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MUSHROOMS: TRENDS IN PRODUCTION AND TECHNOLOGICAL DEVELOPMENT

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1. Introduction

Almost certainly prehistoric man used mushrooms as food. There is ample evidence that the great early civilizations of the Greeks, Egyptians, Romans, Chinese, and Mexicans prized mushrooms as a delicacy, for purported values of a therapeutic nature and, in some cases, in religious rites. Throughout recorded history there is repeated reference to the use of mushrooms as food and for medicinal purposes, and it is not surprising that the intentional cultivation of mushrooms had a very early beginning. We now know that this occurred in China around 600 A.D. with the cultivation of *Auricularia auricula* on wood logs (Chang & Miles, 1987). Other wood-rotting mushrooms such as *Flammulina* and *Lentinus* were later cultivated in a similar manner, but the biggest advance in musrhoom cultivation occurred in France around 1600 A.D. when *Agaricus* was cultivated upon a composted substrate. In the Western world *Agaricus* (champignon or button mushroom) has remained up to the present time the mushroom that is produced in the greatest amounts, but now mushrooms long popular in Asia (e.g. *Lentinus*), and produced there in large numbers are making inroads into Western markets, but in the United States in 1990-91 the production of *Agaricus* still exceeded 99% of total U.S. mushroom production (NASS, 1991). In the years since World War II, there has been a consistent increase in mushroom production which greatly accelerated in the period from 1986 to 1989-90, with an increase of 74.4% and a total world production of 3.79 metric tons valued at about US 7.5 billion dollars (Chang & Miles, in press).

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 (19-35% on a dry weight basis) of good quality (all essential amino acids for man including lysine and methionine which are present in plants in only small amounts). 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, 1982a).

Mushrooms are a special group of fungi. Fungi lack chlorophyll and consequently cannot use solar energy to manufacture their own food as do green plants. However, mushrooms do 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

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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 these materials are either burned, shredded or used as landfill or for improvement of soil quality, even though these wastes constitute a potentially valuable resource for the production of edible food for man. Although physical and chemical technologies may, in some cases, play important associated roles, 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.

One of the most economically viable processes for the bioconversion of lignocellulosic wastes is the cultivation of edible mushrooms. The nutritional value and desirable gastronomic properties of mushrooms are now widely recognised. Of particular significance, especially to regions with populations whose diet is commonly deficient in protein, is the protein content of mushrooms. As previously mentioned, this is relatively high (19 35% on a dry weight basis) as compared with 7.3% in rice, 13.2% in wheat, 39.1% in soybean, and 25.2% in milk. Therefore, although mushrooms rank below most animal meats in crude protein content, they compare very favorably with most other foods (Crisan & Sands, 1978; Li & Chang, 1982b). With respect to essential amino acid indices, amino acid scores and nutritional indices, the overall nutritive value of high grade mushrooms almost equals that of milk. Furthermore, the proteins of commonly cultivated mushrooms contain all the essential amino acids and are especially rich in lysine and leucine which are lacking in most staple cereal foods (Chang, 1980). It is also claimed that mushrooms contain other beneficial health promoting substances (Chang & Miles, 1989; Breene, 1990; Jong & Birmingham, 1990). In addition, the material remaining after the mushroom crop has been harvested can often be used as a valuable additive to the soil, thus increasing its potential for the production of other agricultural and horticultural crops, or possibly being used directly as a source of animal feed.

Many people have been attracted to mushroom cultivation because mushrooms can be grown on waste substrates and do not make the demands upon land space as is the case with most agricultural crops. This certainly is an attractive aspect of mushroom cultivation and, in an environmentally conscious society, the bioconversion of potential pollutants to a food for human consumption is not to be dismissed lightly. As we shall point out, however, mushroom cultivation requires an understanding of certain scientific principles and practical experience in mushroom technology for the successful achievement of a profitable mushroom farm. There is no doubt that if mushroom cultivation technology is properly promoted and developed, mushroom cottage industries will make important contributions to the nutrition and economic welfare of the people in many countries, particularly in developing countries.

The purpose of this article is to describe recent trends in mushroom production and the technological developments for research and cultivation of mushrooms. It should be noted that, in the long term, successful mushoom production must be supported by a background of sound scientific knowledge and technology.

2. Mushrooms and mushroom biology

The world mushroom may mean different things to different people in various countries. In this article, mushroom refers to the definition given by Chang and Miles (in press). In a broad sense "the mushroom is a macrofungus with distinctive fruiting body which can be either epigeous or hypogeous and large enough to be seen with the naked eye and to be picked by hand. Thus, 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 this context, 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) those mushrooms which are considered to have medicinal applications are referred to as medicinal mushrooms, e.g., *Ganoderma lucidum*; (3) those which are proven to be, or suspected of being, poisonous 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 and which may tentatively be grouped together as "other mushrooms". Certainly, this form of classifying mushrooms is not absolute. Many kinds of mushrooms are not only edible, but also possess tonic and medicinal qualities.

It has been estimated that in nature there are approximately 1.5 million species of fungi of which only approximately 5% or 69,000 species, have been described (Hawksworth, 1991). Out of these described species of fungi, there are about 10,000 species of fleshy macrofungi and only a handful of these are lethal (Kendrick, 1985). There are no simple ways to distinguish between edible and poisonous mushrooms. Mushrooms should be eaten only if they have been identified with precision and the history as to edibility of that species is known. About 2,000 species from more than 30 genera are regarded as prime edible mushrooms, but only about 80 of them are grown experimentally, 40 cultivated economically, around 20 cultivated commercially, and only 5 to 6 are produced on an industrial scale (Chang, 1990a). In general, the oriental countries, China, Japan, and Korea grow and consume more varieties of mushrooms than the Western countries. However, in recent years, the production of what are referred to as "specialty or alternative mushroom", mainly *Lentinus edodes* and *Pleurotus* spp., has increased rapidly in Western countries (Chang & Miles, 1991).

When knowledge increases and areas of specialization develop within a discipline, it is convenient to indicate that area of specialization with a self explanatory name. We have suggested that the term **Mushroom biology** be used for the discipline concerned with the scientific study of mushrooms (Chang & Miles, in press). The term mushroom science has been defined as the discipline that is concerned with the principles and practices of mushroom cultivation, and thus dealing solely with cultivation, mushroom science is only one aspect of mushroom biology, the subdiscipline of mycology dealing with mushrooms. That is, mushroom biology includes not only cultivation but it deals with any aspect of mushrooms, such as: taxonomy, development, nutrition, physiology, genetics, pathology, medicinal and tonic attributes, edibility, toxicity, etc.

3. Trends in production

Although various mushrooms have been highly valued as food as a tonic and, in some cases, as medicine for a long period of time, the use of mushrooms has become even more widespread in recent years, as can be witnessed by the increased demands for higher production volumes (Fig. 1). Their popularity is derived from three highly desirable characteristics as food: (1) they have remarkable taste and flavor; (2) they are nutritious; (3) they can be easily processed, dried, pickled, and canned to permit them to be stored and transported from the place of production to the consumer.

In addition to these unique characteristics, many edible mushrooms have been traditionally used in China and Japan for their medicinal and tonic properties. The pharmaceuticals developed from mushrooms in Japan (Table 1) and their pharmaceutical components (Table 2) have been compiled recently by Pai *et al* (1990). Cosmetic products and some healthful beverages have also been produced in China from mushrooms of *Ganoderma*. A variety of proprietary products including health drinks and foods, have also become available on the market, and the demand for these is expected to increase.

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 an overall view, the world production of cultivated edible mushrooms was 2,176 thousand metric tons and 3,794 thousand metric tons in 1986 and 1989/90, respectively (Table 3). In those 3 years, mushroom production increased by 74.4% and 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 43% for *Pleurotus*. The next big increase was 23.6% for *Auricularia*. However, the percentage of the total world production of edible mushrooms for *Agaricus* and for *Lentinus* mushrooms decreased as a consequence of the increase in production of the other cultivated edible mushroom species, in particular *Pleurotus* species (Fig. 2).

A comparison of the mushrooms in 1986 and 1989/90 cultivated in China is given in Table 4. The increase in growth rate for all 12 cultivated mushrooms in China was 175%. *Pleurotus* became the number one cultivated mushroom in China with an increase of 700% during the three years from 1986 to 1989/90. Second in total production was *Auricularia*. These two mushrooms are used mainly for domestic consumption with a small proportion for export to Japan and Hong Kong. In 1989 the percentage of the production of individual species which were exported was 76% for *Agaricus*, 20% for *Lentinus*, 4.4% for *Pleurotus*, and 4% for *Auricularia*. For the first time, China grew over 50% of the cultivated mushrooms produced in the world (1915 MT/3794 MT)

In the three year period from 1986 to 1989/90, the production of edible mushrooms in Japan (Table 5) is most notable for the increase in production of two species, *Hypsizigus marmoreus* and *Grifoia frondosus*. The increase was 94.5% and 175%, respectively. This increase in production was partially offset by decreases in production of *Lentinus edodes* by 9.6% and of *Auricularia auricula-judae* by 25.4%, but with steady increases in production of

Flammulina velutipes and *Pleurotus* spp., there was still an increase of total mushroom production in Japan of 4.4% during this period.

It can be seen from Table 6 that consumption of mushroom in Japan increase significantly in the period from 1986 to 1989/90 since the exports decreased and the imports increased by 39.6% from 17,403 to 24,286 metric tons. In amount, the greatest increase was of *Auricularia auricula-judae* of which 19,875 metric tons were imported (mainly from China) in 1989/90, compared to the 16,299 metric tons in 1986. The highly prized *Tricholoma matsutake*, which is farmed by semi-cultivation techniques, was imported into Japan in the amount of 2,210 MT in 1989/90, an increase of 125.5% over the 980 MT imported in 1986. It is also interesting to note that the import of dried *Lentinus edodes* (shiitake) into Japan increased greatly from 124 MT in 1986 to 2,201 MT in 1989/90 (an increase of 1,675%!) while exports of dried *Lentinus edodes* decreased from 3,538 to 1,439 MT. In general, the shiitake imported into Japan were of lower quality mushrooms to be sold to lower income people who could not afford the expensive high quality mushrooms which have traditionally been a good export item from Japan but which can now be sold more readily in Japan because of the thriving economy in that country.

Total mushroom production in South Korea increased by 37% during the period from 1986 to 1989/90 (Table 7). The greatest amount of this increase was due to *Pleurotus* spp. of which 11,570 MT more were produced in 1989/90 than in 1986, an increase of 44.8%. As was true in China, the mushroom produced in greatest amount was *Pleurotus* spp. Second in production was *Agaricus bisporus*, whose production was 12,025 MT in 1989/90, with little change since 1986. Production of *Lentinus* in Korea increased by 48% to 10,710 MT in 1989/90. It is readily seen that there was considerable change in the amounts of the various species being produced in South Korea during this period, with the most dramatic being the 656% increase in *Flammulina velutipes*, but the amounts are still relatively small - 16 MT in 1986 and 121 MT in 1989/90. *Flammulina velutipes* is grown primarily for export to Japan, as is *Tricholoma matsutake*. In 1989/90 Japan paid a higher price for the *Tricholoma* from South Korea than that from any other country, and Japan bought 84% of Korea's *Tricholoma*. It should be noted that 1986 was an unusual year in *Tricholoma* production in Korea since it amounted to only 311 MT, a drop from 1,313 MT the previous year. The percentage increase in production of *Tricholoma* between 1986 and 1989/90 shown in Table 7 is misleading since production has not yet reached the 1985 amount. Another item of interest in Table 7 is the increase in production of the medicinal mushroom *Ganoderma lucidum* of approximately 307% between 1986 and 1989/90.

4. Trends in technological developments

Mushroom cultivation 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 (Miles & Chang, 1986).

While there is available a solid background of scientific information for these various operations with a number of cultivated species, in many aspects mushroom cultivation is also an art, just as wine making is both a science and an art. Consequently, 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 cultivated mushroom - has developed over the past 50 eyars from a beginning as a risky venture to a largely predictable and controllable industrial process, e.g., 50 years ago the yield was less the 5 kg per square meter in more than 12 picking weeks. The picking was done by hand. Today, the yield can be 50 kg per square meter in 4 picking weeks, and the harvesting can be done by cutting machines. The deep-trough method of cultivation, developed in the UK and adopted in Czechoslavakia with technical refinements, now achieves average yields of 60 kg per square meter (Noble, 1989).

Agaricus in nature is a temperate climate mushroom. It is produced in Western countries where the production involves the most advanced and highly mechanized technology in the mushroom industry. In 1965 Taiwan with a subtropical and tropical climate emerged as the third leading producer of *Agaricus*, although currently it only ranks tenth. This production in Taiwan was possible because it was found that *Agaricus* could be grown profitably on a seasonal basis in the period from September through March. Since then, *Agaricus* has also been grown successfully in countries with similar climatic conditions either seasonally or in cooler mountainous regions. The growth in Taiwan was also notable because *Agaricus* was cultivated on a synthetic compost having rice straw as the main component as there was an absence of a plentiful supply of horse manure. In contrast to *Agaricus* cultivation in Western countries, Taiwan did not use a highly mechanized technology on a relatively few large mushroom farms, but developed the industry as a cottage type enterprise on thousands of farms in which the mushroom houses were constructed of bamboo frames and banana leaves and/or straw and plastic for the roof and siding (Chang & Miles, 1989).

Among the Southeast Asian nations Taiwan consistently led in production of *Agaricus* until recently. Indonesia has now developed the industry using mechanized methods with the farms located on cooler mountainside areas. South Korea has also produced large amounts for export. By 1983 China became the third leading producer of *Agaricus* in the world, and by 1986 it was second only to the USA in total production, but then China slipped to third in 1989/90. This was undoubtedly influenced by the ban of canned mushrooms from China to the United States as a consequence of problems with faulty canning procedures. Much of the production of *Agaricus* in Asia reaches foreign markets as canned mushrooms. This is because of the lower cost of production in Asian countries so that these canned mushrooms can be sold at a lower price than the canned mushrooms produced by the mechanized growers in Western countries. This also had the effect of a larger share of the *Agaricus* mushrooms produced by Western countries being sold fresh. In no small measure this remarkable achievement in modern mushroom industrial development can be attributed to contributions resulting from the vigorous research activities conducted at various academic institutions as well as mushroom research stations. This history of *Agaricus* production technology has shown the way for cultivation of other mushrooms.

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 the early 1970's, a method using "plastic bags", sometimes known as "synthetic logs", was introduced. This method utilizes sawdust based substrate prepared in autoclavable plastic bags and has a shorter production cycle and gives higher yields. The cultivation also usually takes place in a controlled environment, which facilitates a consistent year-round production. This method of production involves the expense of higher energy costs compared with other growing procedures (Chang & Miles, 1989; Cho & Nair, 1987).

Since the introduction of the "plastic bag" method, various patents have been filed on variations of this method. While technical information is difficult to obtain without paying substantial technology fees for detailed production protocols, it would appear that they either differ in the formulation of the substrates (although still using sawdust as the main carbon source) or in the methods of manipulation of the environmental factors which are important in triggering fruit body formation.

One of the main drawbacks of the existing "plastic bag" method is that the quality of the mushroom obtained is considered by many to be inferior to the mushrooms cultivated by the log method. The method of inoculating individual bags using either grain or sawdust based spawn is also laborious, and thorough spawning is not always easily accomplished by shaking after inoculation or by the use of a "spawning channel". Research work jointly carried out by the University of Sydney and The Chinese University of Hong Kong has resulted in the development of a novel method for the cultivation of shiitake which overcomes such shortcomings. The use of a new type of substrate without sawdust and the right formulation results in a substrate preparation which not only is nutritionally suited for fruiting, but also provides better conditions for aeration which is also very important. The introduction of a liquid spawn instead of solid spawn and an improved method of dispensing the spawn reduces labor costs and facilitates thorough spawning. The amount of spawn introduced far exceeds that when sawdust or grain spawn is used. The latter two contain at most less that 1% mycelium based on the dry weight of the carrier. Heavy spawning results in a shorter spawn run period (usually about 6 weeks). The use of synthetic medium also results in reduction of contamination since the medium is not nutritionally rich for other competing microorganisms. The use of strains adapted for growth on the new substrate also helps to produce good quality shiitake. Finally, supplements are introduced, usually after the first cropping, which increases significantly the yield of subsequent flushes. The average biological efficiency is about 60-80% over a period of 6 months. With an extended cropping period, 100% is not unusual.

Vegetative growth of the straw mushroom, *Volvariella volvacea*, occcurs efficiently at 32-34°C and, consequently, it is referred to as a "warm mushroom". A related outstanding feature of *Volvariella volvacea* is its rapid growth - only 8-10 days being required from spawning to harvesting. This can be accomplished by the straw mushroom under favorable conditions, and it is a shorter period from planting to the table than any other vegetable or cultivated mushroom. Since the ability of the mycelium to become colonized with its substrate is weak, the mycelial network is easily broken and disconnected if the compost is disturbed. Thus, mismanagement or improper care during any phase of production of *Volvariella volvacea* will drastically decrease the yield. This species has the the ability to use cellulosic materials more effectively than other cultivated mushrooms; e.g., during the mycelial running stage the optimum C:N ratio for *V. volvacea* is about 40 to 60, for *Agaricus bisporus* it is 16 to 18, and for *Lentinus edodes* it is 20 to 25. It grows quickly and easily on substrates of high cellulosic content including such waste organic materials as paddy straw and cotton wastes. The primordium of the mushroom can be formed 4-5 days after spawning under conditions of favorable environmental conditions and a suitable growth medium. For the reasons just stated, *V. volvacea* has been considered to be one of the easiest mushrooms to cultivate, but even under appropriate conditions the biological efficiency is lower than that of most other cultivated mushrooms.

The use of cotton wastes from the textile mills was first used in 1971 as a substrate for growing the straw mushroom under controlled conditions (Chang, 1972; Yau & Chang, 1972). This use of cotton wastes completely replaced paddy straw in Hong Kong in 1973 for the cultivation of the mushroom in indoor conditions (Chang, 1974). This marked a turning point in straw mushroom cultivation since it was found that cotton waste compost gave a higher and more stable yield (30-45%), earlier fructification and harvesting than occurred under the same conditions with straw as the substrate. With the composted waste cotton substrate, pinheads appeared in 4 days and the first harvest was ready 9 days after spawning. These good characteristics of cotton waste compost have led to the cultivation of the straw mushroom being semi-industrialized in Hong Kong, Taiwan, and Indonesia, as well as in Thailand.

The fact that the oyster mushroom (*Pleurotus* spp.) jumped to second position in total production with 909,000 MT produced in 1989/90 is partially due to new techniques resulting from research into bag culture methods. It is anticipated that continued research will result in increased production of more species, of improved cultivars of such species by breeding techniques, of an extension of the geographic limits imposed by climate to cultivation of certain species, and the development of composting methods for the wood-rotting mushrooms which will reduce requirements for energy. While research may make many things possible, the successful operation and expansion of any enterprise requires trained personnel. Thus, in addition to scientific research, the advancement of the mushroom industry requires centers for training personnel in principles and practices of mushroom cultivation.

5. Requirements to help reach the potential

A. Basic and applied research in all aspects of mushroom biology

Mushroom scientists are working to increase mushroom production by four main pathways. The first is to find better cultivation methods that will increase mushroom production in places where it is already cultivated. The second pathway is to expand growing areas to places such as subtropical or tropical climates where *Agaricus bisporus* has not been grown previously. The third is to preserve the production strains that have already been obtained by promoting sustainable mushroom cultivation systems. The fourth pathway is to use advanced research techniques such as biotechnology to design and breed new strains of mushrooms that will give higher yield and better quality.

At each pathway mentioned above, there are many potential ways in which biotechnology can be applied to improve mushroom yield and quality. As we know, genetics, biochemistry and fermentation technology are three of the most important areas of modern biotechnology. Our present understanding of the developmental genetics of mushroom species is based almost entirely on studies of mutant strains. We know most about the genetics of fruiting body development and least about the genetics of spore formation, maturation, and germination. The discovery of sporeless mutants in *Pleurotus* spp. (Yu & Chang, 1989) will have important economic and health benefits and will also help to further our understanding of sporulation. On the biochemical front, recent research reports have indicated that there are great changes in levels of extracellular enzymatic activity in mushroom mycelium and in the compost and that these changes are associated with the formation of fruiting bodies and the production of flushes of mushrooms (Claydon, *et al.*, 1990; Wood 1980; Wood & Goodenough, 1977; Wood & Leatham, 1983). To be able to control the mushroom flushes is one of the goals of mushroom scientists.

Progress in scientific research and in the application of biotechnology to the culture of mushrooms has resulted in the use of specifically fermented liquid nutrients absorbed on inert physical supports such as vermiculite (Miles & Chang, 1987; Tautorus & Townsley, 1987). This kind of "hydroponic mushroom cultivation" has the potential of enabling a grower to conduct a completely controlled fermentation of the substrate with the use of pre-selected thermophilic microorganisms (i.e., thermophiles which would prevent disease or contamination and stimulate mushroom growth and yield). Eventually, this could become a continuous culture technique in which fresh liquid nutrients could be pumped into the culture tank to obtain high yields in successive flushs (Cho & Nair, 1987; Wood, 1989).

Other potential applications of biotechnology to the mushroom industry include: (1) strain improvement (Miles & Chang, 1986; Peberdy, 1989) (e.g., faster growing strains and strains suitable to different environmental circumstances); (2) selection of thermophilic *Bacillus* and *Humicola* spp. to inhibit mushroom pathogens and promote mushroom growth; and (3) development of techniques to increase the biological efficiency for conversion of agricultural and industrial waste materials.

B. Mushroom gene bank

The basic requirement in breeding for higher yielding and better quality strains of a mushroom species is to have available as large an amount of genetic material as possible so as to increase the amount of variation in the progeny for selection purposes. Hybrid progeny can be generated by conventional breeding methods involving crosses between selected strains within a species by protoplast fusion technique where the two parental cells may come from normally non-mating strains, or by the transfer of genes from one kind of organism to another using recombinant DNA technology. However, since the organism is the only source of the exchanged genomes or the transferred genes, the loss of an individual strain or species can mean the loss of tens or even hundreds of thousands of individual genes. A loss of germplasm from the loss of genes, strains or species will reduce the amount of variation that can occur within the species, thus lessening the capacity for genetic selection and improvement.

The methods of establishing **mushroom gene banks** can consist of *in situ* and *ex situ* conservation activities. The former describes the maintenance of mushrooms, including wild representatives, in natural preserves and will result from the conservation of ecosystems. The latter case, where spores or tissue cultures are preserved outside their area of growth, is the conservation of germplasm. Therefore, in the context of this paper, **mushroom gene bank** means *ex situ* conservation of mushroom germplasm in the form of culture collections of the mushroom species. **Mushroom germplasm** collections are assemblages of genotypes representing wild fruiting bodies, or commercial stocks that are the product of scientific breeding, and their derivatives (e.g., spores, tissues). All this genetic capacity of a particular mushroom species, including both cultivated and wild relatives, can be called the **gene pool** of the mushroom assuming that all the sources can contribute genes to progeny by crossing, fusing, or by other methods of gene transfer. Conserving the world's biological diversity has emerged as a matter of international concern (Abelson, 1991). Characterization of individual cultures which have been collected and preserved is of fundamental importance in establishing the collection of the germplasm of a mushroom. Information on the genetical, morphological, physiological, and biochemical characteristics of the strains is stored in computers to construct a database. The process is called "gen bank accession". The function of this database is expected to provide valuable and rapidly accessible information for future breeding and academic research in mushroom biology.

C. Regional workshops for bringing current information and techniques pertinent to the mushroom species to be grown in the region

During the past decade there has been a great increase in popularity and production of mushrooms in Southeast Asia. This has been due in part to an awareness that mushrooms possess great nutritive properties (apart from their use as a delicacy) and that they can serve as a cheap protein source. An important contributing factor has been the financial and moral assistance received from United Nations agencies such as UNESCO, UNEP, ICRO, and UNU which have conducted training courses and workshops in Asian countries on mushroom production (Chang, 1990b). It is hoped that this trend will continue not only by these agencies but also by other agencies and foundations.

D. International Mushroom Research Centre

Mushroom science, derived from the principles of microbiology, environmental engineering and fermentation technology, has developed in modern times both as the basis for new cottage type industries and for highly developed industrial mushroom growing complexes Thus, the activities stemming from mushroom studies have achieved global dimensions and there are many long term worldwide implications. One such activity is the conservation of mushroom germplasm as a part of the conservation of the world's biological diversity. Conservation of germplasm has emerged as a matter of very serious international concern. The cultivation of mushrooms is a biotechnology that does not require extensive mechanization and produces the results within a short time, bringing direct benefits to developing countries. However, progress in mushroom cultivation and the development of the industry are dependent upon the collective efforts of scientists from the industrialized and developing countries. To achieve effective collaboration of scientists and mushroom biologists throughout the world on mushroom research and production, an international center for mushroom studies and training should be established.

6. Conclusion

In spite of the many conceptual and technical problems in their cultivaion, we foresee a more important role for mushrooms as a source of protein in tropical and subtropical regions, where the shortage of protein the human diet is more marked. We also see no reason why both rural and urban areas cannot share in this new possibility and prospect, especially in view of the 7-fold increase in total world production of mushrooms in the past two decades. The introduction of technology to breed new strains which are adapted to more varieties of climates, and to maximize mushroom production per unit area at minimum cost for the purpose of providing a cheap source of food protein from those agricultural and industrial organic wastes which are abundant in tropical and subtropical regions, is a continuing challenge. Already over 50% of total mushroom production takes place in developing countries where *Lentinus, Volvariella, Pleurotus, Auricularia, Tremella, Pholiota* and *Hericium* are cultivated in greater amounts than they are in the developed nations.

The term **mushroom biology** refers to the discipline that is concerned with the scientific study of mushrooms (macrofungi with distinctive fruiting bodies). It includes all of the activities of mushroom cultivation as well as the various biological subdisciplines, such as genetics, taxonomy, physiology, etc. It is believed that the term mushroom biology will bring together many diverse studies thus facilitating the dissemination of knowledge about mushrooms and greater recognition of this field of science which is increasingly affecting peoples' lives for their betterment.

7. References

Abelson, P.H. (1991). Resources of plant germplasm. *Science* **253**:833.

Breene, W.M. (1990). Nutritional and medicinal value of specialty mushrooms. *J. of Food Production* **53**:833-894.

Chang, S.T. (1972). *The Chinese Mushroom (Volvariella volvacea) - Morphology, Cytology, Genetics, Nutrition and Cultivation.* The Chinese University Press, Hong Kong. 99pp.

Chang, S.T. (1974). Production of the straw mushroom (*Volvariella volvacea*) from cotton wastes. *The Mushroom J.* **21**:348-354.

Chang, S.T. (1980). Mushrooms as human food. *Bioscience* **30**:399-401.

Chang, S.T. (1990a). Future trends in cultivation of alternative mushrooms. *The Mushroom J.* **215**:422-423.

Chang, S.T. (1990b). Biotechnology for mushroom cultivation in developing countries. In: Flegel, T.W., Gunter Tharven & Yongyuth Yuthavong (eds.) *Biotechnology for Small Industries in Developing Countries*, pp.92-97. Text and Journal Corporation, Bangkok, Thailand. 260pp.

Chang, S.T. and P.G. Miles (1987). Historical record of the early cultivation of *Lentinus* in China. *Mushroom J. for the Tropics* **7**:31-37.

Chang, S.T. and P.G. Miles (1989). *Edible Mushrooms and Their Cultivation.* CRC Press, Boca, Raton, Florida. 345pp.

Chang, S.T. and P.G. Miles (1991). Recent trends in world production of cultivated mushrooms. *The Mushroom J.* **503**:15-18.

Chang, S.T. and P.G. Miles (in press) Mushroom biology - a new discipline. *The Mycologist* (U.K.).

Cho, K.Y. and N.G. Nair (1987). Advances in the biotechnology of mushroom cultivation. *Aust. J. Biotechnology* **1**:53-57.

Claydon, N., M. Allan and D.A. Wood (1990). Fruit bodies biomass regulated production of extracellular endocellulase during periodic fruiting by *Agaricus bisporus. The Mushroom J.* **206**:53-55.

Crisan, E.V. and A. Sands (1978). Nutritional value. In "*The Biology and Cultivation of Edible Mushrooms*", edited by Chang, S.T. and W.A. Hayes. pp.137-165. Acad. Press, New York. 819pp.

Jong, S.C. and J.M. Birmingham (1990). The medicinal value of the mushroom *Grifola. World J. Micro. & Biotechnology* **6**:227-235.

Hawksworth, D.L. (1991). The fungal dimension of biodiversity: magnitude, significance, and conservation. *Mycol. Res.* **95**:641-655.

Li, G.S.F. and S.T. Chang (1982a). The nucleic acid content of some edible mushrooms. *European J. Appl. Microb. Biotechnol.* **15**:237-240.

Li, G.S.F. and S.T. Chang (1982b). Nutritive value of *Volvariella volvacea*. In "*Tropical Mushrooms - Biological Nature and Cultivation Methods*", edited by Chang, S.T. and T.H. Quimio. pp.199-219. Chinese Univ. Press, Hong Kong. 493pp.

Kendrick, B. (1985). *The Fifth Kingdom.* Waterloo: Mycologue Publication. 364pp.

Miles, P.G. and S.T. Chang (1986). Application of biotechnology in strain selection and development of edible mushrooms. *Asean Food J.* **2**:3-10.

Miles, P.G. and S.T. Chang (1987). Fruiting of *Lentinus edodes* (Shiitake) in liquid media. *MICREN J.* **3**:103-112.

National Agricultural Statistics Service. (1991). Mushrooms. United States Department of Agriculture, Washington, D.C.

Noble, R. (1989). Growing deep in Czechoslovakia. *The Mushroom J.* **203**:352-353.

Pai, S.H., S.C. Jong and D.W. Lo (1990). Usages of mushrooms. *Bioindustry* **1**:126-131.

Peberdy, J.F. (1989). Fungi without coats - protoplasts as tools for mycological research. *Mycol. Res.* **93**:1-20.

Tautorus, T.E. and Townsley (1987). Biotechnology in commercial mushroom fermentation. *Biotechnology* **2**:696-701.

Wood, D.A. (1980). Inactivation of extracellular laccase during fruiting of *Agaricus bisporus. J. General Microbiology* **117**:339-345.

Wood, D.A. (1984). Microbial processes in mushroom cultivation: a large scale solid substrate fermentation. *J. Chem. Technol. Biotechnol.* **34B**:232-240.

Wood, D.A. (1989). Mushroom Biotechnology. *Intl. Indust. Biotechnology* **9**:5-8.

Wood, D.A. and T.R. Fermor (1982). Nutrition of *Agaricus bisporus* in compost. *The Mushroom J.* **114**:194-197.

Wood, D.A. and P.W. Goodenough (1977). Fruiting of *Agaricus bisporus*. Changes in extracellular enzyme activities during growth and fruiting. *Archives of Microbiology* **114**:161-165.

Wood, D.A. and G.F. Leatham (1983). Lignocellulose degradation during the life cycle of *Agaricus bisporus*. *FEMS Microbiology Letters* **20**:421-424.

Yau, C.K. and S.T. Chang (1972). Cotton waste for indoor cultivation of straw mushroom. *World Crops* **24**:303-304.

Yu, M. and S.T. Chang (1989). Mutants of *Pleurotus florida* deficient in sporulation. *MIRCEN J. Applied Microbiol. Biotechnol.* **5**:487-492.

Table 1. Pharmaceuticals developed from mushrooms in Japan

Name	**Krestin**	**Lentinan**	**Schizophyllan**
Abbreviation	PSK/PSP		
Date for sale	May 1977	December 1985	April 1986
Mushrooms species	*Coriolus versicolor* (mycelium)	*Lentinus edodes* (fruiting body)	*Schizophyllum commune*
Polysaccharide	Beta-1,6 branch; Beta-1,3; Beta-1,4 mainchain	Beta-1,6 branch; Beta-1,3 mainchain	Beta-1,6 branch; Beta-1,3 mainchain
Molecular weight	ca. 100,000	ca. 500,000	ca. 450,000
$[\mathrm{alpha}]_D$	-	+ 14~22°C (NaOH)	+ 18~24°C (H_2O)
Products	1g/package	1mg/vial	1g/2ml bottle
Administration	Oral	Injection	Injection
Indication	Cancer of digestive system, breast cancer, pulmonary cancer	Gastric cancer	Cervical cancer
1985 sale value	556 M$	85 M$	128 M$

Source: Pai *et al.* 1990

Table 2. Pharmaceutical components of mushroom species

Pharmacodynamic	**Component**	**Species**
1. Antibacterial effect	Hirsutic acid	Many species
2. Antibiotic	E-beta-methoxyacrylate	*Oudemanxiella radicata*
3. Antiviral effect	Protein, Polysaccharide	*Lentinus edodes* and *Polyporaceae*
4. Cardiac tonic	Volvatoxin, Flammutoxin	*Volvariella*
5. Decrease cholesterol	Eritadenine	*Collybia velutipes*
6. Decrease level of blood glycogen	Peptide glucan, Ganoderan	*Ganoderma lucidum*
7. Decrease blood pressure	Triterpene	*Ganoderma lucidum*
8. Antithrombus	5'-AMP, 5'-GMP	*Psalliota hortensis*
9. Inhibition of PHA	r-GHP	*Psailliota hortensis, Lentinus 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 *et al.* 1990

Table 3. Comparison of 1986 and 1989/90 world production of cultivated edible mushrooms

Unit: (metric ton x 1000)

Species	Common Name	1986		1989/90		% increase
		Fresh wt.	%	Fresh wt.	%	
Agaricus bisporus bitorquis	Button mushroom	1,215	55.8	1,446	38.1	19.0
Lentinus edodes	Shiitake or oak mushroom	320	14.7	402	10.6	25.6
Volvariella volvacea	Straw mushroom or Chinese mushroom	178	8.2	207	5.5	16.3
Pleurotus spp.	Oyster mushrooms	169	7.8	909	24.0	437.9
Auricularia spp.	Wood-ear	119	5.5	400	10.5	236.1
Flammulina velutipes	Winter mushroom	100	4.6	143	3.8	43.0
Tremella fuciformis	White Jelly fungus/ or "Silver Ear"	40	1.8	105	2.8	162.5
Pholiota nameko	"Nameko" or Viscid mushroom	25	1.1	53	1.4	112.0
Hericium erinaceus	Monkey head mushroom or Hedgehog fungus	-	-	90	2.4	
Hypsizigus marmoreus	Shimeji	-	-	22	0.6	
Grifola frondosus	Sitting-hen mushroom or Limuo, Maitaka	-	-	7	0.2	
Others		10	0.5	10	0.3	
Total		2,176	100.0	3,794	100.2	74.4

Source: Chang & Miles (1991).

Table 4. Comparison of 1986 and 1989/90 production of cultivated edible mushrooms in China

(unit: x 1000 tons)

	1986		1989/90		% increase
	Fresh wt.	%	Fresh wt.	%	
Agaricus bisporus	185	26.6	170	8.9	-2.7
Lentinus edodes	120	17.2	210	11.0	75.0
Volvarilla volvacea	100	14.4	110	5.7	10.0
Pleurotus spp.	100	14.4	800	41.2	700.0
Auricularia spp.	80	11.5	360	18.8	350.0
Tremella fuciformis	50	7.2	100	5.2	100.0
Hericium erinaceus	50	7.2	90	4.7	80.0
Flammulina velutipes	10	1.4	40	2.1	300.0
Pholiota nameko	0.8	0.1	32	1.7	3,900.0
Tremella aurantia	-		3.50	0.2	
Grifola frondosus	-		0.20	0.01	
Dictyophora indusiata	-		0.04	0.002	
Total	695.8	100.0	1,915.74	99.412	175.3

Table 5. Comparison of 1986 and 1989/90 production of cultivated edible mushrooms in Japan

(unit: tons)

Species	1986		1989/90		% increase
	Fresh wt.	%	Fresh wt.	%	
Lentinus edodes	176,800	56.0	159,857	48.5	-9.6
Pholiota nameko	20,079	6.4	21,125	6.4	5.2
Flammulina velutipes	74,378	23.6	83,200	25.3	11.9
Pleurotus spp.	30,050	9.5	36,095	11.0	20.1
Hypsijigus marmoreus	11,493	3.6	22,349	6.8	94.5
Grifola frondosus	2,203	0.7	6,167	1.8	178.0
Auricularia auricula-jadae	205	0.06	153	0.05	-25.4
Tricholoma matsutake	199	0.06	457	0.15	129.6
Total	315,407	99.9	329,403	100.0	4.4

Table 6. Comparison of 1986 and 1989/90 import and export of edible mushrooms in Japan

(unit: tons)

Species	1986		1989/90		% increase	
	Import	Export	Import	Export	Import	Export
Lentinus edodes	124	3,538	2,201	1,439	1,675	-59.3
Auricularia auricula	16,299	-	19,875	-	22.0	-
Tricholoma matsutake	980	-	2,210	-	125.5	-
Total	17,400	3,538	24,286	1,439	39.6	-59.3

Table 7. Comparison of 1986 and 1989/90 production of cultivated edible mushrooms in South Korea

(unit: tons)

Species	1986		1989/90		% increase
	Fresh wt.	%	Fresh wt.	%	
Agaricus bisporus	11,860	26.0	12,025	19.3	1.4
Pleurotus spp.	25,850	56.8	37,420	60.1	44.8
Lentinus edodes	7,238	15.9	10,710	17.2	48.0
Flammulina velutipes	16	0.04	121	0.2	656.2
*Tricholoma matsutake**	311	0.7	954	1.5	206.8
*Ganoderma lucidum***	256	0.6	1,028	1.7	301.6
Total	45,531	100.04	62,258	100.0	36.7

* Semi-cultivated
** Medicinal mushroom

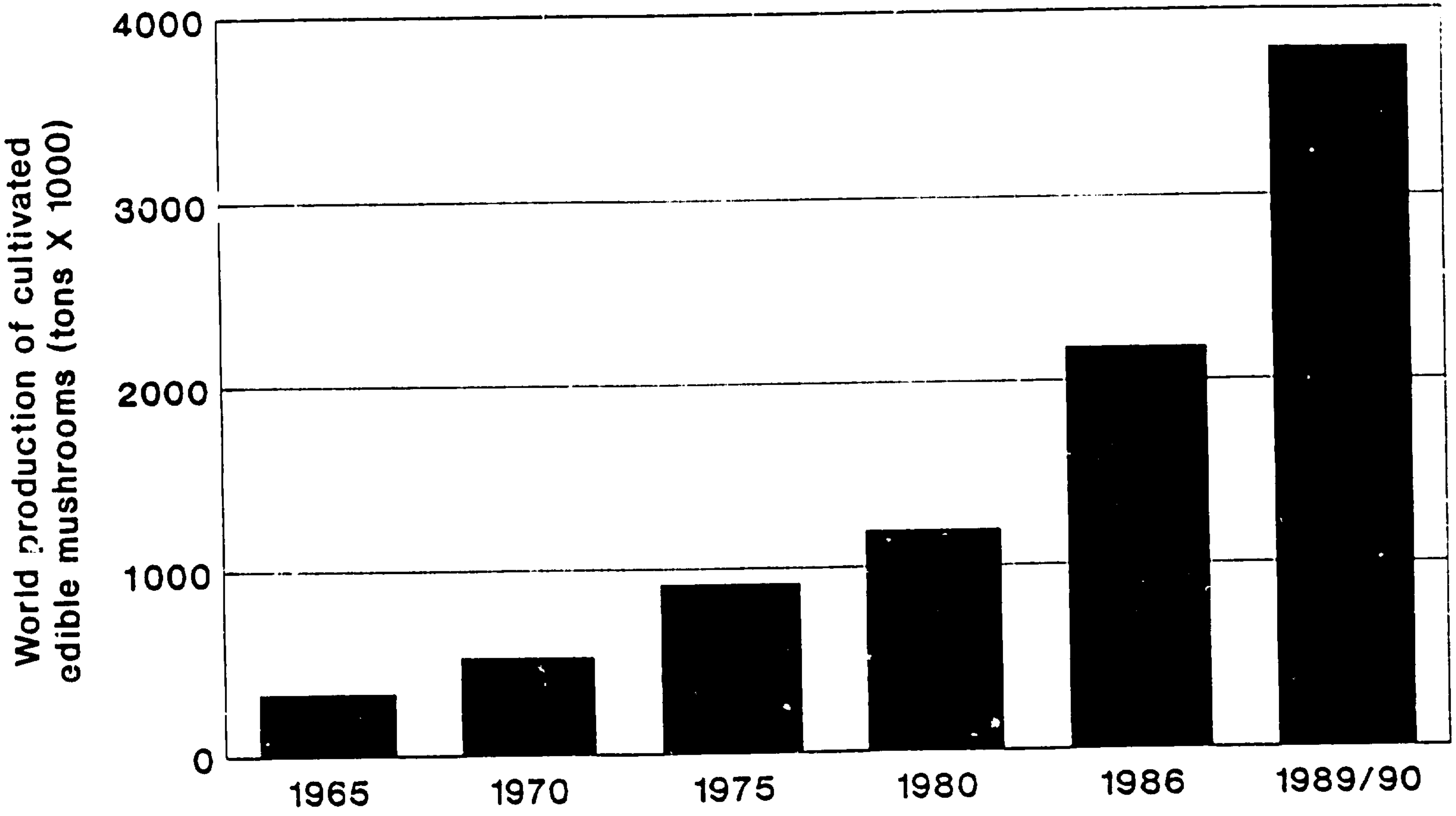

Fig. 1. Annual world production of cultivated edible mushrooms

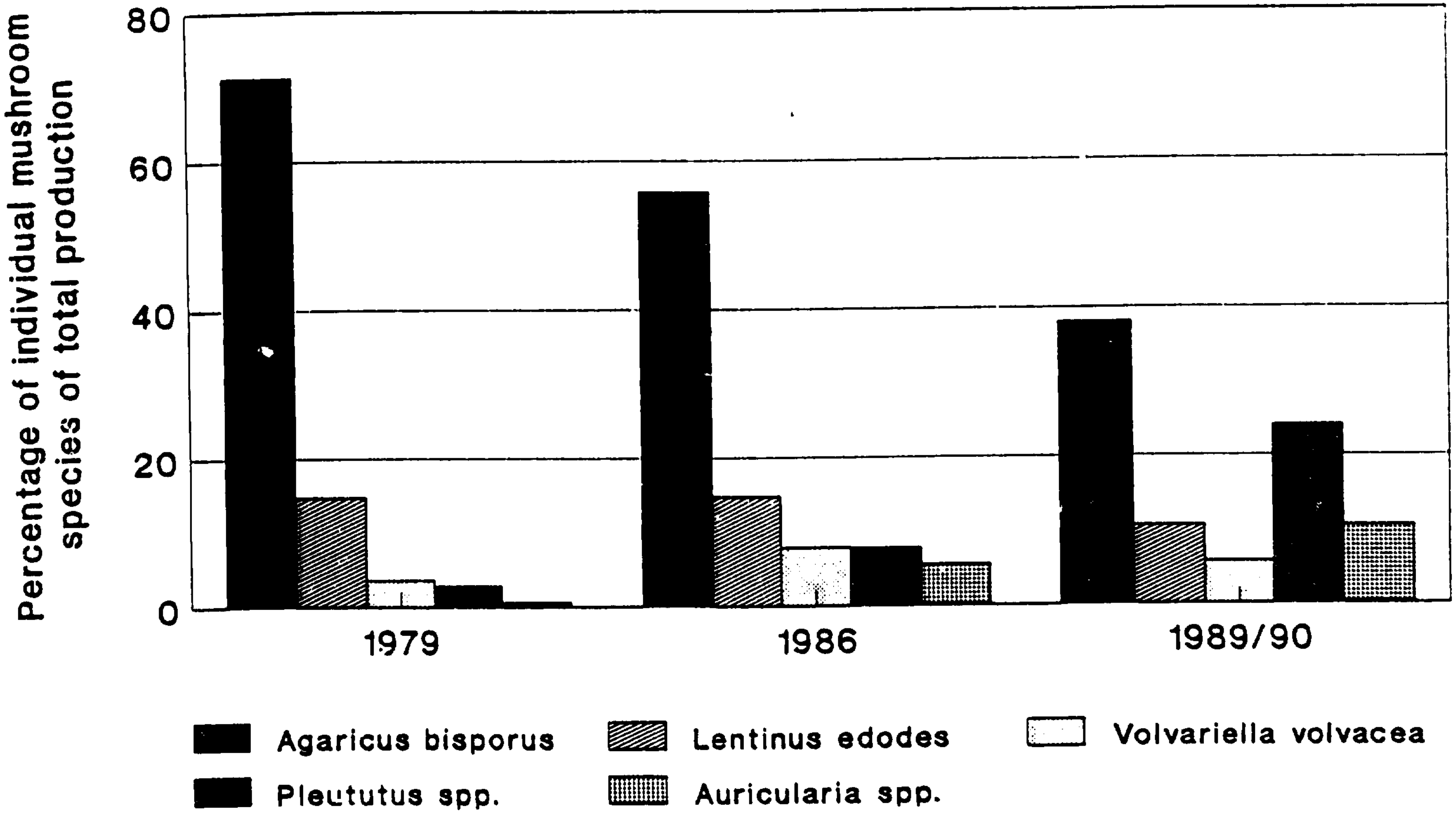

Fig. 2. Percentage of world production of five major mushrooms in 1979, 1986 and 1989/90