How Caffeine Evolved to Help Plants Survive and Help People Wake Up

Coffea canephora, also known as robusta coffee, drying in Laos. Scientists have sequenced its genome to understand how it evolved the ability to produce caffeine. Credit Barbara Walton/European Press photo Agency

By Carl Zimmer, Sept. 4, 2014

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Every second, people around the world drink more than 26,000 cups of coffee. And while some of them may care only about the taste, most use it as a way to deliver caffeine into their bloodstream. Caffeine is the most widely consumed psychoactive substance in the world.

Many of us get our caffeine fix in tea, and still others drink mate, brewed from the South American yerba mate plant. Cacao plants produce caffeine, too, meaning that you can get a mild dose from eating chocolate.

Caffeine may be a drug, but it's not the product of some underworld chemistry lab; rather, it's the result of millions of years of plant evolution. Despite our huge appetite for caffeine, however, scientists know little about how and why plants make it.

A new study is helping to change that. An international team of scientists has sequenced the genome of *Coffea canephora*, one of the main sources of coffee beans. By analyzing its genes, the scientists were able to reconstruct how coffee gained the biochemical equipment necessary to make caffeine.

The new study, published Thursday in the journal Science, sheds light on how plants evolved to make caffeine as a way to control the behavior of animals—and, indirectly, us.

Caffeine starts out in coffee plants as a precursor compound called xanthosine. The coffee plant makes an enzyme that chops off a dangling arm of atoms from the xanthosine; a second enzyme adds a cluster of atoms at another spot. The plant then uses two additional enzymes to add two additional clusters. Once the process is complete, they've turned xanthosine into caffeine.

The process may seem extraordinarily complex, but the new coffee genome study offers a detailed look at how it evolved.

The caffeine-building enzymes belong to a group of enzymes called N-methyltransferases. They're found in all plants, and they build a variety of compounds. Many of these molecules serve as weapons against enemies of the plants. Sometimes, those weapons turn out to be valuable to us. Salicylic acid, first discovered in willow trees, became the basis for aspirin, for example.

The evolution of caffeine in coffee started when the gene for an N-methyltransferase mutated, changing how the enzyme behaved. Later, the plants accidentally duplicated the mutated gene, creating new copies. Those copies then mutated into still other forms.

"They're all descendants of a common ancestor enzyme that started screwing around with xanthosine compounds," said Victor A. Albert, an evolutionary biologist at the University at Buffalo and co-author of the new study.

Scientists had already determined that caffeine was also made in other plants, like tea and cacao, by N-methyltransferases. But by sequencing the coffee genome, Dr. Albert and his colleagues were able to make a more detailed comparison of the genes in different species. They discovered that in cacao, the enzymes manufacturing caffeine did not evolve from the same ancestors as those in coffee.

In other words, the coffee plant and cacao plant took different evolutionary paths to reach the same destination. Evolutionary biologists call this sort of process convergent evolution.

Birds, for example, evolved wings when their finger bones fused together and sprouted feathers more than 150 million years ago. Bats, on the other hand, evolved wings about 60 million years ago when their fingers stretched out and became covered in membranes.

When convergent evolution produces the same complex trait more than once, it's usually a sign of a powerfully useful adaptation. Experiments with coffee plants offer some clues as to why evolution would reinvent caffeine so often.

When coffee leaves die and fall to the ground, they contaminate the soil with caffeine, which makes it difficult for other plants to germinate. Coffee may thus use caffeine to kill off the competition.

Coffee plants also use caffeine to ward off insects that would otherwise feast on their leaves and beans. At high doses, caffeine can be toxic to insects. As a result, insects have evolved taste receptors that help them avoid ingesting caffeine.

But coffee and a number of other plants also lace their nectar with low doses of caffeine, and in that form, it seems to benefit the plants in a different way.

Plants make nectar to feed insects and other animals so they'll spread their pollen. When insects feed on caffeine-spiked nectar, they get a beneficial buzz: they become much more likely to remember the scent of the flower. This enhanced memory may make it more likely that the insect will revisit the flower and spread its pollen further.

"It's a very cool fact that you can use one molecule to do a negative thing and a positive one," said Julie A. Mustard, a neurobiologist at the University of Texas at Brownsville.

It may be a coincidence of biology that caffeine-producing plants have a similar effect on us—toxic at high doses but enhancing our brains at low doses. "They're manipulating all of us," Dr. Mustard said.