Part I

MUSHROOM BIOLOGY - FUNDAMENTAL ASPECTS

CHAPTER 1

MUSHROOM BIOLOGY: THE IMPACT ON MUSHROOM PRODUCTION AND MUSHROOM PRODUCTS

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1. INTRODUCTION

According to the fossil record, mushrooms have existed since the Lower Cretaceous Period (approximately 130 million years ago), long before human beings evolved on this planet. It is probable that, from his earliest beginnings, man has utilized mushrooms as a food and, when we observe present day animals running in the wild and consuming mushrooms, it is easy to believe that prior to man's advent on the planet, animals were consuming mushrooms with relish and enthusiasm. In nature, mushrooms have not only been a source of food for man and other animals, but also have played an important role in the cycling of carbon and other elements through the breakdown of lignocellulosic plant residues and animal dung, which serve as the substrates for these saprophytic fungi. In this way, mushroom species, as agents of decay, help keep the environment from being overwhelmed by the dead organic debris of plants and animals. Simultaneously, mushrooms can produce a wide range of enzymes that degrade complex substrates, following which they absorb the soluble substances so formed for their own nutrition (Wood & Fermor, 1982; Wood, 1984). This absorptive nutrition is a characteristic of mushrooms. These complex substrates, which are generated annually in huge quantities, are agricultural, industrial, and forest waste products. Examples are: cereal straws, coconut and coffee waste products, sugar cane bagasse, sawdust and cotton wastes, etc. (Chang & Miles, 1989). Much of this material is either burned, shredded or used as landfill or for improvement of soil quality, even though these wastes constitute a potentially valuable resource and can be recycled for the production of edible food for man. Although physical and chemical technologies may, in some cases, play important associated roles for handling these wastes, biotechnical approaches are essential for the emergence of practical conversion processes which can be applied to situations in developing countries throughout the world where large-scale capital intensive operations are inappropriate.

Today, we understand much better than we did a few decades ago, the importance and widespread nature of the symbiotic mycorrhizal association that involves fungi with the roots of plants. The growth of these plants is enhanced by minerals received from the fungus which actively absorbs them from the soil, and, in return, the fungus obtains sugars from the plant. Therefore, when we define a mushroom as a macrofungus with a distinctive fruiting body that is large enough to be seen with the naked eye and to be picked up by hand (Chang & Miles, 1992), we must also add that there are some mycorrhizal fungi which are mushroom species.

Although mushrooms were long appreciated because of their flavor and texture, and some for medicinal or tonic attributes, the recognition that they are nutritionally a very good food is much more recent. It is now known that mushrooms have a high protein content of good quality. Furthermore, mushrooms have a high proportion of unsaturated fatty acids, are a good source of several vitamins, fiber and minerals, and they are low in calories, sodium, fat, and cholesterol. In addition, their nucleic acid content is not high enough to limit their daily use as vegetable (Li & Chang, 1982).

Our present conference is concerned with the impact of mushroom biology upon mushroom production (mushroom science) and mushroom products (mushroom biotechnology). Broadly considered, mushroom biology includes any aspect of biology involving species which produce mushrooms as previously defined. Thus, mushroom biology provides the central knowledge for both mushroom science and mushroom biotechnology. It is our hope that this conference will not only provide for the exchange of information, but will also provoke thoughtful planning for future research and encourage collaborative efforts aimed at higher mushroom production and better use of mushroom products and their derivatives.

2. MUSHROOMS AND MUSHROOM BIOLOGY

According to the definition previously stated, mushrooms need not be Basidiomycetes, nor aerial, nor fleshy, nor edible. Mushrooms can be Ascomycetes, grow underground, have a non-fleshy texture and need not be edible. In other words, mushrooms can be roughly divided into four categories: (1) those which are fleshy and edible fall into the edible mushroom category, e.g., *Agaricus bisporus*; (2) mushrooms which are considered to have medicinal applications, and which are referred to as medicinal mushrooms, e.g., *Ganoderma lucidum*; (3) those which are proven to be, or suspected of being poisonous and which are called poisonous mushrooms, e.g., *Amanita phalloides*; and (4) a miscellaneous category which includes a large number of mushrooms whose properties remain less well defined. These may tentatively be grouped together as 'other mushrooms'. Some mushrooms fall into more than one category; for example, mushrooms that are not only edible, but also possess tonic and medicinal qualities. Out of approximately 69,000 described species of the estimated 1,500,000 species of fungi (Hawksworth, 1991), there are about 10,000 known species of fleshy macro-fungi, of which only a handful are lethal (Kendrick, 1985).

The historical records of intentionally cultivated mushrooms are shown in Table 1 and Figure 1. It is estimated that the first mushroom was cultivated around 600 A.D. This was *Auricularia auricula*. The mushroom which is produced in the greatest amount today, *Agaricus bisporus*, was not cultivated until 1600. Of the leading mushrooms of today that were cultivated before 1900, *Agaricus* is the only one that was not first cultivated in China. Note that *Pleurotus ostreatus* was first cultivated in the USA, and several other species of *Pleurotus* were initially cultivated in India.

Mushroom biology is the discipline concerned with the scientific study of mushrooms. It includes not only cultivation but also deals with every aspect of mushrooms, such as: taxonomy, development, nutrition, physiology, genetics, medicinal and tonic attributes, edibility, toxicity, etc. (Chang & Miles, 1992). Through improvement of, for example, taxonomic methods, the discovery and characterization of a great number of new species has recently occurred worldwide. The conservation of mushroom germplasm as part of the conservation of the world's biological diversity has long term worldwide implications. A majority of mushrooms are described as saprophytic, obtaining nutrients from non-living organic materials, so-called compost. The presence of thermophilic fungi in mushroom compost has been shown to be important in promoting growth of mushroom

TABLE 1. Historical record of commonly cultivated mushrooms.

Species	Record first cultivated (Est.)	Source
Agaricus bisporus	1600	Atkins (1979)
Agaricus bitorquis	1961	Singer (1961)
Agrocybe cylindracea	1950	Huang (1984)
Amanita caesarea	1984	Zhu & Xie (1984)
Armillaria mellea	1983	Zhang & Lu (1983)
Auricularia auricula	600	So (659)
Coprinus comatus	1984	Wang & Kang(1984)
Dictyophora duplicata	1982	Lin *et al.*, (1982)
Flammulina velutipes	800	Han (1590)
Ganoderma spp.	1621	Wang (1621)
Gloestereum incarnatum	1989	Zhang *et al.*,(1989)
Grifola frondosus	1983	Zhao & Yang (1983)
Hericium coralloides	1984	Xu & Li (1984)
Hericium erinaceus	1960	Chen (1988)
Hohenbuehelia serotina	1982	Liu & Guo (1982)
Hypsizigus marmoreus	1973	Zhang & Wang (1992)
Lentinus edodes	1000	Wang (1313)
Lentinus tigrinus	1988	Wu & Wei (1988)
Lyophyllum ulmarium	1987	Wang & Zhang (1987)
Morchella spp.	1986	Ower *et al.*,(1986)
Oudemansiella radicata	1982	Ji *et al.*, (1982)
Pholiota nameko	1958	Kaga & Kondo (1958)
Pleurotus citrinopileatus	1981	Shen (1981)
Pleurotus cystidiosus	1969	Miller (1969)
Pleurotus ferulae	1958	Mou & Cao (1986)
Pleurotus flabellatus	1962	Bano & Srinvatava (1962)
Pleurotus florida	1958	Block *et al.*,(1958)
Pleurotus ostreatus	1900	Falck (1917)
Pleurotus sajor-caju	1974	Jandaik (1974)
Poria cocos	1232	Zhou (1232)
Sparassis crispa	1985	Sun *et al.*,(1985)
Tremella fuciformis	1800	Chen (1983)
Tremella mesenterica	1985	Liu (1985)
Tricholoma gambosum	1991	Tian & Yang (1991)
Tricholoma lobayense	1990	Ganeshan (1990)
Tricholoma mongolicum	1991	Tian & Yang (1991)
Volvariella volvacea	1700	Yuen (1822)

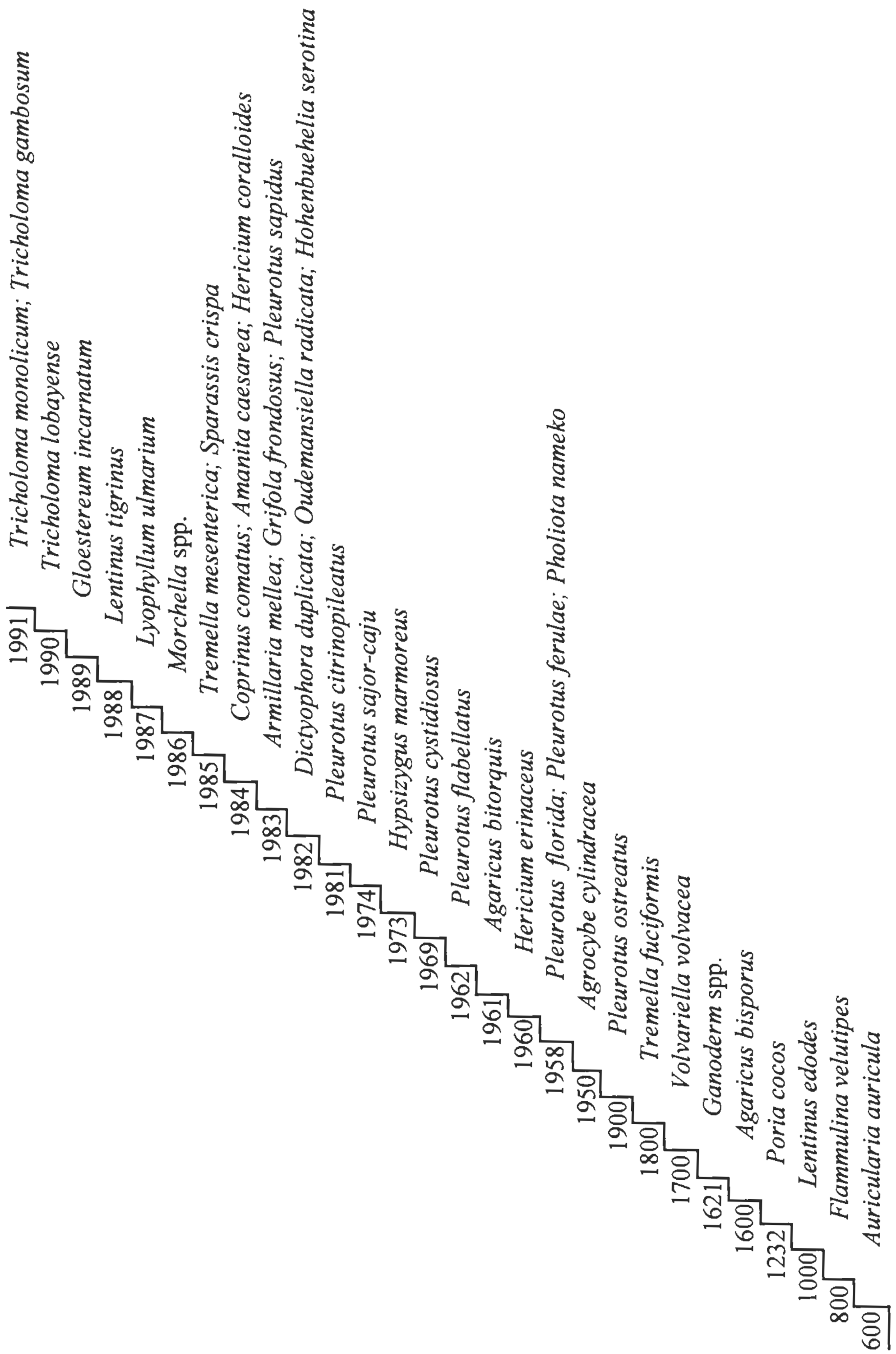


FIGURE 1. Historical record of cultivated mushrooms.

mycelium and for a good yield of fruit bodies (Straatsma *et al*., 1991 ; Straatsma & Sanson, 1993). Those that obtain nutrients from living organisms are called parasitic. Others associated with roots of plants are mycorrhizal mushrooms. According to their nutritional and ecological habits, mushrooms can be divided into two big groups: ectomycorrhizal and non-ectomycorrhizal. Within non-ectomycorrhizal mushrooms are five groups based upon the nature of the substrate upon which they grow - wood, straw, dung, soil, insects (Table 2).

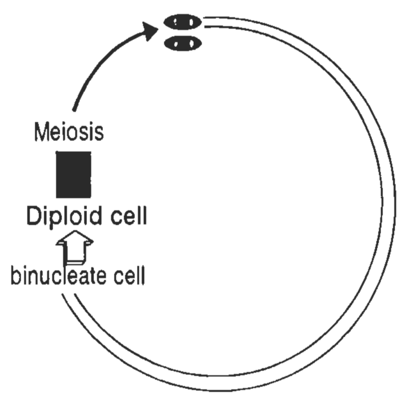
TABLE 2. The ecological habitats and the breeding selection of mushrooms.

Ecological habitats			Important genera	Fruiting by artificial cultivation
Non-ectomycorrhizal mushrooms	Above ground	Wood	*Pleurotus* *Lentinus* *Auricularia* *Tremella* *Hericium* *Pholiota* *Kuehneromyces*	easy ↑
		Straw	*Volvariella*	
	On earth	Dung	*Coprinus* *Agaricus* *Agrocybe* *Stropharia*	
		Soil	*Lepiota* *Dictyophora* *Lepista* *Melanoleuca* *Morchella*	
		Insects	*Cordyceps* *Termitomyces*	
Ectomycorrhizal mushrooms	With roots	Mycorrhizal	*Tricholoma* *Ramaria* *Cantnarellus* *Boletus* *Suillus* *Gomphidus* *Lactarius* *Russula* *Amanita* *Cortinarius* *Rhizopogon* *Terfezia*	difficult

Due to a better understanding of their biological nature and the development of advanced cultivation techniques, more and more new species of mushrooms have been domesticated. About 80 out of 2,000 species which are regarded as prime edible mushrooms have been experimentally grown, 40 economically cultivated, around 20 commercially cultivated, and 5 to 6 have reached an industrial scale in many countries (Chang, 1993). Furthermore, by applying breeding techniques, cultivated strains can be developed that are uniform, of stable yield, specialized for quality, grow on a substrate of a particular composition and are adapted to specific environments. It is worth noting that the breeding program of any organism involves processes central to its reproductive genetics. In mushrooms, breeding systems involve both the mating system and post-meiotic nuclear behaviour. The nuclear behaviour determines whether an outbreeding or substantially inbreeding (self fertile) system controlled by mating-type factors is operative (Fig. 2). Outbreeding results from matings between two compatible single-spore isolates (Takemaru, 1954; Tanaka & Koga, 1972; Raper, 1976). Enforced inbreeding due to spores possessing two mating-type compatible nuclei is called secondary homothallism (Elliott, 1972; Tommerup *et al.*, 1991), in contrast to primary homothallism due to a uninucleate spore which can complete the life cycle without mating (Chang & Yau, 1971). Classical genetics demonstrated the genes that control mating type in these mushrooms. The fructification is directly or indirectly regulated by mating types (Miles, 1993; Wessels, 1993). Molecular cloning techniques demonstrated in *Coprinus cinereus* can identify the proteins coded by the mating type genes (Kues & Casselton, 1992). This analysis can gain insight into how these determine cell type and regulate sexual development. On the one hand, mushroom biology is the basis of mushroom cultivation and production, and it is also the very core of mushroom biotechnology. On the other hand, a knowledge of mushroom biology can enhance many aspects of human endeavour and it can lead on to a variety of other interests such as mushroom hunting, painting and photography.

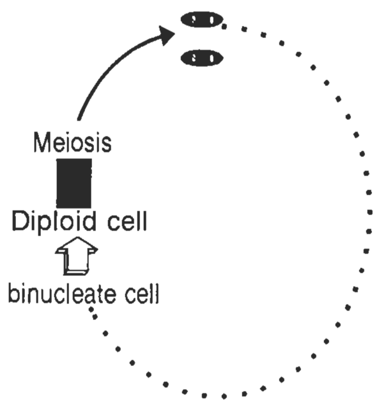
I. Enforced inbreeding types

(a): The pre-diploid binucleate cell is derived from dikaryotic hyphae by a binucleate spore



Laccaria fraterna

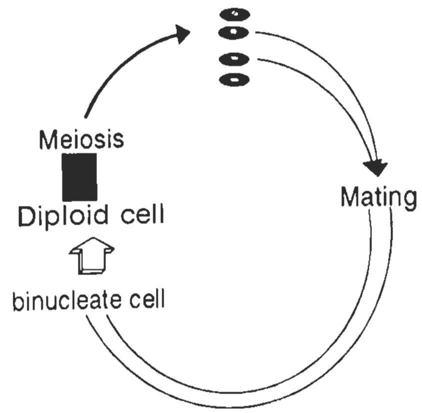
(b): The pre-diploid binucleate cell is derived from multinucleate hyphae by a binucleate spore



Agaricus bisporus

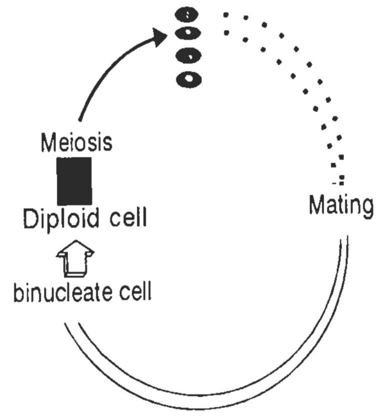
II. Outbreeding types

(a): The pre-diploid binucleate cell is derived from dikaryotic hyphae by mating two compatible monokaryons from uninucleate spores



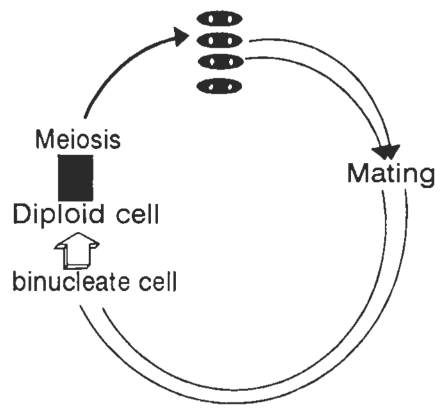
Lentinus edodes

(b): The pre-diploid binucleate cell is borne on multinucleate mycelium resulting from mating two compatible multinucleate hyphae of uninucleate spore origin



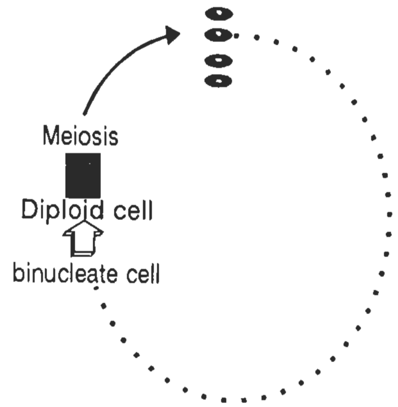
Agaricus bitorquis

(c): The pre-diploid binucleate cell is derived from dikaryotic hyphae which result from mating two compatible monokaryons from binucleate spores



Flammulina velutipes

III. Self-fertile types



Volvariella volvacea

FIGURE 2. Breeding systems of some selected mushrooms. The nuclear behaviour in a basidium is followed: from a binucleate cell to a transient diploid which is immediately followed by meiosis up to spore formation. The nuclear condition in different phases of a mushroom is illustrated.
▬▬▬ diploid; ——— monokaryon; ═══ dikaryon; ▪▪▪▪▪▪▪▪ multinucleate.

3. MUSHROOM SCIENCE

Mushroom science deals with **mushroom production** and encompasses **Mushroom Biology**, **Bioconversion/Composting Technology** and **Environmental Engineering** (Fig. 3). The term mushroom science already exists, but it is generally restrictive in the sense that it has been defined as the discipline that is concerned with the principles and practices of mushroom cultivation and production.

Mushroom Biology encompasses all aspects of mushroom biology as mentioned previously.

Bioconversion/Composting Technology comprises the development and application of systems coupling edible mushroom production and the utilization of organic wastes, with emphasis on lignocellulosic waste materials generated by the agricultural, forest, food processing and textile industries.

Environmental Engineering relates to the analysis and control of environmental factors, e.g., temperature, light, and the concentration of atmospheric gases, which "trigger" the shift from the vegetative growth phase (mycelial or spawn-running phase) to the reproductive phase (fruit body formation) of the mushroom.

Mushroom production is a complicated business. It involves a number of different operations, including: the selection of an acceptable fruiting culture of the mushroom, preparation of spawn and compost, inoculation of the compost, crop care, harvesting, preservation of the mushroom, and marketing. Each of these operations consists of many sequential steps which are equally crucial and important if success is to be achieved in the mushroom business as diagrammed in Table 3. In order to maintain a reasonably high and stable yield of mushrooms, both fundamental knowledge of mushroom science and the accumulative information of practical experience are required.

In Western countries, cultivation of *Agaricus* - the most popular edible mushroom, which is variously known as the white mushroom, button mushroom, champignon, or simply the common

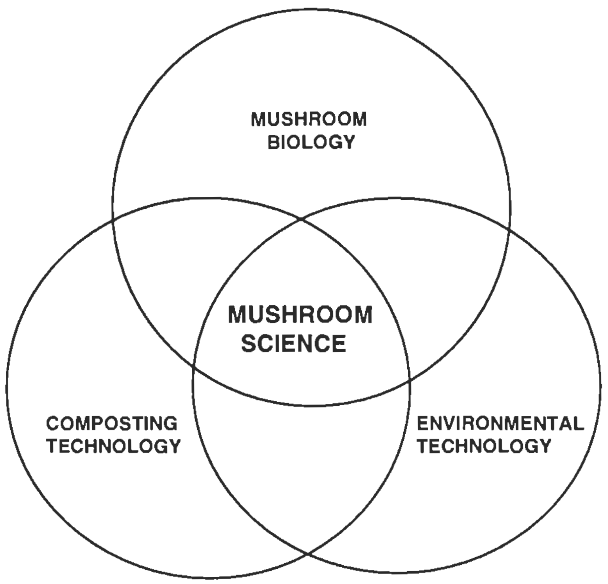


FIGURE 3. Mushroom science: concerned with mushroom production.

cultivated mushroom - has developed over the past 50 years from a beginning as a risky venture to a largely predictable and controllable industrial process, e.g., fifty years ago the yield was less than 5 kg/m^2 in more than twelve picking weeks of harvest. The picking was done by hand. Today, the yield can be 50 kg/m^2 in four picking weeks. The harvesting can be done by cutting machines.

TABLE 3. Major phases of mushroom cultivation.

Major Phases		Main points of consider
Selection of an acceptable mushroom		Location Climate Raw materials Acceptability
↓ Selection of a fruiting culture		Tissue culture Spore culture (a) without mating for homothallic species (b) mating with compatible isolates for heterothallic species Mixture culture Preservation
↓ Development of spawn		Substrate Vigorous growth Free of contamination Avoid use of senescent and degenerate spawn Good survival in storage
↓ Spawing spawn running →	Fructification (mushroom development)	Establishment of mycelium Environmental requirements (a) temperature (b) light (c) aeration (O_2, CO_2) 2(d) pH (e) moisture Casing Watering and care
↑ Composting Preparation of compost		Concept of composting Microbial activity Softening of substrate for ease of colonization Physical characteristics Chemical components Aeration Water content

Source: Chang (1991).

Deeptroughs, developed in the UK and adopted in Czechoslavakia with technical refinements, now achieve average yields of 60 kg/m^2 (Noble, 1989). Another technological development in *Agaricus* has broken the barriers of climate and geography. This mushroom in nature is a temperate climate mushroom, produced in Western countries where the production involves the most advanced and highly mechanized technology in the mushroom industry. But in 1965, Taiwan, with a subtropical/ tropical climate, emerged as the third leading producer of *Agaricus*. This was notable for three reasons. In the first place, Taiwan did not use a highly mechanized technology for the production of *Agaricus* on a relatively few large mushroom farms, but developed the industry as a cottage type enterprise on thousands of farms with small mushroom houses constructed of bamboo frames and banana leaf and/or straw and plastic for the roofs and sidings. In the second place, *Agaricus* had not been grown in a subtropical country previously, but it was found that this was possible on a seasonal basis with a single crop being grown in the period from September through March. Lastly, in the absence of a plentiful supply of horse manure, a synthetic compost was developed with rice straw as the main ingredient (Chang & Miles, 1989).

Lentinus edodes has for many years been grown on wood logs. It usually takes at least 8-12 months for the first flush to occur with the biological efficiency not exceeding 15%. Since being introduced in the early 1970's, the "plastic bag" method (sometimes known as "synthetic logs") has been used. The plastic bag method utilizes a sawdust based substrate contained in autoclavable plastic bags. This method has a shorter production cycle and gives higher yields. The cultivation also usually takes place in controlled environments, which facilitates consistent year-round production at the expense of higher energy costs compared with that of other mushrooms simply because of the longer production cycles (Cho & Nair, 1987; Chang & Miles, 1989).

One of the main drawbacks of the existing "plastic bag" method is that the quality of the mushroom obtained is usually inferior to those cultivated by the log method. The method of inoculating individual bags using either grain or sawdust based spawn is also laborious, and thorough spawning by shaking after inoculation or by the use of a "spawning channel" is not easily accomplished.

Volvariella volvacea is referred to as a "warm mushroom" because it can grow at relatively high temperatures, i.e., vegetative growth at about 32 to 34°C. It is a fast growing mushroom; the time required from spawning to harvesting is only about 8 to 10 days. No other vegetables or cultivated mushrooms can be served as a table dish within such a short time from its planting; but, under favorable conditions, *V. volvacea* can do this. However, the ability of its mycelium to colonize the substrate is rather weak; therefore, the mycelial network in the substrate is easily broken and disconnected if the inoculated compost is disturbed. The yield of mushrooms can be reduced drastically by mismanagement or improper care.

V. volvacea can use cellulose materials more effectively than other cultivated mushrooms; e.g., the optimum C/N ratio for *V. volvacea* is about 40 to 60:1, for *Agaricus bisporus* it is 17 to 18:1, and for *Lentinus edodes* it is 20 to 25:1 during the mycelial running stage. It can grow quickly and easily in uncomposted substrates such as paddy straw and cotton wastes or other highly cellulosic organic waste materials. Under favorable environmental conditions and growth medium, the primordium of the mushroom can be formed 4 to 5 days after spawning. Due to the above-mentioned special biological characteristics of the mushroom, it is considered to be one of the easiest mushrooms to cultivate, but it should be noted that the biological efficiency of this mushroom is lower than other commonly cultivated mushrooms.

With technical advances during the past few decades, cultivation of edible mushrooms has spread all over the world. Since cultivated mushrooms can be grown under different climatic

conditions and on agricultural and industrial wastes, they can be used as an aid in solving many problems of global importance including protein shortage, resource recovery and re-use, and environmental management.

In the overall view, world production of cultivated edible mushrooms was 2,176 thousand tons and 3,794 thousand tons in 1986 and 1989/90, respectively (Table 4). In those 3 years, mushroom production increased by 74.4% at an annual increase of 24.5% (Chang & Miles, 1991). A comparison of production between 1986 and 1989/90 reveals that all cultivated mushroom species increased during that period, ranging from 19% for *Agaricus* up to 437% for *Pleurotus*. The next big increase was 236.1% for *Auricularia*. However, the percentage of total world production of *Agaricus* and *Lentinus* mushrooms decreased as a consequence of the increase in production of the other cultivated edible mushroom species, particularly *Pleurotus* species.

TABLE 4. Comparison of 1986 and 1991 world production of cultivated edible mushrooms.

Unit: (metric ton x 1000)

Species	Common Name	1986 Fresh wt.	1986 %	1991 Fresh wt.	1991 %	% increase
Agaricus bisporus/ bitorquis	Button mushroom	1,215	55.8	1,590	37.2	30.9
Lentinus edodes	Shiitake or oak mushroom	320	14.7	526	12.3	64.4
Volvariella volvacea	Straw mushroom or Chinese mushroom	178	8.2	253	5.9	42.1
Pleurotus spp.	Oyster mushrooms	169	7.8	917	21.5	442.6
Auricularia spp.	Wood-ear	119	5.5	465	10.9	290.8
Flammulina velutipes	Winter mushroom	100	4.6	187	4.4	87.0
Tremella fuciformis	White Jelly fungus/ or "Silver Ear"	40	1.8	140	3.3	250.0
Pholiota nameko	"Nameko" or Viscid mushroom	25	1.1	40	0.9	60.0
Hericium erinaceus	Monkey head mushroom or Hedgehog fungus	-	-	66	1.5	
Hypsizygus marmoreus	Shimeji	-	-	32	0.7	
Grifola frondosus	Sitting-hen mushroom or Limuo, Maitaka	-	-	7.6	0.2	
Others		10	0.5	49.4	1.2	
Total		2,176	100.0	4,273	100.0	96.4

4. MUSHROOM BIOTECHNOLOGY

Mushroom biotechnology concerns **mushroom products** and encompasses **Mushroom Biology, Fermentation Technology** and **Bioprocessing**, and **Marketing and Management** (Fig. 4). Mushroom biotechnology, both as a technology and as the basis for new mushroom products requires industrial development. This kind of industry, like many bioscience industries, operates at the cutting edge of science, and involves numerous regulatory issues. It requires individual or institutional investors who have the background and resources necessary to develop and support the industry.

Mushroom Biology in this context would include, as an additional feature, the identification of medicinals (e.g., anti-tumour, hypocholesterolaemic and immuno-potentiating agents) and other added-value compounds (e.g., flavourants and colourants for the food and beverage industries, additives for the cosmetic industry).

Fermentation Technology and Bioprocessing embodies the development of large-scale systems for the production of added-value compounds and the conversion of mushrooms into other retail products (myco-meat, mushroom-based health drinks, soups, etc.).

Marketing and Management will develop and provide training in business expertise and marketing techniques which are essential to profit-oriented biotechnological enterprises and which constitute a key factor in the commercial success of mushroom-based products. Mushroom market opportunities must be identified in relation to domestic/regional/international markets.

Although various mushroooms have been highly valued as food, as tonics and, in some cases,

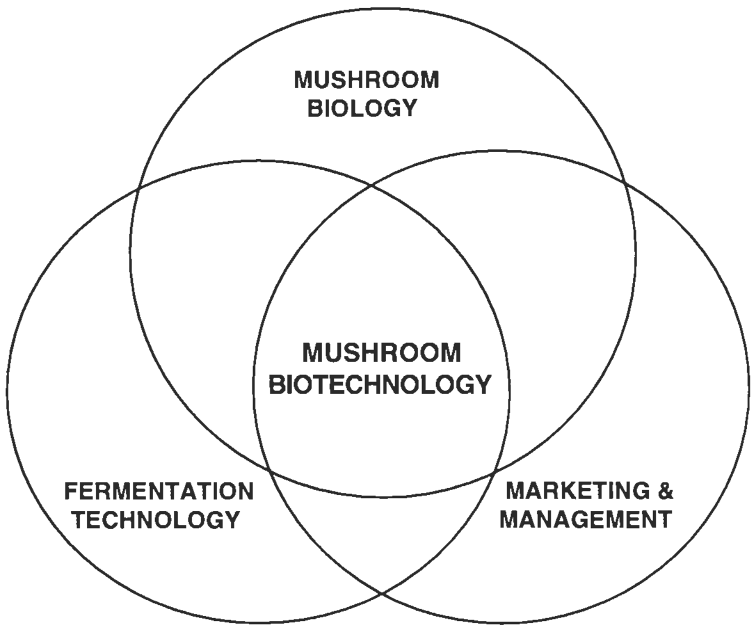


FIGURE 4. Mushroom biotechnology: cencerned with mushroom products.

as a medicine for a long period of time, mushrooms have become even more popular in recent years, as can be witnessed by the increased demands for higher production volumes. Their popularity is derived from three highly desirable characteristics as food: (1) they have remarkable taste and flavour; (2) they are nutritious, not only because they contain high contents of protein with significant amounts of lysine and methionine (which are low in plants), fibres, minerals, and vitamins, but also for what they do not have (high calories, sodium, fat, and cholesterol); (3) they can be easily processed, dried, pickled and canned to allow maximum storage and transportation.

In addition to these unique characteristics, many edible mushrooms have been traditionally used in China and Japan for their medicinal and tonic properties. Chihara (1992) reported that hot-water extracts of some basidiomycetes, such as *Ganoderma applanatus*, *Coriolus versicolor*, etc. markedly inhibited the growth of sarcoma 180. *Lentinus edodes* induced complete tumor regression in 6 out of 10 mice, whereas *Pleurotus ostreatus* was effective in 5 out of 10 mice. Similar degrees of activity were noted in hot-water extracts of many other edible mushrooms, such as *Tricholoma matsutake, Pholiota nameko*, and *Flammulina velutipes* (Table 5). In most cases, active components were β-glucans, although some variations were noted. Furthermore, PSK, a protein-bound polysaccharide preparation (Fukushima, 1989), and PSP, a peptide-bound polysaccharide preparation (Yang *et al.*, 1989), have been extracted from *Coriolus versicolor* which is one of the well-known medicinal mushrooms. In Japan, PSK is reported as the top-selling anticancer drug and its annual sales in 1987 reached 358 M dollars, and accounted for 25.2% of the total sales of anticancer drugs which were worth about 1,000 million dollars per year (Table 6). PSK is widely prescribed for cancers of digestive organs (stomach, oesophagus, colon and rectum). *In vivo* and *in vitro* experiments

TABLE 5. Antitumor activity against sarcoma 180 of extracts from various basidiomycetes and edible mushrooms.

Basidiomycetes or edible mushrooms	Complete regression	Tumor inhibition (%)
Ganoderma applanatum	5/10	64.9
Coriolus versicolor	4/8	77.5
Coriolus hirsutus	2/10	65.0
Trametes gibbosa	1/10	49.2
Lenzites betulina	0/8	23.9
Daedaleopis tricolor	4/7	70.2
Fomitopsis semilaccata	3/10	44.2
Rigidoporus geotropus	0/7	44.8
Hirschioporus fusco-violaceus	1/10	45.5
Phelinus linteus	7/8	96.7
Lentinus edodes	6/10	80.7
Flammulina velutipes	3/10	81.1
Pleurotus ostreatus	5/10	75.3
Amanita rubescens	0/8	72.3
Pholiota nameko	3/10	86.5
Tricholoma matsutake	5/9	91.8
Auricularia mesenterica	0/9	42.6

Source: Chihara (1992).

conducted by Yang *et al.* (1992) have shown that the inhibitory effect of PSP on tumor cells was essentially similar to PSK. It is believed that there is a huge amount of economic potential not only for PSK and PSP, but also for other protein-bound polysaccharide preparations from other mushrooms. Cosmetic products and some healthy beverages have also been produced from the mushrooms of *Ganoderma*. A variety of proprietary products, including health drinks and foods, have also become available on the markets, a trend which is expected to increase with reported satisfaction and acceptability.

5. CONCLUDING REMARKS: LEARN FROM HISTORY

It is important to know how and to what extent the benefits of both mushroom production and mushroom products can be maximized. No matter whether you want to increase mushroom production through the advancement of mushroom science or to enhance the yield of mushroom products through improvement of mushroom biotechnology, it is always important to keep in mind what the past benefits were and the ways by which these benefits were achieved. If we can identify those events and discoveries which have led to the current status of importance of modern mushroom cultivation and mushroom products, is it not reasonable to expect that we can apply this knowledge and make greater leaps and advancements in the mushroom industry, which, in turn, would contribute more to the welfare of humankind? Moreover, if we make the assumption that mushroom science concerns mushroom production and mushroom biotechnology concerns mushroom products, then mushroom science and mushroom biotechnology are the two legs of the mushroom industry. In the past, the mushroom industry concentrated mainly on the production of fresh, canned and dried mushrooms. This means the industry had only one leg. At the present time, in addition to the value of the world mushroom crop estimated to be 7.5 billion dollars in 1990 (Chang & Miles, 1992), a large amount of money is also generated from mushroom products, e.g., in 1987, the value of pharmaceuticals developed from three mushrooms: *Coriolus versicolor*, *Lentinus edodes* and *Schizophyllum commune* was reported to be 769 million dollars annually in Japan (Buswell & Chang, 1993). Surely, there are several other mushroom products e.g., those from *Ganoderma* manufactured and used in China, Korea and Taiwan that are also worth many millions of dollars. The mushroom industry with these two strong legs can now walk steadily. There should be no surprise when, in the next century, the industry starts to run. The bioscience industry is already one of the fastest growing investment sectors in the world.

TABLE 6. The top-ten best-selling anti-cancer drugs in Japan and the United States, 1987.

	Japan			United States		
	Drug	Sales ($ x 10^6)	Percentage of market share	Drug	Sales ($ x 10^6)	Percentage of market share
1.	PS-K	358	25.2	Doxorubicin	86	16.3
2.	OK-432	191	13.4	Cisplatin	79	15.0
3.	Tegafur uracil	177	12.5	Tamoxifen citrate	68	12.9
4.	5-Fluorouracil	104	7.3	Etoposide	52	9.8
5.	Tegafur	101	7.1	Cyclophosphamide	31	5.9
6.	Tamoxifen citrate	63	4.4	Methotrexate	29	5.5
7.	Interferon-β	40	2.8	Megestrol acetate	27	5.1
8.	Lentinan	31	2.2	Mitomycin C	25	4.7
9.	Carmofur	26	1.9	Bleomycin	20	3.8
10.	Estramustine phosphate sodium	25	1.8	Vincristine sulphate	18	3.4

Source: Fukushima (1989).

It is clear from the above that mushroom biology is the very core of both mushroom science and mushroom biotechnology. These two aspects of the mushroom industry will not compete but they will complement each other. To achieve this goal, it is essential that there be cooperation in the exchange of information and technology concerning mushroom production and mushroom products among research scientists, industry, regulatory agencies, governments, and the public. It is hoped that all individual achievements can be shared and spread to all participants at this, the First International Conference on Mushroom Biology and Mushroom Products, and that this will be the first of a series of such international conferences.

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