Resistance: The Facts - History & overview of resistance

• An Overview

Resistance to insecticides was first documented in 1914 by A.L. Melander in the *Journal of Economic Entomology*. He described scale insects, still alive, under a "crust of dried spray" of an inorganic insecticide. Between 1914 and 1946, another 11 cases of resistance to inorganic pesticides were recorded.

Then came development of organic insecticides, such as DDT, and the agricultural industry breathed a sigh of relief, believing that insecticide resistance was an issue of the past. Unfortunately, that feeling of relief quickly faded -- by 1947, housefly resistance to DDT was documented. With every new insecticide introduction -- cyclodienes, carbamates, formamidines, organophosphates, pyrethroids, even *Bacillus thuringiensis* -- cases of resistance surfaced 2 to 20 years later.

This phenomenon is described by some as the "pesticide treadmill." A rise in an insect population causes damage to a commodity; growers respond by attacking the pests with a product to reduce the damage; the pests become resistant to the chemical and the resistant strain is not controlled, which leads to the application of more chemicals. Insecticide resistance climbs, problems increase, more product is applied; eventually growers switch to another pesticide (if one is available). . . and the vicious cycle continues.

Genetics and intensive application of pesticides are responsible for the quick buildup of resistance in most insects and mites. Natural selection by an insecticide allows some insects with resistance genes to survive and pass the resistance trait on to their offspring. The percentage of resistant insects in a population continues to multiply while susceptible ones are eliminated by the insecticide.

Eventually, resistant insects outnumber susceptible ones and the pesticide is no longer effective. How quickly resistance develops depends on several factors, including how quickly the insects reproduce, the migration and host range of the pest, the crop protection product's persistence and specificity, and the rate, timing and number of applications made. Resistance increases fastest in situations such as greenhouses, where insects or mites reproduce quickly, there is little or no immigration of susceptible individuals, and the grower may spray frequently.

• Resistance is Costly; Management is Economical

It has been estimated that insecticide resistance in the United States adds $40 million to the total insecticide bill in additional treatment costs or alternative controls. Better management of pesticides by farmers and the crop experts assisting them, industry specialists say, could reduce this bill and lead to more effective, more efficient use of products.

Consider, for example, that resistance in the Colorado potato beetle (*Leptinotarsa decemlineata*) cost Michigan potato producers $16 million in crop losses in 1991. And, failed cotton production due to resistance in the budworm/bollworm pest complex in India, Thailand, and Mexico collapsed the economics of entire communities.

Despite this, insecticides and miticides are still among the most efficient tools for keeping pest populations under control. Managing pesticides to avoid resistance development is vital to sustainable production of commodities.

WHAT CAUSES RESISTANCE?

Resistance is defined as a reduction in the sensitivity of a population, which is reflected in repeated failure of a product to achieve the expected level of control when used according to the label recommendations for that pest species and where problems of product storage, application and unusual climatic or environmental conditions can be eliminated.

There are several ways insects can become resistant to crop protection products:

- Resistant insects may naturally detoxify or destroy the toxin faster than susceptible insects, or quickly rid their bodies of the toxic molecules (metabolic resistance);
- The site where the toxin usually binds in the insect has been genetically modified to reduce the product's effects (altered target-site resistance);
- Resistant insects may absorb the toxin slower than susceptible insects (penetration resistance); or
- Resistant insects may detect or recognize a danger and avoid the toxin (behavioral resistance).

Pests often utilize more than one of these mechanisms at the same time.

• Metabolic resistance.

Metabolic resistance is the most common mechanism and often presents the greatest challenge. Insects use their internal enzyme systems to break down insecticides. Resistant strains may possess greater levels or more efficient forms of these enzymes. In addition to being more efficient, these enzyme systems also may be broad spectrum, meaning they can degrade many different pesticides.

The earliest reported case of metabolic resistance was DDT-resistant houseflies. Resistance to organophosphates (e.g., carbamates, acylureas) and pyrethroids also can result from this mechanism. If metabolic resistance is suspected, it can be confirmed in a laboratory.

Rotating to a different compound to combat resistance is likely to help only if the second compound is metabolized by different enzyme systems within the target pest.

• Altered target-site resistance.

The second most common mechanism is altered target-site resistance -- a form of resistance caused by a change in the structure of the site or the number of sites where the pesticide causes toxicity to the insect. Some DDT, organophosphate and pyrethroid failures are due to target-site resistance. Changes in insect target sites have been found in several species, including tobacco budworm (*Heliothis virescens*) and the Colorado potato beetle (*Leptinotarsa decemlineata*).

Identifying this form of resistance can be done in the laboratory. Resistance management can be practiced by using different classes of compounds that target different sites; for example, rotating between carbamates and pyrethroids.

• Penetration resistance.

Penetration resistance occurs when insects, such as the housefly (*Musca domestica*), can slow absorption of chemicals into their bodies because their outer cuticle has developed barriers against the products. The bad news is that this can protect insects from a wide range of insecticides.

Penetration resistance is usually present along with other forms of resistance, and reduced penetration intensifies the effects of those other mechanisms. Penetration resistance must be diagnosed in a laboratory, and specialists advise alternating or rotating insecticides from different classes to combat penetration resistance.

• Behavioral resistance.

Behavioral resistance occurs when insects or mites are able to evade contact with insecticides through avoidance. This mechanism of resistance has been reported for several classes of insecticides, including organochlorines, organophosphates, carbamates and pyrethroids.

Insects may simply quit feeding if they come across certain insecticides, or leave the area where spraying occurred (i.e., move to underside of a sprayed leaf, move deeper in crop canopy or fly away from the target area). With transgenic plants, insects may stop short of consuming or eating enough toxin to kill them. Behavioral resistance is hard to diagnose, and few management strategies are known; but rotating or alternating insecticides should delay its effects.

WHAT CAN YOU DO ABOUT RESISTANCE?

We've now covered the background information on insecticide resistance. You know the basics on what it is, how it develops, what it can cost growers, and what forms it takes. The following sections should help you explain to growers how to delay or prevent resistance development on their farms, how to determine whether it is present, and how to manage it if it does become a problem in their operation.

An integrated approach prevents resistance. The ultimate strategy to avoid insecticide resistance is prevention. More and more crop specialists recommend insecticide resistance management programs as one part of a larger integrated pest management (IPM) approach.

Insecticide resistance management, a major IPM strategy, involves three basic components: monitoring pest complexes for population density and t

rends, focusing on economic injury levels and integrating control strategies.

• Monitoring pests.

Scouting is one of the key activities producers can implement as part of their insecticide resistance management strategy. Farmers should follow progress of insect population development in their fields (with or without the assistance of a crop consultant or advisor) to determine if and when control measures are warranted. They should monitor and consider natural enemies when making control decisions. After treatment, they should continue monitoring to assess pest populations and control.

• Focus on economic thresholds.

Insecticides should be used only if insects are numerous enough to cause economic losses that exceed the cost of the insecticide plus application. An exception might be in-furrow, at-planting treatments for early season pests that usually reach damaging levels annually. Encourage farmers to consult their local advisors about economic thresholds of target pests in their areas.

• Integrating control strategies.

Monitoring is just one element of an insecticide resistance management program. To avoid resistance, specialists say growers should consider these major resistance management strategies.

- Take an integrated approach. Incorporate as many different control mechanisms as possible. IPM-based programs will include the use of synthetic insecticides, biological insecticides, beneficial insects (predator/parasites), cultural practices, transgenic plants, crop rotation, pest-resistant crop varieties and chemical attractants or deterrents. Select insecticides with care and consider the impact on future pest populations. Avoid broad-spectrum insecticides when a narrow or specific insecticide will suffice. Even cultural practices, such as destroying overwintering areas, can play a role in managing resistance.
- Time applications correctly. Time insecticide and miticide applications against the most vulnerable life stage of the insect pest. Use spray rates and application intervals recommended by the manufacturer.
- Mix and apply carefully. As resistance increases, the margin for error in terms of insecticide dose, timing, coverage, etc., assumes even greater importance. The pH of water used to dilute some insecticides in tank mixes should be adjusted to 6 to 8. In the case of aerial application, the

swath widths should be marked, preferably by permanent markers. Spryer nozzles should be checked for blockage and wear, and be able to handle pressure adequate for good coverage. Spray equipment should be properly calibrated and checked on a regular basis. Also, in tree fruits, proper and intense pruning will allow better canopy penetration and tree coverage. Use application volumes and techniques recommended by the manufacturers and local advisors.

- Alternate different insecticide classes. Farmers should avoid selecting for resistance or cross-resistance* by repeated use, year after year, of the same insecticide or related products in the same class. Rotate insecticides across all available classes to slow resistance development. In addition, growers should avoid tank-mixing products from the same product class. Rotate product classes and modes of action, consider the impact of pesticides on beneficial insects, and use products at labeled rates and spray intervals.

* Cross-resistance occurs when a population of insects that has developed resistance to one product exhibits resistance to one or more product(s) it has never encountered. Cross-resistance is different from multiple resistance, which occurs when insects develop resistance to several compounds by expressing multiple resistance mechanisms. A classic example of cross-resistance was when many species developed resistance to DDT and subsequently had cross-resistance to pyrethroids.

- Protect beneficials. Select insecticides in a manner that causes minimum damage to populations of beneficial arthropods. Applying insecticides in a band over the row rather than broadcasting or using a product in-furrow will help maintain certain natural enemies.
- Preserve susceptible genes. Some programs try to preserve susceptible individuals within the target population by providing a haven for susceptible insects, such as unsprayed areas within treated fields, adjacent "refuge" fields, or habitat attractions within a treated field that facilitate immigration. These susceptible individuals may outcompete and interbreed with resistant individuals, diluting the impact of resistance.
- Consider crop residue options. Destroying crop residue can deprive insects of food and overwintering sites. This cultural practice will kill pesticide-resistant pests (as well as susceptible ones) and prevent them from producing resistant offspring for the next season. However, farmers should review their soil conservation requirements before removing residue.

• If Resistance is Suspected

If growers encounter control failure and suspect they have a case of insecticide resistance, it's best not to jump to any conclusions until they consult with crop specialists. Several other problems have similar symptoms, so if poor control is experienced, growers should first check for:

- Application error. Were the timing of the application and the dosage correct? Were proper product carriers used? Was the correct application method followed? Was the timing for treatment evaluation incorrect, or does the product require more than one application?
- Equipment failure. Were the spray nozzles blocked? Were all parts of the applicator functioning properly? Was the equipment calibrated for accurate application using recommended spray volumes and pressures?
- Environmental conditions. Did rain or overhead irrigation occur too soon after application? Were temperature, wind or other environmental conditions less than ideal for application?

• Be Certain It's Resistance

If resistance is suspected, there are several steps growers can take to keep the problem from mushrooming. First and foremost, they should not respray with an insecticide of the same chemical class. Their crop protection sales agent should be contacted to help evaluate the cause of control failure. He or she will call additional experts as needed to accurately confirm insecticide resistance.

To confirm resistance, an evaluation of the surviving insects for the level of detoxifying enzymes or the presence of resistant genes will be made by professionals using a number of methods. In some cases, diagnostic doses of a specific product are applied to surviving insects from the field. Depending on available resources, insects may be taken to a laboratory for immunological or DNA diagnostic techniques. Producers should always work with local crop specialists to determine appropriate monitoring and diagnostic programs for their resistance-related situations.

To manage resistant insect populations, crop specialists may want to counsel growers on the following:

- Short-term spray decisions;
- Resistance management tactics;
- Evaluating the success of a resistance management program;
- Tracking resistance status on a farm or field-by-field basis;
- Determining relative tolerance of pests and biocontrol agents.

• Resistance Management of Transgenic Plants

Insecticide resistance management will succeed if growers are willing to educate themselves on resistance management and use appropriate techniques in their total crop production systems. Industry will continue to make strides in the war on insecticide resistance through the development of new effective strategies and control technologies. Transgenic plants in the United States are the newest technologies to make their way into mainstream crop production.

Transgenic plants can help reduce the use of broad-spectrum insecticides, which have the potential to disrupt crop production by upsetting predator/pest ratios and creating secondary pest outbreaks. Transgenic plants are also more target-pest specific, so the amount of damage done to non-target organisms is eliminated, thus maintaining populations of beneficial insects. Pest control can be enhanced with transgenic plants because, typically, different regions of the entire plant contain the control agent, even those areas hard to reach with conventional sprays.

However, transgenic plants have greater potential than traditional insecticides to foster resistance development. Therefore, careful management is critical. As with traditional pesticides, growers should avoid using transgenic plants year after year in large plantings.

Just as monitoring for potential resistance is important with more traditional plants, growers who use transgenic varieties must watch closely for signs of resistance. In transgenic crops, this may be indicated by a small area of plants with pest damage typical of a non-transgenic plant. This damage may result from the accidental presence of unprotected seed, or, depending on the crop, from insects at non-susceptible life stages moving in from nearby weeds. The surviving pests can be gathered and tested for resistance to be sure.

Providing refuges (areas planted with non-transgenic seed) may also head off resistance. These areas preserve a population of pests that are still susceptible to the insect protection. When members of that population mate with any resistant insects that emerge from protected fields, their susceptible genes dilute any resistant genes in the overall population. The ideal size for refuges depends on the target pest and crop. Refer to the seed suppliers' recommendations for more specific information.

• Out of Money, Out of Time

General insecticide use is no longer the answer to pest control. Insects have developed widespread, insecticide-defeating resistance to many traditional treatments, and the industry may not have enough resources to continually develop and supply the market with new products precisely when needed to replace old ones. Growers with resistance problems do not have enough time to wait for new chemistry. It is imperative that the effectiveness of available insecticides be conserved by growers through adoption of these management principles. By working together, insecticide resistance can be managed!

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