Plants evolve away from obsolete defenses when attacked by immune herbivores, study shows

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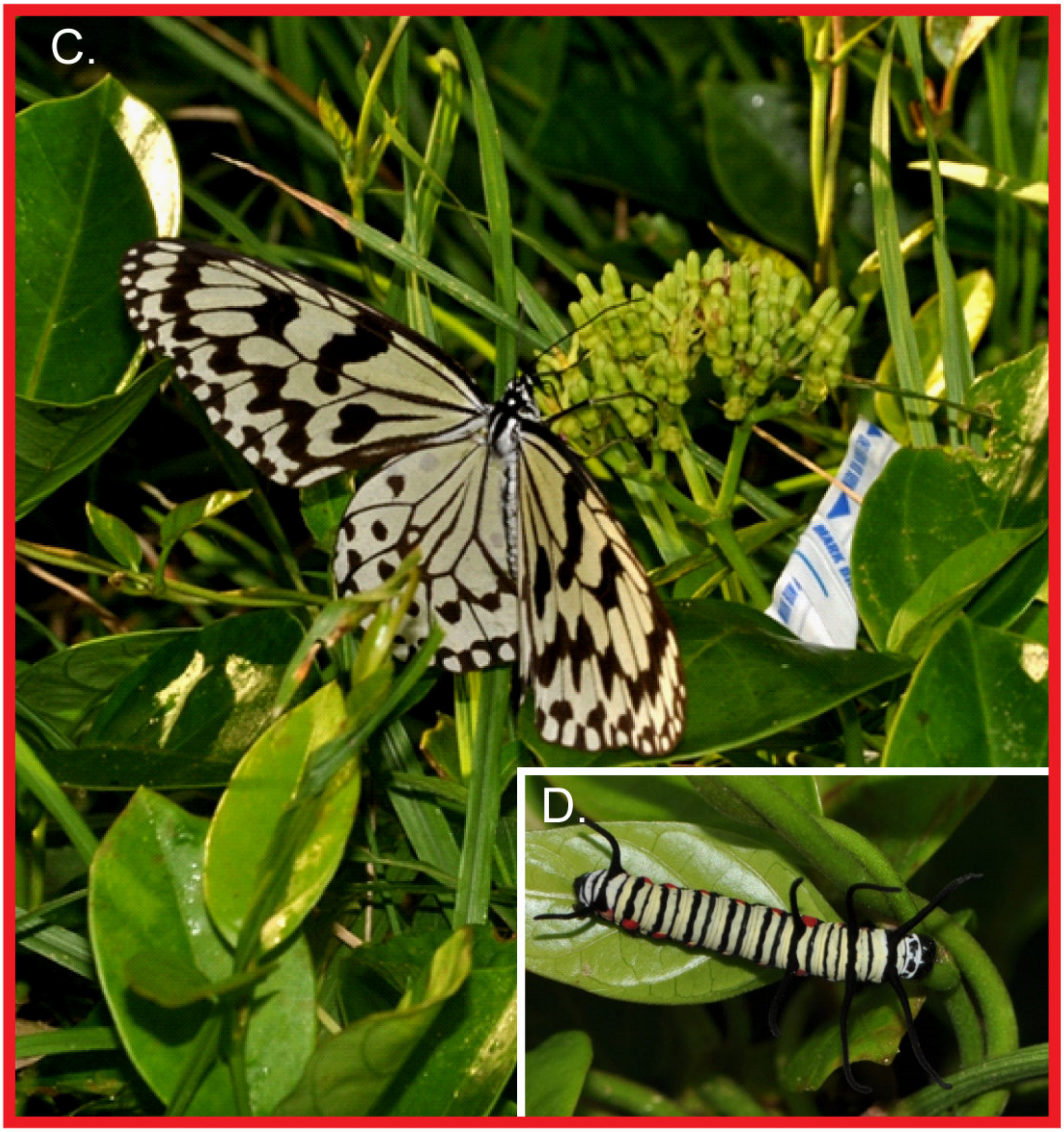

This is Idea leuconoe (Danainae) adult and larva on Parsonsia alboflavescens (Apocynaceae), a dogbane species that DOES produce pyrrolizidine alkaloids. Credit: Drexel University

Do you know what caused soldiers to stop wearing chainmail and steel plate armor? Evolution.

Really, guns made armies drop steel gauntlets and breastplates. Bullets that could punch through armor quickly made it obsolete. So, armies evolved away from armor because it wasn't working any longer and there was no point in spending the resources on it. "Adapt or die," as the saying goes.

Now, new research out of the Academy of Natural Sciences of Drexel University shows that plants similarly adapt away from obsolete defenses.

The study, published in *New Phytologist* and led by Tatyana Livshultz, PhD, assistant curator of Botany at the Academy and an assistant professor in the College of Arts and Sciences, found genetic evidence that multiple lineages of plants, whose ancestors produced a chemical that may deter herbivores, evolved to stop producing it, potentially as a response to a prime foe's immunity.

Livshultz and her team traced the evolution of a gene that is involved in the production of a class of chemicals that are highly toxic to humans and other mammals, called pyrrolizidine alkaloids, in Apocynaceae, a flowering plant family commonly known as the dogbanes and milkweeds. By tracing the gene back, they were able to find out when production of the chemicals first evolved and how many times it was discontinued.

After identifying a single origin of the gene (and, by inference, the chemicals) in the most recent common ancestor of more than 75 percent of current Apocynaceae species, the researchers found evidence that the gene became nonfunctional (and the chemicals "lost" to evolution) at least four different times among that plant's descendants.

Looking for a correlation between the gene's distribution in the plants and interactions with animals unfazed by the defense alkaloids, Livshultz and her team found a significant connection with Danainae (milkweed and clearwing) butterflies.

Almost every species of Apocynaceae eaten by larvae of Danainae is descended from that alkaloid-producing ancestor. Knowing that most species of this lineage of butterflies actually seek out pyrrolizidine alkaloids, it appears that some species in this branch of Apocynaceae may have stopped producing the alkaloids because they were actually attracting milkweed butterflies, not repelling them.

"Pyrrolizidine alkaloids are likely an ineffective defense against Danainae. Furthermore, they are actually beneficial to them since they take in these chemicals for their own defense against their predators," Livshultz explained.

These findings support the "defense de-escalation" hypothesis, which posits that organisms will evolve to stop using precious resources on defense mechanisms if they're not working anymore.

One benefit of defense de-escalation is potentially diverting resources to defenses that do work.

"Apocynaceae species of this lineage produce a number of different classes of defensive chemicals, including cardenolides and other types of alkaloids," Livshultz explained. "It has been shown that cardenolides are at least partially effective defenses against adapted herbivores such as the monarch butterfly, the most familiar species of Danainae to Americans."

Why do any Apocynaceae species still produce pyrrolizidine alkaloids?—"perhaps because they suffer more from other insects that are deterred by these chemicals," Livshultz offered.

Livshultz and her colleagues will further test the hypothesis by reconstructing a very detailed history of the pattern of retention and loss of pyrrolizidine alkaloids in this lineage and ask if exploitation by Danainae is a good predictor of loss.

A better understanding of the dynamics of defense de-escalation is important to understanding co-evolution, the theory that associated species driving each other's adaptations.

"Co-evolution explains how interactions between species can drive the origin of novelty and diversity," Livshultz said.

Additionally, implications from these theories extend beyond plants to humans.

"Understanding the evolution of plant defenses is of practical importance to people, whether we focus on agriculture—herbivorous insects can cause 15 percent reductions in crop yields; medicine—plant secondary metabolites (pyrrolizidine alkaloids are one variety) are an important source of medicinal compounds; or environmental protection—such as developing control strategies for invasive plants," Livshultz said.

More information: Tatyana Livshultz et al, Evolution of pyrrolizidine alkaloid biosynthesis in Apocynaceae: revisiting the defence de-escalation hypothesis, *New Phytologist* (2018). DOI: 10.1111/nph.15061

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