Brain Booster to Go?

By Gail Kay Haines

The first buzzer sounds in seven minutes, and you are still in line at Starbucks. Classmates streak across the street, backpacks flapping and cardboard cups in hand. You already have one tardy this quarter, so maybe you'd better forgo that triple shot mocha grande. But there is a test in chemistry, second period, and you need the boost to get your brain moving. Decisions, decisions.

A hot trend in senior and junior high schools around the country is coffee-shop coffee—the fancier the better. Sometimes, it is not even hot. Coffee-and-crushed-ice concoctions are especially popular. Sugar, whipped cream, pile it on! Chains or local favorites—even a coffee bar in the school lunchroom—offer upscale coffee.

High-calorie extras aside, a cup of coffee is hot water pushed through a scoop of roasted and powdered beans. More than 800 different chemicals go into that famous aroma, making coffee brown and rich, bitter and sweet, stimulating and soothing. When it comes to coffee, it's all in the chemistry.

But will it help you ace your chemistry exam? And is it worth the price—to your nervous system, as well as your wallet?

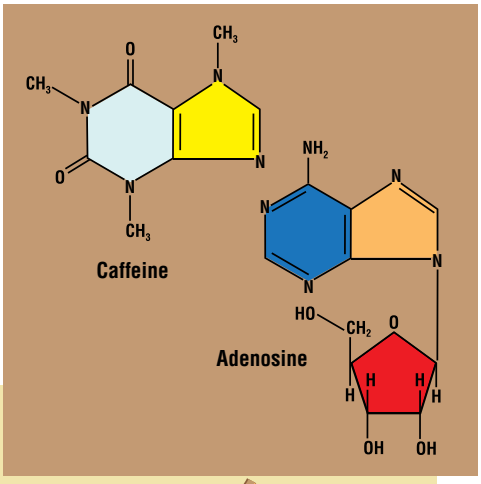
Let's sift the evidence.

How coffee works in the brain

For most coffee drinkers, the underlying allure of coffee is caffeine, the most widely consumed mind-altering chemical in the world. "Caffeine" is the common name for 1,3,7-trimethylxanthine ($C_8H_{10}N_4O_2$), a bitter white powder found in more than 60 kinds of plants around the world, including tea, yerba mate (a popular beverage in South America), and kola nuts.

A brain chemical called adenosine regulates drowsiness. When you are tired, adenosine builds up inside your brain and attaches to proteins on brain cells called adenosine receptors, causing drowsiness. As you drink coffee, molecules of caffeine get inside the brain and bind to these adenosine receptors (Fig. 1), but unlike adenosine, caffeine excites brain cells.

If caffeine blocks enough receptors, you can stay awake for hours, after which the caffeine molecules are broken down and eliminated. Usually, caffeine is effective 15 minutes to 1 hour after your last latte, and the peak lasts about 3 to 3 1/2 hours.



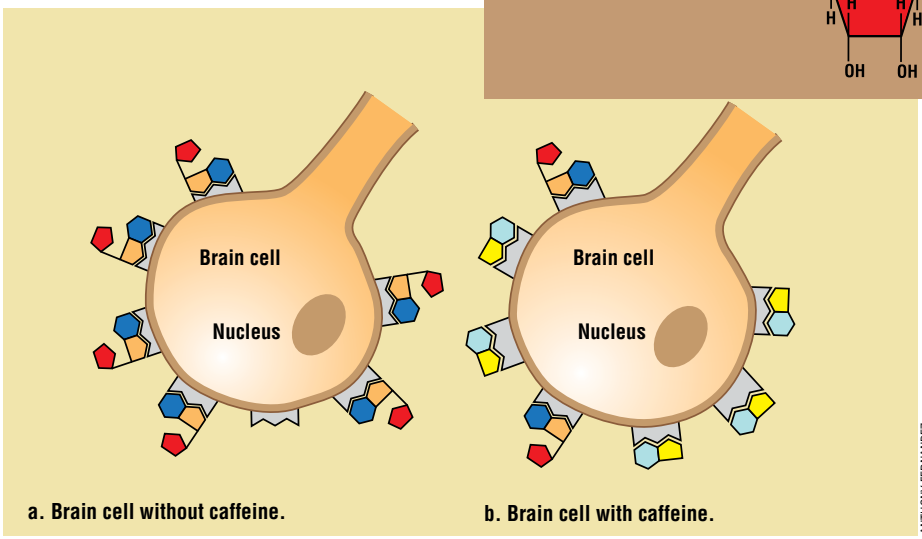


Figure 1. Caffeine and adenosine molecules have similar shapes, so they can both bind to proteins on brain cells called adenosine receptors. When you feel sleepy (a), adenosine molecules bind to most of these receptors, but when you drink coffee (b), some caffeine molecules attach to these same receptors, making you alert instead of sleepy.

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Chemicals in coffee

Scientists have identified more than 800 chemicals in coffee beans, including caffeine, sucrose, and cellulose. Others include proteins and acids such as citric acid, which is found in acidic fruits; tartaric acid, the main acid in wine; and formic acid, the stinging poison secreted by ants.

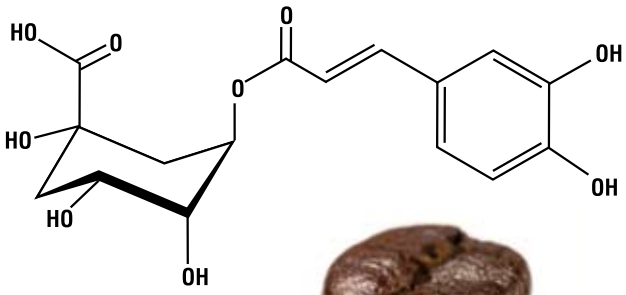
When coffee is roasted, chemical reactions inside the beans destroy some molecules and create new ones. There are different degrees of roasting. Some people prefer lightly roasted coffee—roasted barely a few minutes—while others like it better when the beans have roasted for half an hour. In each case, the chemical composition of the coffee is different.

As coffee beans absorb heat (at temperatures between 188 °C and 282 °C), their color shifts from green to yellow to light brown, and then to dark brown. Oils make their surface shiny. Chemical reactions inside the beans turn carbohydrates and fats into aromatic oils, burn off moisture and carbon dioxide, and alternately break down and build up acids, unlocking the characteristic coffee flavor.

Robert Benck, roastery manager at Batdorf and Bronson Coffee Roasters, Olympia, Wash., started working with coffee while in college. "Both my chemistry and Spanish classes have been useful in my career," he says as he stands in a warehouse filled with *Coffea arabica* beans from places like Mexico, Guatemala, and Costa Rica.

Benck explains that as coffee beans roast, they first pop due to pressure inside and then swell and split. A chemical process, called the Maillard reaction, combines heated sugar and amino acids present in the beans to form hundreds of color and flavor molecules.

After about 12 minutes, a second pop can be heard, and the beans start oozing out oils. At both pops, and for several days after, roasted coffee beans give off carbon dioxide—so much that if coffee bags are sealed too quickly, they can burst.



Example of a chlorogenic acid

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Coffee is not only about caffeine

An important family of chemicals present in coffee is called chlorogenic acids. Scientists are discovering that chlorogenic acids may provide health benefits beyond caffeine's effects. These molecules make up between 6% and 12% of the chemicals present in green coffee beans, while caffeine is only 1% to 2% of the total.

Chlorogenic acids belong to a group of chemicals called antioxidants, which protect cells against damage from free radical molecules formed inside cells. Free radicals can damage DNA and have been associated with Alzheimer's disease, cardiovascular disease, cancer, and diabetes.

ROBERT BENCK

"Coffee is the number one source of antioxidants in the U.S. diet," says Joe Vinson, professor of chemistry at the University of Scranton, Pa. "Chlorogenic acids—primarily from coffee—are probably the major single antioxidant found in the diet."

Peter Martin, a professor of psychiatry and pharmacology at Vanderbilt University, Nashville, Tenn., and Adriana Farah, a chemistry professor at the Universidade Federal do Rio de Janeiro, Brazil, have studied chlorogenic acids and their antioxidant derivatives formed through chemical reactions in roasting coffee beans. They have concluded that light- to medium-roast coffees contain the most of these antioxidants.

"It is hard to know exactly the health effects of these various compounds since they act together," Martin says. "It's as if you were putting together a jigsaw puzzle, and you are studying one piece of the puzzle—that is, each chemical in coffee—at a time."

At Pavia University, Italy, Gabriella Gazzani and colleagues found that green coffee's antioxidant properties are mainly due to chlorogenic acids. Even though chlorogenic acids are degraded up to 70% when coffee beans are roasted, the more roasted the coffee is, the more it contains antioxidants called melanoidins, which are created through the Maillard reaction.

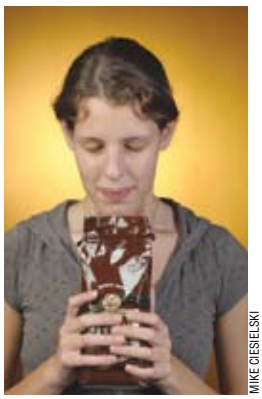
Chlorogenic acids are either absorbed by the stomach and the intestines or broken down into other compounds that are also antioxidants. Vinson and colleagues have shown that chlorogenic acids slow the release of glucose into the bloodstream after a meal, thus lowering blood sugar levels. Other studies show that they reduce the risk of hypertension and type 2 diabetes. Chlorogenic acids also may have other health properties, still being investigated.

Potential benefits against alcoholism and stress-related disorders

Martin and colleagues have made chlorogenic acid derivatives in their laboratory and studied their properties on the brain cells of rats. They have found that these chemicals bind to proteins on the surface of brain cells that also bind to drugs that reduce alcohol craving. These results show that consuming coffee may help people suffering from alcoholism.

Another team of scientists led by Yoshinori Masuo, a researcher at the National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan, has shown that simply inhaling the aroma of roasted coffee may have beneficial health effects. When sleep-deprived rats sniff coffee, proteins in their brain cells are activated to protect them from stress-related damage. In other words, chemicals in coffee's aroma, alone, can relieve stress.

"These results may provide a new way of relieving stress and maybe of helping in the treatment of mental disorders related to stress, including depression, autism, and attention-deficit hyperactivity disorder," Masuo says.



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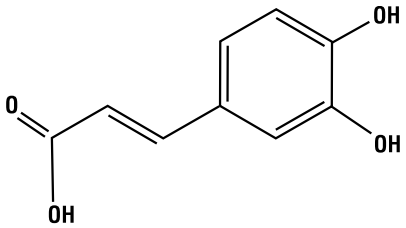
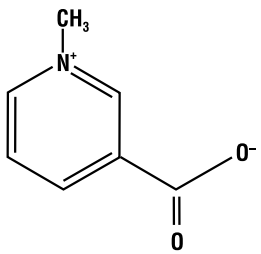


Caffeic acid

Additional health benefits of coffee

Coffee may also protect teeth. Farah, Gazzani, and Beatriz Gloria, a chemistry professor at the Universidade Federal de Minas Gerais, Belo Horizonte, Brazil, have shown that chemicals in roasted—but not green—coffee inhibit the growth of bacteria that cause tooth decay.

The scientists found a variety of different antibacterial chemicals which killed or inhibited the growth of *Streptococcus mutans,* the major cause of dental decay in humans. Also, Gazzani and colleagues applied roasted coffee to hydroxyapatite, a component of tooth enamel—the hard white substance covering a tooth—and showed that small molecules present in coffee prevented *S. mutans* bacteria from binding to it.



Trigonelline

Coffee may also help kill bacteria that infect our guts and lungs. Gloria, Farah, and colleagues have shown that chlorogenic acids, trigonelline, caffeine, caffeic acid, and protocatechuic acid inhibit the growth of enterobacteria, which can cause food poisoning, diarrhea, and typhoid fever. The researchers suggest that these chemicals could be used in foods as a natural preservative to control bacterial growth.

Surprisingly, caffeine and cholorogenic acids may have opposing effects in the brain. Martin and colleagues have found that chlorogenic acid derivatives stimulate adenosine molecules to bind to brain cells, thus acting contrary to caffeine. So, when you drink coffee, the effects of caffeine and chlorogenic acids on brain cells seem to balance out.

Another interesting finding was recently made by Gloria and her team. They discovered that coffee contains tryptophan, a chemical converted by the body into a brain chemical called serotonin that helps regulate sleep, appetite, and mood, and inhibits pain.

So is coffee good for you?

Back to that chemistry exam second period. The timing is right. Your caffeine level will be at its peak. And, as many studies have shown, the drink will improve your mood and increase your mental alertness, cognition, and reaction speed—even your ability to do simple math problems. So far, so good. Will it make you smarter? You wish! There is absolutely no evidence linking coffee with increased brain power—just alert use of your brain.

And is caffeine addictive? Do you risk becoming a "java junkie?" Yes and no. Brains get so used to caffeine's effects that a withdrawal headache can result. But most experts agree that caffeine is not as addictive as illegal drugs, such as heroin and cocaine, because too much caffeine just makes you jittery, and withdrawal symptoms are mild. Caffeine is on the Food and Drug Administration's list of food additives that are "generally recognized as safe."

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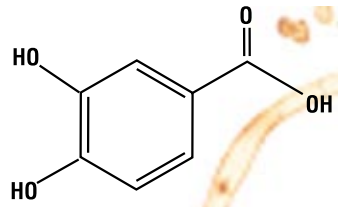

Protocatechuic acid

Here is the bottom line. If coffee works for you, that's great. But food experts suggest drinking no more than three cups of coffee per day. People who regularly consume more may find themselves restless, irritable, and sleepless. Also, some people have caffeine sensitivity. If just one small coffee gives you a red face and a pounding heart, stick to noncaffeinated beverages.

But if you enjoy a mocha in the morning or a latte with lunch, you have plenty of company. Coffee is experiencing a new renaissance, says the National Coffee Association, and it is enjoying yearly sales of more than $11 billion. Coffee is the most traded commodity next to oil and the world's most popular drink next to water.

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Gail Kay Haines is a science writer and book author from Olympia, Wash. Her most recent article, "Corn—The A"maiz"ing Grain," appeared in the December 2006 issue of *ChemMatters.*