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Essential Oils and Organic Acids for the Control of *Varroa destructor* in Honey Bees (*Apis mellifera*)

It wasn't until 1986 that parasitic *Varroa* mites were introduced into the United States (Sammataro and Avitabile 1998). Before that time, beekeeping was a relatively carefree endeavor. A few diseases and parasites existed, but most outbreaks were local and of short duration. Even the most severe of the introduced parasites, tracheal mites (*Acarapis woodi*), were being controlled by genetically resistant stocks of bees when the *Varroa* mite first made its appearance in Wisconsin.

The natural host of *Varroa* is the Asian honeybee, *Apis cerana*, which has co-existed with *Varroa* for thousands of years. *A. cerana* has a highly developed grooming behavior that keeps the mites in check. The Western or European honey bee, *Apis mellifera*, has no such adaptation or natural immunity to this pest. In most cases, the mite can completely destroy a honey bee colony in a year or less. In fact, the *Varroa* mite is blamed for the nearly complete elimination of the wild hives that once blanketed North America and were responsible for much of the pollination of both wild and cultivated plants. When wild hives were at their peak in the 1940s and 1950s, farmers didn't need to rent hives, but could depend on a combination of wild honey bees and native pollinators to produce bumper crops of farm produce.

The *Varroa* mite is destructive of honey bee colonies on two fronts: it sucks the hæmolymph from the bodies of larval, pupal, and adult bees, and injects them with viruses at the same time. Most of the viruses are not new, but have been seen occasionally in times of bee stress. The bees weakened by loss of hæmolymph however are in a constant state of physical stress and so are readily susceptible to the bee viruses.

Beekeepers responded to the *Varroa* epidemic by using in-hive acaricides. These worked quickly and efficiently, but the mites rapidly developed resistance to the chemicals. Beekeepers started using greater dosages and multiple chemicals to maintain control, after which toxic chemical residues began showing up in honey and beeswax. Bee colonies often died after heavy mite infestations and it was often unclear whether they died from mite infestations or the chemical acaricides. In 2006 Colony Collapse Disorder was first described, and many researchers remain convinced that the cause is not a single pathogen, but a combination of chemical residues—especially those used to combat mites—poor nutrition, stress, and viruses.

As the approved acaricides began to fail, interest in "natural" forms of mite control increased. Anecdotal stories of mite control had been surfacing for years, and researchers began to look more closely at these cases and experiment with both essential oils and organic acids in the bee hive. They found—and continue to find—a wide range of action with these natural materials, some of which show differential toxicity between mites and bees. Well over 200 naturally-occurring plant compounds, both essential oils and organic acids, have been tested and analyzed. While many are effective in the controlled atmosphere of the lab, very few have proven efficacious in field trials (Imdorf et al. 1999). The most effective to date—thymol (an essential oil), formic acid, and oxalic acid—have since been marketed commercially while others are still considered experimental.

Many of the organic acids are widespread in nature and some of them—most notably formic acid—are naturally occurring in honey and so leave no toxic residues (Imdorf et al. 2003). The essential oils, however, are complex substances containing many different compounds, some of which are detectable if used while the bees are collecting nectar. “Essential oil” is a general term for “liquid, highly volatile plant compounds, characterized by an intensive, characteristic odor” (Imdorf et al. 1999). The main chemical groups found in essential oils are terpenes and phenylpropanes, and while they are generally not toxic, they have other negative consequences. For example, tasting panels have been able to detect the odor of both wintergreen and peppermint in honey samples taken from treated hives.

Based on these reports, Bogsanov et al. (1999) conducted taste tests using lactic, formic, and oxalic acids, and thymol, camphor, and menthol added to honey at controlled rates. Of the organic acids, formic had the lowest taste threshold at 150-600 mg/kg depending on the type of honey. (Highly flavored honeys mask the flavors at a higher level.) Oxalic acid was next at 300-900 mg/kg, and lactic acid wasn’t detected until it reached 800-1600 mg/kg. In contrast, the essential oils are detectable at extremely low rates. Thymol was detected at a mere 1.1-1.3 mg/kg, camphor at 5-10 mg/kg, and menthol at 20-30 mg/kg.

The organic acids and essential oils work in different ways to control mites. The chief acaricidial effect of organic acids is lowered pH in the hive, a phenomenon easily tolerated by the bees but detrimental to the mites (Wallner 2003). Essential oils have two modes of action in the control of *Varroa* mites. Oils such as wintergreen, patchouli, and tea tree kill mites on contact (Armine et al. 1996) They can be mixed into patties made of vegetable oil and sugar, and placed on the top bars of the hive. As the bees move about the hive, they rub against these patties—or try to remove them—and thus distribute the essential oil throughout. Alternatively, if the oils are mixed into liquid syrup and fed to the bees, the nurse bees then feed them to the larvae. When the mites feed on larvae that have consumed essential oils, their reproduction is interrupted, probably due to interference with the enzymes vital to gestation (Amrine et al. 1996) Depending on the concentration, the mites may be unable to lay eggs or mite development may be delayed. If mites do not reach maturity by the time the honey bee larvae emerge from their cocoons, the immature mites will die.

In 2002 Ardeshir et al. tested a variety of plant essences by first distilling them from the plant using water vapor and then exposing *Varroa* mites to a Petri-dish atmosphere containing the essences. At concentrations of 1 g essence per 100 g water, thyme, savory, rosemary, marjoram, dill, and lavender caused a mite mortality of 95%. At 2 g per 100 g water, the mortality rose to 97%. Spearmint, too, killed 97 percent of the mites at the 2 g/100 level, but was ineffective at the lower level. When the essences were sprayed directly on mite-infected honey bees, thyme, savory, spearmint and dill at 2 g/100g water caused 43-58% mortality of *Varroa* mites. The mortality of honey bees was not significantly different than the control bees (sprayed with water) for thyme, savory, and spearmint, but reached 12% for dill. Other essences tested, including pennyroyal, coriander, cumin, fennel, tarragon, myrtle, lemon and ziziphus, produced no significant mite mortality.

One of the problems encountered with the essential oils and organic acids is their extreme volatility. Ebert et al. (2007) sought to reduce the problems due to volatility in the hive by feeding a number of plant compounds directly to honey bees in sugar syrup. They tested cinnamon oil, clove oil, formic acid, marjoram oil, menthol, oregano, oxalic acid, sage, thyme oil, and wintergreen at several different concentrations and counted bee mortality each day. They found oxalic acid to be most toxic to bees. Menthol and cinnamon oil showed no difference in mortality from the controls fed plain sugar syrup. Wintergreen was the least toxic over an extended period of 14 days. They concluded, however, that any of the substances could be used for mite control, as long as the dosages were carefully monitored.

Other methods of delivery have been tried, including smoke. In Turkey the leaves of various plants were dried, burned, and the smoke directed into the hives. The smoke of tobacco, cedar, thyme, pine, and pyrethrum (chrysanthemum) have all been found effective against the *Varroa* mite (Cakmak et al. 2006), but so far no particular advantage has been found in using smoke as opposed to some other delivery method.

Some of the plant essences are effective on mites that are sealed in the comb with the brood and others are not. Oxalic acid, for example, is not effective against sealed mites, and so is used only in broodless colonies such as those that occur in November. Formic acid, on the other hand, is effective against sealed mites as well as those mites occurring on adult bees. It is also effective against tracheal mites, but has the drawback of corroding metal. Screened bottoms and metal hive covers can be ruined by prolonged exposure. In addition, none of the plant essences are 100% effective in killing mites. They are used to reduce the mite populations to a level that allows the colony to thrive, but annual (and sometimes bi-annual) treatments are necessary to maintain the health of a colony.

Beekeepers wishing to use essential oils or organic acids in the control of *Varroa* mites are encouraged to use a regimen of integrated pest management that includes screened bottom boards, drone freezing, summer splits, powder sugar dusting, and robber control in addition to carefully-timed applications of the essential oils and organic acids.

Screened bottom boards rid the hive of 20-25% of adult mites because, once they fall through the screen, the mites cannot crawl back up into the hive. Screened bottoms have the additional advantage of provided excellent ventilation throughout the hive, an important consideration in disease control.

Drone larvae are particularly attractive to mites and most mite eggs are laid in drone cells. Special frames with large-celled foundation can be placed in the hive and the queen bee will fill these with drone eggs. Once the larvae are capped, the frames can be removed from the hive and placed in the freezer overnight. Freezing kills both drones and mites, and since drones are of little value (except in breeding situations) this is considered acceptable practice. The thawed frames can be replaced into the hive for the bees to clean and reuse. However, caution is warranted if a beekeeper decides to use drone frames. If he fails to remove them on time—about once every three weeks—he will raise bumper crops of both drones and mites.

Any action that disrupts the life cycle of honey bees also disrupts the life cycle of mites. Management techniques such as making summer splits or re-queening disrupt the life cycles enough to significantly reduce mite populations.

Dusting the bees with powdered sugar dislodges the mites from the bees either because the mites have a difficult time holding on or because the powder causes a grooming response in the bees. It has been found that a large number of these mites are in their reproductive state (Oliver 2007) so, over time, it decreases the mite population by more than the number of mites dropped. Powdered sugar is most effective in the late summer and early fall.

Entrance reducers should be used in the fall and in times of nectar dearth to prevent honey robbing. Robbing bees transmit mites freely from hive to hive.

Careful timing in the use of essential oils and organic acids is important for several reasons. First, most of these applications should not be used during a honey flow. Second, many of the treatments are not effective on the mites sealed inside the brood cells, so they must be used at times of low to no brood rearing. Third, many of the treatments have specific temperature requirements. For example, thymol requires day-time temperatures above 57 degrees F about to vaporize properly, while formic acid is harmful to the bees if the day-time temperatures exceed about 80 degrees F.

No matter which regimen a beekeeper uses, it is important to remember that none of the plant extracts will kill all of the mites. Each of the selections in an IPM plan reduces the mite load to some degree, and a combination of actions is more effective than any single one. The methods outlined above work well for the hobby beekeeper or small commercial operator. However, the time and expense of these steps are prohibitive for a large pollination-services provider. The ultimate answer to *Varroa* control will probably come from selective breeding of survivor stock.

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