PART I

MUSHROOM BIOLOGY

Chapter 1

INTRODUCTION TO MUSHROOM BIOLOGY

The biological science that is concerned with fungi is called **mycology**. **Mushroom Biology** is the branch of mycology that deals with mushrooms. We define a mushroom as a macrofungus with a distinctive fruiting body, which may be above ground (**epigeous**) or below ground (**hypogeous**). A macrofungus has a fruiting body of sufficient size to be seen by the naked eye and to be picked up by hand. In our definition, mushrooms need not be Basidiomycetes, nor aerial, nor fleshy, nor edible. Mushrooms can be Ascomycetes, grow under the ground, have a non-fleshy texture, and they need not be edible. Mushrooms have been used by man from very early times as a source of food, and in 1991 they were cultivated for this purpose to the extent of about 4.27 million metric tons (Fig. 1-1).

At one time in history, when biological knowledge was limited to what could be seen with the naked eye, the living world was divided into two kingdoms, plant and animal. Because fungi possessed a cell wall, which is present in plants but absent in animals, fungi were placed in the plant kingdom. This is how the fungi were treated by Linnaeus in his famous "Species Plantarum," published in 1753, and in this way the fungi were classified for many years thereafter. With improvement in optical lenses, it was learned around 1700 that organisms existed that were too small to be seen by the unaided eye. Included here were bacteria, protozoans, yeasts, and unicellular algae. In order to accomodate some of these unicellular flagellate organisms, a new kingdom, the Protista, was suggested as a sort of "catch-all" group for those organisms that did not fit well into either the plant or animal kingdom. Then with the advent of the electron microscope, it was learned that at the subcellular level a major distinction could be made in all organisms on the basis of whether the organism had a true nucleus and **organelles** (membrane-bounded structures in the cytoplasm) or lacked these structures. The former group was referred to as being **eukaryotic** and the latter as **prokaryotic** - the prokaryotic being the more primitive from an evolutionary point of view. The properties of prokaryotic and eukaryotic organisms are compared in Table 1-1. The bacteria (including the actinomycetes) and the blue-green algae (division Cyanochloronta or class Cyanobacteriaceae, depending upon the authority selected) were found to be prokaryotic, and therefore they were placed in a separate kingdom, the **kingdom Monera**. All other organisms were eukaryotic, but it was no longer satisfactory to include the fungi in the plant kingdom, because the fungi are achlorophyllous (lacking in chlorophyll) and thus incapable of carrying on photosynthesis - a fundamental characteristic of plants. Thus, nutritionally, the fungi are **heterotrophic** (requiring preformed organic

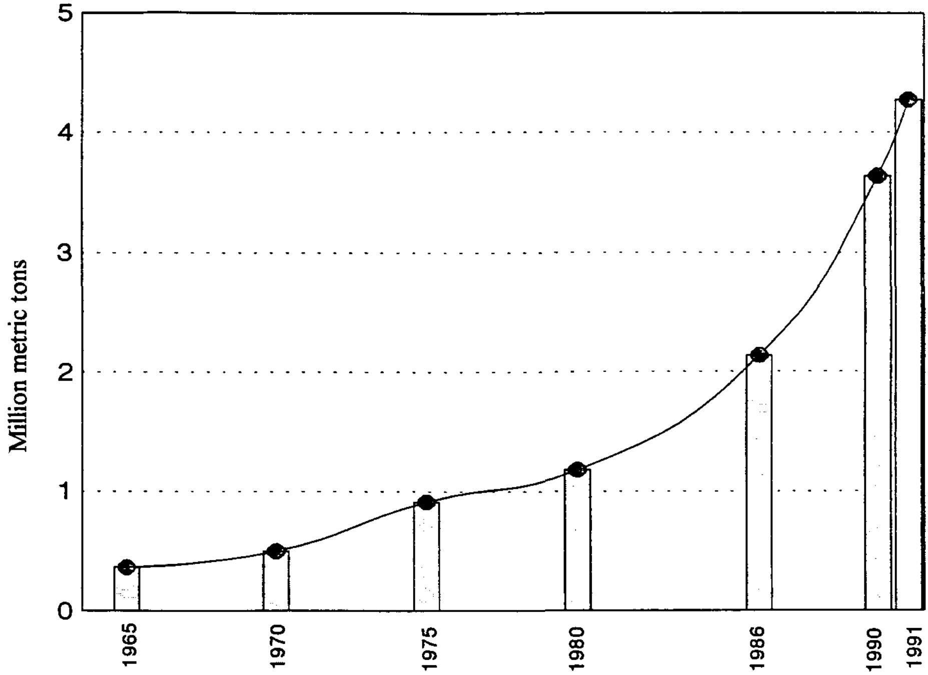

Fig. 1-1. Annual world production of cultivated edible mushrooms, 1965-1991.

Table 1-1. Properties of Prokaryotes and Eukaryotes

	Prokaryotes	**Eukaryotes**
Kingdoms	Monera	Animalia, Myceteae, Phyta, Protista
DNA	DNA unit fibrils of 24Å diameter in closed loop in cytoplasm	DNA unit fibrils of 100Å diameter organized into chromosomes and bounded by nucelar membrane (true nucleus)
Mitochrondria (membrane-bounded respiratory organelles)	-	+
Golgi Apparatus	-	+
Ribosome-associated Endoplasmic Reticulum	-	+
Cytoplasmic Ribosomes	Around 18 nm with mass of 2.8 megadaltons	Around 20-22 nm with mass of 4 megadaltons
RNA and Protein	Synthesized in same compartment	RNA synthesized and processed in nucleus; proteins synthesized in cytoplasm
Genetic recombination	Unidirectional or virus mediated	Involves karyogamy and meiosis

compounds for their energy and growth requirements) as opposed to the self-nourishing, photosynthetic **(autotrophic)** plants. Animals are heterotrophic, too, but they have digestive nutrition as opposed to the **absorptive or osmotrophic nutrition** of fungi, in which organic materials in solution are taken into the fungal cells. Thus, members of the animal kingdom are **heterotrophic with digestive nutrition** (taking food into the body and then breaking it down by a digestive system) and also lack cell walls. Clearly, the fungi do not fit into the **kingdom Phyta** or the **kingdom Animalia**, so they have been placed in a kingdom of their own called the **kingdom Myceteae**. The unicellular, motile organisms and some other eukaryotes, such as the slime molds that do not fit into the plant, animal, or fungal kingdoms, are now placed in the **kingdom Protista** (Fig. 1-2).

A. WHAT ARE MUSHROOMS?

The **macrofungi** with distinctive fruiting bodies commonly occurring in fungi of the class Basidiomycetes and sometimes in the class Ascomycetes, we refer to as mushrooms. Other terms used are fruiting bodies, basidiocarps (for the sexual fruiting body of Basidiomycetes), and ascocarps (for the sexual fruiting body of Ascomycetes). Of the approximately 16,000 species of the class Basidiomycetes, it has been suggested that over 10,000 species produce basidiocarps of sufficient size and suitable texture to be considered as a possible source of food. Of these, about 50% of the species are considered to possess varying degrees of edibility. Contrary to popular opinion, the number of these mushrooms which are poisonous is fairly large, approximately 10%, of which some 30 species are considered to be lethal.

For centuries the medicinal or tonic value of certain mushrooms has been known, and modern research has identified and tested beneficial compounds in these and some other mushrooms. Of course there are some mushrooms which are neither edible, nor poisonous, nor producers of known beneficial metabolites. They may be useful to the mushroom biologist, however, as in the case of the wood-rotting *Schizophyllum commune*, which is used as an experimental organism for the study of the genetic control of sexuality and development of fruiting. It is interesting to note that *Schizophyllum* has now joined the ranks of medicinal mushrooms because of the production of a polysaccharide called schizophyllan, which has been found to be beneficial in the treatment of some cancers.

B. WHERE ARE MUSHROOMS FOUND?

The fungi are commonly described as being ubiquitous. They are found just about everywhere. The mushrooms are rather more selective than other fungi in that the size of the

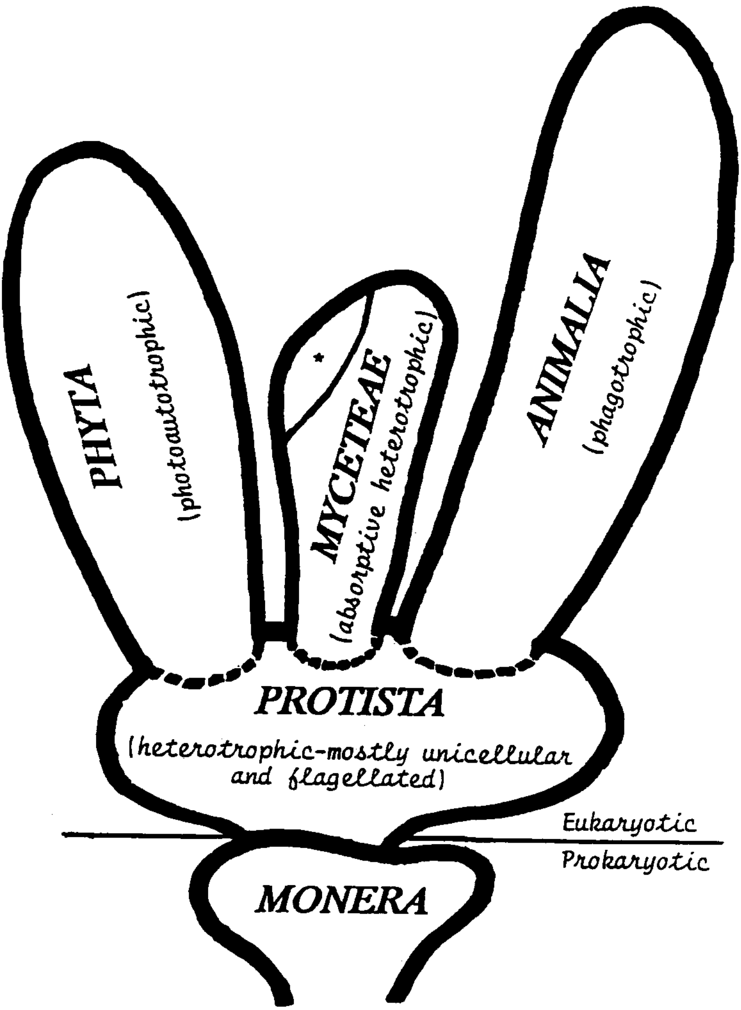

Fig. 1-2. The Five Kingdoms (modified from Kendrick, *The Fifth Kingdom*, 1985)

* Of the approximate 69,000 described fungal species over 10,000 are macrofungi which produce distinctive fruiting bodies, the mushrooms. The science that deals with mushrooms is called Mushroom Biology.

fruiting body requires the availability of more nutrients than are required for the production of asexual spores by microfungi. The distribution of mushrooms is worldwide although their production may be seasonal. Plentiful moisture leads to mushroom formation, and their growth in abundance frequently follows rain. In temperate regions there may be a particular flora of mushroom species associated with the seasons of fall, summer, and spring. Relatively few mushrooms are produced during the cold winter months although there are perennial fruiting bodies that persist during the winter, and the mushroom of *Flammulina velutipes* may form at near-freezing temperatures and survive freezing temperatures. This is the reason that *F. velutipes* has the common name, winter mushroom. Mushrooms are also produced in tropical and subtropical regions. A good example of this is the edible straw mushroom, *Volvariella volvacea*, that grows optimally at 32-35°C and fruits best at 28-32°C. Habitats in which mushrooms are found include grassy meadows and woodlands where they grow upon ligno-cellulosic substrates, such as straw and wood.

C. IMPORTANCE OF MUSHROOMS

1. In Nature

From the standpoint of the fungus, the mushroom is important as the structure in which the sexual spores (meiospores) are produced and from which they are disseminated. It is through sexuality that variation is achieved by producing progeny with attributes for various different environmental conditions. The vegetative growth of mycelium is essential for the subsequent development of the mushroom and this mycelial growth utilizes lignocellulosic materials, such as the polysaccharides of straws and wood, for nutrient materials. Since such substrates are commonly insoluble in water, they are broken down to smaller, soluble units through the activity of enzymes excreted by the fungal cells. (Table 1-2). This **bioconversion** of insoluble plant waste materials to a nutritious food that has a high protein content is one of the important activities of mushrooms.

2. As Food for Man

From ancient times the mushroom has been consumed as a food by man. Initially, it was probably the pleasing flavor and texture that was so attractive and in some societies their use was limited to royalty, but for well over two thousand years some species of mushrooms have also been used as medicinals and tonics. In modern times the cultivation of mushrooms has steadily increased with the annual production, as previously mentioned, of 4.27 million metric tons in 1991. Growing awareness in the past couple of decades of the nutritional merits of mushrooms has increased consumption in an era in which people have become more

Table 1-2. EXTRACELLULAR ENXYME PRODUCTION BY *AGARICUS BISPORUS*

ENZYME ACTIVITY DETECTED	ROLE	NUTRIENT IN GROWTH SUBSTRATE (COMPOST)	PRODUCT OF ENZYME ACTIVITY FOR ASSIMILATION BY FUNGUS	STAGE OF LIFE CYCLE WHERE ACTIVITY UTILIZED
Laccase	Broad role in lignin biodegradation	Phenols or lignin	Lower molecular weight aromatic compounds	Mycelial growth on compost
Endocellulase, Exocellulase, β-Glulosidase (Cellulase Complex)	Cellulose degradation Replenish carbohydrate levels	Cellulose	Sugars	Fruiting body development
Xylanase	Xylan degradation	Xylan (hemicellulose)	Sugars	Mycelial growth on compost
Protease	Protein degradation	Protein	Amino acids	Mycelial growth on compost
Phosphatase	Liberation of phosphate ion	Phosphate esters	Free phosphate	Not known
Lipase	*Lipid degradation*			*Mycelial growth on compost*
DNAase	DNA degradation	DNA	Sugars, nucleic acid bases, phosphates	Mycelial growth on compost
RNAase	RNA degradation	RNA	Sugars, nucleic acid bases, phosphates	Mycelial growth on compost
Laminarinase	Glucan degradation	Glucans	Sugars	Mycelial growth on compost
β-N-Acetylmuraminase (Lysozyme)	Peptidoglycan degradation	Bacterial cell wall polymers	Peptidoglycan fragments	Mycelial growth on compost
β-N-Acetylglucosaminase	Peptidoglycan degradation	Bacterial cell wall polymers	Peptidoglycan fragments	Mycelial growth on compost

Modified from: Wood, Clayton, Burton, Matcham, Allan, Perry, Thurston, Raguz and Yague, in Mushroom Science XIII, Science and Cultivation of Edible Fungi, Vol. 1, ed. by M. J. Maher. A. A. Balkema, Rotterdam, 1991; Sparling, G. P., Fermor, T. R., and Wood, D. A. Measurement of the microbial biomass in composted wheat straw, and the possible contribution of the biomass to the nutrition of *Agaricus bisporus*. SOIL BIOL. BIOCHEM. 14: 60 9, 1982; and Flegg, P.B., Spencer, D. M., and Wood, D.A.. BIOLOGY AND TECHNOLOGY OF THE CULTIVATED MUSHROOM. John Wiley and Sons. New York. 1985 concerned about human nutrition.

3. As Tonics and Medicines

In China there is a long history of the use of many mushroom species as medicinals and tonics. Modern studies of Chinese medicines have succeeded in isolating and identifying compounds from many of these mushrooms, and such compounds have been proven to be beneficial in the treatment of certain ailments. Furthermore, an active area of modern research involves the search in mushroom species for compounds that can be used in the treatment of various cancers, cardiovascular disease, viral diseases, etc. (Table 1-3).

There are various extremely important roles that mushrooms play in the world. Their usefulness to man as food, as tonics and medicinals and also in the bioconversion of waste organic materials to forms that can enter the major nutrient cycles are all of great benefit to both man and nature.

Table 1-3. Pharmaceutical Components of Mushroom Species

Pharmacodynamic	Component	Species
1. Antibacterial effect	Hirsutic acid	Many species
2. Antibiotic	E-beta-methoxyacrylate	*Oudemansiella radicata*
3. Antiviral effect	Protein, Polysaccharide	*Lentinula edodes* and *Polyporaceae*
4. Cardiac tonic	Volvatoxin, Flammutoxin	*Volvariella*
5. Decrease cholesterol	Eritadenine	*Collybia velutipes*
6. Decrease level of blood sugar	Peptide glycogen, Ganoderan	*Ganoderma lucidum*
7. Decrease blood pressure	Triterpene	*Ganoderma lucidum*
8. Antithrombus	5'-AMP,5'-GMP	*Psalliota hortensis*
9. Inhibition of PHA	r-GHP	*Psalliota hortensis* and *Lentinula edodes*
10. Antitumor	Beta-glucan RNA-complex	Many species, *Hypsizygus marmoreus (Lyophyllum shimeji)*
11. Increase secretion of bile	Armillarisia A	*Armillariella tabescens*
12. Analgesic, Sedative effect	Marasmic acid	*Marasmius androsaceus*

Source: Pai, S.H., S.C. Jong, & D.W. Lo. Uses of mushrooms. *Bioindustry* 1:126-131. 1990.