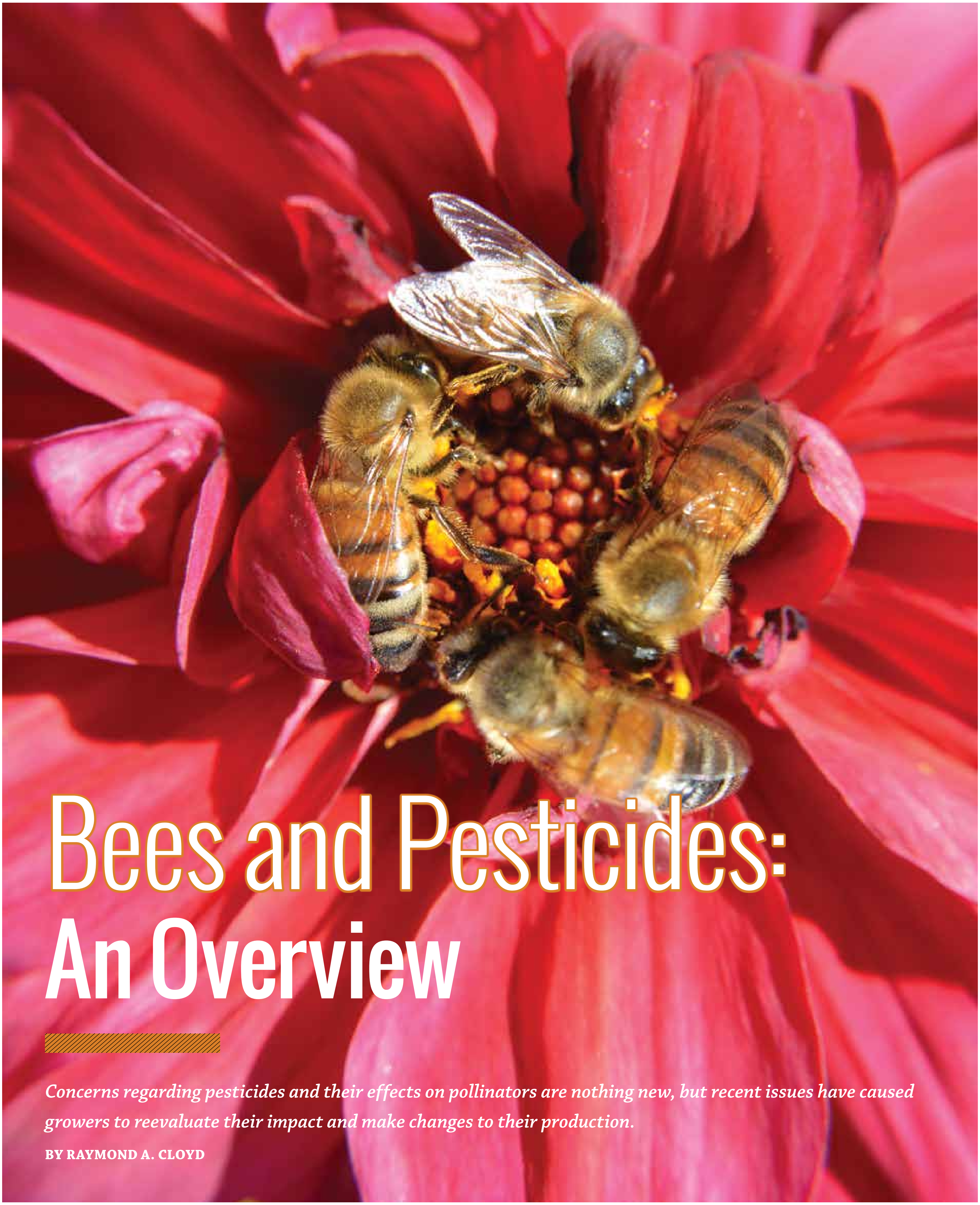

Bees and Pesticides: An Overview

Concerns regarding pesticides and their effects on pollinators are nothing new, but recent issues have caused growers to reevaluate their impact and make changes to their production.

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The issues associated with pesticides, bees and other pollinators have always been controversial. Pesticides, such as insecticides, are designed to kill insects, and bees, including the honeybees and bumblebees. As such, concerns regarding the effects of pesticides on bees are not new. However, recent issues affiliated with the impact of neonicotinoid systemic insecticides on bees (and other pollinators) have resulted in a "reassessment" regarding the impact of pesticides on bees.

Although the emphasis is primarily on the effects of neonicotinoid systemic insecticides, there are a number of non-pesticide related stress factors that are having short- and long-term effects on bee populations worldwide including parasites, diseases, habitat loss, fragmentation and habitat alteration. In some ways, these factors are more likely to have a greater impact than the effects of pesticides. In fact, habitat alteration, especially on farms, may be the most critical factor responsible for bee decline. In addition, chronic or cumulative exposure to multiple interacting stress factors may be responsible for bee losses and causing substantial reductions in wild or native pollinator populations.

The impact of pesticides on bees, however, seems to be the main issue due to the importance of bees as pollinators. The European honey bee, *Apis mellifera*, is not native to the United States; nonetheless, this species is an important pollinator of most agricultural crops, pollinating approximately 130 different crop types valued at $15 to $20 billion in the United States. Moreover, there are additional pollinators including butterflies, moths and native wild bees. In fact, nearly 75 percent of food crops worldwide depend on pollinators for pollination. Therefore, this article will provide an overview of the effects of pesticides on bees with insights on the complex factors and interactions affiliated with how pesticides affect bees. The topics of discussion include: 1) factors associated with bee behavior, 2) factors influencing pesticide exposure and bee toxicity, 3) laboratory vs. field conditions, 4) systemic insecticides, 5) neonicotinoid systemic insecticides, 6) synergism, 7) metabolites, and 8) miscellaneous pesticide interactions.

1) BEE BEHAVIOR

Bees collect pollen and nectar to feed their young (larvae), with pollen and nectar being a major source of nutrition. Adult bees tend to consume more nectar than pollen, whereas larvae prefer to feed on pollen. Bees collect pollen and nectar from multiple sources, which may dilute the effects of foraging on plants treated with insecticides. However, since bees only forage so far away from the hive, there may not be any dilution effects in large agricultural cropping systems.

Most of the pollen and/or nectar in the stomach of a foraging bee is not metabolized. Therefore, bees may only be exposed to a small portion of the insecticide contents. Afterward, nearly all of the pollen and nectar is transported back to the hive. As such, the social interactions among bees need to be considered when evaluating exposure to insecticides.

Bee age also may impact insecticide susceptibility. Moreover, body size may have a direct effect on bee sensitivity to insecticides. Larger bees are more tolerant of insecticides than smaller bees because smaller bees have a greater surface-to-volume ratio.

2) PESTICIDE EXPOSURE AND BEE TOXICITY

The demand for bees for pollination has increased three-fold, enhancing the chances of bees (e.g., honeybees and bumblebees) being exposed to pesticides. There are two types of exposure associated with pesticides (in this case, insecticides) and bees: direct and indirect.

Direct exposure is affiliated with spray residues that result in mortality of the adults. Indirect exposure occurs when dried residues on leaves and/or flowers cause direct mortality or affect behavior. A pesticide's toxicity may vary depending on the route of entry. In most instances, contact (dermal) exposure is less toxic than ingestion (oral) exposure. Although the primary focus has been on neonicotinoid systemic insecticides, other pesticides, including fungicides, can result in direct and/or indirect effects on bees.

The primary route of exposure to bees and subsequent bee poisoning occurs when workers forage on treated crops with open flowers contaminated with insecticide residues either through direct spray applications or via pollen and/or nectar that contains concentrations of the active ingredient of systemic insecticides that have been applied to the soil/growing medium.

Furthermore, any drift during spray applications of insecticides onto weeds that bees forage on may directly affect bees. Bees acquire insecticide residues when foraging on contaminated flowers, which may result in bee death. Consequently, contamination of both pollen and/or nectar is the main source of poisoning affecting honeybee populations (colonies).

Plants not in flower are less of a problem due to the absence of bees. Also, the number or density of flowers associated with a crop governs the number of bees that will visit, which influences the number of bees that may be subsequently affected. Nevertheless, residues in or on pollen and/or nectar may vary in their effects on bees. Insecticide-contaminated pollen and/or nectar returned to the hive and then fed upon by workers or immatures (larvae) may result in a decline of

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the colony. However, insecticide residues may not be present in pollen and/or nectar, and bee behavior (described above) may help to avoid contamination of honey. In addition to direct mortality, there may be sublethal effects after exposure to insecticide residues that result in negative effects on foraging behavior, reproduction, memory/learning ability, overwintering success, colony interactions, pollination and colony vigor.

Residue levels and subsequent toxicity may diminish over time as the insecticide degrades due to environmental parameters such as sunlight (ultra-violet degradation), rainfall and temperature. In fact, temperature can have a significant effect on exposure time, due to the relationship with bee activity. Temperature may impact the exposure of bees to insecticides either in or on pollen and/or nectar as bee activity is greater at temperatures greater than 55° F. However, honeybees do not leave the hive to forage when temperatures are less than 50° F, and they do not forage when night temperatures are greater than 55° F.

Temperature also may affect an insecticide's residual activity. For instance, the residual activity may vary depending on temperature as applications made during low temperatures or cool weather may result in residues remaining longer on plants, consequently increasing the potential for harmful effects to bees. Higher temperatures, however, typically result in less residual activity due to degradation of the insecticide residues, thus decreasing any potential harmful effects to bees.

There are a number of factors associated with insecticides that may impact toxicity to bees and other pollinators including formulation. An insecticide formulated as an emulsifiable concentrate may be less toxic to bees than the same insecticide in a different formulation (soluble powder). For instance, dust formulations of carbaryl (Sevin) can contaminate pollen and subsequently kill bees when insecticide residues are stored in combs or fed to immatures (larvae). However, newer formulations of carbaryl (e.g. Sevin XLR) tend to be less toxic to bees.

One of the most harmful formulations to bees is microencapsulated. Microencapsulated formulations are more toxic to bees because of electrostatic charges resulting in a strong affinity to adhere to the body of bees. The particles of microencapsulated formulations are about the same size as pollen grains, resulting in increased adhesion to the bee body. The plastic capsules may be stored in frames, possibly leading to declines in bee colonies. It also should be noted that the inert ingredients associated with formulations may be more toxic to bees than the actual active ingredient.

Time of day when an insecticide is applied can directly influence the potential effects to bees. Recommendations are always to apply insecticides in the early morning or late evening when bees are less active. In addition, avoid applying insecticides to "bee attractive" plants that are in flower. Moreover, duration of exposure is critical and varies depending on seasonality and flower type, which is primarily based on flower morphology. For example, bees have been observed to spend less time foraging on the flowers of lavender (*Lavandula* spp.) compared to apple (*Malus* spp.). Contact with floral parts is more frequent when bees visit flowers, although this may vary with flower type, which can affect duration of exposure. Differences in foraging among different flower types also may influence the cumulative effects of insecticides. Furthermore, the concentration of an active ingredient in the pollen and/or nectar may vary based on flower type. One issue is what constitutes a "field-realistic dose" in the pollen and/or nectar, which can vary depending on plant and flower type or species and flower age.

3) LABORATORY VS. FIELD CONDITIONS

There is evidence, mostly under laboratory conditions, that insecticides have direct effects and indirect effects on bees associated with learning, memory, foraging and orientation. However, laboratory studies are somewhat artificial since bees are typically fed much higher doses or concentrations of the active ingredient than would be experienced in the field, which may bias any direct and/or indirect effects that would actually occur in the field.

Consideration needs to be given to: 1) sublethal effects (mentioned previously), 2) number of feedings, 3) how the insecticide is applied in the field, and 4) the concentrations bees are exposed to may not be representative of what occurs under field situations. These are just a few of the important factors that lead to discrepancies between lab and field results. There also are issues/concerns associated with "experimental exposures" being representative of what bees may experience in the field. Also, confounding factors and interactions under field conditions are typically not taken into consideration under lab conditions. Although direct or indirect exposure to insecticides may interfere with the olfactory learning process in various ways, the extrapolation of laboratory results to real-life situations may be difficult due to subsequent complex interactions under field conditions.

Lab experiments typically feed bees with a sugar solution or a substance mixed with pollen or nectar that may affect bees differently compared to naturally collected food during foraging. Concentrations of insecticides, under laboratory conditions, may be higher than what is actually present in treated plants, and may be greater than what bees would be exposed to in the field.

Any discrepancies between lab and field studies may be associated with differences in experimental methods or procedures conducted by researchers. Laboratory conditions may be more “stressful” than field conditions, thus indirectly influencing the results obtained. Bees may change their behavior based on their perceptions of an insecticide. For instance, honeybees may reject or avoid sucrose solutions contaminated with insecticides resulting in a reduction in feeding. Thus, under field conditions, any avoidance behaviors may reduce the risk of insecticide exposure from a contaminated food source. In general, field studies have shown no long-term effects on bees (mostly honeybees) based on “environmentally relevant” concentrations or field doses of insecticides, including systemic insecticides.

4) SYSTEMIC INSECTICIDES

Systemic insecticides are those in which the active ingredient is taken up by the root system and translocated or distributed throughout the plant. These insecticides are primarily used to control phloem-feeding insects such as aphids, whiteflies, mealybugs, leafhoppers and soft scales. Systemic insecticides may persist and accumulate in soils although this depends on the number of applications, application rate, persistence and soil type.

In agricultural cropping systems, seed treatments of neonicotinoid systemic insecticides appear to be a major concern. The primary issue has been associated with the aerial dust emitted during planting of seeds that may directly impact bees even though there may not be plants in flower during the planting season. In regards to flowering plants, another issue associated with systemic insecticides is related to concentrations in the pollen and/or nectar, and if concentrations are “high” enough to cause direct or indirect harmful effects. Plus, the concentration of an active ingredient within the pollen and/or nectar may vary across crops and stage of plant growth. The exposure risk to systemic insecticides will be affected by 1) bee body size, 2) flower preference, 3) social behavior of bees, and 4) time of year when

bees are active, which coincides with flowering of treated crops. The potential risks associated with systemic insecticides is not new as previous studies conducted in the 1960s demonstrated that certain systemic insecticides were harmful to bees. In addition, the book, "Silent Spring" (1962) by Rachel Carson, mentions the potential effects of systemic insecticides to bees.

The distribution of flowering plants will influence the exposure risks of bees to systemic insecticides due to the variations in foraging distance. The length of time that bees visit flowers and availability of alternative (suitable) floral resources (contaminated or not) also will impact the direct and indirect effects of systemic insecticides on bees. Moreover, distance between treated fields, nest sites and bee hives may affect the level of exposure with foraging distances influenced by distribution of flowering plants. In addition, the distance of colonies from treated areas may affect the level of bee kills.

The impact of systemic insecticides needs to be investigated on whole colonies, not just individuals. Most research has focused on the effects of systemic insecticides on adults, although the potential exposure (direct or indirect) to larvae also should be considered. In fact, larval development may be impaired or delayed when exposed to the active ingredient of certain systemic insecticides.

In general, systemic insecticides applied as a granule to the soil and before bloom are less harmful to bees. Some systemic insecticides may repel honeybees, which impacts exposure and consequently the ability to pollinate crops. Another issue is associated with flowering weeds visited by bees located in nurseries in which systemic insecticides have been applied, where the leachate may be subsequently absorbed by the roots. Therefore, systemic insecticides, such as neonicotinoid systemic insecticides, should never be applied to plants or weeds in flower.

5) NEONICOTINOID SYSTEMIC INSECTICIDES

Neonicotinoid systemic insecticides are used widely in many facets of agriculture and horticulture including turfgrass, ornamentals, field crops, vegetables and fruit crops. There are two groups of neonicotinoids that vary in their toxicity to bees: nitro and cyano-groups. The nitro-group or *N*-nitroguanidines, including imidacloprid, thiamethoxam, dinotefuran and clothianidin are more directly toxic to bees because they generally last longer in the environment. For example, the soil half-life of the nitro-group is between 75 and 350 days. However, the cyano-group or *N*-cyanoamidines, which includes acetamiprid, are less toxic to bees primarily due to rapid metabolism and a different target site (sub-type) on the nicotinic acetylcholine receptor.

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For instance, acetamiprid (and subsequent metabolites) is, in general, less harmful to bees because the active ingredient is rapidly metabolized by bees. In addition, reports indicate that acetamiprid has a half-life in the soil of less than 25 days. However, it should be noted that acetamiprid can only be applied as a foliar spray.

The levels or concentrations of active ingredients associated with neonicotinoid systemic insecticides in the pollen and/or nectar that bees may be exposed to varies depending on factors such as plant type or species, application rate, formulation and timing of application. Furthermore, neonicotinoid systemic insecticides, such as imidacloprid, have repellent activity. However, any repellent effects may vary depending on the concentration of the active ingredient in the plant, which will subsequently influence exposure of bees, and possibly plant pollination.

6) SYNERGISM

Synergism is associated with a reaction where a chemical that has no insecticidal properties may enhance the toxicity of an insecticide in a mixture. Therefore, synergism may enhance the toxicity of pesticide mixtures to bees. Bees are often chronically exposed to pesticide mixtures or multiple pesticides simultaneously throughout their adult life, which may result in synergistic effects. Honeybees, in general, are rarely exposed to or encounter a single pesticide during foraging. Consequently, any combined exposures may result in synergistic interactions. The synergistic effects affiliated with multiple pesticide exposure may contribute to bee decline. Furthermore, pyrethroid insecticides, systemic insecticides and fungicides are typically available as pre-mixtures (combination products) for plant protection. The active ingredients in pre-mixtures may be synergistic, enhancing toxicity to bees — although these effects are not well-understood and any effects may vary over space (spatially) and time (temporally). In fact, reports have demonstrated that mixtures of neonicotinoid systemic insecticides with certain fungicides may substantially increase bee toxicity.

Pesticide mixtures or combinations of pesticides that include certain fungicides have been reported to enhance the acute toxicity or synergize the activity of insecticides to bees (honeybees in particular). For instance, certain insecticides (not neonicotinoid systemic insecticides) are synergized by ergosterol biosynthesis inhibitor or demethylation inhibitor fungicides, thus increasing bee toxicity. Studies have shown that ergosterol biosynthesis inhibitor fungicides may enhance the toxicity of certain neonicotinoid systemic insecticides and pyrethroids by as much as 1,000-fold. In addition, even the synergist piperonyl butoxide (PBO), when present in pollen and/or nectar, has been shown to increase the toxicity of some neonicotinoid systemic insecticides to bees.

7) METABOLITES

Most systemic insecticides, in general, are converted into metabolites, which are the end products associated with chemical reactions that occur naturally within cells during metabolism.

The metabolites of systemic insecticides are generally more toxic to insect pests than the parent compound. For instance, the metabolites of imidacloprid, including olefin and 4- and 5-hydroxy, may be toxic to bees. Thiamethoxam is converted into the metabolite clothianidin (another neonicotinoid systemic insecticide) that is highly toxic to bees. One issue is the seasonal and geographic differences associated with the frequency of detecting metabolites in the pollen and/or nectar. These metabolites may be present in pollen and/or nectar, subsequently increasing the potential for harmful effects to bees. However, the concentrations in the pollen and/or nectar may vary thus influencing direct exposure.

8) MISCELLANEOUS INTERACTIONS

Another important issue is the interactions associated with miticides used in managing the varroa mite (*Varroa destructor*) in honeybee colonies, which can have indirect effects on honey bee queen longevity. In addition, other pesticides may be encountered by bees. In fact, one of the pesticides most commonly detected in bee hives is the fungicide chlorothalonil. Although herbicides do not directly harm bees, they may reduce the availability of flowering plants for bees and other pollinators, especially in monoculture agricultural farming systems.

CONCLUSIONS

This article has discussed a number of factors affiliated with the complexity and interactions related to pesticides and bees. The contents of this article are based on the abundant scientific literature associated with research conducted on the effects of pesticides on bees. Therefore, I would like to acknowledge the many researchers worldwide that continue to conduct studies that will help to understand and determine how pesticides impact bees. gpn

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