ENY-2110
https://doi.org/10.32473/edis-IN1429-2024

A Guide to Selecting and Using Pesticides During the Blueberry Pollination Period: How Can We Reduce Risk to Pollinators?[1]

Rachel E. Mallinger, John J. Ternest, and Douglas A. Phillips[2]

Introduction

This publication includes information blueberry growers should consider when selecting fungicides and insecticides to apply during bloom and application strategies to minimize harm to pollinators. Insect pollinators, particularly wild and managed bees, are necessary to achieve adequate fruit set and marketable berries in southern highbush blueberry production. Bees facilitate both self-pollination, including pollination within an individual flower or bush, and cross-pollination, or that between bushes of different cultivars. In the absence of insect pollinators, berries may form, but they will be significantly smaller and misshapen and will take longer to ripen than bee-pollinated berries (Danka et al. 1993; Campbell et al. 2018; Mallinger et al. 2021). For these reasons, insect pollinators are essential to the production of marketable and profitable southern highbush blueberries.

Blueberry growers in Florida typically stock their fields with honey bees (*Apis mellifera*) as well as managed bumble bees (*Bombus impatiens*) (Mallinger et al. 2021). Wild insect pollinators, including the native southeastern blueberry bee (*Habropoda laboriosa*), native carpenter bees (*Xylocopa* spp.), and native butterflies and wasps, also contribute to pollination (Campbell et al. 2018; Mallinger et al. 2021; Rogers et al. 2014). Both managed and wild pollinators are susceptible to pesticide applications, especially when those applications occur during the bloom period when pollinators are actively foraging in blueberry fields. Growers must balance disease and pest protection and adequate insect pollination.

How are insect pollinators exposed to pesticides?

Pollinators can be exposed to pesticides in several ways (Figure 1), including those listed below:

1. This document is ENY2110, one of a series of the Entomology and Nematology Department, UF/IFAS Extension. Original publication date August 2024. Visit the EDIS website at https://edis.ifas.ufl.edu for the currently supported version of this publication.

2. Rachel E. Mallinger, assistant professor, pollinator ecology and conservation, Entomology and Nematology Department; John J. Ternest, PhD student; and Douglas A. Phillips, blueberry Extension coordinator, Horticultural Sciences Department; UF/IFAS Extension, Gainesville, Florida 32611.

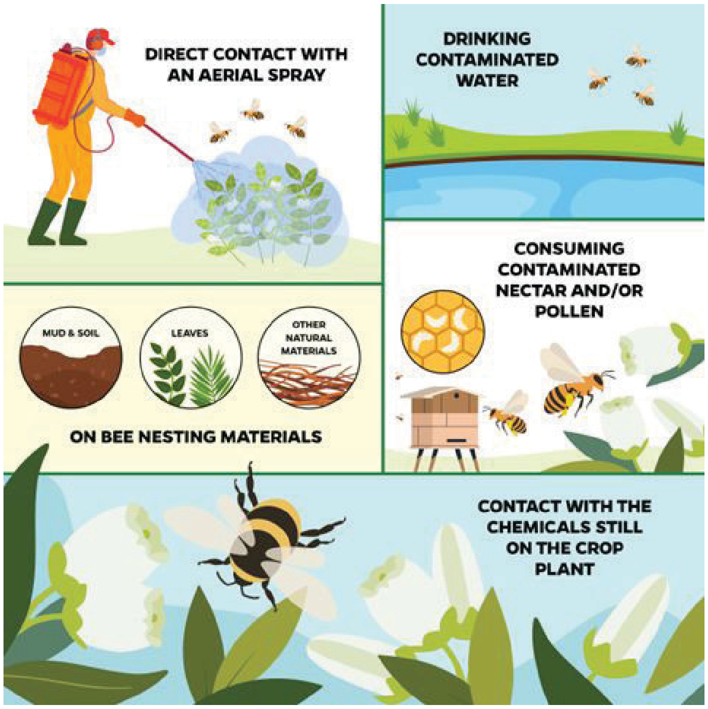

Figure 1. Different ways in which bee pollinators can be exposed to pesticides in blueberry fields.
Credits: Tracy Bryant, UF/IFAS

- Direct contact with an aerial spray: most likely to happen if the pesticide is sprayed during the day and in favorable weather for pollinator activity (warm and relatively sunny).
- Contact with the chemical while it is still active on the crop plant during the period of residual activity: most likely to happen when pesticides are applied in the daytime and during weather favorable for pollinator activity. This also includes contact with pesticide residues on flowering weeds within the crop field or in the vicinity of the crop field.
- Drinking contaminated water: this is particularly an issue when pesticides are applied via irrigation. If there are leaks in the drip irrigation system, or if water pools in low areas of the field, bees may drink the contaminated water. Pesticide residues from other modes of application may also be present in surface or groundwater.
- Consuming contaminated nectar and/or pollen: this is particularly an issue for systemic products. If the pesticide is systemic (i.e., taken up by the plant and expressed throughout the plant tissues), it may be present in the nectar and pollen of the crop plant even well after application. Though the concentration of the pesticide within nectar or pollen is often relatively low, consuming contaminated pollen or nectar can have sublethal effects on adult bees or lethal effects on the bee brood (Yang et al. 2008; Whitehorn et al. 2012; Stoner and Eitzer 2012).
- Via bee nesting materials, including soil, mud, leaves, and other natural materials. Wild bees use a variety of natural materials to create their nests. Contaminated soil, leaves, or other materials can harm wild bee larvae living and growing in these nests. Systemic insecticides have proven to be highly mobile, which increases the likelihood that they will contaminate nesting materials (Goulson 2013; Main et al. 2014; Long and Krupke 2016).

How do pesticides affect pollinators?

The effects of pesticides on pollinators can broadly be classified into lethal and sublethal effects. Lethal effects occur when the pesticide directly kills either adult foraging bees or developing brood. Lethal effects are typically measured by exposing adult honey bees to different concentrations of the pesticide both in contact exposure and oral exposure and determining the lethal dose or lethal concentration that kills 50% of individuals (i.e., the LD/LC 50). The lethal toxicity of a pesticide is sometimes examined with developing brood or with other pollinator species (e.g., bumble bees) and can vary significantly across life stages and species (Mussen et al. 2004; Wade et al. 2019).

In addition to lethal effects, pesticides can have a variety of sub-lethal effects on bees that include impaired learning and memory in adult foragers, weakened immune systems in adults and brood, and a reduction in reproduction, including fewer new queens or fewer total offspring. Pesticide exposure can also affect behaviors directly relevant for pollination, such as the overall foraging activity of individual bees or the attraction of bees to the crop plants (Morandin et al. 2005; Mommaerts et al. 2010; Wu et al. 2011; Gill et al. 2012; Tschoeke et al. 2019).

Pesticides can also interact with one another, especially when they are applied in tank mixes. Some pesticides are known to have synergistic effects, i.e., they enhance the toxicity of other pesticides applied simultaneously. This is especially true for fungicides; while many fungicides are not highly toxic by themselves, they have been found to increase the toxicity of insecticides when both are applied together (Pilling and Jepson 1993; Manning et al. 2017; Wade et al. 2019; Bigante et al. 2021). Fungicides have also been found to have significant sublethal effects on bees, including weakening bee immune systems. For these reasons, while many fungicides are not considered highly toxic to bees, care should be taken when applying them during bloom, especially when applying them simultaneously with insecticides.

Selecting Pesticides During Blueberry Bloom

Insecticides and fungicides that are commonly applied during blueberry bloom in Florida are listed below in alphabetical order of the active ingredient (note that this may not be an exhaustive list) along with their general toxicity to bees and aspects of residual activity or persistence in the environment (Tables 1 and 2). The general toxicity rating is based on the LC/LD 50 to honey bees measured through contact and/or oral exposure with practically non-toxic > 50 ug/bee; low toxicity < 50 and > 11 ug/bee; moderate toxicity < 11 and > 2 ug/bee; and high toxicity < 2 ug/bee (1 ug = 1/1,000,000 g and 1 g ~ 1/30 oz). Note that, counterintuitively, higher-toxicity products have a lower LC/LD 50, indicating that less active ingredient is needed to result in 50% mortality. A high LD/LC 50 conversely means that a large amount of active ingredient is needed to result in 50% mortality, and thus the product is less toxic. When selecting a product to apply during bloom, it is important to look not only at its toxicity but at whether it is systemic, whether it will persist in the environment (i.e. have persistent residual activity), and whether it may produce synergisms (interactions with other chemicals that may increase toxicity of one or more of the chemicals).

Tips for Limiting Pesticide Effects on Bees and Other Pollinators

The following tips can help with decision making and reducing pollinator exposure to pesticides during the blueberry bloom period (Figure 2):

- Implement IPM strategies and other control methods to limit chemical sprays during bloom.
- Use existing action thresholds when possible.
- Follow label instructions. Many products with a high toxicity to bees specify that the product should not be applied in any mode of application during bloom and/or when bees are in the crop field.
- When possible, and especially during bloom, select a non-systemic insecticide with a short residual activity and no to low toxicity to bees.
- When possible, avoid using tank mixes of insecticides and fungicides during the bloom period to reduce synergistic effects.
- Apply pesticides, including fungicides and insecticides, in the evening to allow for the longest period of time to pass before bees forage. Cool temps and/or wet conditions may prolong residual activity.
- If using a pesticide with a moderate to high toxicity to bees during bloom, be sure to follow label instructions and also contact your beekeeper in advance so that they can consider moving or covering hives during application and for a period of time after application.

References

BASF. 2010. Safety Data Sheet Cabrio EG [Data Sheet]. BASF The Chemical Company.

Benjamin, F. E., and R. Winfree. 2014. “Lack of Pollinators Limits Fruit Production in Commercial Blueberry (*Vaccinium corymbosum*).” *Environmental Entomology* 43:1574–1583. https://doi.org/10.1603/EN13314

Besard, L., V. Mommaerts, G. Abdu-Alla, and G. Smagghe. 2011. “Lethal and Sublethal Side-Effect Assessment Supports a More Benign Profile of Spinetoram Compared with Spinosad in the Bumblebee *Bombus terrestris*.” *Pest Management Science* 67:541–547. https://doi.org/10.1002/ps.2093

Brigante, J., J. O. Costa, E. L. G. Espíndola, and M. A. Daam. 2021. “Acute Toxicity of the Insecticide Abamectin and the Fungicide Difenoconazole (Individually and in Mixture) to the Tropical Stingless Bee *Melipona scutellaris*.” *Ecotoxicology* 30:1872–1879. https://doi.org/10.1007/s10646-021-02458-7

Campbell, J. W., C. B. Kimmel, M. Bammer, C. Stanley-Stahr, J. C. Daniels, and J. D. Ellis. 2018. “Managed and Wild Bee Flower Visitors and Their Potential Contribution to Pollination Services of Low-Chill Highbush Blueberry (*Vaccinium corymbosum* L.; Ericales: Ericaceae).” *Journal of Economic Entomology* 111:2011–2016. https://doi.org/10.1093/jee/toy215

Danka, R. G., G. A. Lang, and C. L. Gupton. 1993. “Honey Bee (Hymenoptera: Apidae) Visits and Pollen Source Effects on Fruiting of ‘Gulfcoast’ Southern Highbush Blueberry.” *Journal of Economic Entomology* 86:131–136. https://doi.org/10.1093/jee/86.1.131

Federoff, N. E., J. Melendez, and F. Khan. 2001. EFED RED Chapter for Ziram [Memorandum]. United States Environmental Protection Agency, Washington, D.C.

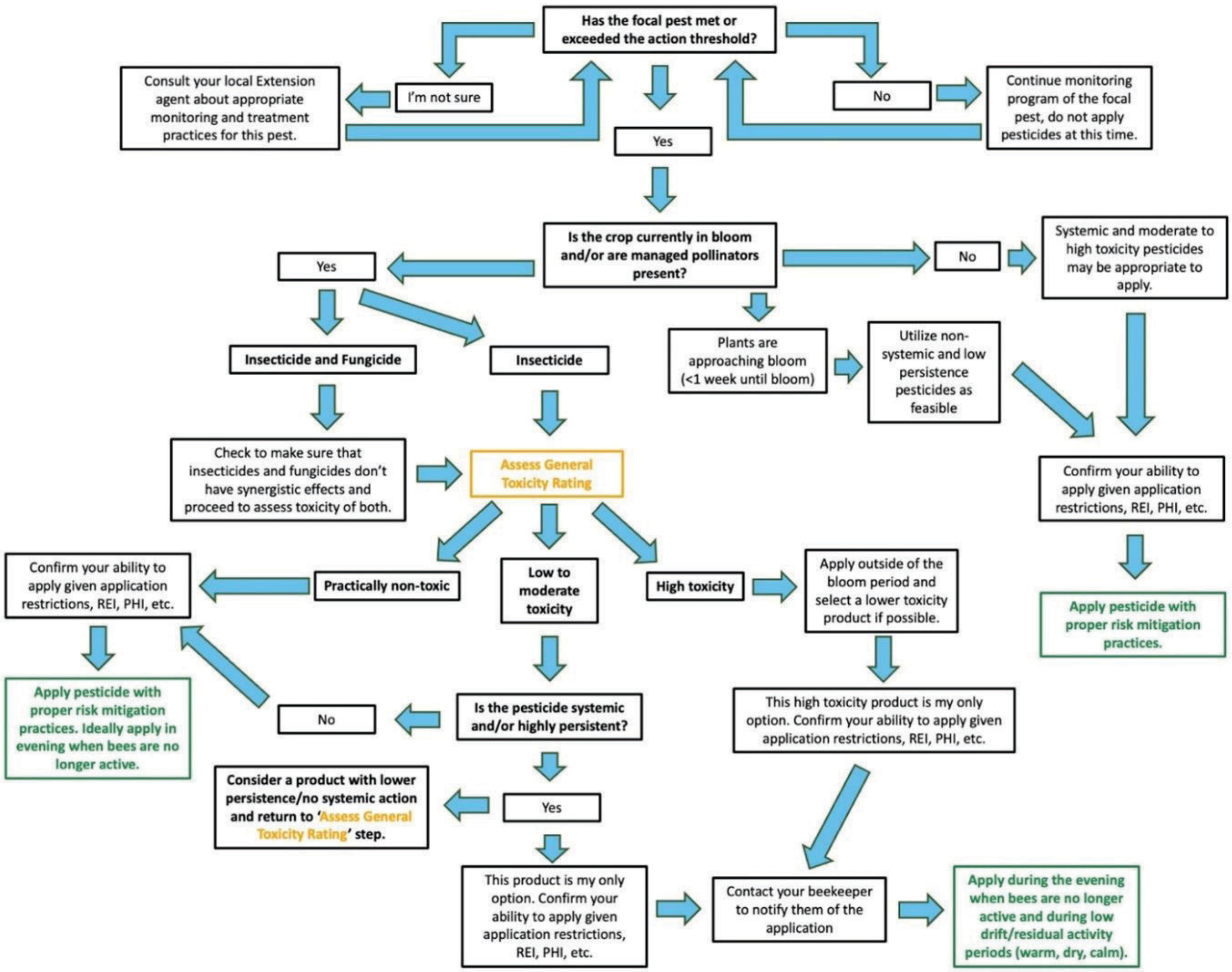

Figure 2. Decision tree with things to consider when selecting and applying pesticides during blueberry bloom. This decision tree should be considered a guide for choosing insecticides and not a specific recommendation or endorsement of any particular pesticides. Follow all label instructions and guidelines for all applications.
Credits: John Ternest and Rachel Mallinger, UF/IFAS

Fisher, A., T. Cogley, C. Ozturk, G. DeGrandi-Hoffman, B. H. Smith, O. Kaftanoglu, J. H. Fewell, and J. F. Harrison. 2021. "The Active Ingredients of a Mitotoxic Fungicide Negatively Affect Pollen Consumption and Worker Survival in Laboratory-Reared Honey Bees (*Apis mellifera*)." *Ecotoxicology and Environmental Safety* 226:112841. https://doi.org/10.1016/j.ecoenv.2021.112841

Gad, S. C., and T. Pham. 2014. "Propiconazole." In Encyclopedia of Toxicology (Third Edition), edited by P. Wexler, 1101–1104. Oxford: Academic Press. https://doi.org/10.1016/B978-0-12-386454-3.01203-3

Gajbhiye, V. T., S. Gupta, I. Mukherjee, S. B. Singh, N. Singh, P. Dureja, and Y. Kumar. 2011. "Persistence of Azoxystrobin in/on Grapes and Soil in Different Grapes Growing Areas of India." *Bulletin of Environmental Contamination and Toxicology* 86:90–94. https://doi.org/10.1007/s00128-010-0170-2

Gill, R. J., O. Ramos-Rodriguez, and N. E. Raine. 2012. "Combined Pesticide Exposure Severely Affects Individual- and Colony-Level Traits in Bees." *Nature* 491:105–108. https://doi.org/10.1038/nature11585

Goulson, D., 2013. "An Overview of the Environmental Risks Posed by Neonicotinoid Insecticides." *Journal of Applied Ecology* 50 (4): 977–987. https://doi.org/10.1111/1365-2664.12111

Lewis, K. A., J. Tzilivakis, D. J. Warner, and A. Green. 2016. "An International Database for Pesticide Risk Assessments and Management." *Human and Ecological Risk Assessment: An International Journal* 22:1050–1064. https://doi.org/10.1080/10807039.2015.1133242

Long, E. Y., and C. H. Krupke. 2016. "Non-Cultivated Plants Present a Season-Long Route of Pesticide Exposure for Honey Bees." *Nature Communications* 7 (1): 11629. https://doi.org/10.1038/ncomms11629

Main, A. R., J. V. Headley, K. M. Peru, N. L. Michel, A. J. Cessna, and C. A. Morrissey. 2014. "Widespread Use and Frequent Detection of Neonicotinoid Insecticides in Wetlands of Canada's Prairie Pothole Region." *PLOS ONE* 9 (3): 92821. https://doi.org/10.1371/journal.pone.0092821

Mallinger, R., J. J. Ternest, and S. M. Naranjo. 2021. "Blueberry Yields Increase with Bee Visitation Rates, but Bee Visitation Rates Are Not Consistently Predicted by Colony Stocking Densities." *Journal of Economic Entomology* 114:1441–1451. https://doi.org/10.1093/jee/toab111

Manning, P., K. Ramanaidu, and G. C. Cutler. 2017. "Honey Bee Survival Is Affected by Interactions between Field-Relevant Rates of Fungicides and Insecticides Used in Apple and Blueberry Production." *FACETS* 2:910–918. https://doi.org/10.1139/facets-2017-0025

Maus, C. 2008. "Ecotoxicological Profile of the Insecticide Spirotetramat." *Bayer CropSci. J.* 61.

Mayes, M. A., G. D. Thompson, B. Husband, and M. M. Miles. 2003. "Spinosad Toxicity to Pollinators and Associated Risk." *Reviews of Environmental Contamination and Toxicology* 179:37–71. https://doi.org/10.1007/0-387-21731-2_2

Miles, M., M. Mayes, and R. Dutton. 2002. "The Effects of Spinosad, a Naturally Derived Insect Control Agent, to the Honeybee (*Apis melifera*)." Meded Rijksuniv Gent Fak Landbouwkd Toegep Biol Wet 67:611–616.

Minnesota Department of Agriculture. 2014. Tolfenpyrad New Use Review [Fact Sheet]. St. Paul, MN, USA.

Mommaerts, V., S. Reynders, J. Boulet, L. Besard, G. Sterk, and G. Smagghe. 2010. "Risk Assessment for Side-Effects of Neonicotinoids against Bumblebees With and Without Impairing Foraging Behavior." *Ecotoxicology* 19:207–215. https://doi.org/10.1007/s10646-009-0406-2

Morandin, L. A., M. L. Winston, M. T. Franklin, and V. A. Abbott. 2005. "Lethal and Sub-Lethal Effects of Spinosad on Bumble Bees (*Bombus impatiens* Cresson)." *Pest Management Science* 61:619–626. https://doi.org/10.1002/ps.1058

Mussen, E. C., J. E. Lopez, and C. Y. S. Peng. 2004. "Effects of Selected Fungicides on Growth and Development of Larval Honey Bees, *Apis mellifera* L. (Hymenoptera: Apidae)." *Environmental Entomology* 33:1151–1154. https://doi.org/10.1603/0046-225X-33.5.1151

Nauen, R, P. Jeschke, R. Velten, M. E. Beck, U. Ebbinghaus-Kintscher, W. Thielert, K. Wölfel, M. Haas, K. Kunz, and G. Raupach. 2015. "Flupyradifurone: A Brief Profile of a New Butenolide Insecticide." *Pest Management Science* 71:850–862. https://doi.org/10.1002/ps.3932

Olker, J. H., C. M. Elonen, A. Pilli, A. Anderson, B. Kinziger, S. Erickson, M. Skopinski, A. Pomplun, C. A. LaLone, C. L. Russom, and D. Hoff. 2022. "The ECOTOXicology Knowledgebase: A Curated Database of Ecologically Relevant Toxicity Tests to Support Environmental Research and Risk Assessment." *Environmental Toxicology and Chemistry* 41:1520–1539. https://doi.org/10.1002/etc.5324

Pilling, E. D., and P. C. Jepson. 1993. "Synergism between EBI Fungicides and a Pyrethroid Insecticide in the Honeybee (*Apis mellifera*)." *Pest Management Science* 39:293–297. https://doi.org/10.1002/ps.2780390407

Rogers, S. R., D. R. Tarpy, and H. J. Burrack. 2014. "Bee Species Diversity Enhances Productivity and Stability in a Perennial Crop." *PLOS ONE* 9:e97307. https://doi.org/10.1371/journal.pone.0097307

Stoner, K. A., and B. D. Eitzer. 2012. "Movement of Soil-Applied Imidacloprid and Thiamethoxam into Nectar and Pollen of Squash (*Cucurbita pepo*)." *PLOS ONE* 7:e39114. https://doi.org/10.1371/journal.pone.0039114

Tschoeke, P. H., E. E. Oliveira, M. S. Dalcin, M. C. A. C. Silveira-Tschoeke, R. A. Sarmento, and G. R. Santos. 2019. "Botanical and Synthetic Pesticides Alter the Flower Visitation Rates of Pollinator Bees in Neotropical Melon Fields." *Environmental Pollution* 251:591–599. https://doi.org/10.1016/j.envpol.2019.04.133

United States Environmental Protection Agency, 1997. EPA Pesticide Fact Sheet Azoxystrobin [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 1998. EPA Pesticide Fact Sheet Mono- and d-potassium salts of phosphorous acid [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 1999. EPA R.E.D. Facts Captan [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 1999. EPA Pesticide Fact Sheet Fenhexamid [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 1999. EPA Reregistration Eligibility Decision Chlorothalonil [Archive Document]. US EPA, Washington D.C.

United States Environmental Protection Agency, 2001. EPA Pesticide Fact Sheet Fluazinam [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 2002. EPA Pesticide Fact Sheet Acetamiprid [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 2003. EPA Pesticide Fact Sheet Boscalid [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 2004. EPA R.E.D. Facts Ziram [Fact Sheet]. US EPA, Washington D.C.

United States Environmental Protection Agency, 2007. EPA Pesticide Fact Sheet Metconazole [Fact Sheet]. US EPA, Washington D.C.

Wade, A., C.-H. Lin, C. Kurkul, E. R. Regan, and R. M. Johnson. 2019. "Combined Toxicity of Insecticides and Fungicides Applied to California Almond Orchards to Honey Bee Larvae and Adults." *Insects* 10:20. https://doi.org/10.3390/insects10010020

Wilhelmy, H. 2004. JAU 6476 a.i. acute effects on the honeybee *Apis mellifera*. [Laboratory Report]. Dr. U. Noach Laboratorium, Sarstedt, Germany.

Whitehorn, P. R., S. O'Connor, F. L. Wackers, and D. Goulson. 2012. "Neonicotinoid Pesticide Reduces Bumble Bee Colony Growth and Queen Production." *Science* 336:351–352. https://doi.org/10.1126/science.1215025

Wu, J. Y., C. M. Anelli, and W. S. Sheppard. 2011. "Sub-Lethal Effects of Pesticide Residues in Brood Comb on Worker Honey Bee (*Apis mellifera*) Development and Longevity." *PLoS ONE* 6:e14720. https://doi.org/10.1371/journal.pone.0014720

Yang, E. C., Y. C. Chuang, Y. L. Chen, and L. H. Chang. 2008. "Abnormal Foraging Behavior Induced by Sublethal Dosage of Imidacloprid in the Honey Bee (Hymenoptera: Apidae)." *Journal of Economic Entomology* 101:1743–1748. https://doi.org/10.1603/0022-0493-101.6.1743

Table 1. Fungicides applied during blueberry bloom, their toxicity and persistence, and special considerations. For residual activity, the half-life listed refers to the amount of time it takes for pesticide residue quantities to be reduced by half.

Chemical	General toxicity rating (high, moderate, low, practically non-toxic)	LC/LD 50 to honey bees (ug/bee)	Mode of action	Systemic/ non-systemic	Residual activity (can be highly variable across studies)	Notes on use/special considerations
Azoxystrobin (ex. Abound): Source: US EPA 1997	Practically non-toxic	> 200 contact	Strobilurin, inhibition of electron transport	Systemic	Moderately persistent in soil; 5–12 day half-life on plants (Gajbhiye et al. 2011)	Number of hoverfly larvae produced was significantly and adversely affected at 0.22 lb/acre
Azoxystrobin and Difenoconazole (ex. Quadris Top) See above for info on Azoxystrobin. Included here is info on Difenconazole Source: Lewis et al. 2016	Practically non-toxic	> 100 contact and > 177 oral	Demethylation (sterol) inhibitor	Systemic	Persistent to very persistent in soil	
Boscalid and Pyraclostrobin (ex. Pristine) For Boscalid: US EPA 2010 For Pyraclostrobin: BASF 2010 For both: Fisher et al. 2010	Practically non-toxic (Boscalid) Practically non-toxic (Pyraclostrobin)	> 166 oral and > 200 contact (Boscalid) > 100 (not specified whether oral or contact) (Pyraclostrobin)	Inhabitation of mitochondrial ATP production in fungal cells (Boscalid) Strobilurin (Pyraclostrobin)	Somewhat systemic (Boscalid) Systemic (Pyraclostrobin)	Degrades slowly, relatively persistent (Boscalid)	Evidence of toxicity to developing brood and worker survival (Boscalid) Evidence of reduced pollen consumption by bees (Pyraclostrobin)
Captan Source: US EPA 1999; Lewis et al. 2016; Mussen et al. 2004	Low toxicity to practically non-toxic depending on study and exposure	> 10 contact and > 100 oral	Respiration inhibitor; non-specific thiol reactant	Non-systemic	Soil half-life <1 to 10 days; foliar half-life of 3–13 days	May be more toxic to developing larvae via oral exposure
Chlorothalonil (ex. Bravo) Source: US EPA 1999	Practically non-toxic	> 181 (not specified whether oral or contact)	Unknown	Non-systemic	Foliar half-life not available; relatively persistent in soil and water; estimated half-life 7–30 days	42-day pre-harvest interval
Copper Hydroxide and other copper-containing products Source: Lewis et al. 2016	Low toxicity to practically non-toxic depending on exposure	> 44.46 contact and > 49 oral	Disrupts enzyme system of fungi; multi-site activity	Non-systemic		
Cyprodinil and Difenoconazole (ex. Inspire Super) Source: Lewis et al. 2016 (both)	Practically non-toxic (both)	> 75 contact and > 112 oral (Cyprodinil) >100 contact and > 177 oral (Difenoconazole)	Inhibits protein synthesis (Cyprodinil); demethylation during sterol synthesis (Difenoconazole)	Systemic (both)	Moderately persistent (Cyprodinil) Persistent (Difenoconazole)	Some evidence for synergisms with insecticide Abamectin (Difenoconazole)

Chemical	General toxicity rating (high, moderate, low, practically non-toxic)	LC/LD 50 to honey bees (ug/bee)	Mode of action	Systemic/ non-systemic	Residual activity (can be highly variable across studies)	Notes on use/special considerations
Cyprodinil and Fludioxonil (ex. Switch) See above for Cyprodinil. Source for Fludioxonil: Lewis et al. 2016	Practically non-toxic (Fludioxonil)	> 100 contact and oral (Fludioxonil)	Pyrrole fungicide; inhibits transport-associated phosphorylation of glucose, reducing mycelial growth (Fludioxonil)	Non-systemic (Fludioxonil)	Long residual activity (Fludioxonil)	
Fenbuconazole (ex. Indar) Source: Lewis et al. 2016	Practically non-toxic	> 200 contact	Inhibits sterol biosynthesis	Systemic	Moderately to very persistent in soil	
Fenhexamid (ex. Elevate) Source: US EPA 1999; Lewis et al. 2016	Practically non-toxic	>200 contact and > 100 oral	Disrupts membrane function	Locally systemic	Not persistent under aerobic conditions	
Fluazinam (ex. Omega) Source: US EPA 2001; Lewis et al. 2016	Practically non-toxic	> 200 contact and > 100 oral	Has some acaricide properties; uncoupler of oxidative phosphorylation	Non-systemic	Moderately persistent	Also tested on bumble bees and mason bees, not toxic (>200 ug/bee)
Fluopyram and Pyrimethanil (ex. Luna Tranquility) Source: Lewis et al. 2016 (both)	Practically non-toxic (both)	> 100 oral and contact (Fluopyram) > 100 oral and contact (Pyrimethanil)	Succinate dehydrogenase inhibitor (Fluopyram) Anilinopyrimidine; inhibits methionine protein synthesis (Pyrimethanil)	Systemic (both)	Persistent in soil (Fluopyram) Moderately persistent in soil (Pyrimethanil)	Has nematicide activity (Fluopyram)
Fosetyl – Al (ex. Aliette) Source: US EPA 1991; Lewis et al. 2016	Practically non-toxic	> 100 oral and contact	Organophosphate fungicide	Systemic	Degrades rapidly in soil but is persistent on vegetation	
Mefenoxam (ex. Ridomil) Source: Lewis et al. 2016	Practically non-toxic	> 100 contact and > 97 oral	Disrupts fungal nucleic acid synthesis	Systemic	Moderately stable under normal environmental conditions	
Metconazole (ex. Quash) Source: US EPA 2007; Lewis et al. 2016	Practically non-toxic	> 100 contact, 85 oral, 50 chronic	Ergosterol biosynthesis inhibitor	Systemic	Moderately persistent	Also non-toxic to bumble bees (> 100 ug/bee)
Oxathiapiprolin (ex. Orondis) Source: Lewis et al. 2016; Olker et al. 2022	Practically non-toxic	> 100 contact and > 40 oral	Oxysterol-binding protein homologue inhibition	Systemic	Moderately to highly persistent in soil; high persistence in water	
Phosphorous acid (ex. K-Phite) US EPA1998	Practically non-toxic	NA	Fungicide, bactericide (general)	Systemic	NA	

Chemical	General toxicity rating (high, moderate, low, practically non-toxic)	LC/LD 50 to honey bees (ug/bee)	Mode of action	Systemic/ non-systemic	Residual activity (can be highly variable across studies)	Notes on use/special considerations
Propiconazole (ex. Tilt) Source: Gad and Tham 2014; Wade et al. 2019	Practically non-toxic	> 100 ug/bee (not specified oral or contact)	Triazole-based; ergosterol biosynthesis inhibitor	Systemic	Slightly persistent to persistent in terrestrial environments	Evidence of synergisms with insecticides, specifically Chlorantraniliprole
Propiconazole and Azoxystrobin (ex. Aframe Plus, Quilt Xcel) *see these active ingredients separately above	See above	See above	See above	See above	See above	See above
Prothioconazole (ex. Proline) Source: Wilhelmy 2004	Practically non-toxic	> 71 oral and > 200 contact	Sterol biosynthesis inhibitor	Systemic	Moderately persistent	
Ziram (ex. Ziram) Source: Federoff et al. 2001; US EPA 2004; Mussen et al. 2004	Practically non-toxic	> 100 ug/bee (not specified oral or contact)	di-methyldithio-carbamate	Non systemic	Not particularly persistent	May be toxic to developing larvae with oral exposure

Table 2. Insecticides applied during blueberry bloom, their toxicity, persistence, and special considerations. For residual activity, the half-life listed refers to the amount of time it takes for pesticide residue quantities to be reduced by half.

Chemical	General toxicity rating (high, moderate, low, practically non-toxic)	LC/LD 50 to honey bees	Mode of action	Systemic/ Non-systemic	Residual activity	Notes on use
Acetamiprid (ex. Assail): Source: US EPA 2002; Lewis et al. 2016	Moderate to low toxicity depending on exposure	8.09 contact and 15.43 oral	Neonicotinoid; nicotinic acetylcholine receptor (nAChR) competitive modulator	Systemic	Degrades rapidly in soil; relatively non-persistent in terrestrial environments	Moderate to low toxicity for bumble bees and mason bees (1.72 to >100 ug/bee)
Acequinocyl (ex. Kanemite) – miticide Source: Lewis et al. 2016	Practically non-toxic	280 contact and 315 oral	Quinoline acaricide; quinoline insecticide; mitochondrial complex III electron transport inhibitor	Non-systemic	Non-persistent in soil	
Cyantraniliprole (ex. Exirel) Source: Lewis et al. 2016	High toxicity	>0.0934 contact and >0.1055 oral	Diamide insecticide; ryanodine receptor modulator	Systemic	Moderately persistent in soil	Typically used pre-bloom
Fenazaquin (ex. Magister) – miticide Source: Lewis et al. 2016	Moderate to high toxicity depending on exposure	1.21 contact and 4.29 oral	Quinazoline acaricide; quinazoline insecticide; mitochondrial complex I electron transport inhibitor	Non-systemic	Moderately persistent in soil	
Fenpyroximate (ex. Portal) – miticide Source: Lewis et al. 2016	Low toxicity via contact exposure; practically non-toxic via oral exposure; higher toxicity with chronic exposure	>15.8 contact; >118.5 oral; >1.129 chronic	Pyrazolium insecticide; pyrazolium acaricide; mitochondrial complex I electron transport inhibitor	Non-systemic	Non-persistent in soil in field setting	
Flupyradifurone (ex. Sivanto) Source: Lewis et al. 2016; Nauen et al. 2014	High toxicity via oral exposure, practically non-toxic via contact exposure	>200 contact and 1.2 oral	Butenolide insecticide; nicotinic acetylcholine receptor (nAChR) competitive modulator	Systemic	Persistent in soil	Moderate contact toxicity to mason bees (10.59); practically non-toxic contact toxicity to bumble bees (>100)
Malathion Source: Lewis et al. 2016	Highly toxic	0.16 contact and 0.40 oral	Organophosphate insecticide; acetylcholinester-ase inhibitor; contact, stomach, and respiratory action IRAC group 1B	Non-systemic	Non-persistent in soil; relatively short dissipation rate on plants	Highly toxic via contact exposure to other native bees
Spinetoram (ex. Delegate) Source: Lewis et al. 2016; Besard et al. 2010	Highly toxic	0.024 contact and 0.14 oral	Spinosyn; nicotinic acetylcholine receptor (nAChR) allosteric modulators – Site I. IRAC group 5	Non-systemic	Non-persistent in soil	
Spinosad (ex. Entrust) Source: Miles et al. 2011; Mayes et al. 2003; Besard et al. 2010	Highly toxic	0.05 oral and 0.0036–0.05 contact	Spinosyn; nicotinic acetylcholine receptor (nAChR) allosteric modulators – Site I. IRAC group 5	Non-systemic	Non-persistent in soil, relatively short residual activity	Once dried (3 hrs – 1 day) its toxicity to bees is significantly reduced

Chemical	General toxicity rating (high, moderate, low, practically non-toxic)	LC/LD 50 to honey bees	Mode of action	Systemic/ Non-systemic	Residual activity	Notes on use
Spirotetramat (ex. Movento) Source: Lewis et al. 2016; Maus 2008	Practically non-toxic to adult bees .	>100 contact and >107.3 oral	Tetramic acid insecticide; acetyl CoA corboxylase inhibitor IRAC group 23	Systemic	Non-persistent in soil	Using spiked sucrose solution, adverse effects to honey bee larvae were seen in the lab; potentially toxic to larvae but not adults. Typically used pre-bloom
Tolfenpyrad (ex. Apta) Minnesota Department of Agriculture 2014; Product label	Highly toxic	0.188 contact and 0.252 oral	METI insecticides; mitochondrial complex I electron transport inhibitor; IRAC group 21A	Non-systemic	Non-persistent in soil	Label states "Application must be made at least 8 hrs before bees forage" and "This product is highly toxic to bees and other pollinating insects" Typically used pre-bloom