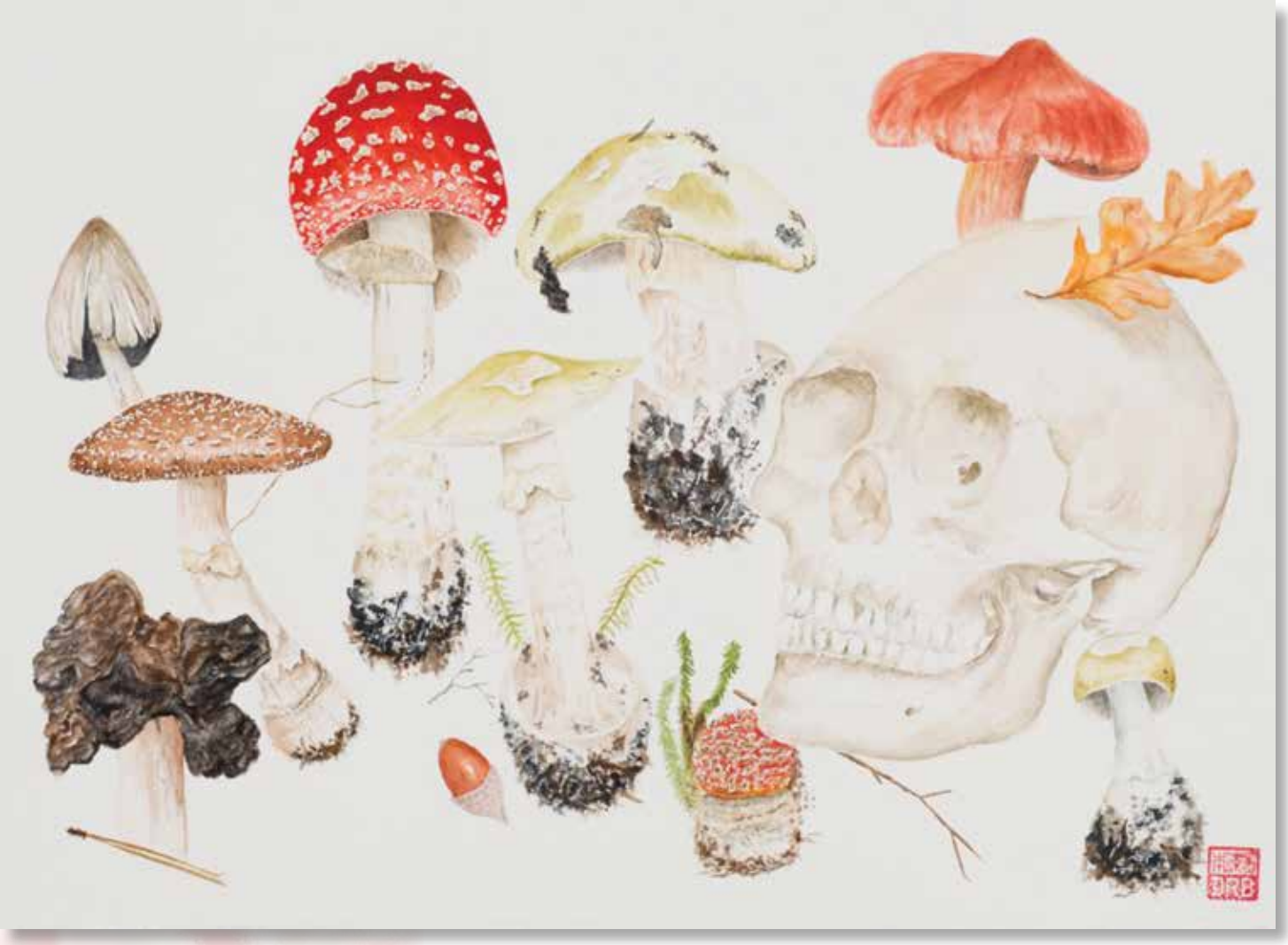

"Correct identification and dose of the mushroom, as well as age, underlying medical conditions, a person's individual metabolism, and genetics all play a role."

Mushroom poisoning: More than identification

Denis R. Benjamin

Case 1

An elderly gentleman approached me after a presentation. "I am really embarrassed. When I was learning about edible mushrooms many years ago I thought the teacher said that the only coral one should eat is the one with a gelatinous center, *Ramaria gelatinosa*. I have eaten them for years and have never had any problems. Now you are telling me that it is the one of the toxic varieties."

Case 2

Four friends share a meal of *Amanita proxima* thinking that they were *Amanita ovoidea*. One develops kidney failure, but not the others.

Case 3

Over 300 people attend a civic banquet and are served thinly sliced raw morels in the salad. About half the guests visited the emergency room with severe GI distress—the rest enjoyed their meal.

Case 4

Eleven cases of gyromitrin toxicity are reported in the Midwest after a wet autumn, producing a bonanza of *Gyromitra esculenta*. No cases were ever reported west of the Rocky Mountains (except for a couple who ate them raw).

Case 5

Ten people eat large quantities of man-on-horseback (*Tricholoma*

equestre) in southwestern France and develop severe muscle damage (rhabdomyolysis). Hundreds of thousands of Poles eat the same mushroom without a problem.

Case 6

Mycophagists on the East Coast enjoy chicken-of-the woods, while many foragers on the West Coast largely avoid them.

Why these striking differences?

Mushroom poisoning usually focuses on a particular species and its toxic molecules. A typical human paradigm: find a culprit and assign blame. This misses many of the nuances of mushroom poisoning in the real world. A similar error was made years ago when Pasteur discovered bacteria and the germ theory of disease swept into fashion. Germs were the cause and had to be eliminated. His contemporary, Claude Bernard, wrote at the time, "… the microbe is nothing. It is the terrain." Both were partially correct and partially wrong, because it is both. So it is with mushrooms. Many factors determine whether or not an individual will exhibit symptoms with a mushroom that is labelled toxic (or edible). The symptoms can vary from trivial to severe.

There is a complex interaction between fungus and mycophagist. These include the many variations in the fungus itself, unique factors in the victim, the meal preparation, and the dose. To be clear, many of these factors are either poorly studied or are unknown.

1. The fruiting body

Let's begin with the mushroom itself. The first assumption is correct identification. Taxonomy is in a continual state of flux and simple morphological characteristics are no longer sufficient. Many of our labels are European in origin and genomics is teaching us that some of these well-described species do not exist in the New World. Many North American species are not as well-studied such that one cannot simply extrapolate results across continents. Even assuming one has correctly identified the mushroom and it has all the genes required to produce an array of secondary compounds, when and how these are expressed is largely unknown. The presence of these toxic molecules and their concentration is variable and depends on location and habitat, mycorrhizal partners or substrate, the stage of development of the fruiting body and others. The toxin may not be evenly distributed within a single sporocarp (Chilton, 1978). In other words, knowing the genome is only a way station to the understanding of the biochemistry of an individual mushroom. There is the effect of proteomics and epigenetics and probably a number of other factors we don't yet know about, all of which determine how much toxin is made and when.

This creates considerable variation in the concentration of a particular toxin—the amatoxins being the best studied (Faulstich, 1976; Beutler, 1980; Wieiland, 1986; Walton, 2018). But it is not known for example why *Gyromitra esculenta* does not produce much gyromitrin on the west side of the continental divide. This has never been formally investigated. There is some suggestive epidemiology, but no biochemical confirmation. Perhaps there are different varieties of *G. esculenta* with different genomes; perhaps it's the habitat, or climate, or a combination. We just don't know.

There are many folktales in the West about chicken-of-the-woods and the digestive problems they sometimes cause. "Don't eat those growing on eucalyptus, or conifers, or before the first frost, or after the first frost, etc., etc." Rather, it appears to be a problem of the use of a common name for very different species. The so-called "chickens" in the West are not *L. sulphureus*, but either *L. gilbertsonii* or *L. conifericola* which have different features (Burdsall et al., 2001). They clearly cause more GI problems than their eastern cousin.

2. The mycophagist (the terrain)

The second important variable is the mycophagist. Age, underlying medical conditions, a person's individual metabolism, and genetics all play a role. Children, the elderly, and the infirm are more vulnerable, but many other factors influence the outcome. Each of our digestive tracts is unique with different microbiomes, and absorptive capacity. It is well known that certain species are not harmed after a mushroom meal containing amatoxin, such as mice and rats. The mechanisms for this apparent insensitivity is not well understood (Walton 2018). While this is an extreme example, there is great variation in how each of us reacts to a particular food.

3. The preparation

The third variable is the meal preparation. Some of the toxic secondary compounds are heat labile and are inactivated with adequate cooking. It is probable that many of the cases of adverse reactions to "edible" mushrooms are a result of eating them raw or insufficiently cooked. This appears to be the case with mushrooms such *Laetiporous sulphureus* and *Armillaria* species. In Europe, *Boletus edulis* and its relatives cause issues when eaten raw in any significant amount. The occasional nibble is harmless to most people, but not a plateful. Meals of raw *Boletus edulis* are responsible for a majority of referrals to some regional poison centers in Italy. That is no surprise since porcini, a generic appellation for a host of different species, is the most commonly consumed wild mushroom in that part of the world.

Most mycophagists are aware that cooking breaks down the chitin cell walls and makes mushrooms more digestible. In addition to inactivating the heat-labile toxic molecules, heat kills the bacteria and molds that can contaminate the surface of mushrooms, depending on where and how they were collected, cleaned, and stored. And if these are not reasons enough for adequate cooking, enhancing the flavor might be the most persuasive. Heat provokes the Maillard reaction of the proteins creating the delicious savory tastes. And getting rid of all the water in the mushroom concentrates other flavor molecules such as MSG, boosting the umami. In addition to adequate cooking, there are some species in which eating the stipe can cause GI distress. The best known examples are the honey mushrooms (*Armillaria* spp.).

Nowhere is the preparation more important than with mushrooms known to contain significant amounts of toxins such as *Gyromitra esculenta* and *Amanita muscaria*. Considerable care and special attention is required to render these into a safe meal.

4. The dose (basic science versus clinical reality, or rats / petri dishes vs. people)

A trap we all fall into is extrapolating observations from the laboratory directly into the human condition. This fallacy is commonplace. The mere presence of a particular molecule in a food is not proof that it will have any impact on human health. If it did, we would eat nothing, for all foods contain toxic molecules—from solanine in tomatoes to cardiac glycosides in potato, cyanide in cassava (manioc, yucca), to lectins in beans and goitrogens in the brassicas (kale, cabbage, etc.) (Dolan et al., 2010; Bajaj, 2016; Berman, 2014; WHO, 2018). We would not even eat porcini or most other "edible" mushrooms as amatoxin has been identified in some collections (Faulstich, 1976). The same is true of molecules said to be beneficial to human health. Many factors determine what physiological or pathological impact they will have on a particular individual, including absorption, bioavailability, genetics, and especially the dose. The dose depends on the mushroom itself and the size of the meal.

There are two striking examples of this dose effect: morels and man-on-horseback. Overindulgence of morels has been associated with a number of neurological affects in a small number of people (Sauvic, 2010; Benjamin, 2015). The rhabdomyolysis associated with *Tricholoma equestre* followed large meals on consecutive days (Bedry, 2001). Many European countries and mycological societies immediately declared this fungus toxic, banning it from market places. More recent studies have seriously questioned the wisdom of this declaration (Ryzymski, 2018; Klimazyk, 2018). In fact, similar rhabdomyolysis has been reported with large meals of other mushrooms, suggesting that the critical factor is the dose (Chwaluk, 2013).

As Paracelsus noted around 1523 AD, the only difference between a food (or medicine) and a poison is the dose ("All substances are poisonous. There is none which is not a poison; the right dose differentiates a poison from a remedy.") This is all the encouragement we need to avoid the deadly sin of gluttony.

References Cited

Bajaj, J.K., P. Salwan, and S. Salwan. 2016. Various possible toxicants involved in thyroid dysfunction: a review. *Journal of Clinical Diagnostic Research* 10(1): FE01–FE03. doi: 10.7860/JCDR/2016/15195.7092

Bedry, R., I. Baudrimont, G. Deffieux, E.E. Creppy, J.P. Pomies, J.M. Ragnaud, M. Dupon, D. Neau, C. Gabinski, S. De Witte, J.C. Chapalain, P. Godeau, and J. Beylot. 2001.

Wild-mushroom intoxication as a cause of rhabdomyolysis. *New England Journal of Medicine* 345: 798–802.
Benjamin, D.R. 2015. Neurological effects of *Morchella* sp. *Fungi* 8(3): 24–25.
Berman, J. 2014. Kale? Juicing? Trouble ahead. *The New York Times* https://opinionator.blogs.nytimes.com/2014/01/01/kale-juicing-trouble-ahead
Beutler, J.A. 1980. Chemotaxonomy of *Amanita*; qualitative and quantitative evaluation of the isoxazoles, tryptamines, and cyclopeptides as chemical traits. Doctoral dissertation. Philadelphia College of Pharmacy and Science.
Burdsall, H.H., Jr., and M.T. Banik. 2001. The genus *Laetiporus* in North America. *Harvard Papers in Botany* 6: 43–55.
Chilton, W.S. 1978. Chemistry and mode of action of mushroom toxins. In: B. Rumack and E. Salzman, eds. *Mushroom Poisoning: Diagnosis and Treatment*. CRC Press, West Palm Beach, FL.
Chwaluk, P. 2013. Rhabdomyolysis as an unspecific symptom of mushroom poisoning: a case report. (In Polish) *Przegląd Lekarski* 70: 684–686.
Dolan, L.C., R.A Matulka, and G. Burdock. 2010. Naturally occurring food toxins. *Toxins* 2(9): 2289–2332. doi: 10.3390/toxins2092289
Faulstich, H., and M. Cochet-Meilhac. 1976. Amatoxins in edible mushrooms. *FEBS Letters* 64(1): 73–75.
Klimaszyk, P., and P. Rzymski. 2018. The yellow knight fights back: toxicological, epidemiological, and survey studies defend edibility of *Tricholoma equestre. Toxins* 10: 468–476.
Rzymski, P., and P. Klimaszyk. 2018. Is the yellow knight mushroom edible or not? A systematic review and critical viewpoints on the toxicity of *Tricholoma equestre. Comprehensive Reviews of Food Science and Food Safety* 17: 1309–1324.
Saviuc, P., P. Harry, C. Pulce, R. Garnier, and A. Cochet. 2010. Can morels (*Morchella* sp.) induce a toxic neurological syndrome? *Clinical Toxicology* 48: 365–372.
Wieland, T. 1986. *Peptides of Poisonous* Amanita *Mushrooms.* Springer, New York; 256 pp.
Walton, J. 2018. *The Cyclic Peptide Toxins of* Amanita *and Other Poisonous Mushrooms*. Springer, New York; 245 pp.
World Health Organization (WHO). 2018. Natural toxins in food. https://www.who.int/news-room/fact-sheets/detail/natural-toxins-in-food.

Lying on the Couch, Rubbing Each Other's Feet

Mom, just relax. Let me take you to a place where there are no bunions, no bruises, no violence, no Donald Trumps, no unhappy thoughts.

—Vivian Trommer, 10

Start with the scent of chanterelle cream sauce
still lingering from dinner. Throw in a few stars—
you can't see them, but you know they are there.

Add a tickle. A giggle. A kitten-ish squeal.
Rub tenderly. Then hard. Then forget for a while
to rub. Add a hum, and the dark that can't enter

the room. Add moon. And cocoon. An impending
soon. And the sound of the river never ending.
An inkling of joy. A hunch of perfect. A hint
of this can't last. Choose that. Distill to precisely
this moment. Any sorrow or pain
that might wish to rise, it is only a background

flavor that shows up how sweet this magic,
how sometimes the best recipe is the one
that uses exactly what we have on hand.

Rosemerry Wahtola Trommer
Colorado