Arsenic in Morels
Morels Collected in New Jersey Apple Orchards Blamed for Arsenic Poisoning

by Elinoar Shavit

A few months ago the New York Mycological Society lost a very good friend. Bill (Wilbur K. Williams) was a dear friend of mine. In the months before his death we had conversations on many issues including mushrooms, organic foods, and what not to expect of alternative medicine. Bill had a unique gift for looking at the obvious from an unexpected angle. He could always pick out the single most worthwhile point in any debate and present it anew in a ridiculous way, exposing its weaknesses. A few weeks before his death we had a conversation about the benefits of consuming fruits and vegetables labeled "organic." Bill said that while farmers who produce such products must adhere to regulations concerning the pesticides and fertilizers they use, there does not seem to be a whole lot of interest in what the soil where these "organic" fruits and vegetables grow contains. It could be arsenic from the natural decomposition of rocks, well-hidden debris from old smelting, or lead and mercury from pesticides banned decades ago. Bill and I used to collect morels and other mushrooms together, so he ended the conversation by saying, "At least mushrooms have the good sense to be particular about where they grow, and we can trust that most of the mushrooms we collect are organic." This is for you, Bill.

Morel hunters can hardly wait for spring when the soil temperature in old apple orchards finally rises above 50° F. Old apple orchards, run-down and unattended, are prime morel-collecting locations. Morels start fruiting when the old trees are dying off and will keep fruiting in the same place year after year, usually around the same trees, until the trees are dead. In East Coast states like New Jersey or New York, where apple growing was an important crop in the 19th and 20th centuries, large quantities of morels can be collected in old orchards each spring. In the early part of the 20th century, however, orchards were sprayed extensively with arsenic-based pesticides, and the components of the pesticides, mostly arsenic and lead, are still present in the soil. This article was written in response to recent concerns that morels, these excellent culinary mushrooms, may accumulate arsenic and other heavy metals from the soil and thus pose a threat to the health of consumers.

Morels are a popular, relatively expensive, early spring delicacy. They can be dehydrated and are available at supermarkets and gourmet stores year-round. Most of the morels sold in markets are collected from the wild, although there have been some efforts to grow them commercially. They are a lucrative cash crop, and many people in the U.S. and elsewhere supplement their income by collecting morels for sale.

Good morel producing spots are not easy to locate nor keep secret. People have been known to leave maps of morel-producing orchards in their wills, and at least one amateur mycology club on the East Coast has collected morels in such an apple orchard for decades. Some of these orchards are so overgrown with poison ivy, prickly rose bushes, honeysuckle, and even elm trees that they look quite wild and "organic," but often nothing is further from the truth. The topsoil, particularly around the dying apple trees, can contain high concentrations of heavy metals like arsenic and lead. These are the long-lasting remnants of decades of dusting with lead-arsenate pesticides used to combat the codling moth and other fruit-tree pests.

Lead arsenate pesticide $(PbHAsO_4)^i$ was introduced in 1892 in Massachusetts for use against the gypsy moth. "Paris green" (copper acetoarsenite) and calcium arsenate were also used but were replaced by lead arsenate in the 1930s because it was cheaper, more effective, and less toxic to the plants. Lead arsenate was recommended by the USDA and quickly became the pesticide of choice. It was applied often, used extensively on millions of acres from the late 1800s to the 1950s (when it was replaced with DDT), and was finally banned from use in fruit orchards in 1988.[15] The arsenic found in the pesticides does not readily break down in the soil, and most of it is still present in the topsoil of previously treated apple orchards, where morels tend to grow.[15]

In August of 2008, while at the North East Mycological Federation's foray in Connecticut, many amateur mycologists heard of the plight of Robert Peabody, a longtime member of the New Jersey Mycological Society. Bob, an experienced and well-respected amateur mycologist, was recovering from a serious case of arsenic poisoning. The source of his arsenic poisoning has not been determined, but Bob's drinking water, immediate environment, place of employment, favorite foods, occupation, and other places where he could possibly have encountered arsenic were ruled out. His hobbies were then put under scrutiny. An avid mushroom hunter, Bob has been collecting culinary mushrooms for many years. His favorite edible mushroom is the morel (*Morchella esculenta*), and since the 1970s he has been known to collect thousands of morels each spring, exclusively in apple orchards. Some wild mushrooms are known to concentrate heavy metals from their growing environment,[21; 35] and since it is well known that apple orchards in New Jersey were treated with lead arsenate pesticides for many years,[36] the favorite explanation for Bob's arsenic poisoning was that for many years he ate morels that accumulated arsenic from the orchards' soils.

Bob's troubles started a few years ago when he went on a weight-management diet to improve his health, but instead of feeling better he felt much worse. Bob's heavy-metal poisoning was not recognized for a long time. His symptoms were mistaken for Multiple Sclerosis (MS) because symptoms resembling those of MS interfered with the normal function of his legs. It is not un-

usual for people suffering from heavy metal poisoning to experience symptoms similar to those of MS[23] and Lyme Disease,[37] which can lead to misdiagnosis and even incorrect treatment. Bob was treated for Lyme Disease, but his condition worsened and his health kept deteriorating. He was tired all the time and kept losing weight even though he was no longer dieting. He suffered from severe headaches, stomach problems, a tingling sensation in his hands and feet, and pains and weakness in his legs. His skin had a gray, ashen color. An observant nutritionist suggested that he could be suffering from heavy-metal poisoning.

Bob sought the help of Scott P. R. Berk, M.D., of the Stockton Family Practice in Stockton, New Jersey. Dr. Berk was especially impressed with the way Bob described the symptoms in his legs; he said that his legs felt like they were tightly wrapped in very hot towels. Dr. Berk tested Bob for heavy-metal concentrations by giving him a urine provocation test. Hair mineral analysis is a cost-effective and painless initial screening test to determine if someone has accumulations of heavy metals in their system. However, Dr. Berk maintains that in order to confirm findings of other tests and to obtain better precision in measurements of long-term exposure to heavy metals, a urine provocation test is preferable. Even though most of the arsenic that enters the body through food gets excreted through the urine within two to three days, enough of it may accumulate in the tissues and vital organs to eventually cause serious damage.[ii; 2;12] In a urine provocation test, the patient is given an oral or intravenous injection of an agent designed to concentrate heavy metals in the urine. The urine is collected for the next 6 to 24 hours for analysis, and the level of arsenic in the urine is then measured in mcg/g Cr (micrograms of arsenic per 1 gram of creatinine[iii]). The provocation test is generally accepted as the most reliable indicator of arsenic exposure.[19] The output of arsenic in the urine can be measured for organic and inorganic (toxic) forms of arsenic, which would indicate if the consumed arsenic could have an adverse effect on the health of the consumer.

Arsenic has a long history of use: as a poison (it was the 16th-century poison of choice of the Borgia Family), in medicine (it was used to treat syphilis in the 1900s before penicillin was introduced), in art (as a green pigment), in the production of glass and semiconductors, as a component in pesticides like lead arsenate, and as a preservative for wood to make it resistant to rotting and decay (in "pressure-treated wood"). It occurs naturally in the water, air, and in soil, from the natural decay of arsenic-rich rocks. Most soils in the U.S. and elsewhere in the world contain some concentrations of arsenic naturally,[34] which vary widely but generally range from about 1 to 40 ppm (parts of arsenic per million parts of soil) with an average level of 3–4 ppm. However, some mining and smelting sites, soils in arsenic-rich geological deposits (like some parts of the U.S. West Coast, or to the point of national disaster as in Bangladesh[14; 24]), and agricultural areas where

arsenic pesticides were applied in the past may contain much higher levels.[iv; 7; 15]

The arsenic in lead arsenate pesticide is not destroyed in the environment. Once in the topsoil, lead arsenate separates into its components which then bind tightly to fine soil particles. The arsenate then tends to remain close to where the pesticide spray landed on the ground, usually following the contour of the sprayed trees. It remains in the topsoil layer (about 10–12 inches deep) because it is poorly soluble and undergoes little vertical redistribution.[15] However, it can change its form by reacting with oxygen or other molecules present in the environment or by the action of bacteria that live in soil or sediment. It is usually found in combinations with other elements such as oxygen, chlorine, and sulfur. Arsenic combined with these elements is called *inorganic arsenic*. Arsenic combined with carbon and hydrogen is referred to as *organic arsenic*.[v; 7; 16]

Exposure to toxic metals has become a rapidly growing source of illness worldwide.[25; 28] Since arsenic is naturally present in the environment, often in high levels, further exposure through food, water, occupation, and soil contamination contributes to what could be increasingly characterized as a defined spectrum of disease.[14; 24; 25] In 2007, the U.S. Department of Health and Human Services, the Agency for Toxic Substances and Disease Registry (ATSDR), and the Environmental Protection Agency (EPA), published their toxicological profile for arsenic. *Inorganic arsenic* was identified as a poison and determined to be a human carcinogen (cancer causing).[7; 15] The International Agency for Research on Cancer (IARC) determined that inorganic arsenic is associated with cancer of the bladder, liver, lung, and skin. It concluded that exposure to inorganic arsenic can also cause skin inflammation, keratoses, peripheral neuropathies (diseases of the nerves of the extremities), and peripheral vascular diseases (diseases of the arteries and veins of the extremities),[vi; 2; 16; 24] anemia, diabetes, and an increased production of free radicals that alter mitochondrial activity and genetic information.[25] Organic arsenic, on the other hand, was found to be far less toxic to humans. It is often referred to as "fish arsenic" since it is found in some fish and shellfish, and it is excreted by the body within a day or so following ingestion.[1; 7; 15; 25; 34]

The World Health Organization (WHO) considers inorganic urine arsenic levels of above 100 mcg/g Cr to indicate an elevated exposure,[1; 38; 39] but the limit set by the NIOSH at a Health Hazard Evaluation (HHE) of workers exposed to arsenic in a uranium enrichment plant[2; 12; 13] was 50 mcg/g Cr of arsenic in urine. The California Department of Health Services agrees with this limit.[1] The result for Bob's urine provocation test was 550 mcg/g Cr.

Dr. Berk was taken aback by the high concentration of arsenic in Bob's system. A result of 550 mcg/g Cr, which far exceeded the toxicity level, was the highest reading of arsenic in a patient's urine test that Dr. Berk had ever encountered. At 9.1

mcg/g Cr, Bob's level of lead was also elevated. Dr. Berk put Bob on immediate weekly chelation therapy with DMPS (2,3-dimercapto-1propanesulfonic acid)[4; 16; 39] to remove the arsenic and other heavy metal particles from his system. In chelation therapy, compounds that bond to metal ions are administered to the patient, often intravenously. These agents bind with the metal ions, separating them from blood proteins. This facilitates their elimination from the body through normal bodily channels. The urine is then evaluated to verify that metal particles are actually clearing out of the body. Chelation therapy is the first-line treatment for acute arsenic poisoning, but its use is not free of controversy.[25; 31]

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Finding the cause of Bob's arsenic poisoning, while important for obvious reasons, was much needed to ensure that he was no longer exposed to the initial cause of his poisoning while he was undergoing chelation therapy to rid his system of arsenic. Although no evidence was offered to support it, the assumption was that Bob got his arsenic poisoning from eating morels that he had collected in arsenic-rich orchards. This unsubstantiated rumor soon became the unofficial explanation for Bob's arsenic poisoning. It quickly spread among concerned culinary mushroom collectors in the East Coast and even found its way into a mycological society's newsletter.[29] Bob's morels seemed to fit the role of the culprit so perfectly that most people have neglected to keep in mind that neither Bob's morels nor the soil they grew in have been tested for arsenic.

Bob did not save any morels; therefore his morels could not be tested for arsenic accumulations. He collected his morels in a considerable number of southern New Jersey apple orchards, but no soil samples have been evaluated for arsenic concentrations, and it is still unknown whether any of these orchards had high arsenic concentrations. There is no evidence that North American morels (*M. esculenta*) accumulate arsenic from their growing environment.[6] Even if morels were found to concentrate arsenic, there is no evidence that arsenic accumulates in the mushroom tissues in its toxic, inorganic, form. In fact, it has been shown that arsenic accumulates in some mushrooms mostly in its organic form.[35] Without more evidence no conclusive answer can be reached regarding the possibility that eating morels collected in New Jersey apple orchards could have caused Bob's arsenic poisoning.

A poisoning case without a definite cause is much like a mystery novel with the villain still at large: there is always a chance that it could strike again. Until such time when samples of morels from Bob's old collecting habitats are available to be evaluated for their heavy metal concentrations, we thought that it would be valuable to determine whether morels collected in arsenic-rich apple orchards in fact accumulate arsenic from their environment. Toward this end, we located an old apple orchard in upstate New York, similar to the old apple orchards of southern New Jersey. Most of these New York apple orchards, like the ones in southern New Jersey, were at their prime at the end of the extensive and intensive lead arsenate pesticide-spraying period of the 1940s and 1950s. There is a high probability that at least some of the orchards in southern New Jersey were sprayed with lead arsenate pesticide.[36] A report by the U.S. Geological Survey and the New Jersey Department of Environmental Protection states that "arsenic was used in New Jersey as a pesticide on cropland, turf, and golf courses. From 1900 to 1980, about 49 million pounds of lead arsenate and 18 million pounds of calcium arsenate were applied to soils . . . Estimates of total arsenical pesticide applications for each county . . . indicate that the largest amounts of arsenic were applied in counties in the Coastal Plain, and in the southern part of the State."[36] Concentrations of arsenic and lead in the topsoil of orchards that were previously treated with lead arsenate pesticides can be much higher than in the topsoil of orchards that have not been treated with the pesticide.[15; 26]

The old New York State apple orchard we located is in an apple-growing region not known to have unusually high concentrations of arsenic, whether naturally or due to human activity (such as smelting or mining). The orchard is on the fringe of a small town and has been a reliable morel-collecting spot for many years. New neighborhoods now stand in place of many old apple orchards in the area, raising health-related issues regarding the heavy metals in their soil, which are the results of years of heavy metal pesticide spraying.[15; 27] The old orchard we targeted still

stands, its soil undisturbed. The decaying remnants of the apple trees around which many morels were collected throughout the years can still be seen. We were unable to determine if this orchard was treated with lead-arsenate pesticide in the 1940s–-1950s when it was an active orchard, since the present owner of the property declined to comment on this issue. However, a retired employee who worked in that orchard during its productive years believed it was. The cleanup level for arsenic in New York State is 20 mg of arsenic to 1 kg of soil, which is similar to 20 ppm (EPA, 2002).[33] If the level of arsenic in the topsoil samples collected from the orchard were found to be considerably higher than the official cleanup level, it could indicate that lead arsenate pesticides were used in the orchard. However, the origin of the arsenic in the soil, while fascinating, has little to do with our goal: to determine whether high arsenic concentrations were present in the orchard's soil, not to determine the origin of such arsenic. We set out to evaluate whether morels that grow in arsenic-rich soils could concentrate enough arsenic from their substrate to affect the health of the people who consume them.

Toward this end and following instructions from the senior manager of the laboratory at Cornell University, seven medium-sized (dry) morels and two samples of the orchard's topsoil (from a depth of 2–10 inches) were collected and sealed. These samples were sent to the Cornell University laboratory for a research plant tissue analysis (HNO_3 digestion) and analysis of heavy metal levels in the soil. Regrettably, the laboratory did not have the tools for determining whether the arsenic found in the samples was in its organic or inorganic form.

The results of the research plant tissue analysis and analysis of heavy-metal levels were surprising. As was expected, the laboratory results showed that the topsoil in the New York orchard contained 39.4919 mg/kg (DM) and 46.3171 mg/kg (DM) of arsenic (Table 1, Soil-1 and Soil-2). This is almost twice the cleanup level for arsenic in soil in New York State. The topsoil samples also contained lead (190. 915 mg/kg [DM] and 132.203 mg/kg [DM] of lead, see Table 1). These results established that considerable amounts of arsenic (and lead) were present in the topsoil of the orchard. These findings support the testimony of the retired employee who remembered that the orchard was treated with lead arsenate pesticides in the past. Lead was found both in the soil and in the morels. At 2.94 mg/kg (DM), the lead content of the morel sample far exceeded the amount of lead allowed in candy, according to the 2006 EPA guidelines (upheld in 2008), which are set at 0.1 ppm (similar to 0.1 mg/kg [DM]).[18] However, while lead and other elements were detected in the morel sample (Table 1), and even though considerable concentrations of arsenic were found in the soil, the laboratory study did not detect arsenic in the morels. The morels we collected in the New York orchard, which grew in arsenic rich soil, did not concentrate arsenic from the soil.

Table 1. Concentrations of select elements determined for New York State apple orchard Morel mushrooms, plus soil samples removed from the same orchard. Samples were collected by E. Shavit and submitted for analysis on 8/21/2008. All tests were performed by the Cornell Nutrient Analysis Laboratory, Cornell University, Ithaca, NY. Results for Lead (Pb) and Arsenic (As) shown in red. Concentrations are in mg/kg for all values; "<det" where below the detection limit.

Isolate No.	Al	P	S	Mn	Fe	Co	Mo	Pb
Morel Sample	49.8	10706.2	2161.2	21.58	270.68	1.13	<det	2.94
Soil-1	17459.3	451.751	241.724	738.031	16452.7	5.6488	<det	190.915
Soil-2	22668.2	550.022	227.263	632.385	22325.2	7.1457	<det	132.203

Isolate No.	Cd	Na	Mg	K	Ca	As	B	Zn
Morel Sample	1.63	41.95	865.78	24042.1	736.06	<det	1.25	101.6
Soil-1	0.7045	179.953	3473.6	4044.72	2320.88	39.4919	23.7147	86.8579
Soil-2	0.6971	236.048	4414.2	5619.13	2315.57	46.3171	32.9312	80.9091

An analysis of one sample of *M. esculenta* collected from one possibly contaminated old apple orchard is clearly of limited value. These results cannot indicate if Bob's New Jersey morels did or did not accumulate arsenic from their soil and certainly not if morels do or do not concentrate arsenic from their substrate. However, these results can support the claim that morels that grew in arsenic-rich soil in one New York State orchard did not concentrate arsenic from their environment. Consuming the morels in this sample would not result in arsenic poisoning, even for habitual morel consumers, because no arsenic was found in them.

Bob's chelation therapy took almost nine months to complete, but it was successful. According to Dr. Berk, Bob's urine arsenic level is now 17 mcg/g Cr, down from 550 mcg/g Cr. Bob was fortunate that his serious arsenic poisoning was detected in time, and that the chelation treatment prescribed to him by Dr. Berk proved effective. He is feeling much better and has been able to resume his life, including his mycological interests. The cause of his arsenic (and lead) poisoning remains unknown, but fingers are still pointed at the many mushrooms Bob consumed in his decades of collecting culinary mushrooms in the wild. It is entirely possible that in the state of New Jersey, where arsenate pesticides were used liberally for a long period of time, Bob could have picked and consumed species of edible mushrooms that accumulate arsenic and other elements from their growing environment.[35] Bob's severe arsenic poisoning emphasizes the need to further understand the tendency of certain culinary mushrooms to accumulate arsenic and other potentially toxic elements from their habitats.

In conclusion, it is not possible to determine if the morels that Bob consumed caused his serious arsenic poisoning, if the regular consumption of other mushroom species contributed to his condition, or if mushrooms were the cause at all. It has not yet been determined if long-term consumption of any mushroom species collected in a variety of

Mushrooms Accumulating Heavy Metals and Accumulating Taxa

The issue of mushrooms accumulating arsenic and other heavy metals took center stage following the disastrous accident at the nuclear plant in Chernobyl, Ukraine. Mushrooms collected from areas of the fallout were found to accumulate high levels of certain radioactive compounds and heavy metals in their fruitbodies.[17] Since then, studies aimed at the safety aspect of consuming culinary mushrooms collected in the wild were conducted in a number of European countries. The aim was to determine to what extent mushrooms concentrated certain heavy metals from their growing habitat and whether the regular consumption of such mushrooms would present a health risk. Species of fungi collected from a variety of habitats were tested for arsenic and other heavy metal concentrations.[vii; 35] Some species were found to concentrate heavy metals from their environment, and species of certain genera have demonstrated a tendency to accumulate particular heavy metals from their substrate. These are known as "accumulating taxa."[5; 35] Most accumulating taxa among edible mushrooms that have been shown to concentrate arsenic can be found in two orders of Basidiomycetes: Agaricales and Gasteromycetales, in particular in the families Agaricaceae, Tricholomataceae, and Gasteromycetaceae. These do not include the family Morchellaceae, to which morels belong. Most of these studies concluded that even though certain species may have a tendency to accumulate particular heavy metals, on average mushrooms were not found to accumulate high amounts of arsenic even from arsenic-rich environments.[35]

In a study conducted in Hungary by Prof. J. Vetter, 162 fruitbodies of 37

commonly collected edible mushrooms were tested for their concentrations of arsenic. Vetter was concerned with the health of consumers of edible mushrooms collected in the wild. He suggested that the three factors that could influence this issue were the frequency with which people consumed particular species of mushrooms (such as members of accumulating taxa), the form in which these mushrooms were consumed (a pound of fresh mushrooms contains only one tenth the arsenic found in dry mushrooms), and the form in which arsenic was present in the mushrooms (inorganic or organic). Vetter did not include morels in his study, but eight genera of the original 37 species that were evaluated in his study demonstrated that they accumulated arsenic in all the collecting habitats, and that they were accumulating taxa for arsenic. Among the accumulating taxa that concentrated arsenic from their substrate were some choice edible species of *Agaricus, Calvatia, Collybia, Laccaria, Lagermannia, Lepista, Lycoperdon,* and *Macrolepiota* (particular results can be seen in Note ix, Table 2, reprinted with Prof. Vetter's permission). The highest reading of arsenic concentration in this study was recorded in fruitbodies of *Laccaria amethysthea* (146.9 mg/kg [DM]).[35]

There seems to be a general consensus on the issue of arsenic concentration in mushrooms among a number of studies (including studies that Vetter refers to in his own research). While a study conducted in Turkey emphasized the significantly high arsenic concentrations observed in some species (like *Amanita muscaria* and *L. amethysthea*),[35] another study concluded that, generally speaking, high concentrations of arsenic were uncommon in wild mushrooms. In that study, most wild mushrooms were found to contain only 1–2 mg/kg of arsenic in dry matter.[31; 35] This is the same conclusion reached by a study conducted in England and Scotland where berries and mushrooms growing in the wild were evaluated for levels of arsenic. These results were published by the MAFF and the Department of Health in Scotland in a food surveillance information sheet (# 199). In their report, the authors concluded that the concentrations of arsenic in the samples of fungi and blackberries studies, even in those collected from roadsides, were, in general, acceptable. In most cases the level of arsenic in the mushrooms and blackberries was less than 1 mg/kg, the statutory limit for commercial foods. However, even when the level of arsenic was found to be higher, the authors estimated that the total dietary intake of arsenic from eating these berries and mushrooms would contribute only 5% to the total estimated dietary intake. The JECFA's Provisional Tolerable Weekly Intake for arsenic from food is 8%.[11; 20]

Fruitbodies of European *M. esculenta* (morels) were included in a study conducted in Italy, and their levels of arsenic were evaluated. It was an extensive study conducted by Cocchi et al. with the help of the Mycological Society of Bresadola (who provided samples of mushrooms for analysis). The purpose of the study was twofold: to assess the impact that heavy metal concentrations in common edible mushrooms could have on the health of the general public, and to evaluate the possibility of using mushrooms as bioindicators of environmental contamination.[5] This large study tested 1194 samples of 60 species of commonly occurring edible mushrooms from one Italian province for accumulations of heavy metals.[5] The study showed that European *M. esculenta* accumulated some amounts of arsenic, but that with a few striking exceptions the amounts of arsenic that most evaluated edible mushrooms accumulated from their habitats were generally modest.[viii; 5] The data collected did not support the hypothesis that mushrooms could be potential bioindicators of environmental pollution with heavy metals because particular species were found to accumulate high amounts of certain metals even when the amounts of these metals in the soil were not high. However, the tendency demonstrated by some fungi to accumulate certain metals could serve a useful taxonomic purpose.[5]

Regrettably, most of these studies did not evaluate the form of the arsenic accumulated in the tissues of the evaluated mushrooms. Vetter holds that this information is crucial when setting out to determine a possible threat to the health of habitual consumers of wild mushrooms as well as to the general public. In Vetter's study, most of the arsenic accumulated in the mushrooms was found in its organic form, and only a small percentage was found to be in the toxic and carcinogenic inorganic form.[35] He shared the opinion presented in other studies that even habitual

consumers of mushrooms collected from the wild may not consume quantities large enough to cause health problems. He concluded that since "the quantity of [wild-growing mushrooms] consumed (daily or weekly) is relatively low, and the frequency of consumption is also low, then the toxicological risk is negligible."[35] Based on the studies mentioned in this article and on his own research, Vetter came to the conclusion that members of a given genus will always have high (or higher) levels of arsenic than members of other genera that were also collected from the same growing habitat.[35] He claimed that all the accumulating taxa observed were saprotrophic in the manner in which they obtained nutrients, and did not include mycorrhizal or xilophagous species.[ix (Table 2); 35] As noted, some studies evaluating fruitbodies of European *M. esculenta* for concentrations of arsenic found that they concentrated arsenic.[5] While genetic differences between the European and the North American *M. esculenta* could possibly account for different tendencies in arsenic concentration by these species on the two continents, and even though the North American *M. esculenta* was shown to develop ectomycorrhyzal connections,[6] not enough information is available to determine the arsenic accumulation tendencies of either one.

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habitats in the state of New Jersey, where large areas have been contaminated by heavy metals, could be the cause of heavy metal poisoning. However, the issue of arsenic accumulations in Bob's New Jersey morels will be revisited in the spring. With Bob's assistance, samples of morels and topsoil from the areas where he collects his morels will be evaluated for concentrations of arsenic and other elements. Since arsenic accumulated by some mushrooms was found to be organic in form and therefore not a serious health risk, any arsenic found in Bob's morels will be evaluated to determine if the arsenic accumulated in the mushrooms is inorganic or organic arsenic.

It has become clear that mushroom collectors have a responsibility to familiarize themselves with the tendency of some edible mushrooms to accumulate certain heavy metals from their environment. Consequently, they should also familiarize themselves with the levels of heavy metals in their regularly visited mushroom collecting sites. These could be favorite places like old apple orchards during morel season, planted spruce stands where *Boletus edulis* is routinely collected each season, or large oaks at the road sides in small New England towns when *Grifola frondosa* is in season. Inexpensive, simple-to-use test kits are available online. Dr. Berk suggests that since the symptoms of heavy metal poisoning can be similar to those of MS and Lyme Disease, habitual consumers of mushrooms collected in the wild should familiarize

themselves with these symptoms and let their physicians know that some popular culinary mushrooms can concentrate heavy metals. Even though some of the studies presented here did not find a need for concern, culinary wild mushrooms should not be collected from known contaminated sites. Such sites are too numerous to mention, but some obvious ones are roadsides, manicured lawns, orchards previously sprayed with pesticides, mining and smelting areas, stream banks in agricultural areas, cotton fields, and naturally occurring arsenic-rich soils (information on levels of arsenic and other heavy metals in soils is available online for most states).

Even though the cause of Bob's arsenic poisoning remains unknown, his plight brought the issue of safe consumption of edible wild mushrooms to the attention of a larger audience. Bob's arsenic poisoning case, regardless of its cause, should concern and inspire amateur and professional mycologists alike. The North American Mycological Association (NAMA) and the Mycological Society of America (MSA) may want to consider following the lead of mycological societies in Italy and Britain, and initiate similar surveys of heavy metal concentrations in popular edible mushrooms collected in North America.

Notes

i. From the EPA Pesticide Fact Sheet: the chemical name of lead arsenate is Acid Orthoarsenate ($PbHAsO_4$). Basic Orthoarsenate – $Pb_4(PbOH)(AsO_4)_3$. Its trade names were Lead Arsenate, Gypsine, Security, Talbot, and its EPA Shaughnessey Code was Standard (Acid) 013502. Pesticide type: Growth regulator, insecticide, herbicide, and fungicide. Chemical family: inorganic Arsenicals. U.S. and foreign producers: Mechema Chemicals, Ltd.[8; 9]

ii. Dr. Steven H. Ahrenholz, Ph.D., CIH, investigator for the National Institute for Occupational Safety and Health (NIOSH), wrote in his Health Hazard Evaluation Report, "Inorganic arsenic is eliminated from the body through metabolism and urinary excretion . . . [but] the total amount excreted in urine accounts for about 60% of the absorbed amount . . . Concentrations of inorganic arsenic and its metabolites in the urine of the general public are usually below 10 mcg/g Cr in European countries, but slightly higher in the United States."[2; 12; 30]

iii. Creatinine is a waste molecule produced in the muscles. It is transported through the bloodstream to the kidneys, which dispose of it through the urine. It serves an important diagnostic indicator of kidney function, and is a normal urine component used to adjust for differing urine concentrations.

iv. In Bangladesh (and India), very high concentrations of arsenic are found in the ground water and well water, causing devastation to entire communities.[3; 13; 14; 23]

v. In its metallic state, arsenic exists in the environment in a number of allotropic forms (a behavior of some elements that can exist in different forms where their atoms are bonded together in a different manner), and in a number of ionic forms (a type of chemical bond that can often form between metal and non-metal ions).[16]

vi. For reference on arsenic and public health, arsenic toxicity, and arsenic poisoning see Marcus, 2007; Medline Plus; Saha, 2003; and DHHS-PHS, 2007.

Table 2. Arsenic contents of the analyzed, wild-growing, common, edible mushrooms. n.d. Not detectable, i.e. the concentration of arsenic is lower than 0.05 mg/kg (DM).

Mushroom species	Code of habitats (time of harvesting)	Arsenic content (mg/kg DM) (arithmetical mean±SD)	Minimum and maximum values (mg/kg DM)
Agaricus arvensis Schaeff.:Fr.	9 (1985); 2 (1993); 1 (1993)	4.61±3.24	2.01–8.25
Agaricus augustus Fr.	3 (1985)	11.90±0.22	11.7–12.12
Agaricus campestris L.:Fr.	2 (1993)	4.01±0.23	3.88–4.24
Agaricus esettei Bon	3 (1984); 9(1994); 8 (1994); 6 (1996)	7.56±7.18	1.67–18.38
Agaricus langei (Moel.) Moell.	1 (1996)	12.90±0.29	12.60–13.21
Agaricus purpurellus (Moell.) Moell.	4 (1984)	14.90±0.41	14.50–15.40
Agaricus silvaticus Schaeff.:Fr.	2 (1985); 2 (1985)	4.60±0.30	4.30–4.90
Agaricus silvicola (Vitt.) Sac.	7 (1999)	14.60±0.62	13.98–15.20
Armillaria mellea (Fr.:Fr.) Staude	13 (1996); 6 (1987); 8 (1994, 1994); 9 (1993, 1994, n.d. 1995);3 (1995, 1997); 1 (1996, 1997); 5 (1998)	1.45±0.11	1.34–1.56
Calvatia excipuliformis (Scopol.:Pers.) Perdeck	1(1998)		
Calvatia utriformis (Bull.:Pers.) Jaap	9 (1993); 10 (1995)	18.30±0.93	17.51–19.24
Cantharellus cibarius Fr.	2 (1985) n.d.		
Clitocybe odora (Bull.: Fr.) Kummer	7 (1987); 8 (1993, 1994); 9 (1993, 1994); 1 (1998)	2.72±1.70	0.10–3.93
Collybia butyracea (Bull.:Fr.) Gill.	9 (1993, 1994); 5 (1998); 11 (1998)	30.76±20.78	7.96–58.3
Craterellus cornucopioides (L.:Fr.) Pers.)	8 (1994); 1 (1993, 1996, 1998); 6 (1996); 7 (1999) n.d.		
Fistulina hepatica (Schaeff.:Fr.) With.	8 (1994, 1995); 6 (1999); 3 (1999) n.d.		
Hericium coralloides (Scop.:Fr.) Gray	8 (1994); 3 (1993, 1994, 1995); 4 (1993) n.d.		
Hirneola auricula-judae (Buill.:Fr.) Berk.	3 (1985); 9 (1994); 1 (1996) n.d.		
Hydnum repandum (L.) Fr.	10 (1995); 6 (1996); 7 (1998) n.d.		
Hypholoma capnoides (Fr.:Fr.) Kummer	7 (1986, 1993, 1994); 4 (1985); 9 (1993) n.d.		
Laccaria amethysthea (Boel.: Hooker) Murr.	10 (1985); 14 (1995); 6 (1996); 1 (1996, 1998)	59.30±55.9	4.09–146.9
Laccaria laccata (Scop.:Fr.) Cooke	9 (1995); 10 (1995); 1 (1116); 11 (1998)	9.49±6.85	1.84–16.4
Lactarius deliciosus (L.) Gray	9 (1993, 1995); 1(1996); 11 (1998)	1.62±1.13	0.10–2.99
Lactarius deterrimus Gröger 1 (1998);	2 (1998) n.d.		
Langermannia gigantea (Batsch:Pers.) Rostk.	4 (1985)	7.08±0.22	6.86–7.30
Lepista flaccida (Sowerby:Fr.) Patouillard (earlier: *L. inversa* (Scop.:Fr.) Pat.)	3 (1993); 9 (1993); 1 (1993, 1996, 1998); 6 (1996); 5 (1998); 11 (1998); 7 (1999)	7.15±6.77	2.02–30.2
Lepista nebularis Fr. *Clitocybe nebularis* (Batsch:Fr.) QuØl.	10 (1984); 4 (1985, 1994, 1995); 2 (1993); 1 (1993, 1996, 1998); 9 (1995); 6 (1996); 5 (1998); 7 (1999)	1.29±0.79	1.14–2.32
Lepista nuda (Fr.:Fr.) Cke.	2 (1993); 8 (1993); 1 (1993, 1996); 7 (1998, 1999); 5 (1998)	5.46±5.55	1.60–20.2
Lycoperdon perlatum (Pers.) Pers.	8 (1993); 7 (1993, 1998, 1999); 9 (1994, 1995); 6 (1996); 1 (1996, 1997)	5.84±4.04	0.43–11.7
Macrolepiota procera (Scop.:Fr.) Sing.	1, (1993); 8 (1995); 9 (1994, 1995); 3 (1998); 7 (1999)	4.84±5.67	
Macrolepiota rhacodes (Vitt.) Sing.	9, (1985, 1993, 1994, 1995); 1 (1996); 7 (1993, 1998, 1999) 3 (1996)	17.23±11.32	2.32–42.6
Pleurotus ostreatus (Jacq.:Fr.) Kummer	15 (1985); 1 (1996); 5 (1998); 9 (1999) n.d.		
Pleurotus pulmonarius (Fr.) QuØl.	15 (1985); 9 (1985); 3 (1994); 7 (1999) n.d.		
Stropharia aeruginosa (Curt.:Fr.) QuØl.	9 (1993); 4 (1994, 1996); 1 (1996); 5 (1998); 7 (1999) n.d.		
Suillis granulatus (L.:Fr.) Roussel	12 (1985) 7 (1985) n.d.		
Suillus grevillei (Klotzsch.:Fr.) Sing.	7 (1993, 1996, 1998)	2.0±0.7	1.41–2.59
Tricholoma terreum (Schaeff.:Fr.)Kummer	4 (1984); 12 (1993, 1995); 1 (1996); 5 (1998) n.d.		

vii. For reference on a number of these studies, check Falandysz and Bielawski, 2001; MAFF, DH, SE, 2000; www.ncbi.nlm.nih.gov/pubmed/17852381; www.pjoes.com/pdf/10.1/67-71.pdf; and Pelkonen, Alfthan, and Jarvinen, 2006.

viii.   Other metals were favored by different species. The measured levels of cadmium (Cd) in *Boletus edulis* (porcini) exceeded the recommendation of the World Health Organization (WHO). Species of *Agaricus* (*A. bitorquis* and *A. arvensis*) concentrated levels of mercury (Hg) within a range of 5-19 mg/kg (DM) while, according to WHO, the weekly intake of mercury should not exceed 0.3 mg/kg (DM). Levels of cadmium 50 times the maximum weekly allowance recommended by the WHO were measured in samples of *Agaricus macrosporus*.[5]

ix. See Table 2, above.

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