In the Garden of Good and Evil

Mushroom hunters can tell the difference

The Bay Area is the perfect habitat for mushroom hunters. The culture of culinary obsession, the warm and moist winter climate, the abundance of conifers and hardwood trees, and even the region's relaxed attitude toward experimenting with mind-altering substances... But who are the mushroom hunters, and how can you, the aspiring mushroom hunter, join their ranks?

Mushroom hunters come in all ages, with varying degrees of affinity for mushroom-themed clothing. They seek wild fungi for their taste, medicinal qualities, or psychoactive effects. For them, mushroom hunting is more than a hobby. It has to be, explains Tom Bruns, a professor in the Department of Plant and Microbial Biology: "Calling them amateurs doesn't do them justice. These people are very well informed." Mushroom hunters must be good at what they do, because misidentifying a mushroom could be fatal.

While the East Bay is home to edible wild chanterelles and porcinis, it is also home to a number of toxic mushrooms, which will make you sick, and poisonous mushrooms, which can kill you. The poisonous varieties are often dead ringers for other edible, tasty species. True mushroom hunters know their mushroom biology, and are well aware that the size, color, texture and odor of the stalk, cap, or gills can be used to distinguish between species. Some species change color when they are bruised or sliced in half and their juice oxidizes. Other species can only be identified after microscopic spore analysis. It's a tricky business, which requires more than just a simple key or field guide.

How can you join these mushroom hunters and dine on wild porcini risotto without worrying about getting sick or dying? The most interesting option by far is to sign up for Tom Bruns's course, California Mushrooms, PMB 113. Offered in the fall, the course takes advantage of the early part of the mushroom season (which stretches from October through March, peaking in December and January). Students collect and learn to identify over 50 genera and build their own extensive collections throughout the semester.

Mushrooms are the fruiting bodies of fungi and exist to produce and disperse spores. The many types of fungi in the wild have diverse methods of obtaining food. Mycorrhizal fungi form symbiotic relationships with trees, providing them with nutrients and receiving carbon in exchange. Parasitic fungi get carbon from plants but give nothing in return. Saprophytic fungi obtain their carbon from dead or rotting debris.

Many species of saprophytic fungi, such as oyster mushrooms and common button mushrooms, can be easily cultured. Mycorrhizal species, which require a host tree, must be found in the wild; hence the high price of chanterelles at Monterey Market. However, mushroom hunters who know the locations of blewit and porcini patches can eat like kings—for free. You can dine with them if you join the Mycological Society of San Francisco and attend the Culinary Group's monthly dinners. The Society publishes a newsletter and hosts forays to regional parks where seasoned hunters pass on their knowledge (though

Amanita calyptrata—photo taken in the Jackson State Forest, on a fieldtrip for California Mushrooms, PMB 113.

Ramaria sp., Jackson State Forest.

PHOTO COURTESY: TOM BRUNS

perhaps not the locations of their secret porcini patches).

Another way to become familiar with mushrooms is to visit the Mycological Society's annual Fungus Fair—this year, it was held at the Museum of California in Oakland. Here, chefs from renowned Bay Area restaurants give cooking demonstrations. Local mushroom experts, including Bruns, give talks. There are also booths where you can try your eye at identifying mushrooms, peruse fabrics colored with mushroom dyes, learn about medicinal mushrooms, and, at perhaps the most popular table, learn about the psychoactive mushrooms that can be found in nearby parks.

One group of psychoactive mushrooms contains a chemical called psilocybin, which, when ingested, is converted to psilocin. Psilocin is structurally similar to serotonin, a chemical naturally present in the brain. It is thought that psilocin changes the brain's signal-to-noise ratio. Stimuli that the brain usually considers to be noise are instead considered to be signals, resulting in synesthesia, the simultaneous perception of more than one sense. Two species of mushrooms that contain psilocybin grow in the Bay Area: *Psilocybe cyanescens* and *Psilocybe fibrilosa*. Both are small and brown, and resemble several species of poisonous mushrooms.

The psychoactive Amanitas, those Alice-in-Wonderland-ish red mushrooms with white polka dots, comprise a separate group. Their active ingredient is the chemical muscimol. *Amanita muscaria* can be found in the Bay Area, but they contain a small amount of muscimol and a large amount of toxic compounds that make people sick. Amanita muscaria from Eastern Europe contains more muscimol, resulting in stronger psychoactive effects and greater popularity.

At a talk at this fall's Fungus Fair, amateur mycologist Debbie Viess warned that while mushroom hunters may be familiar with the species present in the Bay Area, they shouldn't attempt to show off their skills in other regions: "This knowledge doesn't travel to other places." Perfectly edible mushrooms from the East Coast, Europe and Asia have toxic or poisonous look-alikes here in the Bay Area. Recently, an Oakland resident died after eating *Amanita phalloides*, the Death Cap mushroom, which she mistook for an edible species common in her native Taiwan. "Posters to warn people about the Death Cap mushroom are printed in many languages to target immigrant communities," says Anne Pringle, a UC Berkeley post-doctoral fellow.

Recent work by Pringle has shown that the Death Cap mushroom was actually introduced from Europe. "There is a great oral tradition in the amateur community here," explains Pringle. "They thought *Amanita phalloides* was introduced—and it turns out they're absolutely right." Investigating historical descriptions, herbarium specimens, and genetic data, she found that the first confirmed California specimen of the Death Cap was collected in 1945. "There were probably multiple introductions of this species," she says, because *Amanita phalloides* in California are not genetically similar enough to have come from a single introduction.

Because of the severe consequences of a misidentified mushroom, aspiring mushroom hunters are encouraged to learn their lessons well. At the final exam for California Mushrooms, says Bruns, completely deadpan, "the students are presented with three mushrooms, one of which is poisonous. They have to eat two."

Good...or evil? The experts at the Mycological Society of San Francisco's annual Fungus Fair will tell you.

PHOTO COURTESY: TOM BRUNS

PHOTO: JENNIFER SKENE

Jennifer Skene *is a graduate student in integrative biology.*

Want to know more?
Visit the Mycological Society of San Francisco's website at www.mssf.org

Visit the Oakland Museum of California online at www.museumca.org

VIDEO IMAGES: ZUOREN WANG

Kristin Scott and colleagues used the proboscis extension reflex (triggered when a leg touches a droplet of sugar water, right) to characterize a sweet taste receptor gene in fruit flies.

Flies Taste Like Mammals

Vertebrates, invertebrates encode taste signals with the same "molecular logic"

On the second floor of LSA, postdoc Zuoren Wang glues a fruit fly to a glass slide, its legs wriggling in the air. Working under a microscope, he dunks its feet into a spherical drop of a sugar solution and watches it extend its proboscis in a reflexive feeding maneuver. Around the corner, PhD student Aakanksha Singhvi examines transgenic flies in which fluorescent proteins illuminate individual taste cells. This technique allows her to trace those cells' projections into the fly's tiny brain and document the neural anatomy of taste in unprecedented detail.

Those experiments and others—carried out in Kristin Scott's laboratory in the Department of Molecular and Cell Biology and the Helen Wills Neuroscience Institute and published last summer in *Cell*—produced two remarkable conclusions.

First, the insect taste system is organized in much the same way as that of vertebrates. On any particular taste neuron, the taste receptors—surface proteins that bind to small "tastant" molecules—will bind only to bitter or sweet tastants, for example, but never to both. Flies have, in other words, dedicated sweet and bitter taste neurons, just like we have on our tongues. Moreover, the parts of the fly brain responsible for taste perception likewise appear to be segregated not only by sweet or bitter, but also by the location of the taste on the fly's body.

Taste ranges over only a handful of "qualities", each corresponding to a particular type of receptor protein: sweet, recognizing sugars and related compounds; bitter, recognizing a wide range of plant alkaloids and related compounds; salty, recognizing sodium and potassium ions; and sour, recognizing hydronium ions from acids. Mammals also have a receptor for "umami"—"yummy taste" in Japanese—recognizing the amino acid glutamate, which in nature signals a protein source.

Scott and her colleagues propose that this relatively simple system leads to a simple pair of behavioral responses: to eat sweet or moderately salty food sources and reject bitter, acid, or very salty food sources. But in flies there are two anatomical twists that Scott's group has exploited. First, flies have taste neurons on their wings and legs, so they taste food at the ends of their appendages and then turn toward desirable sources to feed. (Fish, incidentally, have taste receptors all over their bodies; taste researchers like to call them "swimming tongues.") Second, the female fly's egg laying organ also has taste cells, so egg-filled mothers can deposit their broods directly onto food sources. "Time flies like an arrow," according to Groucho Marx, "and fruit flies like a banana."

Clues to how sensory perceptions are represented in the brain have previously been found in various sensory systems in diverse animal models. The neurons at the center of the vertebrate retina, for example, make projections to the center of a certain brain area, while neurons from the left and right edges of the retina make connections on opposite edges of that area. Thus the brain tissues that process visual signals embody a map of the retinal image. Similarly, our sense of touch is represented as a distorted map of the body surface stretched over the touch center of the brain. How taste circuits in vertebrate brains are organized remains unknown. But researchers presume that, since the cells of the tongue are organized by taste quality, the taste center in the brain is likewise segregated anatomically by taste quality. The hypothesis, in other words, is that there are distinct brain areas that process sweet, bitter, salty, sour, and umami stimuli.

Scott's team showed that the fly's brain anatomy encodes two qualities of taste

in parallel: what it tastes like, and where it is on the fly's body. They observed, for example, that taste cells on the end of a fly's leg send projections further towards the hind end of the fly's brain than taste cells on its proboscis. Furthermore, a bitter and sweet cell side by side on the proboscis will project to distinct targets within the proboscis taste area of the brain. In general, each taste organ sends nerves to distinct targets in the brain, and within those areas, bitter and sweet neurons seem to connect to distinct groups of target neurons.

So much for taste representation in the brain. How does each taste neuron genetically encode taste sensitivity? The proboscis extension reflex Wang observes has been known for 30 years. But he put it to new use in order to characterize the function of specific taste receptor genes. Sixty-eight taste receptors have been identified in the sequenced genome of the fruit fly. Scott's group removed specific taste neurons by genetically programming them for death—they drove a diphtheria toxin gene only in cells that produce that taste receptor, eliminating all cells that contain a certain receptor, one at a time. Then they put these flies to a sweet and bitter taste test. Using this method they characterized one bitter and one sweet receptor. The remaining 66 gene products are presumed to include sour and salty receptors, as well as other sweet and bitter receptors, but none have been characterized except the two in Scott's studies.

With only four taste categories, why does the fly genome contain so many taste receptor genes? Probably because of the molecular diversity of tastant molecules. While sugars, chemically speaking, are a relatively simple class of molecules, the compounds that evolution has dictated animals avoid—the bitter tastants, in other words—are remarkably diverse. It's now known that in both flies and mice a single bitter taste cell contains many different types of bitter receptors. "This organization," Scott explains, "would allow animals to recognize many different compounds as bitter, without being able to tell them apart."

Scott started her career at Berkeley only two years ago, after a postdoctoral fellowship in the laboratory of Richard Axel at Columbia. Axel shared last year's Nobel Prize with another former postdoc, Linda Buck, for the identification of the genes encoding olfactory (smell) receptors.

"Our long term goal," Scott says, "is to understand the neuronal circuits in the brain" that underlie taste. In order to begin to explain taste behavior in terms of connected groups of neurons, they aim to identify the individual neurons in the brain that receive input from taste cells, and then determine which neurons they connect to in turn. To trace these neural circuits, postdoctoral fellow Sunanda Marella and PhD student Walter Fischler have been using transgenic flies with neurons whose fluorescence intensity changes when they become active. Instead of having to poke randomly around the tiny fly brain with electrodes, recording taste response activity in one cell at a time, their method will allow real time microscopic observation of the activity of whole groups of neurons in the taste areas of the fly brain—a technique known as "functional imaging."

Meanwhile, Scott's group is screening for mutants with defects in taste-mediated behavior. Ultimately, they hope to identify genes required in the fly brain for those behaviors and uncover more clues to the underlying neural circuits and how they function. "Functional imaging," Scott explains, "will be the platform for all of these studies."

James Endres Howell *is a graduate student in molecular and cell biology.*

Want to know more?
Check out "Taste representations in the Drosophila brain": Wang Z. et al, *Cell*. **117**, pp. 981-991 (2004).

Visit Kristin Scott's lab at mcb.berkeley.edu/labs/scott