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IN DEFENSE OF THE FUNGI

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For three days, during the ABC 2002 symposium and in the dozens of papers written and presented at these proceedings, we've heard a multitude of negative accounts about those "terrible" fungi around us. Time and time again, the destruction they cause to our magnificent historical, cultural, and artistic pieces has been emphasized with vigor. They have been labeled as nasty, rotten, foul, dirty, putrefying, destructive culprits whose aim is to undermine all the treasures of cultural heritage we have so creatively and carefully produced throughout the ages. It saddens me to have heard all these dreadful things attributed to the fungi, for they are, without doubt, one of the most important forms of life on earth. True, they are seasoned animal and plant pathogens and masters at biodegradation, but that is what they are supposed to do! We would surely be in a sorry state if fungi found other ways of eating and left our organic matter to pile up around us. They truly are amazing, for they nourish us, they medicate us, they titillate our taste buds, they inebriate us, they make us hallucinate, and in the end, they dispose of us. In the next few pages, I'd like to tell you some things about these wondrous fungi—what they are, where they come from, how they live, and why we should be grateful to them.

WHAT ARE THESE DREADFUL THINGS? In the classification scheme, fungi are organisms that are neither plant (Kingdom Plantae) nor animal (Kingdom Animalia); they are in a Kingdom of their own, (Kingdom Eumycota). Recent genetic studies of their DNA reveal that they are more closely related to animals, and therefore humankind, than they are to plants. In scientific terminology, the Kingdom Eumycota has an elaborate taxonomic series of levels, but to simplify things all the fungi may be divided into three groups—molds, mushrooms, and yeasts. Of the three, molds and yeasts are of primary concern to conservators, while the mushrooms include some that are more of a culinary delight, and others that are not so delightful!

Molds are filamentous in structure; their body is composed of threads called "hyphae." The hyphae are themselves composed of microscopic units or cells, which, when attached in long chains, are visible to the naked eye. A mass of hyphae, whether growing on a ripened fruit or an exquisite piece of moisture-soaked artwork, usually forms a disc-shaped, more or less flattened matting termed a "mycelium." A hyphal strand placed in the center of a suitable medium in a culture dish will produce a mycelium that will grow and increase in size circumferentially to the edge of the dish. It is the hyphal strands that form the substance of the fungi and are the "culprits" that digest away and deteriorate the substrate from which it draws nourishment.

Mushrooms, the most recognized and probably the most treasured of the fungi, are also composed of filaments of hyphae. Most of the mushroom hyphae are underground, decomposing the roots of some tree, the litter of fallen leaves or branches, or the remains of some long-dead insect or animal. The mushroom itself is composed of a massive number of intertwining hyphae, and, actually, the mushroom is to the fungus what an apple is to a tree. The mushroom forms only when the fungus has had its fill of nutrients and is ready to extend itself above ground and disseminate spores. The so-called "fairy ring" is a result of the circumferential growth of the hyphae underground, similar to the mycelial mat growing in a culture dish. The mushrooms form along the periphery of the colony. As the colony ages, the older, center portion dies out and what we see above ground is a ring of living fungus tissue.

Yeasts are so different from either molds or mushrooms it is a wonder that they are called fungi. Their body plan is very simple, and they most closely resemble bacteria in their structure, except they are much larger. These fungi are spherical cells and form short or long chains that are excellent at digesting living or dead plant material and animal remains, as well as finding their way into ears, eyes, and other human crevices that are best left unmentioned.

THEY'RE EATING AWAY OUR WORLD! One of the most astonishing attributes of the fungi is the variety of materials they can eat. While green, chlorophyll-bearing plants are capable of manufacturing their own food source (carbon compounds) from carbon dioxide and water, animals and fungi must rely on complex carbon compounds already formed. They must live on the products directly or indirectly made by plants. Fungi first claim an area upon which to grow, and then begin to digest their surrounding by using a huge storehouse of enzymes. These masters of digestion have evolved an enzyme system that rivals that of humans, and in some ways surpasses it—consider that they can eat and digest wood.

Fungi differ from animals in the way they obtain their nutrients. Animals take food (a large complex of molecules) into their bodies and by the use of selective enzymes digest the material into smaller, usable molecules that are then absorbed into the cells that make up the digestive system. Fungi have not evolved a cavity or mouth; therefore they cannot absorb large complexes of molecules. Their method of obtaining nutrients or eating is unique: They secrete digestive enzymes from their hyphal cells into their immediate environment. The enzymes that are released digest the material upon which the fungus is growing, and then the hyphae absorb the smaller, simpler molecules into their cells. It is this process of fungal digestion that frustrates so many, especially the art conservator, for the nutrients used by the fungus may be the deteriorated remains of an historical document or cultural piece. With the exception of plastic, fungi can eat and digest almost any kind of material—anything containing cellulose, most proteins, including the chitin of insects, and an array of lipids. Pages can be filled with the specific kinds of materials fungi can digest. And when they partner with some algae and form lichens, these hungry organisms are capable of chipping away at stone, marble, and granite.

THEY START FROM A TINY BEGINNING Each new fungus, regardless of the size of the grown colony, has a simple beginning: It starts from a spore. There are meager requirements for spores to begin their "reign of terror"; they germinate in the presence of a little moisture and a broad range of temperature, the optimum being between 25 and 30°c. Although it's a much less complex machine than a seed, the fungus spore behaves the same way a seed does. It absorbs water, swells, kicks its enzymes into gear, and grows a little germ tube, the forerunner of literally thousands of genetically identical hyphae that will eventually make up the visible colony. But the little spore cannot land just anywhere and expect to flourish; the landing pad must be, in most cases, composed of some variety of organic matter. Once penetration of the surrounding material has been achieved, the hyphae will begin to elongate, produce side branches, and proliferate. As the hyphae grow they release both enzymes and metabolic byproducts we term "mycotoxins." The fungi are no fools—they never release all their digestive enzymes, as that is too costly in terms of energy loss. Instead, the enzymes they secrete are specific for the meal at hand—amylases for starch digestion, cellulases for wood, paper, and other cellulose-containing material, cutinases for plant leaf and young stem surfaces, and an array of other enzymes capable of taking apart the most complex structural design of animal or plant parts. Because there is fierce competition for nutrients out there, the fungus's best strategy is to keep freeloaders, such as bacteria and other microbes, from moving in on their territory and eating the goods. And the fungi do it quite effectively; they have evolved an elaborate assortment of metabolic byproducts that are released into the surroundings and are toxic to other fungi, microbes, and even small insects and animals.

GRANDMOTHER'S PORTRAIT WASN'T MOLDY YESTERDAY! The big question on everyone's minds, I'm sure, is "What makes mold grow so fast?" It follows that if a fungus intends to live from one generation to another, the mother colony must find a way to produce offspring and spread them out a bit. And the colony does just that—as the hyphae continue to grow and mature, they begin to generate spores, called conidia. But, really, the fungi overdo it! Colonies may produce hundreds of thousands, and even millions of spores over and over again. If they all found a suitable place to land and reproduce, we'd be totally swamped by mold. But they don't and we aren't. Only a very few land on a suitable substrate with the right environmental conditions to allow them to germinate.

Another amazing attribute of fungi is that they can produce these conidia with or without sex. Day-to-day production of conidia is a rather simple task accomplished by their proliferation from the mother colony. Terminal hyphae develop simple or elaborate stalks, branches, or heads upon which spores are formed and pinched off. Because most of the time the conidia are dry and powdery, they are easily whisked away by the slightest breeze, or attached and carried away by insects that may have inadvertently come in contact with the colony. The massive populations of fungus spores are generated without sex, that is, without the intervention or cooperation of another colony of the same fungus. They are derived from a single lineage; therefore all the millions of spores that are produced, with the exception of a spore mutation or two, are genetically identical to those of the parent colony and to each other. Learned mycologists often refer to this massive reproductive strategy as "fungus amplification" because it produces so much so fast. However, like every other living creature, the fungi are sexual as well. Books have been written about the why, ways, and when of fungal sexual encounters, and these matters are much too complicated and confusing for discussion here. The essential thing to know is that when the environmental conditions of temperature, nutrient level, and moisture are conducive, and a particular mold finds itself in the company of another sex, a union of the two strains will ensue. The exchange of genetic material between them will result in the production of hundreds or thousands of conidia that are now genetically different from both parent colonies and, often, from each other.

Many people may still be convinced that this world would be a much better place to live if we were free of, at least, snakes, mosquitoes, and fungi. I can't speak for snakes and mosquitoes, but I can assure you that without the fungi life would be nonexistent for some, miserable for many, and a lot less exciting for most. The attributes of fungi, both good and bad—mostly bad—are well documented in hundreds of volumes and thousands of scholarly papers. The subjects discussed during this symposium focused on the evil that fungi do, and, believe me, they commit evils much more serious than the biodeterioration of artworks, documents, monuments, and other historical materials. But because many of you will read the papers presented in this volume and leave with a one-sided view of the fungi, I think it only fair to pay tribute to some of the good they do.

MUSHROOMS, A CULINARY DELIGHT Who among us has not enjoyed the succulent taste of the oyster mushroom (*Pleurotus ostreatus*), or shiitake (*Lentinus edodes*), morels (*Morchella esculenta*), chanterelles (*Cantharellus cibarius*), the common meadow mushroom (*Agaricus bisporus*), or, if you can afford them, black or white truffles (*Tuber melanosporum* and *T. magnatum*)? Some 20 edible species are now grown worldwide and enjoyed by almost every culture. Steak, lamb, pork, sausages, and pizza would surely be lacking without these succulent morsels, and where would mushroom soup be without the "'shrooms?" I clearly remember as a child, during the spring and fall months, being taken by my father, along with several other of his seven sons, into the forests of Connecticut to collect mushrooms. It was a ritual, every Sunday after attending church, or often instead of church. We never collected all of the edible species, only the ones my father knew for certain were edible. Later in the day, mom would take over in the kitchen and prepare some dishes that were so delectable, they are among my favorites to this day—mushrooms pickled in wine vinegar with garlic and herbs; mushrooms fried with Italian sausage, bell peppers, and onions; mushrooms with a variety of pastas and sauces. It is a wonder I ever left home!

For much of our history, while European and Asian cultures regularly gathered and consumed fleshy fungi, most of the English-speaking world looked upon mushrooms or "toadstools" as evil, mysterious, and poisonous creations of elves, witches, or devils. Mushrooms, after all, grew only where lightening strikes the forest floor, or on the very spot wetted by the semen of mating deer. Or even worse, it was a common belief that mushrooms grew wherever witches and warlocks urinated, expectorated, or defecated upon the ground. It's a blessing that we've at least passed that historical period!

Mushroom tissue contains a number of chemical compounds that can be nutritional, hallucinogenic, poisonous, or a combination of the three. The nutritional value of mushrooms has been well established in recent years. Although not considered a health food by most nutritionists, mushrooms do contain several amino acids, as well as carbohydrates and high levels of minerals and vitamins. They are free of cholesterol, low in calories, and high in fiber. They contain an insignificant amount of fat (although of course the fat content will increase substantially when mushrooms are prepared the way a lot of people like them—sautéed in olive oil or butter, or smothered with gravy!)

With about 10,000 species of mushrooms growing in the wild, only a handful are poisonous, and, of those, an even smaller number are deadly. How, then, do we account for the significant number of deaths that occur each year from mushroom poisonings? The answer is that the deadly ones are common, appear often during the growing season, usually smell great, and are very good looking! *Amanita virosa*, the "death angel," is a perfect example; it is almost pure white and really looks angelic—but looks can kill! Even though I'm Italian, I offer rather conservative advice for the would-be mushroom pickers who are inexperienced at distinguishing between safe and poisonous mushrooms—buy your mushrooms at the grocery store. Many guides and texts have been written that deal with mushroom poisonings, how to recognize edible and poisonous varieties, and how to identify mushrooms and other fleshy fungi in the field. In addition to Lincoff and Mitchel (1977), Arora (1986), Phillips (1991), Schaechter (1997), and Barron (1999), you can find over 550 publications dealing with the subject of mushrooms listed on the Internet.

A DIFFERENT KIND OF TRIP "The sacred mushrooms of Mexico," "magic mushrooms of Russia and Siberia," "soma of the gods," "Teonanacatl," and "black 'shrooms from California" all are designations for extraordinary mushrooms that are hallucinogenic. *Psilocybe cubensis, P. mexicana, Amanita muscaria*, and species of *Conocybe, Gymnopilis*, and *Stropharia* are the ones most often associated with mindaltering chemicals. The chemicals tend to work on the central nervous system and result in reactions that have been described as feelings of happiness, liberation, or religious awakening, or as having spiritual overtones. Rage, violence, and disorientation may also result, depending on the amount of mushroom consumed and the mental state of the individual, as well as on his or her physiological condition. Whether the "trip" is a good one or a bad one, it is not uncommon for the individual to conclude the experience with what I call NDS—nausea, diarrhea, and sleep. While several excellent texts discuss this topic in detail, the classical work must be credited to Wasson and Wasson (1957). There is also an authoritative treatment by Lincoff and Mitchel (1977), an informative and readable update by Benjamin (1995), and one devoted entirely to *Psilocybe* and related genera, the most notable of hallucinogenic mushrooms (Stamets, 1996).

GIVE US THIS DAY OUR DAILY BREAD AND WINE It is often difficult to believe that yeasts (*Saccharomyces cereviseae* and several other species) are absolutely essential for the very existence of bread and wine. Both substances depend on the biochemical activities and byproducts of this productive fungus, a process often referred to as alcoholic fermentation. When yeasts are supplied with even a simple source of food and some moisture, they flourish. Provide them with a little sugar from grapes or starch from flour, and they can do marvelous things! As the yeasts consume the nourishment, the cells begin to grow and divide prolifically. Two byproducts are always generated—carbon dioxide and ethyl alcohol. Which of the byproducts is desired depends entirely upon whether the fermentation is done by a brewer for beer, by a distiller for wine and other forms of alcohol, or by a baker for bread. Note the use of the word "byproducts" rather than "waste products." On earth nothing organic is ever wasted, for one organism's byproduct will most certainly be another organism's sustenance. The brewer and distiller are interested primarily in the alcohol byproduct, while the baker is interested in the carbon dioxide gas that is generated by the respiring yeasts. The purpose of promoting alcoholic fermentation in baking is to provide gas production, which is responsible for the rising process in the bread; the alcohol burns off in the oven and releases that heavenly aroma around the kitchen. The various flavors and textures of bread result from the various grains used, the flavors added, and the degree to which yeasts are allowed to ferment the starch.

Although wine is usually fermented grape juice, it can be made by using several kinds of fruits, herbs, or even flowers. Once the plant parts and yeasts are added and some liquid is supplied, the yeasts begin to do their thing; the organic base is slowly consumed, gas is produced and released, and the sugars are converted to alcohol—a miraculous evolutionary process! In wine, the alcohol concentration reaches about 12% before the yeasts begin to die. Some wines, such as sherry, are fortified; that is, alcohol is added to them after the fermenting process is complete. Wines vary tremendously in color and taste. The flavor of red wines comes from the grapes used, the strain of yeasts, and the specific fermentation process. When finished, wines come in all shades of red, pink, and white. White wine is fermented from skinned red grapes, white grapes, or apples. For the serious drinker, "hard liquor" is also credited to fermentation by yeasts. Scotch is the product of fermented barley, rye comes from fermented rye, and we get bourbon from fermented corn.

SOME MOLDS ARE GOOD FOR YOUR HEALTH! For better than 50 years fungi have played a major role in our medical well-being. Although it has only been a short time that fungus compounds have been processed or manufactured for medicinal purposes, their use as aids to combat infection dates back to the Egyptians. In fact, when the remains of a Stone Age man who had been traveling some 5,000 years ago in the Tyrolean Alps was discovered in 1991, he was carrying with him tissue from three different mushrooms. Current research suggests that some of the mushrooms may have served as a source of medicine. Ancient humans most assuredly gathered mushrooms not only to eat but also as a means of curing many ailments. In many Asian cultures, especially China and Japan, mushrooms have been used for centuries for medicinal purposes. Certain mushrooms are believed to fight infection, enhance vitality, and promote good health. Shiitake (*Lentinus edodes*), an edible and delicious mushroom, not only tantalizes our palate, but also contains lentinan, a chemical that enhances the activity of the immune system. This substance has been shown to be extremely useful in boosting the activity of a cancer patient's natural interferon and interleukin production, which is then capable of fighting tumors. Today, in the western world, while mushrooms are enjoyed over steaks and in numerous other dishes, they are less commonly used to heal our bodies, but other fungi abound that are able to fight infectious microbes that invade us.

It began with the discovery of penicillin, from the fungus *Penicillium chrysogenum*, by Alexander Fleming in 1928. Today, our doctors can prescribe a plethora of pills made of fungus derivatives that we take casually to help cure us of bacterial as well as fungal infections. Until recent times, these microbes would have killed us. Griseofulvin, derived from *Penicillium griseofulvum*, is an antifungal agent rather than one that is antibacterial. It is one of the major drugs used today for fighting mycoses (fungal infections of the nails, toes, and several other epidermal and subdermal infestations). Within recent years many new fungus-derived drugs have made their way into general use. Cyclosporin, derived from *Cylindrocarpon lucidum* and *Tolypocladium inflatum,* suppresses the activity of the immune system and is, therefore, widely used in organ transplants to inhibit tissue rejection by the recipient. Even in the lowering of cholesterol and the treatment of heart disease and arteriosclerosis, fungi are playing a positive role. Compactin and Lovastatin are only two of the commercial drugs produced by several species of fungi, among which are *Penicillium, Aspergillus, Trichoderma,* and *Hypomyces.*

In addition to blemishing thousands of pieces of artwork, *Aspergillus niger* grown under the proper culture conditions produces an enzyme that can lower methane gas production. What a tremendous advantage for some human digestive systems! The enzyme is now incorporated into a commercial product that can be taken by the more gaseous individuals in our society. The remedy, called Beano, which is now advertised frequently in magazines and seen on national TV in the evening when we are trying to enjoy dinner, is available in drugstores throughout the U.S. and Canada. It's just another small measure of the good molds do!

Some fungi team up with other organisms, resulting in the formation of some interesting partnerships. One of these is known as Kombucha, a gelatinous, symbiotic growth composed of yeasts enclosed in a matrix of bacteria. Kombucha tea, whose reputation has become widespread, is a drink derived by culturing the two organisms on a mixture of tealeaves, water, and sugar. The symbionts begin to grow on the surface of the tea and secrete a number of amino acids into the liquid. After a week or two of mellowing, the liquid is filtered and consumed at a quantity of 150 ml or more per day. One has to be brave to drink the mixture after seeing it; I was! The bouquet is sweet-smelling and the flavor is subtle, with a lightly acidic aftertaste. The drink, which has been popular in various parts of the world for over a thousand years, has recently become very fashionable in the west; my batch came from California. Although its medicinal properties are questionable, people who drink it are convinced of its health benefits, which they claim include, among many others, cure or suppression of AIDS, curing of various types of cancer and arteriosclerosis, lowering of blood pressure, enhancement of the sex drive, and the reversal from graying to natural hair color in mature adults.

PLEASE PASS THE ROQUEFORT CHEESE Cheese is a protein-lipid, semisolid or solid material manufactured from milk. While bacterial fermentation is primarily responsible for the basic production of cheese, some of the world's finest cheeses are indebted to fungi for their distinctive tastes and textures. Whether they be mild, sharp, or pungent, their flavor, texture, and aroma result from the activity of yeasts or molds. In a very organized and systematic way, the molds feed on the milk products by secreting proteolytic and lipolytic enzymes. The enzymes break down the protein and lipid components of the milk and absorb the reduced molecules into their hyphae, which then release a number of chemicals into the cheese. Even when the cheese is freshly purchased from the market and we hurry home for a delightful morsel accompanied by a glass of red wine, keep in mind that fungi may have started eating that cheese months ago! The fungal hyphae are responsible for the blue "veining" often found in cheese, while their released byproducts offer a multitude of flavors and textures. The flavor of many varieties of cheese, then, is a result of the delightful and universal activity we often call "rotting." *Penicillium roqueforti* is the mold responsible for rotting (ripening might be a more tasteful word) the blue-veined variety of cheeses like Roquefort, blue cheese, Stilton, and that delightful Italian treasure, Gorgonzola. *Penicillium camemberti* plays the crucial role in the maturation of Camembert and Brie. While *P. roqueforti* works on the inside of the cheese, *P. camemberti* starts digesting the milk product from the outside and works in, resulting in a cheese that is hard on the outside and soft (slightly digested) on the inside.

WHEN ALL IS SAID AND DONE Fungi do indeed threaten humankind when one considers the tremendous damage they can to our crops, our livestock, our historic treasures, and our health. On the other hand, through their continuous process of decomposition, they help our world renew its resources by returning chemical elements back into the fabric of the earth for their eventual regeneration. Moreover, fungi not only benefit humans directly with food, medicine, and an array of products, their association with other animals and plants can enhance our lives as well. When we weigh all of the good against all of the not so good, we can't help but declare that fungi are fantastic!

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For well over 25 years Constantine Alexopoulos and his coworkers have produced the most authoritative textbook in the field of mycology; it is now in its fourth edition (Alexopoulos et al., 1996). Several more, excellent ones have appeared within recent years, the most current of which is Kendrick (2000). Throughout the past half-century numerous classical books have been published that cover the history, folklore, and general nature of mushrooms and fungi; some of the best are Rolfe and Rolfe (1925), Large (1940), Ramsbottom (1953), Gray (1959), and Christiansen (1961). More recently several extremely readable and delightful books on fungi have been published; two in particular are Hudler (1998) and Moore (2001).

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