QnAs with May R. Berenbaum

Insects and plants often share a complicated relationship, and University of Illinois, Urbana–Champaign entomologist May Berenbaum has a fine understanding of its chemistry. Berenbaum, a member of the National Academy of Sciences, has long studied how insects and plants evolve chemical arsenals to survive together, pitting cunning defense against toxic offense. Author of a number of popular science books on coevolution, Berenbaum won the 2011 Tyler Prize for Environmental Achievement for her contributions to entomology. Among her many pursuits is an exploration of the likely cause of honey bee die-offs across the United States, an affliction called colony collapse disorder. Berenbaum shares her entomological expertise with PNAS readers to provide a fresh perspective on the disorder and its fallout.

May R. Berenbaum.

PNAS: How did the still-mysterious outbreaks of colony collapse disorder start?

Berenbaum: In 2006, a string of reports of mysterious disappearances of bees from apiaries surfaced. What was disturbing about these disappearances was the sudden loss of the worker bees, which forage for nectar and pollen. There were no dead bodies; they just disappeared, leaving behind the queen, nurse bees, grubs, honey, and other food resources in the hives. The situation turned into a crisis by the middle of February the following year, leading to a shortage of bees for pollinating hundreds of thousands of acres of almond trees in California. That's when colony collapse disorder made headlines in the *New York Times*. Soon, Congress paid attention, and, ever since, researchers have been trying to solve the mystery. There have been recurring reports of bee declines in many countries, but we don't have a molecular diagnostic for colony collapse disorder.

PNAS: Can you give our readers a sense of the economic impact of the disorder?

Berenbaum: The beekeeping community implemented an annual survey to determine the rate of bee loss across the country. It's been hovering around 30% since their first report in 2008. Almond growers rent hives for pollination services, and the rental price of a colony of bees has risen in some places by almost 10-fold since the onset of the disorder. That, in turn, can affect the cost of food items whose production depends on the bees. The economic impact could be significant, because nearly 90 crops in North America depend on honey bees for pollination.

PNAS: Yet the likely culprits remain largely unknown.

Berenbaum: Apiculture is a multibillion dollar industry; yet, it's remarkable how little research has been directed toward improving it. One study to emerge in the wake of the disorder was a metagenomic survey of honey bee microbes that revealed a link to a pathogen called the Israeli acute paralysis virus. The virus had been previously reported in Israel, but its presence in the United States wasn't known until that 2007 *Science* report. However, subsequent studies of bees that had been frozen before the outbreak revealed that the virus had been in the United States even before the outbreak, suggesting that it is less likely to be a causative agent. In 2009, our report in PNAS describing a microarray-based comparison of healthy bees and those that had succumbed to the disorder suggested a link to viral pathogens called picorna-like viruses. We also found fragments of ribosomes, the protein-manufacturing machinery of cells, in the affected bees. Our hypothesis was that viral overload causes the bees' ribosomes to break down, leaving them susceptible to other kinds of stress. Since then, other groups have reported links to other pathogens, notable among which are two species of fungus of the genus *Nosema*. However, there's no clear consensus, except that many players may be involved.

PNAS: Pesticides and climate change are also among the suspects.

Berenbaum: Bees have a long history of experiencing collateral damage in agricultural pesticide use. Naturally, pesticides were suspected as a cause early on. Eye-opening studies have found staggering amounts of a range of pesticides on bees and in their hives. No one knows how these pesticides affect the bees, and it's possible that they simply override the bees' detoxification ability at high concentrations and in multiple combinations. Climate change, on the other hand, is unlikely to be directly behind a phenomenon with a sudden onset, even though there may be sundry indirect effects. Also, as a species with a cosmopolitan distribution, honey bees are extraordinarily tolerant of a wide range of climates, ranging from the cold winters of Canada to the tropical summers of Brazil.

PNAS: What about the physical act of trucking bee hives from field to field for pollination, a practice not uncommon among growers?

Berenbaum: It's clear that traveling by trucks is stressful for bees, but there has been no definitive link with the disorder. Still, it's an intriguing factor.

PNAS: The outbreak was first reported in 2006. Is there anything about its timing that might point to its origin?

Berenbaum: In 1922, Congress passed the Honey Bee Act, which prohibited the importation of honey bees into the United States to protect American bees against diseases. The ban was lifted in 2005, thanks, in part, to the needs of almond growers, who lobbied for an exemption to import Australian bees for pollinating almonds. For the first time in decades, honey bees entered the United States from elsewhere. To be sure, the Australian bees have never directly been linked to the disorder, but globalization of apiculture can redistribute bee viruses, which means that diseases once geographically restricted can now be more widespread.

PNAS: How did you become interested in colony collapse?

Berenbaum: I'm no bee expert but became interested in the disorder mainly through our participation in the international effort to annotate the honey bee genome. We were particularly interested in studying bee genes encoding a group of pesticide detoxifying enzymes called cytochrome P450 monooxygenases. Our conclusion from those studies was that bees, puzzlingly, have far fewer of these enzymes than do other insects. That launched us into bee toxicology. When the outbreak struck, Diana Cox-Foster at The Pennsylvania State University, which was the ground zero, as it were, for both colony collapse disorder and the research efforts to unravel the disorder, asked us whether we would be interested in using our honey bee microarray facility to look for a footprint of pesticide exposure in the afflicted bees. We didn't find one, but that's how I got involved.

PNAS: In previous years, the Tyler Prize has gone to prominent scientists, such as E. O. Wilson, Jane Goodall, Tom Eisner, and Jerrold Meinwald. How do you feel about sharing the honor with them?

Berenbaum: Several of the Tyler laureates are my scientific heroes. I've always thought of them as Olympians, and of myself, if within the Pantheon at all, as being more like Robigus, the god of wheat rust and mildew [laughs]. So, it's a staggering honor to be included in this list of prominent people.

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