Insects show how DNA mistakes become evolutionary innovation

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One of the more difficult aspects of evolution for some people to swallow is the notion that random copying errors in DNA can add up to anything useful.

In two recently published projects, however, scientists show how typos can indeed lead to improvements. In numerous species of insects, they document the DNA errors that led to changes that are not only beneficial but also brilliant. Various species of beetles, aphids, butterflies, and moths have independently acquired genetic errors that allow them to eat highly toxic plants and then use the toxins to defend themselves against predators.

The toxins in question, called cardenolides, are made by several plants including milkweed, which is the staple food for monarch butterfly caterpillars. The toxin kills by binding to and disabling a protein shared by all complex animals and needed for transmitting nerve impulses and other key functions.

Being toxic to all animals is a nice defense mechanism for a plant, said Princeton University biologist Peter Andolfatto, senior author of one of the papers. "But these insects are amazing." More than two dozen species have independently acquired mutations in the same gene - the one that holds the recipe for the protein the plant toxin targets. The mutation allows the insects to make an alternative version the toxin can't affect.

But many of the insects developed resistance in a tricky way - by creating a duplicate copy of this gene.

"Now they can play a completely different game," Andolfatto said. "They keep one copy basically untouched and take the other copy and start to explore some new evolutionary paths." Those with duplicate genes end up with a resistant form and a vulnerable one.

Then the insects pulled off another evolutionary trick, he said. They underwent changes in nearby parts of the DNA that tweaked the way the two different copies of the gene were activated in various parts of the body.

The altered, toxin-resistant gene was more active in the gut, where cells would have to deal directly with the chemical assault. But in the brain, the original, more vulnerable gene is more active, perhaps, Andolfatto said, because the original version of the protein is more effective there.

Evolution, Aldolfatto said, combined three different approaches to solving one problem. And these changes happened on a parallel track in completely different species.

How does he know these adaptations didn't evolve just once in a common ancestor? Andolfatto said the poison-eating insects they studied are very distantly related, having diverged about 300 million years ago. All of them have much closer relatives that don't tolerate the toxin.

He and colleagues from Princeton and the University of the Andes in Bogota, Colombia, published their work in last week's issue of the journal *Science*. A similar project led to a recent publication in the *Proceedings of the National Academy of Sciences*.

"These are both excellent papers that describe an amazing example of convergent evolution," said University of Chicago evolutionary biologist

Marcus Kronforst. "You see all these distantly related insects independently evolving to the same selective pressure - solving the problem in the same way."

It's true that there are many more bad than good mutations, but organisms are riddled with hidden mutations - DNA spelling changes that don't cause any obvious effect. When a species moves into an environment with a toxic plant, a few individuals may carry a previously hidden mutation that endows them with some degree of resistance.

"Now those individuals are set up to be really successful because they and their offspring can feed on these plants and nobody else can use this resource," Kronforst said.

The mutation might have been floating around before the insects encountered the poisonous plants, or cropped up afterward. "Either way the story is the same," he said. "The mutations pop up randomly, but they are beneficial in the current environment. That's natural selection in action."

There's an added bonus: Poison-eating insects can store the toxins and thus become poisonous themselves. In monarchs, the butterflies continue to carry the toxin even though they no longer eat the milkweed that nourished them as caterpillars.

Of course, sickening a predator doesn't do you much good if you get eaten in the process. Kronforst said he's studying the way toxic insects evolve distinctive "warning" colors, allowing predators to learn to avoid them.

And where you find toxic insects with warning colors, he said, you often find nontoxic "mimics" that adopt the same colors and avoid being eaten themselves. Kronforst is working out the DNA alterations that lead to these advantageous color changes in both the toxic insects and the imitators.

Sometimes, he's found, a group of individuals within a species will crop up with a new warning color. In the butterflies he studies, some are yellow and some are white, and they prefer mating with individuals of their own color. Such mating preferences can trigger the formation of a new species.

The way new species are born is another longstanding puzzle in evolution that DNA is helping scientists to solve.

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