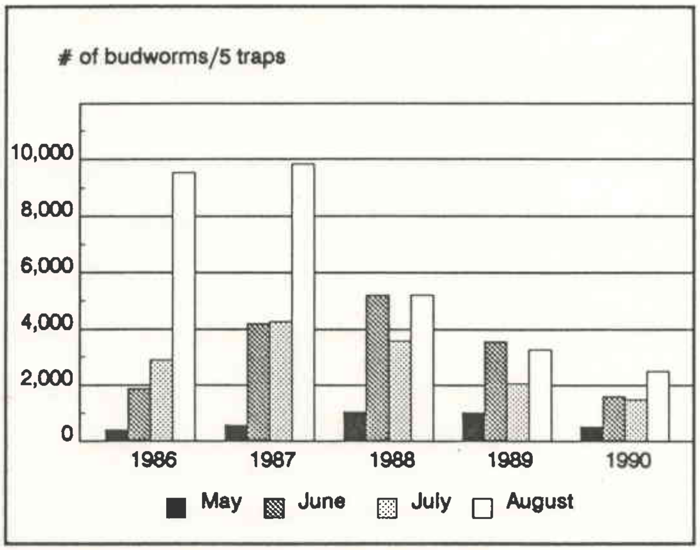

Figure 2. *Heliothis virescens* pheromone trap catches at the Red River Research Station

Leaf dip bioassays in 1989 confirmed the trend of increasing resistance during the season (Figure 3). Resistance levels increased from June through August as determined by the AVT and leaf dip bioassay. The LC_{50} values for the leaf dip bioassay ranged from 10.6 ppm in June to 34.8 ppm in August. Thus the cypermethrin was 35, 94, and 116 times more toxic to the LSU-lab strain of tobacco budworms than to the June, July, and August field collections, respectively.

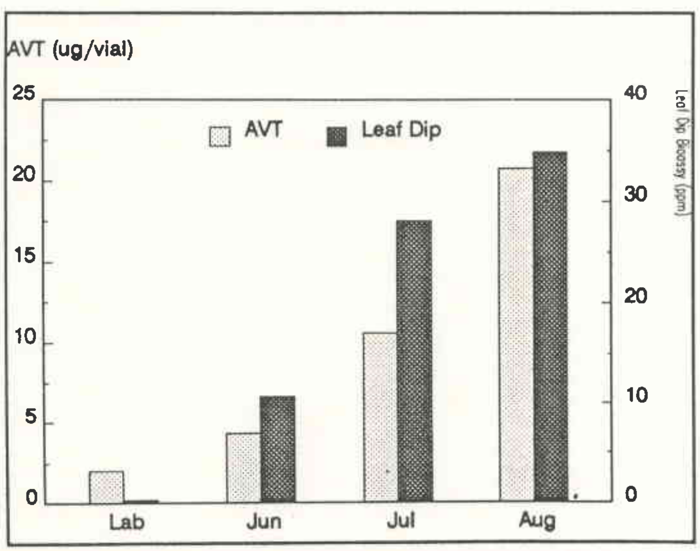

Figure 3. LC_{50} values showing the relationships between AVT and leaf dip bioassay results at the Red River Research Station, 1989

Male and female tobacco budworm moths did not differ significantly in their response (LC_{50} or LC_{90} levels) to cypermethrin in AVT (Figure 4 - LC_{50} values only). Also, the responses did not differ significantly based on the life stage that was field collected (eggs vs. adults).

Finally, AVT results indicated no significant difference in LC_{50} levels for adults tested from pheromone traps compared with adults (29% males) hand-collected about the same time (Table 1). Also, AVT results indicated no significant differences between adults tested from pheromone traps and adults obtained from either field collected eggs or from field collected adults reared in the lab for one generation (Table 1).

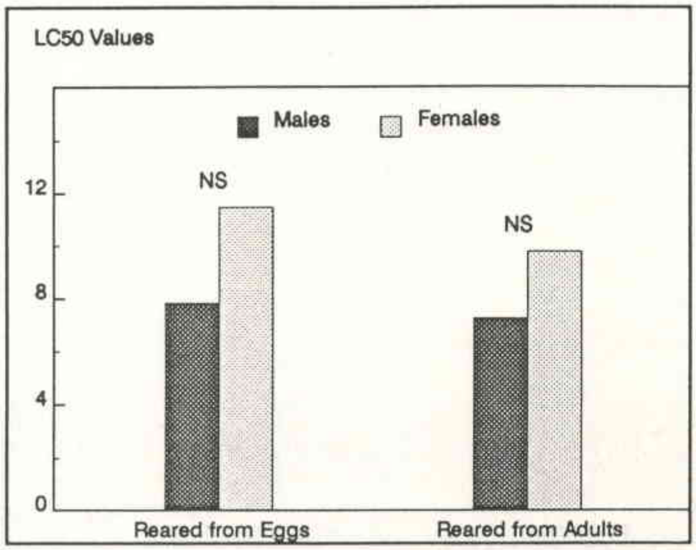

Figure 4. Response of male and female tobacco budworm moths to 10μg of cypermethrin per vial at the Red River Research Station, 1989.

SAMPLE	DATE	LC-50 (95% CL)
Trap adults	8/31	11.46 (8.30-15.00)
Field adults	8/30-31	11.65 (6.48-18.18)
Field eggs - adults	8/30	9.33 (6.37-13.06)
F.A.* - eggs - adults	8/29	8.28 (1.92-17.20)

* - Field adults

Table 1. AVT results of tobacco budworms collected by hand and in pheromone traps at the Red River Station, 1989.

In summary, the response of male tobacco budworm moths to a discriminating dose (10 μg/vial) of cypermethrin indicated that tolerance to cypermethrin increased during each season and has increased from season to season since 1987. The leaf dip bioassay conducted in 1989 also showed that tolerance to cypermethrin increased during the season and the results corresponded well with the AVT. Despite a rather high level of resistance in the tobacco budworm population in 1990, field control problems were not encountered due to very light pressure. The AVT response of male and female tobacco budworm moths was documented and it was found that they did not differ significantly in their response to a discriminating dose of cypermethrin. Additionally, tobacco budworm moths captured by hand (29% males) responded to cypermethrin in the AVT in the same manner as moths captured in pheromone traps. Furthermore, there was no significant difference in the AVT response of moths reared from eggs collected in a field compared with moths captured in nearby pheromone-baited wire cone traps.

For further information on pyrethroid resistance in Louisiana see: Graves, 1989, 1990; and Micinski *et al.*, 1990, 1991.

References:

Graves, J. B., B. R. Leonard, A. M. Pavloff, S. Micinski, G. Burris, and K. Ratchford. 1989. An update on pyrethroid resistance in tobacco budworm and bollworm in Louisiana. pp. 343-46. In Proc. Beltwide Cotton Prod. Res. Conf., Nat. Cotton Council, Memphis, Tenn.

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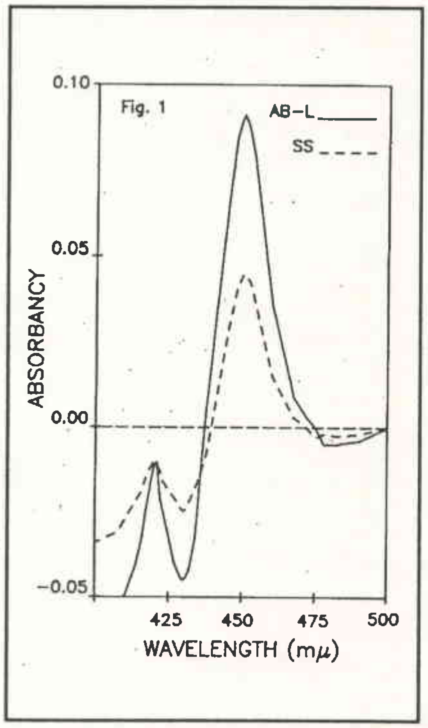
Two Abamectin-Resistant Strains of Colorado Potato Beetle

Two abamectin-resistant strains of Colorado potato beetle were established in our laboratory. The AB-FD strain was established through an intensive selection in field cages over 2 years (i.e., 6 generations) followed by further laboratory selection. The AB-L strain was established by treating adult male beetles with the mutagen ethyl methanesulfonate and selecting progeny at a discriminating dose of abamectin. Resistance levels for both the AB-Fd and AB-L strains were 23-fold and 15-fold at LD_{50} and LD_{97}, respectively. Both resistant strains had little mortality at 10 ng/larva, while this dose caused approximately 99% mortality in a susceptible strain. There was no cross-resistance in the abamectin-resistant strains to dieldrin, azinphosmethyl, or permethrin. Resistance in both strains was autosomal, incompletely dominant, and polyfactorial.

There was a high level of synergism to PBO in both the AB-FD and AB-L strains (SR - 19 and 15, respectively). There was no difference between the abamectin-mortality curves of the susceptible strain and the AB-L strain treated with PBO. There was a moderate level of synergism to the esterase inhibitor DEF (SR - 5), while no synergism was observed with the glutathione-S-transferase synergist, DEM.

Both abamectin-resistant strains had elevated levels of cytochrome P450 (e.g., AB-L, Fig. 1). There was also a significant increase in the oxidative metabolites 3"desmethyl avermectin B_{1a} and 24-hydroxy avermectin B_{1a} under in *vivo* and *in vitro* conditions (Table 1). An additional unidentified metabolite (fraction 14) was also observed. This demonstrates that oxidative metabolism is partially responsible for abamectin resistance in these strains. Furthermore, the increase in the levels of these water-soluble metabolites is the probable reason for the increase in the level of excreted radiolabelled compound in the abamectin-resistant strains (Table 2).



Elevated carboxylesterase activity (i.e., 2.5-fold increase in V_{max}) *was* also observed in the abamectin-resistant strains (Fig. 2). Currently, work is being done to isolate these carboxylesterase(s) and determine if they are hydrolyzing abamectin or acting as a sequestering agent. Other work now underway includes the involvement of the GABA-chloride channel and toxicity determinations of other avermectins to the abamectin-resistant strains of CPB.

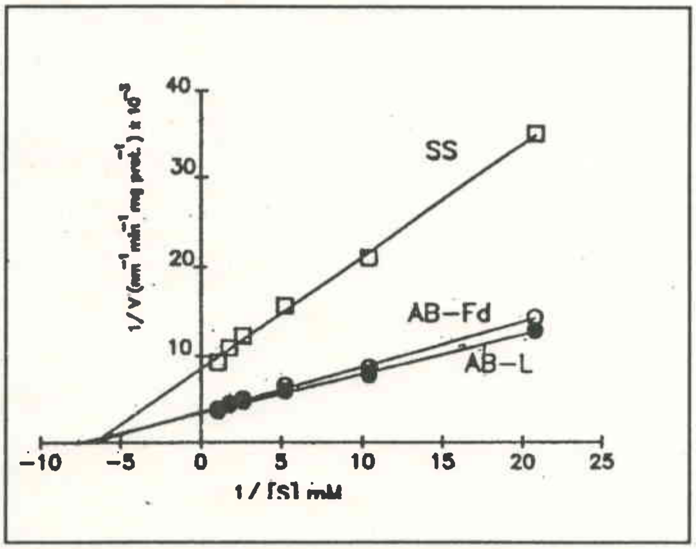


Table 1. *In vivo* and *in vitro* metabolism of [3 H]Avermectin B_{1a} by susceptible (SS) and abamectin-resistant (AB-FD & AB-L) strains of CPB.

Assay and Metabolites	SS	AB-FD	AB-L
	(% of applied dose in sample SD)		
In Vivo[a]			
Avermectin Bla	32.71 3.61	35.80 5.50	33.35 4.45
3"Des-methyl	1.26 0.18	2.30 0.28[b]	1.51 0.19
24-OH	0.45 0.01	1.16 0.21[b]	0.87 0.21[c]
Fraction 14	0.58 0.03	1.8 3 0.69[c]	1.50 0.50[c]
In Vitro			
Microsomes			
(NADPH)			
Avermectin Bla	77.00 5.03	64.30 11.07	72.198.40
3"Des-methyl	2.72 0.21	6.37 0.01[b]	5.210.72[b]
24-OH	N.D.[d]	1.50 0.75[b]	0.720.27[b]
Fraction 14	N.D.	3.33 1.00[b]	1.340.74[b]

[a]Extract from excrement collected from CPB at 6 hr, N-3. 3HI Avermectin Bla was applied at 0.46ng/larva.

[b]Significantly different from the SS strain, t test, P, N-3.

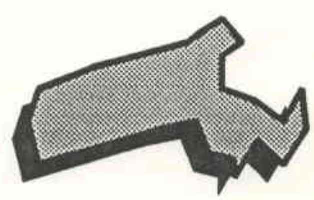
[c]Significantly different from the SS strain, t test, P, N=3.

[d]Not detected

Table 2. Pharmocokinetics of I 3H]Avermectin Bla (0.46ng/larva) in fourthinstar larvae of the susceptible (SS) and abamectin-resistant (AB-FD & AB-L) strains of CPB.

Post-treatment Interval (hr)	SS	AB-FD	AB-L
	(% of applied dose in sample SD)		
External Rinse			
0	90.2 ± 5.0	93.2 ± 3.2	94.7 ± 3.0
1	40.6 + 6.7	49.8 ± 10.9	49.2 ± 4.3
2	34.3 ± 4.7	33.7 ± 2.8	32.8 ± 2.1
6	15.8 ± 2.3	17.2 ± 3.8	22.2 ± 3.1[a]
Internal Extract			
0	2.0 ± 1.8	1.2 ± 0.9	1.2 ± 1.0
1	21.8 ± 5.2	19.1 ± 7.3	25.2 ± 7.0
2	26.1 ± 4.6	22.9 ± 8.2	21.8 ± 1.8
6	37.6 ± 4.7	23.6 ± 5.8[a]	25.3 ± 1.7[a]
Excrement Extract			
0			
1	18.3 ± 11.0	19.3 ± 3.8	22.4 ± 4.2
2	30.3 ± 12.2	36.4 ± 8.6	26.2 ± 0.9
6	27.8 ± 2.0	42.2 ± 11.7[a]	35.3 ± 5.1[a]

[a] Significantly different from the SS strain, t test, P, N=4



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Pyrethroid & Endosulfan Resistance in *Heliothis armigera* in Australia - 1990/91

The Australian Insecticide Resistance Management Strategy has been in place now for eight seasons. For the first six seasons the pyrethroid window was of 42 days duration. For the past two seasons, this has been reduced to 35 days while the synergist Pbo (piperonyl butoxide) was introduced for the first time into commercial use in the 1990/91 season.

The impact of shortening the pyrethroid window was to separate the moth and larval selection phases which resulted in smaller twin peaks in 1989/90 season, instead of the larger single peak of previous years. The impact of Pbo was to interrupt the selection of moths within the stage 2 window, remove the stage 3 peak and limit the overall seasonal increase in pyrethroid resistance to the lowest level recorded so far in all three study areas. The high stage 1 pyrethroid resistance level in the Namoi/Gwydir & Inverell areas was probably due to the use of pyrethroids for armyworm control in winter cereals in spring. This is the first host crop of the season for *Heliothis armigera* which occurs on winter cereals at the same time as armyworm and thus can be selected inadvertently with sprays applied for armyworm control. Normal stage 1 levels were recorded at Emerald where armyworms were not a problem. The residual pyrethroid resistance not suppressible by Pbo has increased slightly following the first season of commercial use of Pbo. This situation will require close scrutiny to ensure that we are not selecting for the Pbo insensitive resistance mechanism. The unsprayed pool of susceptible *Heliothis armigera* continues to be slowly contaminated with resistant moths migrating out of the intensively sprayed cotton areas. Thus the effectiveness of the refugia as a source of dilution for pyrethroid resistance is being gradually eroded.

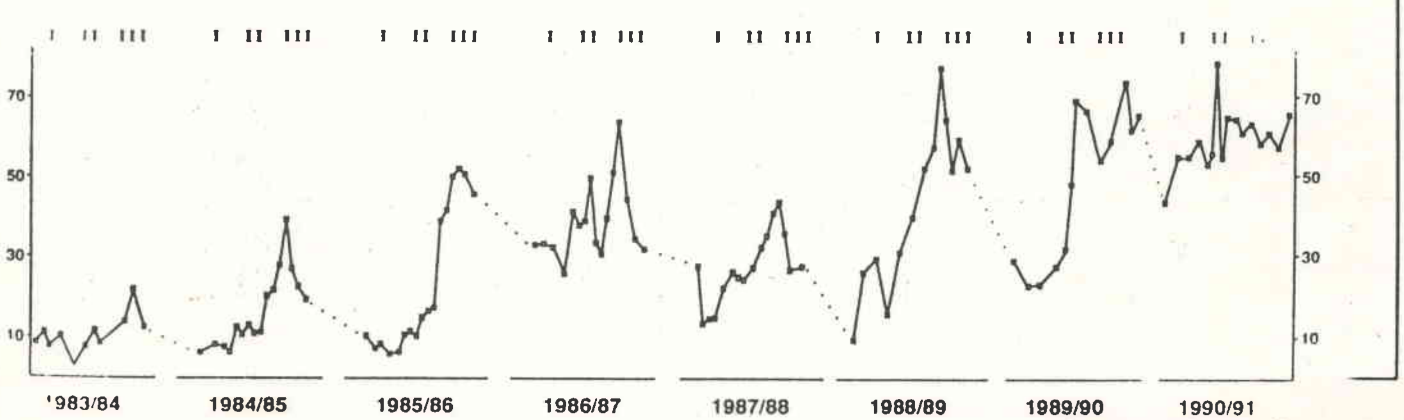
Endosulfan resistance levels this season are the highest recorded so far and reflect the increasing reliance on endosulfan in the Australian cotton industry. However, despite these high mid to late season levels, endosulfan resistance in stage 1 has in the past consistently dropped back to low levels (that is, less than 1 0%). The unsprayed dryland areas are also remaining relatively uncontaminated and are thus still an effective source of dilution for endosulfan resistance. Endosulfan resistance at this point seems much easier to manage than the pyrethroid resistance problem. The reason for this is not entirely clear but it may be simply due to the fact that most endosulfan has so far been targeted mainly on *Heliothis punctigera* dominant populations in stage 1. If there is increased use of endosulfan against predominantly *Heliothis armigera* populations in stage 2, then the situation could quickly change for the worse. The generally higher endosulfan resistance levels in Queensland reflect both the higher *armigera* pressure and strong reliance on endosulfan in parts of Queensland.

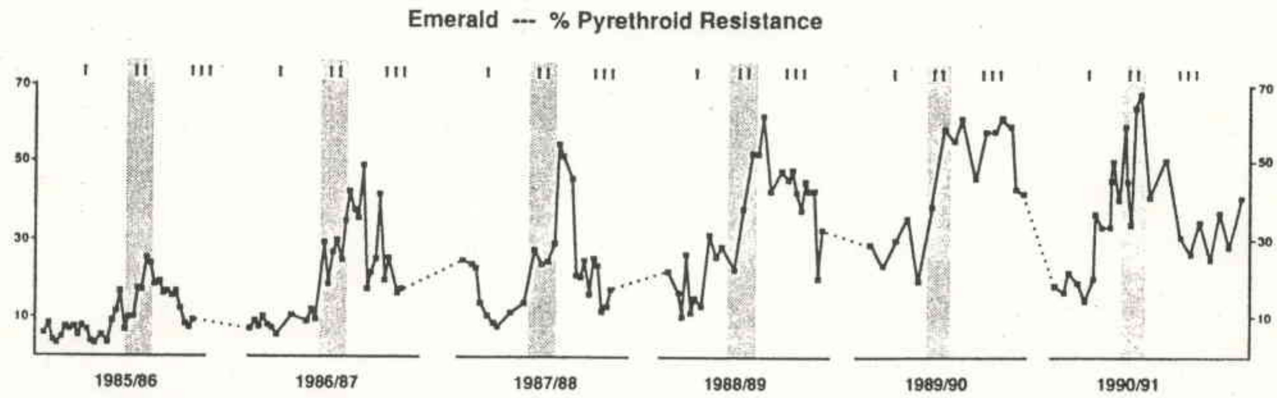
% SURVIVING DISCRIMINATING DOSE

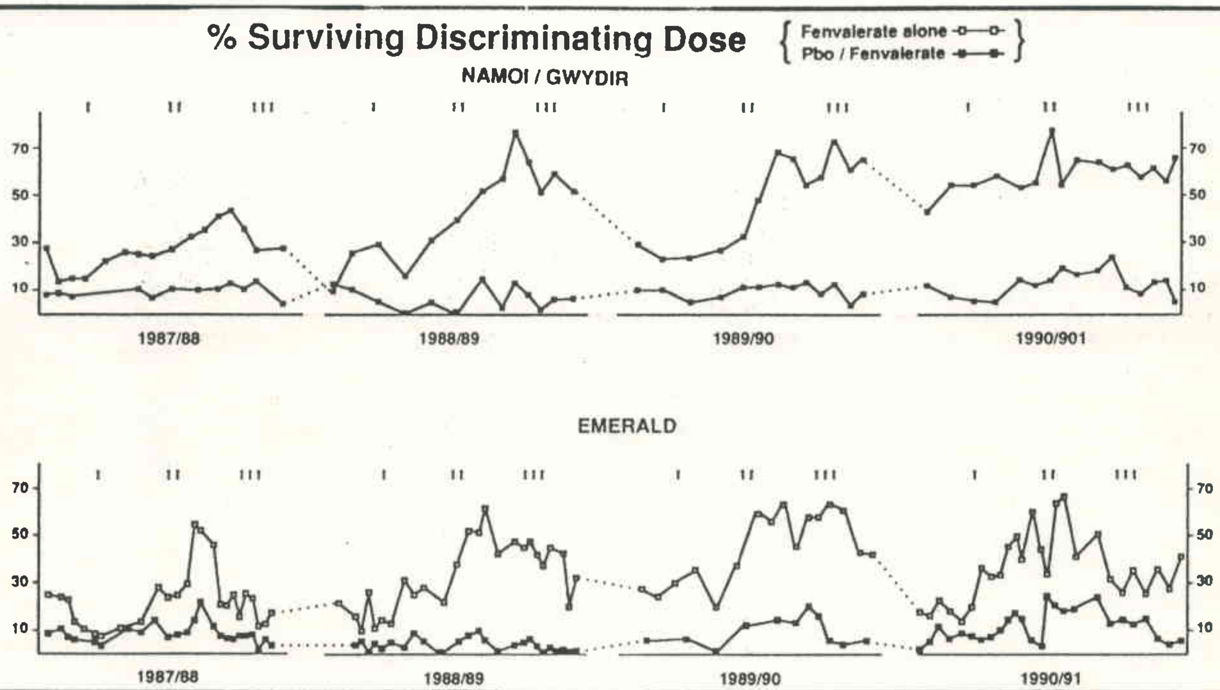
		FENVALERATE			ENDOSULFAN		
STUDY AREA	SEASON	I	II	III	I	II	III
Namoi/Gwydir	1983/84	9.3	9.5	14.6	-	-	-
	84/85	7.5	12.9	27.9	-	-	-
	85/86	7.8	13.0	44.5	-	-	-
	86/87	32.2	36.7	42.9	7.1	16.7	20.1
	87/88	19.8	30.1	38.4	7.3	17.6	23.0
	88/89	19.6	42.4	60.7	8.8	13.2	10.6
	89/90	24.7	45.3	62.5	9.2	14.8	15.9
	90/91	55.7	61.1	61.5	12.2	22.7	31.3
Emerald	1985/86	6.8	17.1	14.4	-	-	-
	86/87	8.8	26.5	29.8	7.7	20.6	17.3
	87/88	15.9	27.1	27.0	9.5	14.3	13.7
	88/89	19.8	38.7	44.3	8.1	13.6	7.1
	89/90	27.9	44.6	54.6	3.1	21.0	20.9
	90/91	24.7	52.2	34.5	10.1	37.1	16.0
Inverell	1987/88	10.2	20.4	19.0	11.3	10.5	5.8
	88/89	21.9	28.9	41.7	9.4	4.8	5.4
	89/90	22.1	32.7	38.2	4.0	5.2	7.1
	90/91	47.8	34.6	45.1	3.4	8.5	10.8

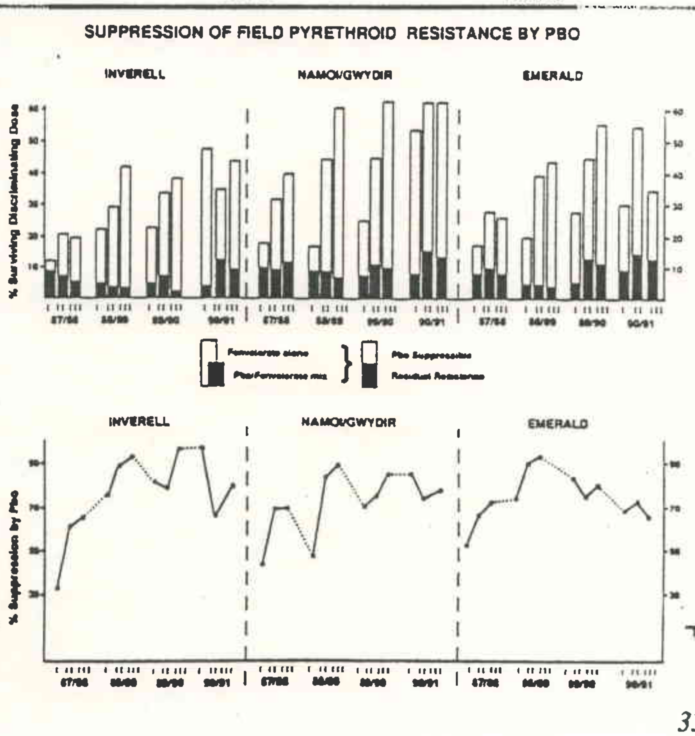
Average pyrethroid and endosulfan resistance levels in *Heliothis armigera* for each Stage(I, II & III) of the Resistance Management Strategy, for three study areas (the Namoi and Gwydir valleys of northern NSW, the Emerald Irrigation Area of central Queensland and a sample of the unsprayed refugia area centred on Inverell in northern NSW).

Namoi/Gwydir — % Pyrethroid Resistance



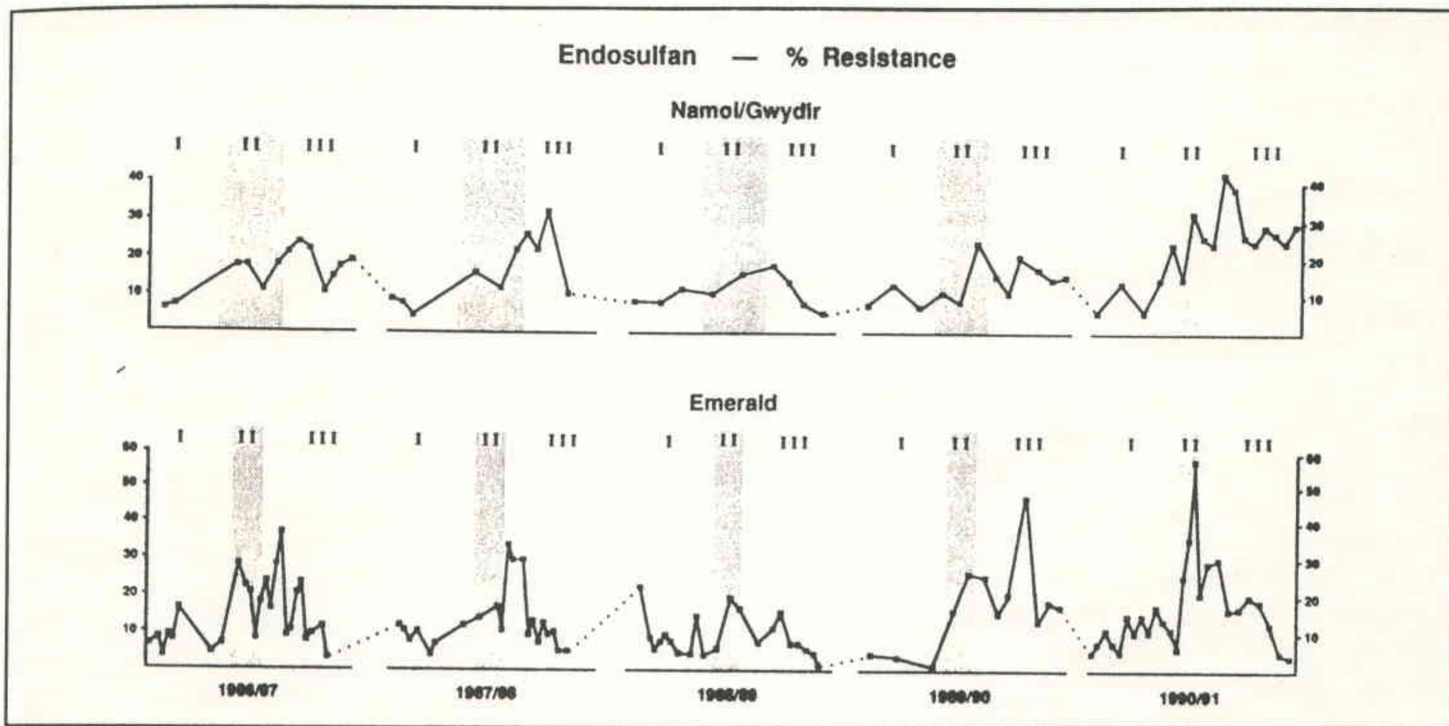






INDEX of TOTAL SEASON SELECTION PRESSURE (increase in pyrethroid resistance between the start of the season and the end. i.e. Stage III + Stage I)

Season	Namoi/Gwydir	Emerald	Inverell
1983/84	1.6	—	—
84/85	3.7	—	—
85/86	5.7	2.1	—
86/87	1.3	3.4	—
87/88	1.9	1.7	1.9
88/89	3.1	2.2	1.9
89/90	2.5	2.0	1.7
90/91	1.1	1.4	0.9



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Possible Approaches for Insecticide Resistance Management in Cotton in China

The following notes were prepared for the ICAMA Resistance Meeting held in Beijing last March (see Madame Zhang's article in this volume). Although these comments refer specifically to the resistance problem in Chinese cotton, they may prove useful as general "discussion points" for similar resistance situations in other countries.

It would be unwise to transplant a 'foreign' resistance management strategy into China without first adapting it to the special needs and conditions applicable to China. To do this effectively, it is important to obtain a certain base level of information to allow the Strategy to at least 'get off the ground'. Some of this information may already be available, most probably not. Most likely there will be a large knowledge gap to fill and it would be wise to spend the coming cotton season in attempting to fill these gaps. This would then allow a more appropriate Strategy to be designed specifically for the Chinese situation. Of course, the Chinese authorities may feel that, in the worst affected areas, it may be absolutely necessary to do something now, rather than later. In such cases, a "best guess" Strategy could be implemented but it would be essential to remain flexible and allow future research findings to adjust it as necessary.

The following list includes suggested areas for research and comments on the basic information needed to design a workable Resistance Management Strategy.

Range of effective products

What products work against the main pests and at what rates? Are there any chemical groups not being utilized in China which could be? eg. endosulfan, thiodicarb, *Bacillus thuringiensis* (Bt), benzoylphenyl urea chitin inhibitors, methomyl, amitraz, pirimicarb, chorpyrifos etc.

The full range of control options for all pests *(Heliothis,* mites, aphids, whitefly etc.) should be explored and effective rates documented. Only when the full range is known, do you have the flexibility to choose the optimum use pattern.

Mixtures versus Single Products

There is much controversy in this area. In the early stages of a resistance problem, it is probably best to use rotations of single compounds at the fully effective field rates. However, as the resistance problem deteriorates, you will be forced into using "cocktail mixtures" but because of the increased costs, these will most often be "half strength" mixes. These have real problems in terms of resistance management and most thinking is that they will create more problems than they solve. The first resort to mixtures should be conventional/biological (eg. Bt) insecticide mixes (particularly mixtures with endosulfan, thiodicarb and perhaps pyrethroids). Mixtures of conventional insecticides (eg. pyrethroids/organophosphates, endosulfan/pyrethroids etc.) should be treated with caution.

Ecological Pest data

The following questions need to be answered:-

- What are the major pests? When are they pests? Are they resistant? Are there sibling species to *H. armigera* present?
- What are the host plants for each pest? What are the key source crops? What is the selection pressure on these alternate hosts? Is there a susceptible refugia? and how big is it in relation to the sprayed area?
- What is the seasonal abundance of the pests? Is there long term light trap data etc. available?
- How many generations per season? Is there a diapause? How long for one generation?

Agronomic data

- How are the host crops grown? When are they grown? Is there flexibility to reduce the cotton growth period without sacrificing yield (ie. grow early crops)?
- What is the cropping pattern of the alternative host plants?
- What cultivation practices are undertaken? How do these impact on the survival of *H. armigera* pupae?

Pesticide use data

- Which crops are sprayed and how much? What chemical groups are used?
- What are the application methods? What equipment is used? What formulations are used? Who makes the decision to spray?

Toxicology data

Resistance monitoring is best done using discriminating doses although conventional full bioassay lines are also useful for cross resistance studies etc. It is suggested that base line data for all chemical groups be obtained (if not already) and discriminating doses calibrated. Resistance mechanisms to each group should be identified and cross resistance patterns identified. It is critical to distinguish these from multiple resistance. Initial synergism studies should be done in the laboratory to determine the significance of metabolic detoxification mechanisms (egg. piperonyl butoxide on pyrethroids, esterase inhibitors on organophosphates etc.).

Supply and Distribution -

These can be serious constraints for successful resistance management, particularly in rotation type Strategies limiting the use of certain chemical groups to specific time periods. The appropriate products must be available in sufficient quantities when needed. This sounds simple enough but in practice, can be a major problem. These problems must be addressed and resolved, if resistance management is to be successful

Other Issues

What is the role of government, the agrochemical industry, state advisers etc? and how do they interact? What regulations on pesticide use are currently in force in China? What institutions and organizations (and which individuals) are interested in doing research (including monitoring) on resistance? Further discussion on the design, implementation and servicing of an insecticide resistance management Strategy can be found in Forrester (1 990) *Pestic. Sci.* 28, 167179.

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Characterization of Altered Acetylcholinesterases from Colorado Potato Beetle

We have previously reported in this newsletter and elsewhere the occurrence of altered acetylcholinesterases (AChEs) from insecticide-resistant Colorado potato beetles, and have recently conducted experiments to characterize the altered AChEs. A number of insecticides were tested for their ability to inhibit AChE activity as measured by the Ellman method. Table 1. shows a general summary of our results.

There is a wide variation in the sensitivities of AChEs from the tested strains. Not unexpectedly, the AChE from each strain is least sensitive to the pesticide used in selecting it for resistance. However, it was somewhat surprising that there were large differences in inhibition between classes of pesticides (i.e. oxime vs. aryl carbamates). It appears that populations of Colorado potato beetle may have alterations in AChE which confer resistance to only a narrow range of pesticides. This would allow the grower to continue controlling the pest using alternative pesticides. However, multiple resistance mechanisms can also be present in this pest. For example, the Long Island strain has increased metabolism through mixed function oxygenase enzymes as its major mechanism of resistance. Thus, it is necessary to conduct extensive monitoring and testing to determine which, if any, alternative pesticides may be effective for Colorado potato beetle control.

Table 1. Insensitivity of Acetylcholinesterases from Colorado Potato Beetle Strains to Various Inhibitors

Inhibitor	Susceptible	Long Island	Montcalm
Carbofuran	--	--	++
Carbaryl	--	+	++
Aldicarb	--	--	--
Methomyl	--	--	--
Azinphosmethyl oxon	--	++	--
Phosmetoxon	--	++	+
Eserine	--	+	--

+indicates relative insensitivity to inhibitor

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Operational Influences on Endosulfan Resistance in Coffee Berry Borer in New Caledonia

Selection with insecticides can lead to insecticide resistance, but it is seldom possible to identify operational influences directly responsible for effects observed in the field. In the case of coffee berry borer (*Hypothenemus hampei)*, a cosmopolitan coffee pest, we have related several factors to the emerging picture of endosulfan resistance in New Caledonia (Brun *et al* 1989, 1990). Not surprisingly, resistance was higher in field with a recent history of endosulfan use. Interestingly, resistance frequency was also higher in intensive fields grown under full sun, compared to traditional fields with more widely spaced trees grown under native forest canopy. The lower resistance frequency observed in traditional fields is probably partly due to factors such as physical obstruction reducing insecticide deposition, but the cooler daytime temperatures in shady fields would also be expected to reduce the mortality resulting from endosulfan applications (Brun & Suckling in press), hence lowering selection in traditional fields.

We have also detected rapid decreases in resistance frequency away from roadsides, and can relate these clines to application methods. Coffee fields have been sprayed from roadsides, using truck-mounted sprayers. These directional sprayers deposit the majority of the insecticide within 10-20m of the point of application (Parkin *et al.* in press). Transects with bioassays of beetles in filter paper packets and in coffee berries exposed to field treatment indicate differential mortality between resistant and susceptible strains, and hence selection, which reduced with distance from the point of application. Removal of endosulfan use led to some reversion in resistance between years, while continued use increased the frequency of resistant phenotype (Brun & Suckling in press).

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Brun, L. O., C. Marcillaud, V. Gaudichon and D. M. Suckling. 1989. Endosulfan resistance in *Hypothenemus hampei* (Coleoptera: Scolytidae) in New Caledonia. J. Econ. Entomol. 82:1311-1316.

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Brun, L. O. and D. M. Suckling. Field selection of endosulfan resistance in coffee berry borer (Coleoptera: Scolytidae) in New Caledonia. J.Econ. Entomol. (in press).

Parkin, C. S., L. O. Brun and D. M. Suckling. Spray deposition in relation to endosulfan resistance in the coffee berry borer *Hypothenemus hampei* (Coleoptera: Scolytidae) in New Caledonia Crop Protection (in press).

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The Analysis of Plasmid-Mediated Streptomycin Resistance in *Erwinia amylovora.*

Streptomycin-resistant mutants of *Erwinia amylovora* were isolated from an apple orchard in Michigan and from crabapple trees adjacent to the same orchard in 1990. Isolates that grew on King's medium B amended with 100 μg/ml of streptomycin sulfate were considered to be resistant strains, whereas isolates that failed to grow on this medium were considered to be sensitive strains. Growth of the resistant strains was not inhibited in a filter-paper disk assay (0.06-5 μg of streptomycin sulfate), but growth of sensitive strains was inhibited at concentrations as low as 0.06 μg of streptomycin sulfate.

Only sensitive strains were detected in an additional 19 apple orchards sampled for resistant strains. In colony blot hybridizations, an internal portion of the streptomycin-resistance gene (probe SMP3) from strain Psp36 of *Pseudomonas syringae* pv. *papulans* hybridized with all streptomycin-resistant strains of *E. amylovora*, but not with streptomycin-sensitive strains. Probe SMP3 hybridized at 2.7-kb restriction fragment from *AvaI*-digested total genomic and plasmid DNA of two resistant strains of *E. amylovora* and to a 1.5-kb fragment of DNA from strain Psp36 of *P. s. papulans*. The probe did not hybridize with digested DNA from sensitive strains. A 33-kb plasmid was present in all streptomycin-resistant field strains but not in streptomycin-sensitive strains. Streptomycin resistance was transferred by matings to four streptomycin-sensitive recipient strains of *E. amylovora* from each of two streptomycin-resistant donor strains. Transconjugants also contained the 33-kb plasmid. DNA from resistant strain Ea88-90 from Washington did not hybridize with the probe, indicating that this strain contains a resistance system unrelated to that in streptomycin-resistant strains from Michigan.

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Working Groups

Insecticide Resistance Action Committee (IRAC)

Further meetings of the Insecticide Resistance Action Committee were held in November 1990 in Brighton, UNITED KINGDOM (UK) and in April 1991 in Valencia, Spain. Dr Solang United kingdom (uk) of Ciba Giegy and Mr Robin Slatter of Wellcome Environmental Health, newly elected Chairmen of the Rice Working Group and Public Health and Vectors Working Group respectively, were welcomed to the latter meeting as new members.

Centrally the attention of IRAC is being directed towards the International Organization for Resistant Pest Management (IORPM) described in a previous article in this Journal in August 1990. The work of this organization will lead to an international congress, now postponed to 1992, and will subsequently aim to coordinate resistance management programs worldwide.

Abstracts of papers presented at the IRAC Conference held in New Orleans in April 1990 have been published by GIFAP in the FRAC/IRAC Newsletter No. 6 (November 1990).

In addition, an update of the international survey of the status of insecticide resistance in the field, carried out by IRAC, has been published in issue No. 7 of the FRAC/IRAC Newsletter.

At a recent meeting of the Insect Growth Regulator Efficacy Group, it was agreed that membership of IGREG should be transferred to form the membership of a revised, augmented Field Crops Working Group. Plutella resistance, including that to benzoylureas, remains the most important subject for this group. However, the revised Working Group has a wider brief and because the range of crops and species involved is so extensive, the items to be addressed require careful selection.

The following is a summary of recent activities within the IRAC Working Groups:

Cotton Group

This Group is directing its attention towards validation studies for the monitoring methods, particularly Method No. 7, which includes leaf-eating larvae of Lepidoptera (including *Heliothis*) on cotton. It also proposes to present a paper on insect resistance in world cotton with trends and strategies at the International Plant Protection Conference in Brazil in August 1991.

Rice Group

In view of the fact that the major rice growing area lies in Eastern Asia, the basic activities of the Rice Group are being developed with a view to more Japanese involvement. The Group is exploring the possibility of contracting Universities/Research Institutes in Eastern Asia to undertake bioassays on the Brown Plant Hopper, *Nilaparvata lugens* using the IRAC Test Method No. 5. This would generate the required baseline data as well as evaluating the method itself. Two requests for research funding are being considered.

Fruit Crops Group

In addition to the Methods published in the FRAC/IRAC Newsletter No.5, the Fruit Crops Working Group have drafted a Method for the Californian Red Scale (*Aonidiella aurantii).* Research aimed at characterizing cross-resistance patterns in Tetranichus urticae, funded by IRAC at Cornell University, USA, has been completed and a paper on IRAC's Spider Mite Resistance Strategy will be presented at the International Symposium on "Achievements and Developments in Combating Pesticide Resistance" to be held at Rothamstead Experimental Station UNITED KINGDOM (UK) in July 1991.

The strategy developed for Spider Mites in top fruit has been adapted for *Panonychus citri* and other citrus mites.

Field Crops and Vegetables Working Group

The active core work of the newly constituted group will center on vegetables, potatoes and sugar beet, although other crops will kept under review as necessary.

An important aspect of the recent survey is the appearance of pyrethroid resistance in Portugal and Yugoslavia in the Colorado Potato Beetle. The wider status of resistance in Eastern Europe is unclear and East European contacts are being established to clarify this situation.

A study on resistance in Plutella *xylostella* has been commissioned with Dr Cheng in Taiwan. This is now well advanced in a comparison of his standard method with IRAC's Method No.7. Field selection with acylureas has also commenced.

Stored Products Group

The Stored Products Group's presentation at the Fifth International Conference on Stored Products Protection, Bordeaux, September 1990, was welcomed by delegates and was an opportunity to publicize the work of IRAC.

Work is continuing on a method for evaluating insect susceptibility to synthetic pyrethroids. In addition, studies have taken place with the Central Science Laboratory in Slough, UNITED KINGDOM (UK) with a view to publishing discriminating doses for *Cryptolestes ferrugineus* and *Oryzaephilus surinamensis*.

The Group is currently concerned over resistance to phosphine. There is a need for a single biochemical/miniaturized technique for monitoring resistance because currently a small fumigation chamber is required.

Public Health and Vectors Group

Individual members of the Working Group, representing GIFAP, attended the WHO Expert Committee Meeting on Insecticide Resistance, held in Geneva in March 1991. Attendees were able to make contributions to the overall discussion which concentrated on all aspects of vector resistance. Shortfalls in the WHO test kits for detecting resistance in vectors were highlighted with a result that further development work on a more suitable test kit is to be recommended. The final report should be issued late 1991 - early 1992.

The Working Group was also represented at the first meeting of the IOPRM Public Health and Vectors Task Group, also held in Geneva in March.

Pyrethroids Efficacy Group

The Group report that an upward trend in pyrethroid resistance of *Heliothis* on cotton is confirmed but still under control. In India, a strategy of *Heliothis* resistance management by rotating products has been developed and efforts are being directed towards a program for *Heliothis* resistance management in Colombia.

Ectoparasite Working Group

Although there is still little interest in an international group, the informal Working Group on resistance in arthropods of veterinary importance in the USA is now well established and will hold its next meeting in July 1991. Problems being addressed include widespread resistance in horn flies, for which the use of insecticidal ear tags are thought to be principally responsible. Housefly resistance in animal housing is also recognized as a serious and widespread problem. The current resistance situation in fleas affecting pets, which may be exacerbated by the use of insecticidal collars, is also receiving attention.

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ALS/AHAS Inhibitor Resistance Working Group

Several new classes of herbicides kill plants by inhibiting the same enzyme, acetolactate/acetohydroxyacid synthase (ALS/AHAS). These herbicides have proven to be very effective and are widely used. However, resistant weed populations have also developed to several ALS/AHAS inhibitors. In order to more effectively address the problem of these resistant weed populations, a new intercompany group has recently been formed, the ALS/AHAS Inhibitor Working Group (AIRWG). The present officers of AIRWG are: Dr. Walt Reed-chairman, Dr. Dale Shaner-vice chairman and secretary, and Ms. Chris Carson-treasurer.

AIRWG is a working group of the Herbicide Resistance Action Committee (HRAC). HRAC is a technical sub-group of the Agriculture and Environmental Committee of the International Group of National Associations of Manufacturers of Agrichemical Products (GIFAP). AIRWG is made up of representatives from 8 chemical companies who either have or are developing herbicides that kill plants by inhibiting ALS/AHAS. The goals of AIRWG are to provide a forum to discuss the problem of weed populations developing resistant to ALS/AHAS inhibitors, to exchange information concerning resistance, and to fund research of mutual benefit concerning resistance to ALS/AHAS inhibitors.

The meeting of AIRWG in Big Sky, Montana held in September, 1990 focussed on the problem of sulfonylurea resistant weed populations in cereals. Seven university researchers shared their data and views on ALS/AHAS inhibitor resistant weed populations in cereals.

As a result of this meeting, AIRWG and HRAC are funding two research projects. One project, supervised by Dr. Donn Thill, University of Idaho, Dr. Phil Westra, Colorado State University and Dr. Peter Fay, Montana State University, will test randomly selected populations of *Kochia scoparia* in Idaho, Colorado, and Montana for resistance to ALS/AHAS inhibitors. This project will run for 3 years. The purpose of this study is to determine the frequency of resistance to ALS/AHAS inhibitors in the present kochia populations and to provide a baseline of information on this resistance.

The other 3 year study, supervised by Dr. Don Thill and Dr. Carol Mallory-Smith, University of Idaho, will determine the effect of pollen flow and seed dispersal on the spread of genes for ALS/AHAS inhibitor resistance in weed populations. This work will focus on an open pollinating species, *K. scoparia* and a closed pollinating species, *Lactuca* serriola for the pollen flow experiment. For the seed dispersal study, Drs. Thill and Mallory-Smith will examine the flow of resistant seed from *L. serriola*, a short distance, wind-dispersed species, and *S. iberica*, a long distance, wind-dispersed species.

The next meeting of AIRWG will take place in September, 1991 in Minneapolis, Minnesota and will focus on the potential for developing resistance to ALS/AHAS inhibitors in maize and soybeans.

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Professional Opportunities

Graduate Research Assistant

- Location: University of Hawaii, Honolulu
- Areas of Interest: Ecological, genetic, or evolutionary aspects of Insecticide Resistance.
- Minimum Qualifications: B.S. in Entomology or related field. Must be admitted as a classified graduate student.
- Desirable Qualifications: Research experience. Ability to work independently.
- Salary: Stipend (start at $13,320 for Ph.D., $12,318 for M.S.) plus tuition exemption and medical benefits.
- Available: January 1992. Annual renewal dependent on satisfactory progress and availability of funds.
- Deadline: September 1, 1991 (for January 1992 admission) or until filled.

To Apply: Send CV, GREs, transcripts, and 3 reference letters to Bruce Tabashnik, Department of Entomology, University of Hawaii, Honolulu, HI 96822. Phone: (808) 956-8261, FAX: (808) 956-2428

Postdoctoral Research Positions

Two postdoctoral positions to conduct research on insecticide resistance are available at the Department of Entomology, University of Hawaii. For details, please contact: Marshall Johnson (808) 956-8432, Bruce Tabashnik (808) 956-8261, Diane Ullman (808) 956-2452

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