Biologists track the invasion of herbicide-resistant weeds into southwestern Ontario

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A field of soy bean plants on Walpole Island in southwestern Ontario entirely overrun by common water hemp. Credit: Julia Kreiner

A team including evolutionary biologists from the University of Toronto (U of T) have identified the ways in which herbicide-resistant strains of an invasive weed named common waterhemp have emerged in fields of soy and corn in southwestern Ontario.

They found that the resistance—which was first detected in Ontario in 2010—has spread thanks to two mechanisms: first, pollen and seeds of resistant plants are physically dispersed by wind, water and other means; second, resistance has appeared through the spontaneous emergence of resistance mutations that then spread.

The researchers found evidence of both mechanisms by comparing the genomes of herbicide-resistant waterhemp plants from Midwestern U.S. farms with the genomes of plants from Southern Ontario.

"We used modern methods of genome analysis to look at the genetic similarity of different populations of these plants," explains Julia Kreiner, a Ph.D. candidate in the Department of Ecology & Evolutionary Biology (EEB) in U of T's Faculty of Arts & Science and lead author of a study published today in *Proceedings of the National Academy of Sciences*.

"To our surprise, we found that the genomes of some resistant plants in Ontario were nearly identical to those in very distant U.S. plants. This was evidence that the Ontario plants were very closely related to the U.S. plants and suggests that the former came from seeds that were just picked up from one field and dropped in another."

While Kreiner and her collaborators did not determine exactly how the seeds were physically transported, this propagation—known as gene flow—is typically accomplished in different ways. Seeds can be carried by water, or in the digestive tracts of animals, or from field to field by way of farm equipment. And especially with a wind-pollinated plant like common waterhemp, genes can also be spread via wind-borne pollen.

The same DNA analysis identified some resistant plants that did not genetically match any other plants suggesting they appeared through the independent emergence of a genetic mutation conveying resistance.

The researchers were surprised to discover both mechanisms at play.

"We have two regions, Walpole Island and Essex County in southwestern Ontario, where waterhemp populations evolved resistance," says Stephen Wright, a professor in ecology & evolutionary biology at U of T and a co-author of the study.

"Because of their proximity, our expectation was that they would have shared the same origin of resistance. But our results suggest different origins—from the movement of seed from a source population in the U.S. as well as independent evolution of resistance in a local population."

According to John Stinchcombe, also a professor in ecology & evolutionary biology at U of T and a co-author, "One of the most striking findings is that we see both ways that weeds could become resistant happening on really short time scales. Evolution is happening very quickly, and using multiple mechanisms."

Detlef Weigel, a co-author from the Max Planck Institute in Germany added, "Because herbicide-resistant waterhemp had appeared in the U.S. long before such plants were found in Canada, we were convinced that evolution of herbicide resistance is very rare and had occurred only once. Now that we know that it can occur repeatedly, the next question is whether one can slow down the evolution of new genetic variants that make waterhemp herbicide resistance."

In addition to the U of T cohort, co-authors included weed scientists from the University of Illinois and the University of Guelph Ridgetown Campus; and genome and developmental geneticists at the Max Planck Institute for Developmental Biology in Germany.

The researchers studied strains of the common waterhemp—aka Amaranthus tuberculatus—that are resistant to glyphosate, one of the most widely used herbicides in the world, commonly known by its trade name Roundup.

"Waterhemp is one of the most problematic agricultural weeds in North America," explains Kreiner. "In the U.S., common waterhemp and the closely related Amaranthus palmeri are causing all kinds of havoc in terms of crop productivity and crop yields."

"Waterhemp first appeared in one county in Ontario in the early 2000s. And as of this year, we've found them in seven different counties in the province. So, it's spreading."

Kreiner suggests that the findings underline the importance of strictly following agricultural practices designed to minimize gene flow and staunch resistant strains as they arise.

"The fact that we're seeing a spread involving all of these mechanisms shows that managing the problem is a real challenge and that it will require integrating management approaches across different scales," explains Kreiner.

For example, it illustrates the importance of thoroughly cleaning agricultural residue from rented farm equipment—which is used on multiple farms in a season—in order to minimize the transport of seeds from field to field.

"It also shows the importance of practices like rotating herbicides from season to season," says Kreiner. "And rotating crops between corn, soy and wheat. It's practices like these that will minimize the emergence of resistance and limit seed movement."

At the same time, Kreiner warns that the occurrence of herbicide resistance is an inevitable evolutionary process and that the challenge requires further study.

"Management practices still don't treat the underlying cause, which is that herbicide resistance is evolving repeatedly," she says. "And so with these new genomic resources and approaches, I'm now trying to understand what makes a weed a weed. What are the factors that might make these weeds more likely to evolve resistance and be more problematic than others?

"At this point, we're running out of herbicides. These plants have evolved resistance to pretty much every herbicide we've come up with. And it doesn't seem like there's ever going to be a herbicide that a weed can't eventually evolve resistance to.

"There may be other strategies for controlling these weeds—like weed-control technologies based on robotics and machine learning," she suggests. "But even then, the weed has a way to evolve around that, so it's a really difficult challenge."

More information: Julia M. Kreiner et al, Multiple modes of convergent adaptation in the spread of glyphosate-resistant Amaranthus tuberculatus, *Proceedings of the National Academy of Sciences* (2019). DOI: 10.1073/pnas.1900870116

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