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Report for United Nations Industrial Development Organizaion (UNIDO) on the Creation of An International Centre/Network for Mushroom Cultivation Technology

By

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Foreword

This study was undertaken in response to an invitation from United Nations Industrial Development Organization (UNIDO) to:

(i) formulate proposals for the establishment of an international network/centre for the bioconversion of waste materials to food and useful products by edible fungi, with special emphasis on helping developing countries,

(ii) to prepare a project document for the creation of an International Network/Centre for Mushroom Research and Training (ICMRT).

Information accured during field visits, undertaken within the past three months, to farmers, research institutes and traders in China, Nepal, Bangladesh and India, and data obtained from a survey questionnaire distributed to 14 countries, have been used extensively in the preparation of this document.

Mushrooms have been used as a food for centuries. However, although more than 2,000 species of edible mushrooms are known, only a few of these have been investigated thoroughly as to their commercial potential. In recent years, one has witnessed rapidly multiplying demands for many different kinds of edible mushrooms in both local and international markets. From this study, we keenly sense that mushrooms will play pivotal roles in food production and environmental protection for which there is growing international concern both in terms of the present status and future projections. Different kinds of mushrooms will continue to appeal to organic gardeners, commercial growers, researchers, nutritionalists, food and pharmaceutical industries and ecological managers. Indeed, we foresee a huge leap in the popularity of mushrooms as the public becomes increasingly aware of their highly desirable nutritional, tonic and medicinal qualities, and their contribution to environment preservation.

These include:

- remarkable taste and flavour
- high content of high quality protein, especially rich in essential amino acids which are lacking in staple cereal crops and other plant foods
- medicinal/biological properties such as immunopotentiation, hypocholesterolaemic activity, and antitumour and cardiotonic effects
- ease of cultivation, throughout the year indoors and for several months of the year outdoors
- ease of post-harvest processing (drying, pickling, canning), storage and transportation
- role in the recycling organic wastes generated by the agricultural, forest and food processing industries.

Mushroom science, derived from the principles of microbiology, environmental engineering and fermentation technology, has developed in modern times both technologically and as a basis for new cottage type industries and highly developed industrial mushroom growing complexes. Thus, the activities centered around mushroom studies have achieved global dimensions and hold many long-term, worldwide implications. These include the conservation of mushroom germplasm as part of integrated efforts aimed at safeguarding the world's biological diversity which 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 results with a short space of time, thereby bringing direct benefits to developing countries. However, progress in mushroom cultivation, the development of the industry, and full realisation of the nutritional and medicinal benefits of mushrooms and mushroom products are dependent upon

(i) the collective efforts of scientists from industrialized and developing countries
(ii) the training of personnel in the many facets of mushroom biology and mushroom cultivation technology.

This can only be achieved effectively by the establishment of an international centre for mushroom studies.

It is estimated that the cost of establishing such a centre will be in the region of US$4 million with funding of the same magnitude, in the form of an endownment, required for on-going recurrent expenses. Subject to acceptance of the recommendation that an international centre be established, it is proposed that an Implementation Committee, consisting of a panel of relevant experts, be created to undertake the detailed planning of the centre.

Acknowledgement

We should like to express our sincere gratitude to UNIDO, Vienna, Austria for the opportunity to undertake this study. Our sincere appreciation also goes to the many government and non-government institutions and organizations who provided us with information. Finally, we wish to thank the staff of the Department of Biology, The Chinese University of Hong Kong, for technical and clerical assistance.

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1. Introduction

1.1. Background

During the past decade there has been a great increase in the popularity and production of mushrooms throughout the world and particularly in Southeast Asia. This has been due, in part, to a growing awareness that mushrooms, apart from their delicacy, have a high nutritional value, possess important tonic and medicinal properties, and can serve as a cheap source of protein. Another contributing factor has been the financial assistance and additional support from United Nations agencies for conducting training courses, workshops and conferences on mushroom research and production in many Asian countries. This study was undertaken in response to an invitation from the United Nations Industrial Development Organization (UNIDO) to formulate proposals for the establishment of an international network/centre for the bioconversion of organic waste materials into food and other useful products by mushrooms, with special emphasis on developing countries.

1.2. What is a mushroom?

This is not a new question or a new issue. The word mushroom may mean different things to different people and different countries. Specialized studies, and the economic value, of mushrooms have reached the point where a clear definition of the term 'mushroom' is now warranted. This will be of considerable benefit at a time when the number of cultivated mushrooms species is rising, when production of established cultivated mushrooms continues to show a steady expansion (Figure 1), and when an increasing number of countries and people are engaged in mushroom cultivation as an agricultural or industrial technology. In this report, 'mushroom' is defined in the broad sense as "a macrofungus with a 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" (Chang & Miles, 1992). Thus, mushrooms need not be Basidiomycetes, nor aerial, nor fleshy, nor edible. Mushrooms can be Ascomycetes, grown underground and have a non-fleshy texture. Mushrooms can be divided into four categories: (1) those which are edible and fleshy and fall into the edible mushroom category, e.g. *Agaricus bisporus*; (2) those which are considered to have medicinal applications and are referred to as medicinal mushrooms, e.g. *Ganoderma lucidum*; (3) those which are proven to be, or suspected of being, poisonous e.g. *Amanita phalloides*; (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'. This form of classifying mushooms is not absolute; many kinds of mushrooms are not only edible but also possess tonic and medicinal properties.

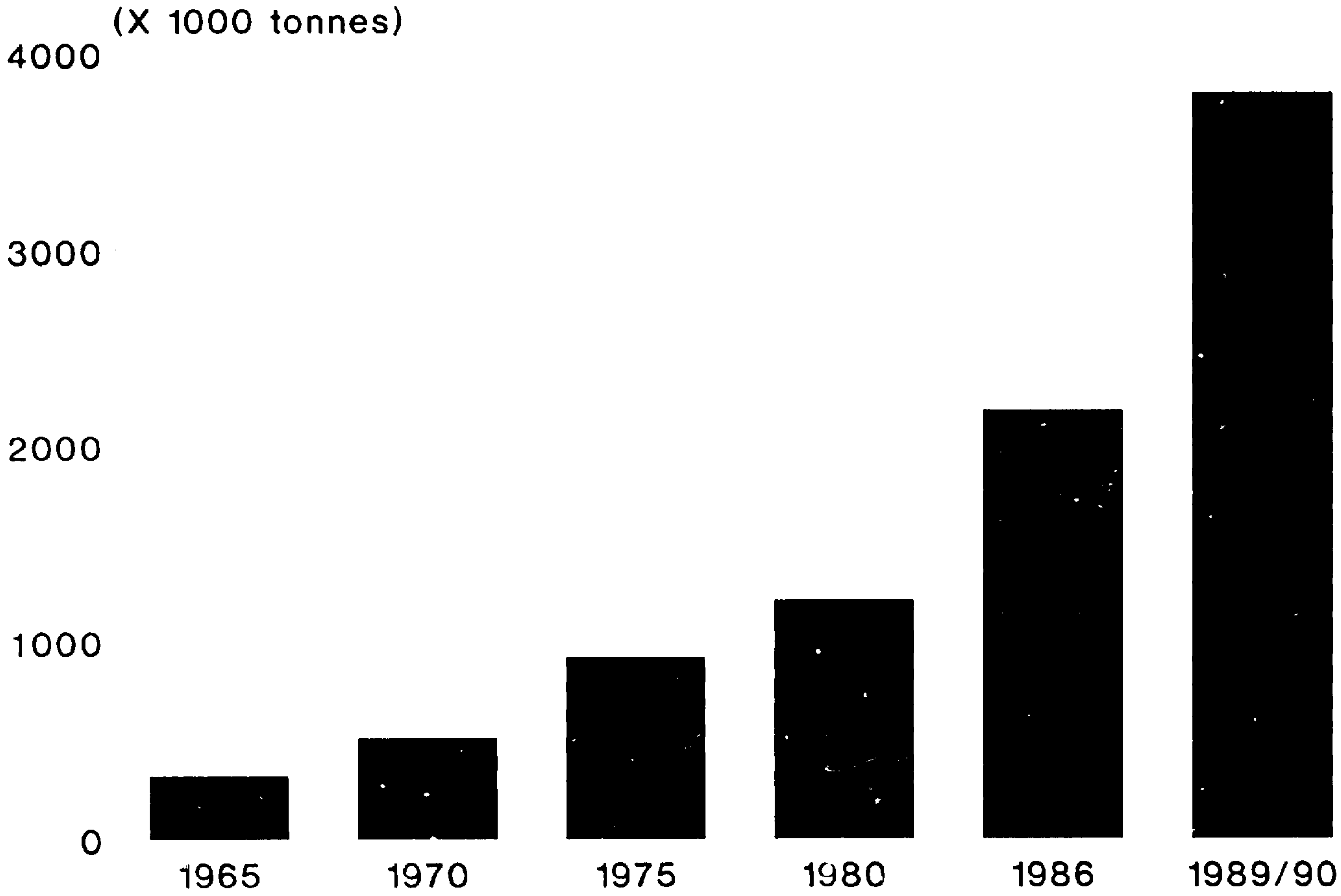

Fig. 1. Annual World Production of Cultivated Edible Mushrooms

Table 1. Comparison of the numbers of known and estimated total species in the world of selected groups of organisms.

Group	Known species	Total species	Percentage known (%)
Vascular Plants	220000	270000	81
Bryophytes	17000	25000	68
Algae	40000	60000	67
Fungi	69000	1500000	5
Bacteria	3000	30000	10
Viruses	5000	130000	4

Source: Hawksworth (1991)

Table 2. 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 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)

1.3. Magnitude of mushrooms

Although the number of known species of fungi is put at between 69,000 to 80,000, it is conservatively estimated that 1.5 million species exist (Table 1) (Hawksworth, 1991). The fungi are regarded as the second largest group of organisms in the biosphere after the insects, estimates of which range between 10-80 million (Stork, 1988). Thus, known fungal species constitute only about 5% of the estimated total and, therefore, the large majority of fungi are still unknown. Out of 80,000 described species of fungi, there are about 10,000 species of fleshy macrofungi and only a handful of these are lethal. There are no simple ways of distinguishing between the edible and the poisonous and a mushroom should only be eaten if it can be identified with precision. About 2,000 species from more than 30 genera are regarded as prime edible mushrooms but only about 80 of these are grown experimentally, about 40 are cultivated economically, and only 4 to 5 are produced on an industrial scale (Chang, 1990).

1.4. History

Prehistoric man almost certainly used mushrooms as food and there is ample evidence that the great early civilizations of the Greeks, Egyptians, Romans, Chinese and Mexicans prized mushrooms as a delicacy, for purported therapeutic value and, in some cases, for use in religious rites. Throughout recorded history, there is repeated reference to the use of mushrooms as food and for medicinal purposes, and it is therefore 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 cultivated later in a similar manner, but the greatest advance in mushroom cultivation occurred in France around 1600 A.D. when *Agaricus* (champignon or button mushroom) was grown upon a composted substrate. In the years since World War II, there has been a consistent increase in mushoom production which greatly accelerated in the period from 1986 to 1989-90. A 74.4% increase was recorded during this latter period and total world production in 1989-90 amounted to 3.79 million metric tons valued at about US$ 7.5 billion (Table 2, Chang & Miles, 1991). In the Western world, *Agaricus* has remained the most extensively cultivated mushroom in quantitative terms and in the United States in 1990-91 still exceeded 99% of total U.S. mushroom production. However, mushrooms long popular in Asia (e.g. *Lentinus*), and produced there in large quantities, are now making inroads into Western markets.

1.5. Nutrition

Although mushrooms have long been appreciated for their desirable gastronomic properties of flavour and texture, and some for their medicinal and/or tonic attributes, they are only recently recognized as a food of high nutritional quality. Of particular significance, especially to regions with populations whose diet is commonly deficient in protein, is the protein content of mushrooms. It is now known that this is relatively high (19-35% on a dry weight basis) as compared to 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 favourably with most other foods (Crisan & Sands, 1978; Li & Chang, 1982a). 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 (Table 3). Proteins of mushrooms contain all the essential amino acids and are especially rich in lysine and leucine which are lacking in most staple cereal foods. Furthermore, mushrooms contain a high proportion of unsaturated fatty acids, are a good source of several vitamins, minerals, fibre and other health promoting substances, and are low in calories, sodium, fat and cholesterol (Chang & Miles, 1989; Breene, 1990; Jong & Birmingham, 1990; Buswell & Chang, 1992). In addition, the nucleic acid content of mushrooms is not high enough to limit their daily use as a vegetable (Li & Chang, 1982b). Another compelling advantage of mushroom protein is that it can be produced with greater biological efficiency than proteins from animal sources. It is true that, in some highly industrialized countries, cultivation of the *Agaricus* mushroom is a highly sophisticated operation requiring a sizable capital outlay for controlled environment facilities. However, production of other mushroom species requires relatively little in terms of large-scale equipment, facilities, capital and land, and the mushrooms themselves often have less complicated demands in terms of processing.

1.6. Medicinal and tonic properties of mushrooms

Although mushroom have traditionally been used in China and Japan for their medicinal and tonic properties, this aspect of mushrooms remains largely unexploited. However, there has been a recent upsurge in interest in traditional remedies for the treatment of various physiological disorders and numerous biologically active compounds have been reported in mushrooms as a result. Lists of pharmaceutical products developed from mushrooms in Japan (Table 4) and their active components (Table 5) have been compiled recently by Pai *et al.* (1990). *L. edodes* (shiitake) contains a drug Lentinan which has been shown to stimulate production a polypeptide, Interleukin 1. This compound has metabolic, hormonal, immunologic and haematologic activities. Lentinan induces prostaglandin formation, stimulates T-lymphocytes which are depressed in cancer states and also in AIDS, and has an anti-viral effect through the production on Interferon gamma. The reported effect on longevity it probably due to these anti-cancer, anti-viral and anti-inflammatory functions. Medical evidence has shown that ingestion of shiitake also prevents blood platelets from adhering to each other and thereby reducing the

Table 3. Comparison of nutritive value of mushrooms with various foods.

Essential amino acid indexes		Amino acid scores		Nutritional indexes	
100	pork; chicken; beef	100	pork	59	chicken
99	milk	98	chicken; beef	43	beef
98	mushrooms (high)	91	milk	35	pork
96	*V. diplasia*	89	mushrooms (high)	31	pork
91	potatoes; kidney beans	71	*V. diplasia*	28	mushroom (high)
	P. ostreatus	63	cabbage	27	*V. diplasia*
88	corn	59	potatoes	26	spinach
87	*A. bisporus*		*P. ostreatus*	25	milk
86	cucumbers	53	peanuts	22	*A. bisporus*
79	peanuts	50	corn	21	kidney beans
76	spinach; soybeans	46	kidney beans	20	peanuts
74	*L. edodes*	42	cucumbers	17	cabbage
72	mushrooms	40	*L. edodes*	15	*P. ostreatus*
69	turnips	33	turnips	14	cucumbers
53	carrots	32	mushrooms (low)	11	corn
44	tomatoes	31	carrots	10	turnips
		28	spinach	9	potatoes
		23	soybeans	8	potatoes
		18	tomatoes	6	carrots
				5	mushrooms (low)

Ranking based on essential amino acid indexes, amino acid scores and nutritional indexes as calculated against the FAO reference protein pattern. Values for mushrooms represent the mean of the three highest values (high) and the three lowest values (low).
Source: Crisan & Sands (1978) and Li & Chang (1982a)

Table 4. 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
$[alpha]_D$	-	+ 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 5. 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	*Psallliota 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

formation of clots. Cosmetic products and some healthy beverages have also been produced in China from mushrooms of *Ganoderma*.

1.7. Bioconversion of waste materials

Mushrooms are a special group of fungi. Unlike green plants, fungi lack chlorophyll and consequently cannot use solar energy to manufacture their own food. However, mushrooms do produce a wide range of extracellular enzymes that enable them to degrade complex organic substrates into soluble substances which can then be absorbed by the mushroom for its own nutrition (Wood & Fermor, 1982; Wood, 1984). This absorptive nutrition is a characteristic of mushrooms. Many of the complex substrates suitable for mushroom cultivation are waste products, huge quantities of which are generated annually through the activities of agricultural, forest and food processing industries. Examples include cereal straws, bagasse, banana leaves, coffee grounds, sawdust, and cotton wastes from textile factories (Chang, 1991). These agricultural and industrial waste products are found in abundance in those developing regions of the world with economies which are still basically agricultural. Currently, much of this material is either burnt, shredded and/or composted for landfill or improvement of soil quality, even though these wastes constitute a valuable resource for human food production. Edible mushroom production also represents an attractive method of upgrading lignocellulosic wastes. The nutritional quality of the material remaining after mushroom harvesting may be improved sufficiently for use as an animal feedstock. Alternatively, the residue can be used as a soil fertilizer and conditioner, thereby increasing production of other agricultural and horticultural crops. Thus, edible mushroom cultivation represents one of the most economically viable processes for the bioconversion of certain types of organic wastes and 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.

1.8. Cottage industry

Many people have been attracted to mushroom cultivation precisely for the reasons described above. The use of cheap, readily available raw materials, and reduced demands on land space compared to other agricultural crops, are attractive features of mushroom cultivation particularly where large-scale capital-intensive operations are inappropriate. Aslo, in an environmentally conscious society, the bioconversion of potential pollutants into a food for human consumption, is not to be dismissed lightly. There is no doubt that mushroom cultivation technology, if properly promoted and developed, can be translated into thriving 'cottage industries' which will make important contributions to the nutrition and economic welfare of many people, particularly in developing countries. It is interesting to consider the recent cultivation history of *Agaricus bisporus* as a good reference for the cultivation of other edible mushrooms. Fifty years ago, the yield of *Agaricus* was less than 5 kg/m^2 (1 lb/sq ft) in more than twelve picking weeks. The picking was done by hand. Today, the top yields of this mushroom can reach 50 kg/m^2 (5.3 lb/sq ft) in four weeks and the harvesting can be done using a cutting machine. However, mushroom cultivation and the successful achievement of a profitable mushroom farm requires an understanding of certain scientific principles and practical experience in mushroom technology. Commencement of mushroom production on a cottage industry scale can be undertaken by villagers once they have acquired some limited technical knowledge. Once the basic skills are mastered, further progress will follow as a result of the natural ingenuity of the people and the adoption of modifications befitting the local environment. However, for a successful cottage mushroom industry, some cooperative operations are essential; e.g. collective preparation of high quality compost for mushroom production, centralized processing systems to ensure high quality mushrooms for marketing.

1.9. Mushroom science

Although the cultivation of edible mushrooms dates back many centuries, research in this field is still relatively adolescent and limited to certain scientific institutes in developed countries. Only in recent years have research and extension laboratories been established in a few developing countries through the aid of national and international agencies. Mushroom science embodies the principles of microbiology, environmental technology, and solid state fermentation in the conversion of domestic agricultural, and industrial inorganic waste materials into food for humans. The technology for mushroom cultivation can be primitive, as in rural farming of *Volvariella* and *Pleurotus* mushrooms. It can also be highly industrialized, as in *Agaricus* and *Lentinus* production in urban areas, in which advanced technology and equipment are used. Biological efficiency, i.e. the yield of fresh mushrooms in proportion to the weight of compost at spawning, can reach 100% in experimental tests, with 40-60% as a good average value per crop.

The activities centered around mushroom studies have achieved global dimensions and hold many long term implications. These include the conservation of mushroom germplasm as part of the need for wider protection of the Earth's biological diversity which has emerged as a matter of serious international concern. However, progress in mushroom cultivation and the development of the industry are dependent upon the collective efforts of scientists from both industrialized and developing countries. To achieve the most effective collaboration, an international research and training centre for mushroom studies should be established.

1.10. Mushroom biology

Mycology is the science concerned with fungi, of which around 80,000 species have been described. Fungi are important to human for a variety of reasons. They are the principle causal agents of plant diseases as well as some significant diseases affecting humans. Through their fermentative activities, fungi are major fabricators of several important products such as ethyl alcohol, citric acid, and the antibiotic, penicillin. With annual production valued at US$7.5 billion, the edible mushroom is certainly not to be ignored. Several terms for this important branch of mycology have been used in the past, each with its own merit. However, if the matter of definitions is considered more deeply, it appears that there is a place for a new term. The new term is **mushroom biology**. Mushroom biology is the new discipline concerned with the scientific study of mushrooms (Chang & Miles, 1992). The term **mushroom science** already exists, but is restrictive in that it has been defined as the discipline concerned with the principles and practice of mushroom cultivation. Confined solely to mushroom cultivation, mushroom science is only one aspect, albeit a significant one, of mushroom biology. Mushroom biology takes in not only cultivation but embraces all aspects of mushrooms including taxonomy, development, nutrition, physiology, genetics, pathology, medicinal and tonic attributes, edibility, toxicity, etc.

Professor S.T. Chang, Department of Biology, The Chinese University of Hong Kong, and his colleagues and collaborators have combined their own research data with available information on mushroom biology and mushroom cultivation collected from numerous sources worldwide to produced several volumes in the field. These books, which are listed below, have formed a basis for further academic research, technical extension and marketing promotion of mushrooms.

(1) *The Chinese Mushroom (Volvariella volvacea) - Morphology, Cytology, Genetics, Nutrition and Cultivation.* (Chang, 1972). The Chinese University Press, Hong Kong.
(2) *The Biology and Cultivation of Edible Mushrooms.* (Chang & Hayes, 1978). Academic Press, New York & London.
(3) *Tropical Mushrooms: Biological Nature and Cultivation Methods.* (Chang & Quimio, 1982). The Chinese University Press, Hong Kong.
(4) *Edible Mushrooms and Their Cultivation.* (Chang & Miles, 1989). CRC Press, Inc., Boca Raton, Florida.
(5) *Technical Guidelines for Mushroom Growing in the Tropics.* (Quimio, Chang & Royse, 1990). Food and Agriculture Organization, Rome.
(6) *Culture Collection and Breeding of Edible Mushrooms.* (Chang, Buswell & Miles, 1992). Gordon & Breach, Inc., Philadelphia.

2. Survey of On-going Work and Efforts in Different Areas of the World

2.1. Edible mushroom species already under cultivation

As mentioned in section 1.3, out of 80,000 described species of fungi, there are about 10,000 species of fleshy macrofungi. About 2.000 species from more than 30 genera are regarded as edible (Table 6). Unfortunately, some other mushrooms are very poisonous and there are no general guidelines for distinguishing between the poisonous and edible species. Only about 80 of the "edible" types are grown experimentally and about half of these have been cultivated economically. Approximately 20 edible mushrooms have been grown commercially but only about 5 or 6 (*Agaricus, Lentinus, Pleurotus, Auricularia, Volvariella, Flammulina*) are produced extensively (i.e. in several countries) on an industrial scale (Table 7). In general, the oriental countries, China, Japan and Korea, grow and consume more varieties of mushrooms than the western countries. However, in recent year, the production of what are referred to as "specialty mushrooms", mainly *Lentinus edodes*, and *Pleurotus* spp., have increased rapidly in western countries (Chang & Miles, 1991).

The important cultivated edible mushrooms are *Auricularia auricula, A. polytricha, A. fuscosuccinea, Tremelia fuciformis, Hericium erinaceus, Lentinus edodes, Pleurotus ostreatus, Flammulina velutipes, Agrocybe cylindracea, Volvariella volvacea, V. bombycina, Kuehneromyces nameko, Pholiota adiposa, Dictyophora incusiata, D. duplicata, Hypsizigus marmoreus, Grifola frondosus*, etc. Many wild mushrooms have been used by the native of various parts of the world. The important ones are: *Morchella esculeta, M. conica, M. angusticeps, M. crassipes, Cantharellus cibarius, Boletus edulis, Suillus luteus, Paxillus involutus, Gophidius viscidus, Lactarius deliciosus, Russual delica, R. virescens, Hohenbuehelia serotina, Calocybe gamblsa, Leucopaxillus giganteus, Aemillariella mellea, A. tabescens, Trucholma matsutake, T. mongolicum, T. terreusm, T. flavorireus, Agaricus campestris, A. arvensis, Naematoloma sublateritum*, etc. The important pharmaceutical ones are: *Poria cocos, Tremella fuciformis, Polyporus myclitae, Shiraia bambusicola, Cordycepts sinensis, C. sobolifera, Polyporus umbellatus, C. oriolusvesicolor, Gloeostereum incarnatum, Armillariella mellea, A. abescens, Hericium erinaceus, Calvatia gigantiea, C. lilacina, Myconastrum corium, Lycoperdon perlatum, L. pyriformis*, etc.

2.2. Climatic conditions

Mushrooms are produced in both the more-developed and the less-developed countries under a wide range of conditions ranging from outdoor cultivation in relative primitive facilities to indoor cultivation in insulated, vapour-proof buildings fitted with highly sophisticated computerized environment control systems.

In general, there are two distinguishing phases in the growth and development of a cultivated mushroom in its compost. These are the vegetative

Table 6. Genera of Prime Edible Mushrooms

Basidiomycetes	
Agaricus bisporus	*Lentinus edodes*
Amanita caesarea	*Lepista nuda*
Armillaria mellea	*Lyophyllum decastes*
Auricularia polytricha	*Marasmius oreades*
Boletus edulis	*Pleurotus ostreatus*
Cantharellus cibarius	*Pholiota nameko*
Calvatia gigantea	*Polyporus frondosus* (*Grifola frondosus*)
Clitocybe geotropa	*Russula aureta*
Coprinus comatus	*Stropharia rugoso-annulata*
Cortinarius spp.	*Termitomyces albuminosus*
Dictvophora indusiata	*Tremella fuciformis*
Flammulina velutipes	*Tricholoma matsutake*
Gloeostereum incarnatum	*Volvariella volvacea*
Hericium erinaceus	
Lactarius deliciosus	
Ascomycetes	
Morchella esculenta	*Tuber melanosporum*

Table 7. Species of Commercially Cultivated Edible Mushrooms

*Agaricus bisporus**	*Flammulina velutipes**
*Agaricus bitorquis**	*Lentinus edodes**
Auricularia auricula	*Lyophyllum ulmarium*
Auricularia polytricha	*Pholiota nameko*
Auricularia fuscosuccinea	*Pleurotus ostreatus**
Dictyophora indusiata	*Pleurotus sajor-caju*
Dictyophora duplicata	*Pleurotus cystidiosus*
Gloeostereum incarnatum	*Pleurotus cornucopiae*
Grifola frondosa	*Pleurotus florida*
Hericium erinaceus	*Stropharia rugoso-annulata*
Hypsizygus marmoreus (=*Pleurotus elongatipes* and = *Lyophyllum shimeji*)	*Tremella fuciformis*
	*Volvariella volvacea**

*Species produced on an industrial scale.

stage and the reproductive stage. In practice, the former refers to the spawn running phase and the latter to the fructification phase. Martin and Demain (1978) and Esser (1980) used "growth phase" and "reproductive phase" to describe the transition from mycelial growth to the formation of a specific morphogenetic structure in many fungi in the fermentation industry.

After planting the spawn onto a prepared compost, the mushroom mycelium will grow from the spawn into the compost and colonize the substrate. During the period of mycelial colonization, the mycelium secretes enzymes into the substrate food base, some of which is broken down to more simple, soluble organic compounds which can be transported into the hyphae where they may accumulate for the subsequent metabolic uses of the fungus. After a certain period of growth, the mycelia may achieve interconnections among themselves and interwindment with the substrate. The former facilitates the translocation of nutrients while the latter provides a stronger physical support for fruiting body formation. At this state of development the mycelium may be said to have become "established". This means that the mycelium is ready to enter the reproductive stage if the environmental "triggers" for fructification are provided.

The transition from vegetative stage to the stage of fruiting body formation in mushrooms is controlled by environmental factors. The optimum temperature for fruiting is generally lower than the optimum temperature for mycelial growth (Kurtzman, 1979). The temperature necessary for vegetative growth and for fruiting must be considered in selection of an acceptable mushroom (Table 8 and 9), and it should be pointed out that strains or dikaryotic stocks of a species may differ in their required temperature ranges and optimal values so that even within a single species selections can be made. Certainly, CO_2, light and other environmental factors can act as a "trigger" for fructification in some mushrooms. However, if the optimum growth conditions are known for a particular mushroom species and climatic conditions are known for a particular region, matching the two is feasible. Furthermore, by using appropriate breeding techniques, it is possible to extend the range of climatic conditions under which any one mushroom species will grow. In most cases, however, some sort of climatic control will be required to optimize growth and production rates and to minimize exposure to undesirable weather.

An examination of the history of the cultivation of *Agaricus bisporus* shows that, in many counties, cultivation has become virtually independent of external climatic conditions. Progress towards similar independence has also been achieved for other cultivated mushrooms and it is likely that the trend towards more precise climatic control will continue.

2.3. Growth substrates for mushroom cultivation

Table 8. Temperature Range, Substrate Type, Production-Cycle Time, and Approximate Yield of Edible Mushrooms from Nonaxenic Culture Methods

Species	Substrate	Temperature range: Mycelial growth	Temperature range: Fruiting	Production cycle time	Yield[a]
Little or no pretreatment					
Lentinus edodes	Wood logs (outdoors, sometimes protected)	5-35 (24)[b]	6-25 (15) autumn (10) winter (20) spring	3-6 yr spring/autumn	40
Auricularia auricula	Wood logs (outdoors, sometimes protected)	15-34 (28)	15-28 (22-25)	2-5 yr spring/autumn	2-12
Auricularia polytricha	Wood logs (outdoors, sometimes protected)	10-36 (20-34)	15-28 (24-27)	1-2 yr	20-40
Tremella fuciformis	Wood logs	5-38 (25)	20-28 (20-24)	3-6 yr 7 months/yr	10-30
Some pretreatment					
Volvariella volvacea	(1) Rice straw (outdoor)	15-45 (32-35)	22-38 (28-32)	4-6 weeks	6-10
	(2) Cotton waste, rice straw (indoor)	15-45 (32-35)	22-38 (28-32)	2-3 weeks	30-45
Pleurotus sajor-caju	(1) Pasteurized cereal straw (indoor)	14-32 (25-27)	10-26 (19-21)	4-10 weeks	80-100 or more
	(2) Fermented cereal	14-32 (25-27)	10-26 (19-21)	4-10 weeks	80-100 or more
Long Composting process					
Agaricus bisporus	Composted cereal straw/ animal manure mixtures	3-32 (22-25)	9-22 (15-17)	14-16 weeks	65-80
Agaricus bitorquis	As above	3-35 (18-30)	18-25 (22-24)	14-16 weeks	40-65

[a] kg Fresh weight/kg d.m.
[b] Figures within parentheses are optimal values.
Source: Smith, *et al.* (1988).

Table 9. Temperature Range, Substrate Type, Production-Cycle Time, and Approximate Yield of Edible Mushrooms from Axenic Culture Methods

Species	Substrate	Temperature range		Production-cycle time	Yield[a]
		Mycelial growth	Furiting		
Flammulina velutipes	Sterilized sawdust, rice bran mixtures (polypropylene bottles)	3-34 (18-25)[b]	6-38 (8-12)	12-20 weeks	70-100
Lentinus edodes	As above (polythene bags)	5-35 (24)	6-25 (15) autumn (10) winter (20) spring	3-6 months	60-100
Auricularia auricula	As above (polythene bags)	15-34 (28)	15-28 (22-25)	8-10 weeks	20-25
Auricularia polytricha	As above (polythene bags)	10-36 (20-34)	15-28 (24-27)	6-8 weeks	70-85
Tremella fuciformis	As above (polythene bags)	5-38 (25)	20-28 (20-24)	6-8 weeks	80-100

[a]kg Fresh weight/100 kg d.m.
[b]Figures within parentheses are optimal values.
Source: Smith, *et al.* (1988).

Mushrooms are grown, not directly on soil as are other crops, but on organic substrates, either untreated or composted. These substrates are mostly waste materials, from the agricultural, forest and foods processing industries as may also include textile factory wastes. By using these materials for mushroom cultivation, these otherwise negative-value by-products can be recycled to produce additional food for human consumption. In the process, adverse environmental impacts may be avoided and waste disposal problems reduced or even eliminated. Examples of such materials include cereal straws, corn cobs, sawdust, bagasse, wood pulp, cotton waste, oil palm waste, banana leaves, poultry wastes, coconut husks, tree bark and leaves. Using appropriate technology, it should be possible to develop combinations of edible mushroom species and organic waste substrate suitable for any raw material which is readily available in a particular region. An additional benefit is that the spent compost remaining after the mushrooms have been harvested may also serve as animal feedstock, soil conditioner or fertilizer.

2.4. Acceptability of product to local end-user

One of the most important factors to take into account when determining the suitability of a particular mushroom species for cultivation in less developed countries is the acceptability of the product to the intended market. Any food product must be acceptable to the indigenous population, either traditionally or through commercial promotion, otherwise there is no market value. If the mushroom is to be marketed fresh, it must be a species which is acceptable on the basis of its organoleptic qualities to the people in the area where it is cultivated. Acceptability can be determined for a previously cultivated species by examination of import records, if avaiblable, or by testing for market acceptability with fresh mushrooms imported for that purpose. The selling price, which will be dependent upon production costs, will also need to be within the purchaser's range.

2.5. Quality control

Process and quality control measures vary widely in different parts of the world. In our survey conducted for the preparation of this report, responses to the section requesting information on quality control were as follows:

Malaysia: all mushrooms must be fresh and visually free from any sign of disease. No processing is involved at this stage since all mushrooms are sold fresh.

South Africa: Quality control is governed by the Department of Agriculture but the best control is the consumer. Since the market is limited, high quality mushrooms sell the best.

New Zealand: Problems encountered in meeting quality control requirements (and control measures employed) are bacterial blotch ('Conquer'), *Verticillium* ('Benlate'), and insect and general fungus control (chlorinated water and 'Bravo').

Mexico: At present, mushroom cultivation (*Agaricus* and *Pleurotus*) in Mexico is not carried out in highly controlled environments and much of the work is done by hand. Therefore, mushroom quality is normally too low for export purposes. Only one *Agaricus* farm owned by a US company is producing high quality mushrooms for the US market. However, the recent free trade agreement between Mexico and the USA will force Mexican growers to make appropriate investments in order to produce high quality mushrooms.

Hungary: The quality control measures applied are different according to the various needs of commerce.

Poland: Quality control measures employed are those required for exporting *A. bisporus* to the EEC.

Japan: Quality control parameters of *L. edodes* include the size, thickness and shape of the fruit body. Some problems encountered with elongated stipes and the water content of the fruit body. Parameters for *F. velutipes* include the appearence of the fruit bodies, and the neatness of the fruit body bunches, and for *P. nameko* the size and colour of the fruit body. Problems encountered include the water content of the former and monokaryotization of mycelia of *P. nameko* during spawn running.

In view of the increasing range of raw materials used as substrates for mushroom cultivation, the potential for uptake of toxic substances from the substrate and transfer to the fruit body is an important consideration. We are not aware of any current guidelines which refer to this particular aspect of mushroom quality control. However, the modern mushroom grower is acutely aware of the importance of chemical and physical factors in compost preparation and the necessity to avoid contaminated substrates and water. Chemical and physical factors include the actual manipulation of the compost and its ingredients as well as the structure of the material. Mushroom growers make liberal use of the senses of sight, smell and touch, to determine the quality of the raw materials for compost, and to evaluate the progression of the composting process as well as the quality of the final compost material. The compost, which is prepared to well-documented commercial procedures, actually results from a number of complex physical, chemical and microbial processes that comprise "composting".

3. Mushroom Production Levels

During the period 1986 to 1989/90, worldwide mushroom production increased 72.5%, from 2,182 thousand tonnes in 1986 to 3,763 thousand tonnes in 1989/90. If 88.8 cents per pound, reported as the average price received by growers in the United States in 1990/91 (NASS, 1991), is used for the purpose of estimating the value of the total world mushroom crop, the figure for the 1989/90 financial year totalled US$7,485,058,500. The upward trend in world production of cultivated edible mushrooms is clearly indicated in Fig. 1. There is a particularly sharp increase in growth over the last five years. This trend is expected to continue due to advances both in our basic knowledge of mushroom biology and in the practical technology associated with mushroom cultivation.

3.1. *Agaricus*

Of all mushroom species currently under cultivation, production levels of *Agaricus* (*A. bisporus/bitorquis*), the 'button' mushroom are by far the highest. Since *A. bisporus* requires a temperature of 24°C for mycelial growth and 14-18°C for fructification, it is widely grown in temperate regions of the world. *Agaricus bitorquis* is closely related to *A. bisporus* and is sometimes referred to as the field mushroom. Some advantages of *A. bitorquis* include virus resistance, longer shelf life, resistance to bruising and, depending on the particular climate of the region, a higher optimum growth temeprature. Both spawn run and production temperatures are about 5°C higher than those required by *A. bisporus*, and *A. bitorquis* is more popular in warmer regions. The main disadvantage with higher temperature, however, is the tendency for greater pest development. In addition, the time to the first flush and the interval between flushes for some lines of *A. bitorquis* may be longer than those for *A. bisporus*. Furthermore, the inherent yield potential is lower for *A. bitorquis* than it is for *A. bisporus*.

World production of *Agaricus* in 1989/90 totalled 1,424,000 tonnes fresh weight. However, although a comparison of production between 1986 and 1989/90 reveals that all cultivated mushroom species increased during that period, the percentage increase for *Agaricus* was only 16.1% (197,000 tonnes) compared to 437.9% (740,000 tonnes) for *Pleurotus* spp. (oyster mushrooms). Thus, the percentage of total world production of *Agaricus* mushrooms decreased from 56.2% in 1986 to 37.8% in 1989/90 as a consequence of the increase in production of the other cultivated edible species (Figure 2). A comparison of the world production of *Agaricus* mushrooms in 1986 and 1989/90 is given in Table 10.

3.1.1. *Agaricus* production in the Americas

The United States remains the major producer of the *Agaricus* mushroom. Since 1966/67, the industry in that country has experienced an almost continuous expansion (Figure 3). In the 25 years up to 1990/91, output has increased from 74,825 tonnes to 340,058 tonnes, an average annual increase of 6.63% (Table 11).

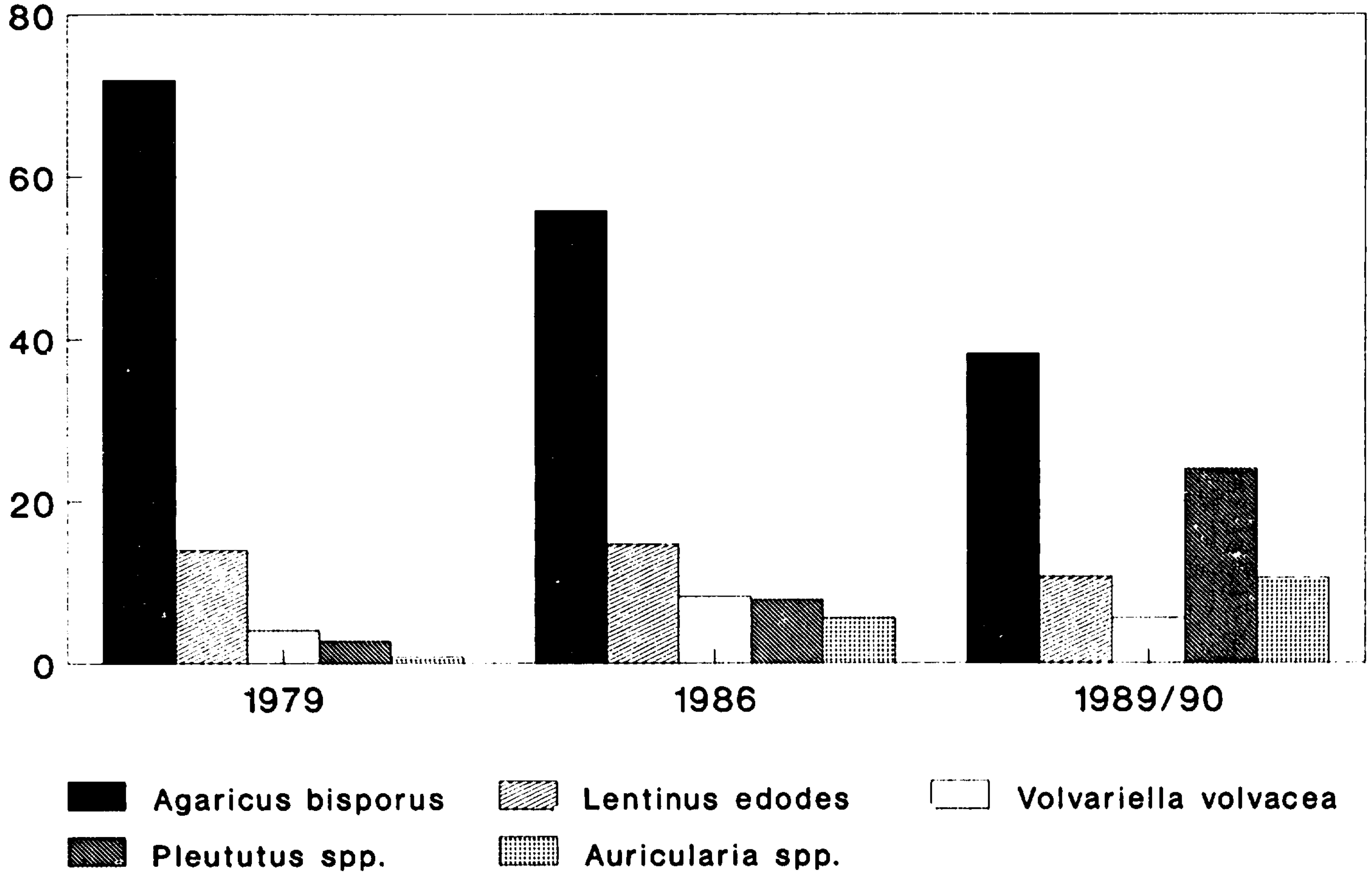

Fig. 2. Percentage of World Production of Five Major Mushrooms in 1979, 1986 and 1989/90

Table 10. Comparison of 1986 and 1989/90 world production of *Agaricus* mushrooms

(Unit: x 1000 tons)

	1986		1989/90		% increase
	Fresh wt.	%	Fresn Wt.	%	
U.S.A.	279	23.0	324	22.4	16.1
China	185	15.2	170	11.8	-8.1
France	165	13.6	200	13.8	21.2
Holland	115	9.5	140	9.7	21.7
England	95	7.8	118	8.2	24.2
Italy	75	6.2	100	6.9	33.3
Canada	51	4.2	51	3.5	0
Spain	45	3.7	50	3.4	11.1
W. Germany	38	3.1	43	3.0	13.2
Taiwan	35	2.9	30	2.1	-14.3
S. Korea	12	1.0	12	0.8	0
Belgium	16	1.3	20	1.4	25.0
Ireland	16	1.3	23	1.6	43.8
Australia	14	1.1	20	1.4	42.9
South Africa	11	0.9	11	0.8	0
Poland	4	0.3	9	0.6	125.0
Others	59	4.9	125	8.6	111.9
Total	1,215	100.0	1,446	100.0	19.0

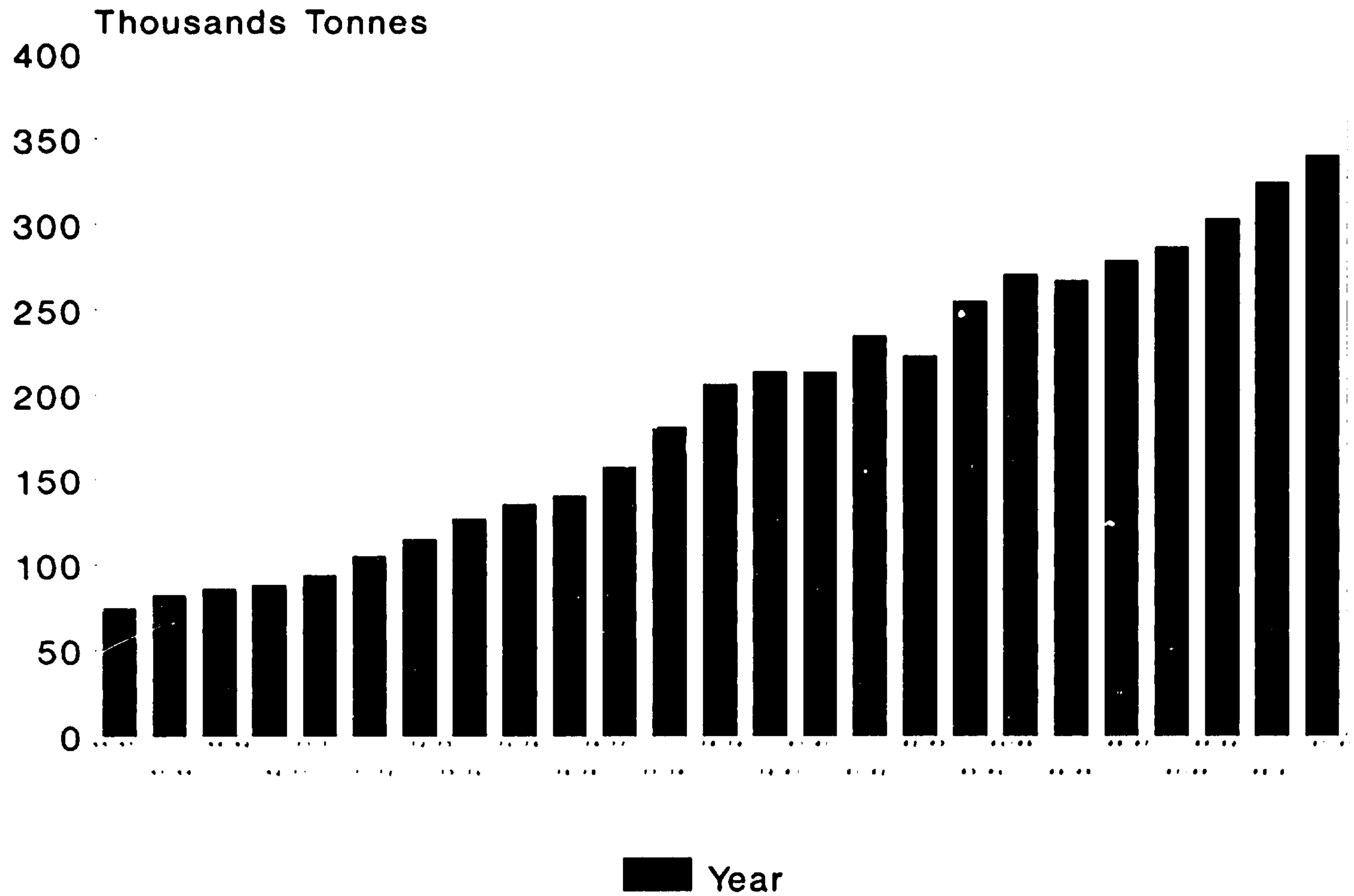

Fig. 3. Production of *Agaricus* Mushroom from 1966-1991 in USA

Table 11. Production of *Agaricus* Mushroom from 1966-1991 in USA.

Year	Total Production* (Tonnes)	% increase
1966-67	74,825	
1967-68	81,938	+9.51
1968-69	85,666	+4.55
1969-70	87,967	+2.69
1970-71	93,834	+6.67
1971-72	104,979	+11.88
1972-73	115,246	+9.78
1973-74	126,812	+10.04
1974-75	135,699	+7.01
1975-76	140,570	+3.59
1976-77	157,500	+12.04
1977-78	180,900	+14.86
1978-79	205,992	+13.87
1979-80	213,280	+3.54
1980-81	213,056	-0.11
1981-82	234,640	+10.13
1982-83	222,698	-5.09
1983-84	254,778	+14.41
1984-85	270,273	+6.08
1985-86	266,768	-1.30
1986-87	278,763	+4.50
1987-88	286,669	+2.84
1988-89	302,976	+5.69
1989-90	324,407	+7.07
1990-91	340,058	+4.82
Average:		+6.63

* Total production, fresh market and processing volume of sales estimates are primarily *Agaricus*, but also include specialty mushrooms through 1986-87. Statistics after 1986-87 are for *Agaricus* only.
Source: NASS (1991).

Canada is also a major producer of *Agaricus* mushrooms although production in 1986 and 1989/90 remains constant at 51,000 tonnes annually. The only other available data describing *Agaricus* (*A. bisporus*) production in this region apply to Mexico. Latest figures (1991) report an annual production of 10,332 tonnes valued at approximately US$27 million. Domestic consumption is 80% of this figure.

3.1.2. *Agaricus* production in Europe

In 1989/90, France, Holland, England and Italy produced 558,000 tonnes fresh weight of *Agaricus* mushrooms or 39.1% of the total world production. These four EC countries, ranked second, fourth, fifth and sixth among the world's producers, showed major increases (21.2-33.3%) in production of *Agaricus* over the period 1986-1989/90. Other major European *Agaricus*-producing countries are Spain, Germany, Belgium, Ireland, Poland and Hungary. Annual production both Spain and Germany in 1989/90 increased by 5,000 tonnes, or 11.1% and 13.2% respectively, over ouput in 1986. In Belgium and Ireland, annual production in 1989/90 showed an increase of 4,000 and 7,000 tonnes, respectively, over the 1986 figure and represented equivalent percentage increases of 25% and 43.8%. The most drastic increases in annual *Agaricus* production in recent years, albeit from a lower base level, has occurred in Hungary and Poland. In Hungary, annual production rose from 4,500 tonnes (fresh weight) in 1986 to 18,000 tonnes (valued at US$27 million) in 1990/91, an increase of 300%. Domestic consumption accounts for 80% of production. In Poland, annual production in 1986 was 4,000 tonnes, rising to 9,500 tonnes in 1990 but then falling back to 6,500 tonnes in 1991. The half-yearly output for 1992 is estimated to reach 3,700 tonnes. Domestic consumption of *Agaricus* in Poland rose from 20% in 1990 to 80% in 1991/92.

3.1.3. *Agaricus* production in Asia

Agaricus cultivation in China dates back to the 1930's when the mushroooms were sold in fresh state. However, since 1970, production of mushrooms including *Agaricus* has increased rapidly with the development of the canning industry. In 1975, the annual output of *Agaricus* was 28,000 tonnes (Figure 4). In 1986 this figure had reached 185,000 tonnes. However, *Agaricus* production in China, ranked second in 1986, has fallen back to 150,000 tonnes in 1990/91, a drop of 19.1% on the 1986 figure. China remains the world's largest *Agaricus* exporting country. In 1989, 76% of China's *Agaricus* production was exported. Production of *Agaricus* also decreased by 33.3% and 14.3%, corresponding to 0.7 and 0.8 thousand tonnes fresh weight, in South Korea and Taiwan, respectively. More recent figures from Korea reveal further falls in production, from 10,281 tonnes in 1990 to 8,992 tonnes in 1991. Over this period, there was an increase in domestic consumption from 61.2% to 79.9%, equivalent to approximately 900 tonnes fresh weight, and a fall in exports equivalent to just under 2,200 tonnes. The value of the total South Korean *Agaricus*

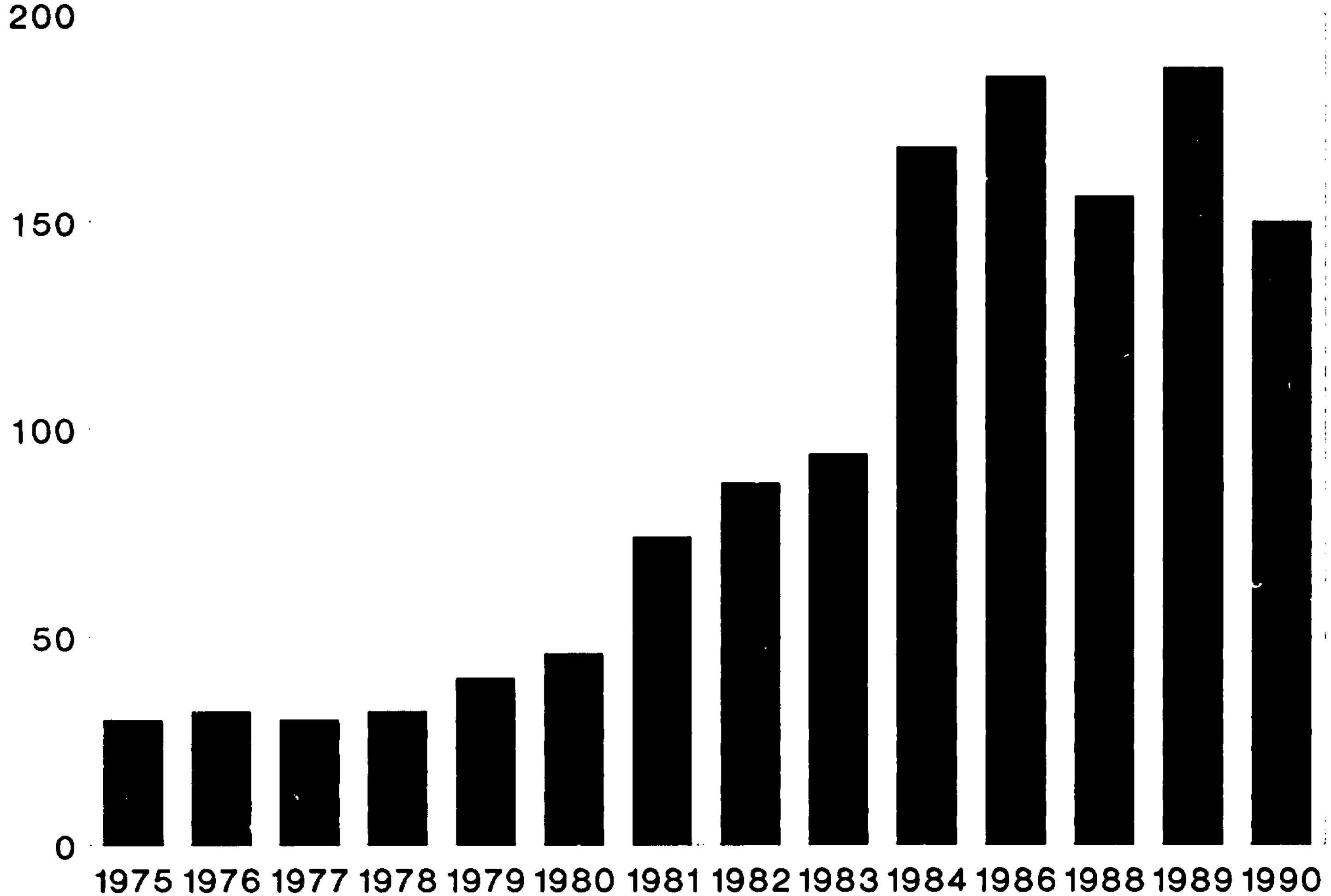

Fig. 4. The Annual Production of Agaricus Mushrooms in China. (x1000 tonnes)

Source: Wang & Wu (1988)

crop in 1990 and 1991 is estimated at US$20.56 million and US$17.98 million, respectively. *Agaricus* mushrooms are produced in other countries of Southeast Asia including Indonesia and Thailand. Total production figures fo Indonesia are not available. However, a privately-owned mushroom company, p: .rt of P.T. Mantrust in Jakarta, produces over 100 tonnes of *Agaricus* mushrooms daily. The entire production is processed in the company's own canneries for export, mainly to the United States. Based on a 1990/91 market study of the average wholesale price of US$1,400 per tonne for canned *Agaricus* mushrooms (Table 12, annual production is worth approximately US$50 million. According to the only data available to us, annual production of *Agaricus*(*A. bisporus*) in Thailand is put at only 250 tonnes and valued at US$290,000. Domestic consumption accounts for 80%. In 1991, about 6,000 tonnes of *Agaricus* mushrooms were produced in India, or 80-85% of total mushroom production. Highest production levels were recorded in Punjab (2,000 tonnes), Sonepat (near Delhi) (1,000 tonnes) and Uttar Pradesh (1,000 tonnes). Small quantities of *Agaricus* are also cultivated in Malaysia for the domestic markets only.

3.1.4. *Agaricus* production in Oceania

Annual production of *Agaricus* in Australia rose almost 43% over the period 1986 to 1989/90, from 14,000 to 20,000 tonnes. Total national production of fresh and processed *Agaricus* mushrooms in Australia in 1990/91 was 24,914 tonnes with a value of US$69.7 million based on an average price of US$2.75 per kg. Fresh production amounted to 22,704 tonnes (with a value of US$65.5 million based on an average price of US$2.88 per kg) and processed mushrooms to 2,210 tonnes (with a value of US$3.2 million based on average price of US$1.47 per kg). The total output represents a further 24.6% increase compared to 1989/90. Based on the information supplied by growers, it is anticipated that there will be a further 16% growth in production for the financial year 1991/92. The general increasing trend since 1975, and especially in the last 6-7 years, in Australian mushroom production and in the total value of the crop is shown in Figure 5. It is interesting to note that consumption of mushrooms *per capita* in Australia has increased from 1.17 kg (2.57 lbs) in 1983/84 to 2.11 kg (4.65 lbs) in 1990/91. The upward trend since 1974/75, and again especially over the past 5-6 years, in total sales of domestic and imported mushrooms versus total population in the country is seen in Figure 6. Latest data from New Zealand show an annual ouput of 6,900 tonnes valued at US$14.5 million. Ninety-three percent is consumed by the domestic market.

3.1.5. *Agaricus* production in Africa

Official production figures are available only from South Africa. Annual production levels in 1986 and in 1989/90 remained constant at 11,000 tonnes although output has recently risen to close on 20,000 tonnes with a wholesale value

Table 12. 1990/91 Market Study Average Wholesale Price

Mushrooms		**US$/tonne**
Agaricus	(Canned)	1,400
Auricularia	(Dried)	4,896
Lentinus	(Dried)	6,800
Volvariella	(")	2,100
Agaricus	(")	1,476
Pleurotus	(")	850
Agaricus	(Dried slices)	5,600
Boletus	(Dried)	9,300
Agaricus	(Brained)	1,200

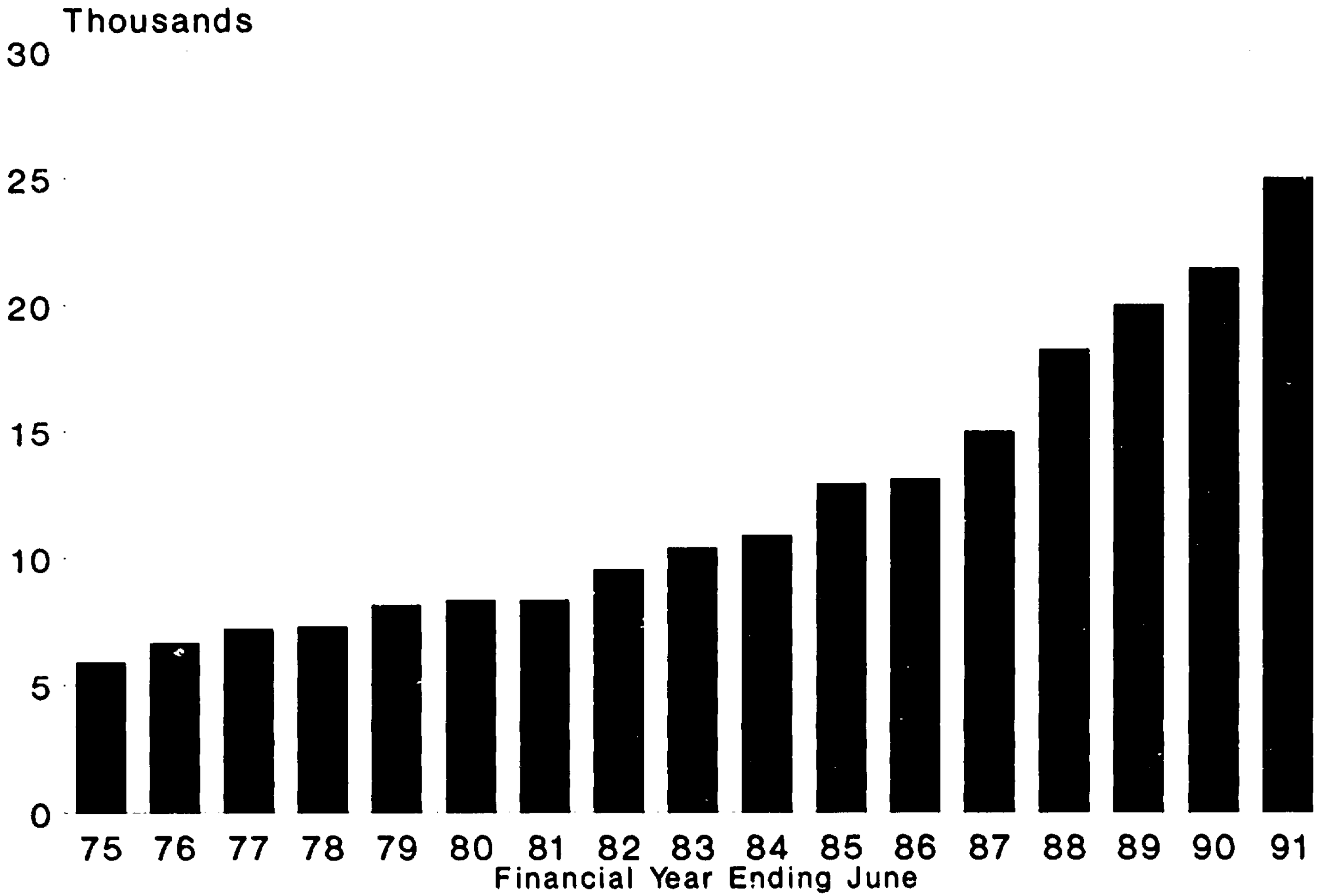

Fig. 5. Australia Mushroom Sales Financial Year Ending 1975 to 1991 (tonnes)

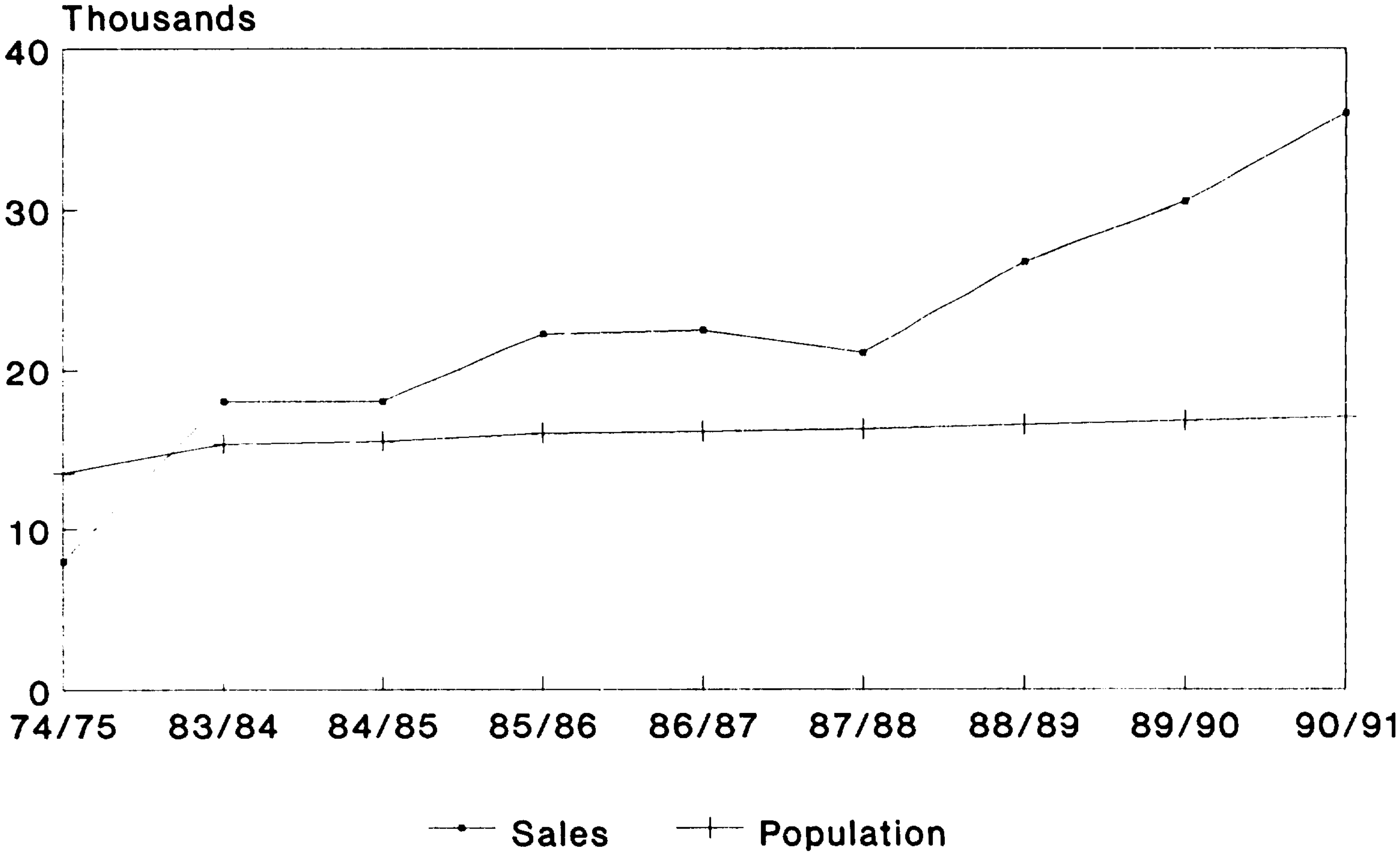

Fig. 6. Total Sales (Domestic & Imported Mushroom) VS Total Population - 1974/75 to 1990/91

of about US$100 million. About 20% of total production is canned of which a small proportion is exported; the domestic market absorbs most of the industry's output. *Agaricus bisporus* is the only species produced in significant quantity in the country. Annual production of *Agaricus* in Kenya currently stands at 375 tonnes. Domestic consumption accounts for the total crop, valued at US$1.1 million.

3.1.6. Consumption of *Agaricus* worldwide.

Agaricus is the most widely consumed mushroom although annual consumption *per capita* varies widely according to region. The mushroom is most popular in Europe, North America and Oceania and less so among the countries of Southeast Asia. Latest available figures (1986) reveal that highest annual *per capita* consumption of 2,900 gms occurs in Canada, closely followed by the Netherlands, Belgium, Germany, France, Switzerland and Denmark all of which have annual *per capita* consumption levels of 2,000 gms or above (Table 13). Annual *per capita* consumption in Japan in 1986 was only 100 gms. However, in this country, and in most other countries of southeast Asia, specialty mushrooms (see below) are far more popular.

The following so-called 'specialty' mushrooms have traditionally been cultivated and consumed in southeast Asia for many centuries and have recently acquired a greater importance in countries of Western Europe and in North America.

3.2. *Lentinus*

Cultivation of *Lentinus* (*Lentinula*) *edodes*, known by its common name of "shiang-gu" in China and "shiitake" in Japan, originated in China sometime during 1000 and 1100 A.D. cultivation practices were probably first developed in the mountainous region of China located in the three modern-day provinces of Llung-Chyan, Ching-Yuan and Jung-Ning. In nature, *L. edodes* grows on the dead wood of deciduous trees such as oak, beech, chestnut and hornbeam. It is a temperate mushroom whose fruiting temperature of <20°C even for a 'warm' strain precludes cultivation under ambient conditions in the lowlands of southeast Asia.

Lentinus edodes is one of the six most important cultivated edible mushrooms from the standpoint of total production. Worldwide production of *Lentinus* in 1986 totalled 314,000 tonnes fresh weight or 14.4% of total cultivated mushroom output, rising to 393,000 tonnes or 10.4% of total output in 1989/90. This represents a 25.2% increase in overall *Lentinus* production over the period. Althoug, until recently, cultivation of *Lentinus* has been almost an exclusive Asian industry, this mushroom has become more and more popular outside Asia and it is now being cultivated Europe, North America and Australia.

Table 13. World consumption of mushrooms (*Agaricus* species) per person 1986 (grams).

Country	**Fresh**	**Processed**	**Total**	**% Fresh**
Canada	1,600	1,300	2,900	55
Netherlands	2,300	400	2,700	85
Belgium	1,100	1,400	2,500	44
W. Germany	600	1,800	2,400	25
France	1,000	1,300	2,300	43
Switzerland	800	1,300	2,100	38
Denmark	1,000	1,000	2,000	50
Great Britain	1,700	100	1,500	94
Sweden	200	1,600	1,800	11
USA	800	800	1,600	50
Ireland	1,300	200	1,500	87
Australia	1,000	500	1,500	67
Austria	1,000	400	1,400	71
Spain	700	200	900	78
New Zealand	400	500	900	44
Italy	600	300	900	67
Norway	200	500	700	29
Finland	100	300	400	25
Japan	0	100	100	-

Source: ISMS Newsletter (1988).

3.2.1. *Lentinus* production in the Americas

Estimated production of *Lentinus edodes* in the United States was 700 tonnes in 1983 (0.3% of world production), falling to just 200 tonnes (0.1% of world production) in 1986. However, during period 1986-1989/90, production of *L. edodes* rose by 785% to 1,771 tonnes (Table 14). Production in Canada in 1983 was less than 100 tonnes but, according to the most recent estimates available, it rose to 150 tonnes in 1986. *L. edodes, L. boryanus*, and *L. lepideus* are also under experimental cultivation in Mexico.

3.2.2. *Lentinus* production in Europe

Although *Lentinus* is under commercial production in several European countries, production is not under official control and precise production figures are not available. In 1986, Holland and Finland produced 75 and 30 tonnes, respectively, with output in the former country rising over six-fold to 500 tonnes in 1987. However, this figure still represented only 0.1% of total world production for that year. Belgium was the only other European country reported to produce *Lentinus* in 1986. More recent estimates are available only for Hungary where annual production over the past 2-3 years amounted to just 5 tonnes valued at US$30,000. Of this total, 95% were exported. *Lentinus edodes* is cultivated in small quantities in Spain, and is under experimental cultivation in Poland.

3.2.3. *Lentinus* production in Asia

Since 1970, annual production of dried and fresh *Lentinus* in Japan, mainly from woodlogs, has continuously declined. Even so, until 1987, Japan was the largest producer of *Lentinus* mushroom accounting for 90% of world production in 1978 and 80% in 1984. In 1986, Japan produced 176,800 tonnes fresh weight or 56% of world production. By 1989/90, this figure had fallen to just under 160,000 tonnes or 48.5% of total production. Latest data reveal an annual output of 79,134 tonnes fresh and 11,238 tonnes of dry mushrooms valued at US$1.07 billion. Domestic consumption accounted for all the fresh mushroom output whereas 1,568 tonnes (14%) of the dry *Lentinus* were exported mainly to Hong Kong, Taiwan, Singapore, United States, Canada and Australia. Japanese imports of dried shiitake rose from 124 tonnes in 1986 to 2,201 tonnes in 1989/90, an increase of 1,675%. In the past few years, consumption of fresh *Lentinus* in Japan has been maintained within the narrow range-band of 49-53% of total mushroom consumption expressed as the fresh equivalent weight.

Since 1987, the major producer of the *Lentinus* mushroom has been China. In 1986, total output was 120,000 tonnes fresh weight rising 75% by 1989/90 to 210,000 tonnes. Since 1985, China has exported the mushroom to Japan to where

Table 14. Specialty Mushrooms: Number of Growers, Total Production, Volume of Sales, Price per Kg, and Value of Sales, July 1 - June 30* in USA.

Year and Variety	Growers	All Sales			
		Total Production	Volume of Sales	Price per Kg	Value of Sales
	Number	1,000 Kg		Dollars	1,000 Dollars
1988-89					
Shiitake		1,690	1,607	10.38	16,669
Oyster		686	653	5.99	3,920
Others		256	242	5.91	1,427
US	233	2,632	2,502	8.79	22,016
1989-90					
Shiitake		1,800	1,703	9.76	16,616
Oyster		759	719	5.75	4,142
Others		290	265	6.37	1,689
US	215	2,849	2,687	8.35	22,447
1990-91					
Shiitake		1,841	1,770	9.19	16,265
Oyster		695	677	5.88	3,979
Others		351	306	6.92	2,115
US	288	2,887	2,753	8.11	22,359

* Specialty mushroom estimates represent growers who have at least 200 natural wood logs in production or commercial indoor growing area.

Source: NASS (1991).

20% of the Chinese production in 1989 was exported. However, the mushroom produced in China is still inferior in quality compared to Japanese product.

L. edodes production in South Korea during the period 1986 to 1989/90 rose 48% from 1,034 to 1,530 tonnes fresh weight. Latest output data reveal a continuing increase in production from 1,648 to 1,761 tonnes dry weight, valued at US$ 36.29 and US$51.32 million, in 1990 and 1991, respectively. Domestic demand for the mushroom has also increased, accounting for 35.9% and 50.9% of total production in 1990 and 1991, respectively.

Small-scale cultivation of *Lentinus* commenced in Thailand in 1977, in the Philippines in 1979, Singapore in 1980, and in Malaysia in 1983. Production in Malaysia is solely for domestic consumption. Current *L. edodes* production in Thailand is put at about 150 tonnes fresh weight and valued at US$470,600.

3.2.4. *Lentinus* production in Oceania

The only *L. edodes* production figures for this region relate to New Zealand where the annual production over the past 2-3 years has been estimated at 11 tonnes fresh weight and valued at US$150,000. Domestic consumption accounts for all the mushrooms produced.

3.2.5. *Lentinus* production in Africa

There is limited, but rapidly expanding, cultivation of *L. edodes* in South Africa. Shiitake is also cultivated experimentally in Kenya.

3.3. *Pleurotus*

Pleurotus is one of the choice edible mushrooms which has gained importance during the last decade. It is cultivated in the tropics and in many countries in the sub-tropical and temperate zones. Several species are now available for cultivation including *P. ostreatus* (oyster mushroom), *P. cystidiosus* (abalone mushroom), *P. florida* (probably a variant of *P. ostreatus*) (white oyster), *P. sajor-caju* (grey oyster), *P. flabellatus* (pink oyster), *P. sapidus*, *P. eryngii*, *P. cornucopiae* and *P. columbinus*. *Pleurotus* spp. have a high saprophytic colonizing ability and can grow on virtually any agricultural waste substrate.

Pleurotus now ranks the second most important cultivated edible mushroom in terms of overall world production. Total output in 1989/90 was 909,000 tonnes fresh weight, increasing by 437.9% from just 169,000 tonnes in 1986. This figure represents 24.2% of the world's total production of all types of cultivated mushrooms.

3.3.1. *Pleurotus* production in the Americas

Pleurotus spp have recently become popular as a 'specialty' mushroom in the United States and, during the period 1986 to 1989/90, production increased by 256% from 200 tonnes fresh weight in 1986 to 713 tonnes in 1989/90. *Pleurotus* spp are also cultivated solely for domestic consumption in Mexico. Current output is estimated at 360 tonnes and valued at US$1.17 million.

3.3.2. *Pleurotus* production in Europe

The top producers of *Pleurotus* mushrooms in Europe are France and Italy. Hungary also produces 2,500 tonnes (valued at US$6.25 million) annually of Hungarian hybrids, 60% of which are exported.

3.3.3. *Pleurotus* production in Asia

China produces by far the most *Pleurotus* mushrooms with annual output in 1989/90 estimated at 800,000 tonnes fresh weight. Production has increased rapidly in the past 5 years and this figure represents a 7-fold increase over output recorded in 1986. This mushroom is grown mainly for domestic consumption with a small proportion (4.4%) exported, mainly to Japan and Hong Kong.

Latest annual production figures from Japan for *P. ostreatus* show an output of 33,475 tonnes, all for domestic consumption, valued at US$196 million. *P. abalonus* (*P. cystidiosus*) is also cultivated commercially in this country.

Various species of *Pleurotus* mushrooms are cultivated commercially in Thailand including *P. ostreatus, P. eous, P. cystidiosus* and *P. sajor-caju* although actual production figures are not available at this time.

Annual production of *P. ostreatus* and *P. sajor-caju* in S. Korea increased from 43,732 tonnes in 1990 to 51,782 tonnes in 1991, all for domestic consumption. Crop values totalled US$87.5 and US$103.6 million, respectively.

Pleurotus mushrooms are also cultivated in India where production in 1991 is estimated at 600 tonnes, and in Malaysia where small quantities of *Pleurotus* (*P. cystidiosus, P. ostreatus*) are cultivated solely for domestic consumption.

3.3.4. *Pleurotus* production in Africa

South Africa has recently started to cultivate different species of *Pleurotus* and production currently stands at ca 50 tonnes per annum. Kenya is also cultivating *Pleurotus* for domestic consumption only with annual production currently standing at 12 tonnes and valued at US$36,000.

3.4. *Volvariella*

Volvariella volvacea, commonly know as the straw or Chinese mushroom, is the most popular mushroom in Southeast Asia. Just as *Agaricus* means 'mushroom' in Western countries, to the people of Southeast Asia countries, 'mushroom' is understood to be the straw mushroom. Cultivation probably began in China about 300 years ago but it was only around 1932-35 that the mushroom was introduced into the Philippines, Malaysia and other Southeast Asian countries by overseas Chinese. Since then, its cultivation has spread to other countries outside the region where tropical conditions favourable to growth exist. Several species of *Volvariella* have reportedly been grown for food. *V. bombycina* and *V. diplasia* have been cultivated in India although the validity of *V. diplasia* is doubtful since it differs from *V. volvacea* only in colour; the former is white while *V. volvacea* is blackish. *V. bombycina*, on the other hand, differs from *V. volvacea* in terms of habitat as well as colour. World production in 1986 totalled 178,000 tonnes fresh weight and increased to 207,000 tonnes by 1989/90, a rise of 16.3%. China is the greatest producer of *Volvariella*; annual production in 1989/90 was 110,000 tonnes fresh weight, up from 100,000 tonnes in 1986. Small scale cultivations of *Volvariella* are also found in Thailand, where total output in 1988 was estimated to be 6,500 tonnes, in India with an annual production in 1991 of 400 tonnes, and in Malaysia.

3.5. *Auricularia*

Species of *Auricularia* are characterized by gelatinous fruiting bodies. In China, they are known as "Mu Erh", which means woody ear or ear of the tree. Their English name is wood ear fungus, because of the shape of the fruiting body.

The earliest record of *Auricularia* dates back to 200-300 B.C. when several kinds growing in Keinwei, China, were gathered for food in the rainy season and dried in the sun. The mushroom has been pickled for food and used as a medicine for the treatment of piles, sore throat and anaemia. Today, the cartilaginous basidiocarps are popular not only among Chinese but also in many other countries of Southeast Asia. Unfortunately, perhaps because of their physical texture and colour, these black mushrooms do not seem to attract Western consumers except for use in soups. However, on the basis of their nutritional value and delicacy, it seems likely that they will ultimately gain worldwide acceptability.

Two main species are now cultivated commercially: *A. auricula* and *A. polytricha*. *A. auricula* is thin and light-coloured and is generally preferred to the thicker, larger and darker, more tropical species *A. polytricha* which is commonly grown in Taiwan.

World production of *Auricularia* spp. in 1989/90 totalled 400,000 tonnes fresh weight, increasing from 119,000 tonnes in 1986, a rise of 236.1%. The highest production of *Auricularia* by far occurs in China where corresponding figures for 1986 and 1989/90 were 80,000 tonnes fresh weight. In terms of total production, this mushroom ranks second in China after *Pleurotus*, and is grown mainly for domestic consumption with only 4% exported, mainly to Japan and Hong Kong. Cultivation of *Auricularia* also appears weil accepted in Thailand where production constituted 3.3% of the world's total in 1986. Ninety per cent of the dried production in Taiwan is exported, mainly to Hong Kong, Japan and the United States. *A. auricula* is also cultivated commercially in Japan although production fell from 205 tonnes in 1986 to 153 tonnes in 1989/90. However, imports of this mushroom increased 22% in 1986 compared to 1989/90 from 16,299 tonnes to 19,875 tonnes.

3.6. *Flammulina velutipes*

Flammulina velutipes, also called the 'winter mushroom', is grown at lower temperatures and its commercial cultivation has developed rapidly in Southeast Asia in recent years to the point where the mushroom ranked sixth in total worldwide production in 1986. Due to its taste, texture and pleasing appearence, it is readily accepted in Western countries.

World production of *Flammulina velutipes* in 1989/90 totalled 143,000 tonnes fresh weight, a rise of 43% on the 100,000 tonnes recorded in 1986. Latest available annual production figure from Japan for *F. velutipes* shows an output of 92,255 tonnes, all for domestic consumption, valued at US$408 million. Production of this mushroom in Japan has increased steadily from 74,378 tonnes fresh weight in 1986 and 83,200 tonnes in 1989/90. Annual production in China has also risen sharply in recent times. The period from 1986 to 1989/90 saw a 300% increase from 10,000 tonnes to 40,000 tonnes. Although there was a massive increase in the production of *Flammulina* in South Korea during the period 1986 to 1989/90 (from 16 to 121 tonnes fresh weight), updated figures show that annual production of this mushroom in S. Korea fell from 404 tonnes in 1990 to 345 tonnes in 1991. Domestic consumption accounted for the total output. Crop values totalled US$2.02 and US$1.73 million, respectively.

3.7. *Tremella fuciformis*

T. fuciformis, commonly known as the white jelly fungus or the "silver ear" mushroom, has been used as a special luxury food itme in China for many decades.

World production of *Tremella fuciformis* in 1989/90 totalled 105,000 tonnes fresh weight, a rise of 162.5% on the 40,000 tonnes recorded in 1986. China accounted for virtually all of this with 100,000 tonnes. *Tremella* is also cultivated commercially in Japan although no production figures are available.

3.8. *Pholiota nameko*

World production of *Pholiota nameko*, "Nameko" or Viscid mushroom, rose from 25,000 tonnes fresh weight in 1986 to 53,000 tonnes in 1989/90, an increase of 112%. Chian is again the major producer with an estimated output in 1989/90 of 32,000 tonnes, an increase of 3,900% over the 800 tonnes for 1986. Most of the remainder are grown in Japan where latest available production figures for *P. nameko* show an annual output of 22,083 tonnes, all for domestic consumption, valued at US$116 million.

3.9. *Hericium erinaceus*

H. erinaceus, sometimes referred to as the "Monkey head" mushroom for the "Hedgehog fungus", is cultivated in China where output rose from 50,000 tonnes fresh weight in 1986 to 90,000 tonnes in 1989/90.

3.10. *Hypsizigus marmoreus* (*Lyophyllum ulmarium*)

H. marmoreus, or Shimeji, is cultivated in Japan where production increased almost 95% over the period 1986 to 1989/90 from 11,493 tonnes to 22,349 tonnes fresh weight. Latest available production figures from Japan for this mushroom reveal an annual output of 29,757 tonnes, all for the domestic market, valued at approx. US$200 million.

3.11. *Grifola frondosa*

World production of *G. frondosa*, the "sitting hen" mushroom, was estimated at 7,000 tonnes fresh weight in 1989/90. The mushroom is cultivated commercially in Japan, where production rose from 2,203 tonnes in 1986 to 6,167 tonnes in 1989/90, and in China where the only figures available put production at 200 tonnes in 1989/90.

3.12. *Ganoderma*

Countries where *Ganoderm lucidum* is cultivated include South Korea, China and Malaysia. Annual production of *G. lucidum* in S. Korea fell from 4,126 tonnes dry weight in 1990 to 1,024 tonnes in 1991; domestic markets accounted for the total output. Crop values totalled US$154.7 and US$38.4 million, respectively.

3.13. *Tricholoma matsutake*

Japan and South Korea are the leading producers of *T. matsutake*. Annual production in Japan increased from 199 tonnes in 1986 to 457 tonnes fresh weight in 1989/90, a rise of almost 130%. Japanese imports of this mushroom also increased by 125.5% over the same period, from 980 to 2,210 tonnes. After increasing over 200% from the 1986 figure of 311 tonnes, annual production of *T. matsutake* in S. Korea fell from 945 tonnes in 1990 to 324 tonnes in 1991; crop values fell accordingly from US$60.36 to US$55.72 million, respectively. Exports accounted for 88.4% and 99.1% of production in 1990 and 1991, respectively.

3.14. *Dictyophora indusiata*

This mushroom is cultivated commercially in China where production in 1989/90 was estimated at 40 tonnes.

3.15. *Agrocybe cylindracea*

This mushroom is now cultivated commercially in Japan although no official production figures are available.

4. Cultivation Methods and Facilities

Mushroom cultivation can be a relatively primitive type of farming , or a highly sophisticated agricultural activity requiring a sizeable capital outlay for mechanized equipment. The straw mushroom, *Volvariella volvacea*, is commonly grown in Southeast Asian countries on small, family-type farms. In contrast, cultivation of the *Agaricus* mushroom may be highly industrialized with a few farms producing a disproportionally large percentage of a country's output as is the case in any Western nations.

Although simple in concept, there are various intricacies associated with the process of mushroom cultivation which must be understood for the enterprise to be successful. In every case, the ultimate aim is to obtain the maximum yield from a given surface area per period of time by the use of high yielding strains, by shortening the cropping period, or by increasing the number of high yielding flushes. To achieve maximum yield requires an understanding of substrate materials and their preparation, appropriate control of physical, chemical and biological parameters (e.g. moisture content, pH, temperature, competitive microflora), and proper management of mushroom beds, including mushroom pest and disease control.

The major phases of mushroom cultivation are shown in Table 15 and are:

Table 15. Major Phases of Mushroom Cultivation

Major Phases	Main points to 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 sp. (b) mating with compatible isolates for heterothallic species Mixed culture Preservation
↓	
Development of spawn	Substrate Vigorous growth Free of contamination Avoid use of senescent and degenerate spawn Good survival of storage
↓ Spawning ↓	
Spawn running → Fructification (mushroom development)	Establishment of mycelium Environmental requirements (a) temperature (b) light (c) aeration (O_2, CO_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).

(a) selection of an acceptable mushroom, (b) requirement for the selection of a fruiting culture, (c) development of spawn, (d) preparation of compost, (e) mycelial (spawn) running, and (f) mushroom development.

(a) before any decision to cultivate a particular mushroom is made, it is important to determine if that species possesses organoleptic qualities acceptable (either traditionally or through commercial promotion) to the indigenous population and/or an export market, if suitable substrates for cultivation are plentiful, and if environmental requirements for growth and fruiting can be met without excessively costly systems of mechanical control. There is considerable variation among edible mushroom species in the temperatures suitable for vegetative growth (spawn running or mycelial running) and fruit body development.

(b) a "fruiting culture" is defined as a culture with the genetic capacity to form fruiting bodies under suitable growth conditions. The stock culture which is selected should be acceptable in terms of yield, flavour, texture, fruiting time, etc.

(c) a medium through which the mycelium of a fruiting culture has grown and which serves as the inoculum or "seed" for the substrate in mushroom cultivation is called the mushroom spawn. Failure to achieve a satisfactory harvest may often be traced to unsatisfactory spawn. The potential of the spawn is ultimately set by the genetic constitution of the fruiting culture used in its manufacture. Ideal environmental conditons and management cannot overcome the limitations of a genetically inferior stock used for spawn production. Although the mushroom stock is of prime importance in determining the merits of a spawn, consideration must also be given to the nature of the substrate material used in spawn manufacture. This influences the rate of vegetative growth in the spawn substrate and also the rate of mycelial growth and filling of the beds following inoculation (spawn running). Some of the substrates used in spawn production include various grains, (rye, wheat, sorghum), rice straw cuttings, cotton waste, rice hulls and cotton seed hulls. Availability and cost of the spawn substrate are also important . Some other obvious features of a good spawn include freedom from contamination, vigorous growth, and good survival in storage.

(d) while a sterile substrate free from all competitive microorganisms is the ideal medium for cultivating edible mushrooms, systems ivolving such strict hygiene are generally too costly and impractical to operate on a large scale. However, substrates for cultivating edible mushrooms normally require varying degrees of pretreatment in order to promote growth of the mushroom mycelium to the practical exclusion of other microorganisms. To accomplish this, certain chemical and physical qualities must be built into the substrate. Some edible species (*Lentinus edodes, Pholiota, Tremella*) can utilise lignocellulosic wastes, e.g. wood, with little or no pretreatment, other (*Volvariella volvacea, Pleurotus* spp) can colonize plant material, e.g. cereal straws, after some composting, physical and/or chemical pretreatment, while *Agaricus bisporus* requires a lengthy controlled composting of cereal straws with manures or other nitrogen rich additives. For *Flammulina* and some *Pleurotus* spp., sterile substrates are prepared by autoclaving sawdust/rice bran mixtures or straw. The substrate must be rich in essential nutrients in forms which are readily available to the mushroom, and be free of toxic substances which inhibit growth of the spawn or may be taken up (and perhaps concentrated) by the fruit body. Moisture content, pH and good gaseous exchange between the substrate and the surrounding environment are important physical factors to consider.

In practice, composting is accomplished by piling up the substrates for a period during which various changes take place so that the composted susbtrate is quite different from the starting material. A substrate consisting of agricultural and chemical materials other than animal manure, after composting, is called a "synthetic compost". Synthetic composts have been devised using numerous formulations of just about every type of agricultural waste product and residue. All these materials consist mainly of cellulose, hemicellulose and lignin. Some bacteria readily attack the polysaccharide components cellulose and hemicellulose and, under suitable conditions, bring about their decomposition. However, the lignin component is more resistant to bacterial attack. The more-readily degraded carbohydrates serve as a nutrient source for bacteria and fungi and levels diminish after composting as a consequence of the metabolic activities of the microorganisms in the compost. This makes the substrate less favourable for growth of these potential competitors to the growth of mushrooms. The metabolic activities of the microorganisms also have other effects: (a) conversion of simple nitrogenous materials, such as nitrates and ammonia into complex proteins, thereby increasing the protein content of the compost required for later growth of the mushroom mycelium, and (b) a drop in pH. Research on mushroom composts has been extensively reviewed (Nair, 1991).

Many of the princip..s of this complicated process of composting are recognized and general guidelines are available for the grower. In practice, modifications are necessary to meet the various local conditions encountered. These may be necessitated by availability of raw materials, the microflora in the composting area and, especially important, the species of mushroom to be cultivated. The highly industrialized technology developed for the cultivation of *Agaricus* cannot be followed unmodified for the commercial production of the straw mushroom, *Volvariella volvacea*.

(e) following composting, the substrate is placed in beds where it is generally pasteurized by steam to kill off potential competitive microorganisms. After the compost has cooled, the spawn may be broadcast over the bed surface and then pressed down firmly againist the substrate to ensure good contact, or inserted 2-2.5 cm deep into the substrate. Spawn running (mycelial running) is the phase during which mycelium grows from the spawn and permeates the substrate. Good mycelial growth is essential for mushroom production and will depend on proper maintenance of the beds and mushroom house in terms of temperature, moisture content, humidity and aeration.

(f) under suitable environmental conditions, which may differ from those adopted for spawn running, primordia formation occurs followed by the production of fruiting bodies. The appearence of mushrooms normally occurs in rhythmic cycles called "flushes". Harvesting is carried out at different maturation stages depending upon the species and upon consumer preference and market value. Suitable temperature, humidity, and ventilation controls must be maintained during the cropping period since these factors will affect the number of flushes and the total yield obtained.

Cultivation conditions used for different mushroom species in different countries are detailed in the following section.

4.1. *Agaricus*

Composting is prepared to well-documented commercial procedures. In Phase I of the process, locally-available raw materials are built into piles which are periodically turned, watered, and formed. Initial breakdown of the raw ingredients by microorganisms takes place in Phase I. This phase is usually complete within 9-12 days, when the materials have become pilable, dark brown in colour and capable of holding water; there is normally a strong smell of ammonia. Phase II is pasteurization, when undesirable organisms are removed from the compost. This is carried out in a steaming room where the air temperature is held at 60°C for at least 2 to 4 hours. The temperature is then lowered to 50°C for 8 to 12 hours, for conditioning to take place. CO_2 is maintained at 1.5 to 2% and the ammonia level drops below 10ppm. Following Phase II composting, the substrate is cooled to 30°C for *A. bitorquis* and to 25°C for *A. bisporus*.

4.1.1. *Agaricus* cultivation in China

Traditional methods for mushroom cultivation in China were largely dependent on the natural climate. In some regions, such as Fujien and Kwangtung, the harvesting period extended from December to April of the following year. In other places, including Shanghai, Zhejiang, Jiangsu and Sichuan, mushrooms are designated according to the cropping season and are divided into autumn mushrooms (harvested from October to December) and spring mushrooms (from March to May). Traditional composting was done outdoors over a period of one month with five or six turnings each at intervals of 5-6 days. After outdoor composting, the compost was used to fill the shelf beds. After fumigating with formalin, the compost was ready for spawning. Raw materials used for compost production are determined largely by local availability. In China, the main materials are dried cattle manure and rice straw, sometimes mixed with barley and/or wheat straw. Auditives normally include urea, ammonium sulphate, calcium super-phosphate and gypsum. The ratio of dried cattle manure and rice straw used in compost preparation varies from 5:5, 6:4, 4:6 (Wang & Wu, 1988).

The average unit yield of mushrooms in Chian was formerly very low (approx. 4.5 kilograms per square metre) due to three main reasons:

(i) Growing rooms were poorly constructed. Heat insulation was unsatisfactory and both the air and bed temperatures could not be controlled adequately.
(ii) Use of poor quality or inappropriate spawn.
(iii) Use of primitive methods for preparation of compost in which no Phase II (controlled heating) step was included.

Of these, inferior compost quality was considered to be the primary reason for the low yields. Therefore, Unit 1978, a new Phase II technology already used for compost preparation in France, The Netherlands and the United States, was introduced by Professor S.T. Chang of the Chinese University of Hong Kong and scientific consultant for SRIFFI. Since its introduction, the new technology has spread throughout China and has resulted in a 20-40% increase in unit area yield compared with the old composting, Phase I is shortened to 12-18 days with three to four turnings at intervals of three of four days each. After outdoor composting, the compost is rapidly distributed on the shelf-beds or structured into a 'tunnel'. Phase II composting consists of two successive stages, i.e. pasteurization and of the compost to 60-62 °C by the introduction of live steam or by the use of coal or charcoal heating furnaces. The compost is kept at this temperature for 2 to 4 hours while the air temperature is maintained at a higher level. The temperature is then reduced to, and maintained at, 50-60 °C by the admission of a regulated amount of fresh air and this conditioning step carried out over a period of 4 to 6 days. The compost after Phase II is colonized by a greyish white growth of actinomycetes and *Humicola* mycelium can be seen on the surface of the beds. The colour of the compost turns dark brown and the odour of ammonia can be detected. The compost becomes soft but retains a certain degree of elasticity. After cooling to 25 °C, the compost is ready for spawning.

4.1.2. *Agaricus* cultivation in Indonesia

The largest, privately-owned mushroom farm in the world is located in the mountains of the Dieng Djaya area, northwest of the city of Yokjakarta in central Java (Vedder, 1991). Two thousand mushroom houses for *Agaricus* cultivation are built in three locations, all within a couple of miles distance, at an altitude of approximately 2,000m on the Dieng plateau. At these altitudes, the temperature range (10-20°C) is suitable for *Agaricus* cultivation even though the overall climate is tropical. However, the region has a high annual rainfall (approx. 4m) and high humidity is often a probem to the grower. Also, considerable excavating has been necessary to proivide sufficient level ground for the growing houses. The major disadvantage is the requirement to transport most of the materials (i.e. compost, casing, spawn) by truck to the growing area and the mushrooms back down to the cannery. This part of the operation requires 150 trucks per day to drive along roads which are narrow and winding, sometimes with an elevation up to 15%. Over 2,000 workers also have to pick up in the early morning from surrounding villages and taken back to their homes at the end of the working day. Furthermore, all the facility's electricity has to be generated *in situ*. However, in addition to the obvious benefits of a high value product, the spent compost serves to improve the quality of the volcanic soil of the region for growing green crops such as potatoes, tobacco, cabbage, corn, etc. Since 1985, the mother company has also introduced a satellite system whereby young farmers can apply for a unit of 3 growing rooms of approx. $80m^2$ each and a simple 3-room house. A number of young farmers thus became self-employed mushroom growers and obtained their practical training at a specially built training and experimental facility. These growers receive the ready-made blocks of compost in plastic bags from the mother unit, as well as the pasteurized casing soil. The mushrooms produced are taken to the company's cannery for processing and the contract is set up in such a way that after 7 years the grower owns the unit but still obtains the composting, casing etc from, and delivers the crop to, the company.

In 1988, the company built another farmers-complex at Lake Merdada, where 320 families have their own mushroom farm. The 960 growing rooms are initially filled by a contractor after which the grower takes over full responsibility for casing, watering, etc. The harvesting is also done by the grower, usually with the help of his wife. Although the farms are small, with a production capacity of approximately 20,000 kg per year, the grower's income is at least 3 times greater than would be realised from paid employment. The company's latest development is at Sumber where another 800 young farmers have units.

The mother company itself presently operates 2 large blocks of growing houses. The oldest, built in 1980 at Karangbakal, has 340 growing rooms of $250m^2$ each, while a further 300 sheds, with a growing surface of $600m^2$ each, are located at Pasurenan. Total daily production is approx. 100 tonnes fresh mushrooms daily.

The Dieng Djaya company employs 10,000 people including those involved in diversification projects such as asparagus and baby corn cultivation.

Compost is prepared at the Karangbakal farm, with production capacity of 300 tonnes of compost per day, and at a newer facility, with a covered area of about

100,000m² and a daily production capacity of 1,200 tonnes, situated at a lower altitude about 25 km from the growing area. The main ingredient is sugarcane bagasse together with chicken manure, fishmeal, kapok seed meal and gypsum. The compost is pasteurized using the tunnel system and, after 6 days of standard Phase II treatment, the compost is spawned and pressed into blocks by hand prioy to wrapping in perforated plastic foil. Currently, the main problem with composting is attainment of the required level of selectivity such that, after spawning, some spots with competitor-molds and red-peper mites are often found.

The company also has its own spawn plant with a daily production of 12,000 litres of *Agaricus* spawn on sorghum grain and 5,000 litres *Volvariella* and *Lentinus* spawn. The strains are mainly selections produced from commercially available hybrid strains and tested for local conditions in special test-training facilities.

Picking is all done by hand by over 2,000 women employed by company as well as by the satellite growers and their wives. To ensure the highest possible quality and to improve efficiency, the company operates on-going training programmes for harvesters. Average yields of 12 kg trimmed mushrooms per m^2 in 32 picking days are not that high compared with the better farms in Europe and the U.S. Mushrooms are quickly delivered to the canneries and the normal timespan between harvesting and labelling the can or jar is only 3-4 hours. The company's biggest buyer is the American company Green Giant which sets high quality standards which are maintained by a staff of quality assurance people.

In part of their test and training facilities, the company also produces 1.5 tonnes of *Lentinus* mushrooms weekly on a sterilized substrate of bagasse, sawdust and rice hulls. The main part of this product is dried due to the limited market for fresh shiitake mushrooms in Indonesia. Straw mushrooms (*Volvariella*) are grown in the more tropical regions (30-35°C, high humidity) in the plains around Yokjakarta. In 360 growing sheds in three locations, the Dieng Djaya company produces approx. 40 tonnes per day of *Volvariella* using pasteurized straw and cotton waste as a growing medium. Almost 2,500 women are picking and peeling the mushrooms which are processed immediately in a special cannery for export in glass fars mainly to the U.S., and to Asian and European countries.

4.1.3. *Agaricus* cultivation in India

Dhar (1992) reported that cultivation of the white button mushroom *Agaricus bisporus* in India is of very recent origin, having been initiated during the 1960's in Solan, Himadalpradesh with encouraging results. At first, the entire production was canned for export but as production increased, domestic consumption of fresh mushrooms occurred in those areas where *Agaricus* was cultivated. Now both medium and large size mushroom cultivation units for *Agaricus* have developed in many areas of India. These farms have a daily output of 300-1,000 kg of fresh mushrooms

Initially, mushroom cultivation in India was confined to the hill regions of the country. *Agaricus*, and also *Pleurotus* (oyster) mushrooms are grown regularly in these areas and the larger commercial units are located there. However, due to easier and cheaper availability of new substrate materials and a ready access to markets, mushroom production has moved into the plains. There are now large concentrates of seasonal production around Delhi supported by spawn laboratories. In the peninsula areas, the higher temperatures encourage the year-round production of *Pleurotus* and *Volvariella* (paddy straw mushroom).

In most of the seasonal growing areas, compost is still prepared by the traditional long method (20-30 days) without any Phase II (pasteurization). Average yields range from 60-80 kg/tonne compost in 6-8 weeks cropping period. Medium and large cultivation operations are able to adopt a short method of composting and crop under environmentally-controlled conditions. These more modern production methods yield 150-160 kg/tonne compost. The lower yields obtained in long composting operations are compensated for by low production costs. Wheat is the chief new substrate material although rice straw is being used successfully in some areas. Horse manure is also used depending on availability.

In 1991, total production of all types of mushrooms in India touched 7,000 tonnes. Highest production levels were recorded in Punjab (2,000 tonnes), Sonepat (near Delhi) (1,000 tonnes) and Uttar Pradesh (1,000 tonnes). About 80-85% of mushrooms produced in India are *Agaricus* and the remainder are oyster and paddy straw mushrooms. Therefore, in 1991, mushroom cultivation facilities in the country realised about 6,000 tonnes of white button mushrooms, plus 600 and 400 tonnes of *Pleurotus* and *Volvariella volvacea*, respectively.

4.1.4. *Agaricus* cultivation in other countries

Mexico: The mushroom is grown on composted and pasteurized substrates consisting of wheat straw, horse and chicken manure, cotton seed meal and gypsum. Both and plastic bag and tray cultivation procedures are adopted on about an equal basis. Temperature range: 23-28°C.

Hungary: *Agaricus bisporus* is grown at 15-19°C in beds or bags containing pasteurized straw and horse manure compost.

India: "Long" composting methods (no Phase II pasteurization) are still adopted for *Agaricus* cultivation by some seasonal farms. Average yields range from 60-80 kg/tonne compost in 6-8 weeks cropping period. More modern production methods yield 150-160 kg/tonne compost. Wheat is the the chief new substrate material although rice straw is being used successfully in some areas. Horse manure is also used depending on availability.

South Africa: There are some 40 production units in the country, of which a few are very large, Dutch-type shelf farms with a capacity of ca 60 tonnes per week. South Africa also has 2 spawn laboratories producing Hauser and Lambert spawn. Some Le Lion Spawn is also imported directly.

Kenya: *A. bisporus* is grown at 18-22°C on pasteurized wheat straw using the bag cultivation technique. *Pleurotus* is cultivated at 18-22°C on pasteurized wheat straw plus maize cobs, again adopting the bag cultivation method. *Lentinus* is cultivated experimentally on Wattle (*Acacia mearnsii*) sawdust.

New Zealand: *A. bisporus* is grown at 16-20°C on pasteurized straw in beds, trays and bags. *L. edodes* is cultivated on synthetic logs composed of sterilized sawdust. *Pleurotus* spp. and *Flammulina velutipes* are cultivated experimentally in bags containing straw and sawdust, as is *Tuber melanosporum* and *Tricholoma matsutake* on inoculated oak and hazel seedlings.

South Korea: *A. bisporus* and *A. bitorquis* are grown on beds of pasteurized rice straw using fruiting temperature ranges of 15-17°C and 20-25°C, respectively.

4.2. Cultivation of *Lentinus*

In Japan, both the log and the sterilized sawdust bag method are adopted for cultivating the shiitake mushroom. In S. Korea, the oak tree log method is adopted almost exclusively. Cultivation of *Lentinus* in China is either by wood logs or by plastic bags. In recent years, the bag method has markedly increased both outdoors and indoors.

In Thailand, *L. edodes* is cultivated in the highlands of the north and northeast where the climate is cool and suitable oak logs are available. A log of 10-20 cm diameter and 1 metre in length can yield around 0.5 kg of mushrooms over a two-year period. Production is also undertaken on sawdust substrate contained in plastic bags, this method having the advantage of a shorter cropping period (3-6 months). In Singapore, shiitake production is based entirely on the plastic bag method using sawdust or woodwaste in environmentally-controlled mushoom houses. Malaysia's shiitake enterprisers are located in the highlands and employ the plastic bag method. In New Zealand, *Lentinus* is cultivated on synthetic logs composed of hardwood sawdust. In Mexico, *L. edodes* is grown experimentally at 23-25°C in plastic bags containing sawdust from the fast-growing tropical tree *Bursera simaruba*. *L. lepideus* is grown experimentally at 23-25°C in polypropylene

Plastic bags containing pine sawdust and wheat bran. In Hungary, *L. edodes* is cultivated commercially at 15-24°C in bags of sterilized or pasteurized compost composed of straw, corncobs and wastes from the timber industry. In Poland, *L. edodes* is grown indoors on sterilized sawdust contained in plastic bags. In S. Korea, *L. edodes* is cultivated on oak logs using the fruiting temperature range of 10-20°C.

4.3. Cultivation of *Pleurotus*

The different species of *Pleurotus* are suited for growing within the temperature range of 15-30°C. *P. sajor-caju* is tolerant of a tropical temperature of 28-30°C although it fruits faster and produces larger mushrooms at 25°C during cooller months or in the highlands of the tropics. This is the species now popularly grown in the tropical Southeast Asian countries, including India. *P. abalonus* prefers lower temperatures of 22-24°C and is most popular among the Chinese. *P. ostreatus* is the so-called low temperature *Pleurotus*, fruiting mostly at 12-20°C. This species is more suited to the temperature climates of Europe and the United States, although many growers in the U.S. are also producing *P. sajor-caju*.

Like the other mushrooms, *Pleurotus* spp can be grown on various agricultural waste materials, with the use of different technologies. They grow well on different types of lignocellulosic materials, converting the materials into digestiable and protein-rich substances, suitable for animal feeds. *Pleurotus* spp. may be produced in the tropics on a mixture of sawdust and rice bran, rice straw and rice bran, sawdust and ipil-ipil leaves and other combinations of tropical wastes. Other wastes such as corn cobs, cotton waste, sugarcane bagasse and leaves, corn leaves, grasses, rice hulls, and water hyacinth leaves are also good growth substrates for this mushroom. The substrates used in each region depend on local availability of agricultural wastes. Most of the substrates require sterilization or pasteurization before use.

Some examples of regional variations in cultivation conditions used to grow *Pleurotus* spp. are described below:

Mexico: *Pleurotus* spp. are grown between 23-30°C on a substrate comprised of pasteurized barley and wheat straw, coffee pulp, and corn stubble contained in plasic bags.

Hungary: *Pleurotus* spp. are grown between 15-22°C on bags of pasteurized straw and corncobs.

Japan: *P. ostreatus* grown on sterile sawdust contained in bottles.

S. Korea: *P. ostreatus* and *P. sajor-caju* on beds of pasteurized cotton waste or rice straw using fruiting temperature ranges of 12-17°C and 20-25°C, respectively.

Thailand: *P. sajor-caju* and *P. cystidiosus* are grown on bags of pasteurized softwood sawdust over the temperature range of 23-32°C and 23-30°C, respectively.

4.4. Cultivation of *Tremella*

The early cultivation of *T. fuciformis* was similar to that used for *L. edodes*. Logs were placed in the vicinity of other logs on which the fruiting bodies of *Tremella* were present and inoculation simply occurred by chance dissemination of spores from the fruiting bodies. Later, the inoculation of pure culture spawn, which was composed partly of wood or of sawdust and rice bran was introduced and subsequently adopted by commercial growers. In recent years, large scale cultivation on 'artificial logs' composed of a synthetic substrate, using a mixed culture inoculum of *T. fuciformis* and the ascomycete *Hypoxylon archeri* which gives better yields, was started in Fujian Province, China. The ascomycete helps the *Tremella* in the digestion of the wood and provides some residual nutrition. Cultivation is carried out on a substrate consisting of selected broadleaf sawdust, rice bran, and gypsum or lime (62-68% water content) packed into heat-resistant plastic bags about 50cm in length and 9-10cm in diameter. Four to six holes (1cm diameter x 0.5-1.2cm deep) are made in the 'logs' using a special tool like an auger and the holes are then covered with special ruberized fabric. The bags are sterilized in a steamer or an autoclave for 6-8 hours and then inoculated. Initially, bags are maintained at 28-30°C in an incubation room for a few days until there is visible growth of the mycelium after which the temperature is lowered to 25-28°C. After about one month, the bags are moved to the mushroom house, the hole covers carefully removed and a gentle current of air provided so that the development of the primordia will not be retarded. Environmental management for fruiting generally involves controlling aeration, temperature, humidity and light. The condition in which one can barely see without the help of additional light sources during daytime is the most suitable light level for the production of fruit bodies of *Tremella*. An optimum humidity (85-90%) is provided by spraying water around the mushroom house. Ambient temperature shoudl be about 20-27°C. Within 7-10 days, primordia will begin to form on the open holes and the mushrooms will be ready for harvesting in another 5 days. Yield for each bag should be approximately 35-50 gm dry weight.

4.5. Cultivation of *Volvariella*

Several techniques are adopted for the cultivation of *Volvariella volvacea*, which thrives in the temperature range of 28-36°C and a relative humidity of 75-85%. Detailed descriptions of the various methods are given in the Food and Agriculture Organization Plant Production and Protection Paper No.106: "Technical

Guidelines for Mushroom Growing in the Tropics" and will not be repeated here. Choice of technologies usually depends on personal preference, and on the availability of substrates and the amount of resources available. While the more sophisticated indoor technology is recommended for the industrial-scale production of the mushroom, most of the other technologies are low-cost and appropriate for rural area development, especially when production is established at the community level.

Two examples of regional variations in cultivation conditions used to grow the straw mushroom are given below.

Mexico: *V. volvacea* grown experimentally at 32-38°C on beds of fermented and pasteurized barley straw and cotton waste.

Thailand: *V. volvacea* is cultivated over a temperature range of 25-38°C in beds of pasteurized straw, cotton waste of kapok waste.

4.6. Cultivation of *Auricularia*

Auricularia may be cultivated on natural logs or on synthetic logs using sawdust and plastic bag technology. Cultivation on natural logs is particularly recommended in areas where suitable trees are abundant and accessible. The mushroom does not have any specific trees species requirement and almost any tree species except pines may be used. Most commonly adopted are members of the *Fagaceae* or oak family.

Synthetic logs are composed of sawdust packed into heat-resistant plastic bags. After sterilization, the bags are inoculated with grain or sawdust spawn. This technique was developed in Taiwan in the early 1970's. Further details are available in the FAO publication.

Two examples of regional variations in the cultivation conditions used to grow *Auricularia* are given below.

Mexico: *A. polytricha* at 25-27°C on *Inga* wood in plastic bags and *A. fusosuccinea* grown experimentally at 23-25°C on *Quercus* Sawdust in plastic bags.

Thailand: *A. auricula* is cultivated over a temperature range of 23-32°C in bags containing sterilized or pasteurized softwood sawdust.

4.7. Cultivation of *F. velutipes*

Initially, cultivation of *F. velutipes* was carried out on natural logs. However, it is now routinely grown on the sawdust of most conifers. Mixtures of both hardwood and softwood sawdusts are also very satisfactory. In addition to the sawdust (80%), rice bran (20%) is incorporated in the medium. The ingredients are thoroughly mixed, water is added to produce a moisture content of 58-60%, and the medium is mixed again before dispensing into polypropylene bottles or bags and sterilized. Further details of the cultivation procedure are described in the FAO publication.

4.8. Cultivation of *P. nameko*

Japan: Cultivated on sterile sawdust contained in bottles.

4.9. Cultivation of *L. ulmarium*

Japan: cultivated on sterile sawdust contained in bottles.

4.10. Cultivation on *Ganoderma lucidum*

S. Korea; cultivated on sterile oak or poplar sawdust contained in bottles or in the from of artificial logs using a fruting temperature range of 28-32°C.

4.11. Edible mushroom under experimental cultivation

Some examples of edible mushrooms under experimental cultivation in various regions of the world are given below.

Hungary: *Agaricus macrosporoides, Lepista (Clitocybe) nuda, Pleurotus eryngii, Polyporus tuberaster, Calvatia gigantea.*

Japan: *P. adiposa* in sawdust bottle culture at 19°C during the spawn run and 15-17°C and 90% relative humidity for fruiting. *Hohenbuehelia serotina* and *Tricholoma irinum* in sawdust bottle culture at 17-22°C for the spawn run and 15°C and 90% R.H. for fruiting. *Agrocybe cylindracea* in sawdust bottle culture at 25°C for the spawn run and 20°C and 90% R.H.> for fruit body development. Other species under experimental cultivation are *Pholiota aurivella, Creolophus spathulatus* and *Fistulina hepatica.*

South Korea: *Agrocybe aegerita* using sterilized pine sawdust bottle culture at 15-18°C. *Hypsizigus marmoreus* using sterilized poplar sawdust bottle culture at 13-15°C. *Grifola frondosa* using sterilized oak sawdust bottle culture at 25-30°C.

Mexico: *Volvariella volvacea*

4.12. Wild mushroom species collected for human consumption

Some examples of wild mushrooms collected for human consumption in various regions of the world are given below.

New Zealand: No significant collection of wild mushrooms. Misuse of *Psilocybe* spp. Investigation of the potential of *Rhizopogon* and *Tricholoma* spp.

Mexico: Include *Amanita caesarea* in *Pinus-Quercus* forests during summertime, *Tricholoma ponderosum, Russula brevipes, Ramaria flava, Hypomyces lactifluorum, Lactarius deliciosus* and *Lactarius indigo* in *Pinus* forests in summer. *Lentinus boryanus, Cantherellus cibarius, Cantherellus odoratus* and *Morchella* spp. from *Quercus* forests.

Japan: Include *Tricholoma matsutake* in red pine forests in the autumn (15-19°C); *Rhizopogon rubescens* in pine forests near the sea coasts in spring and autumn; *Lyophyllum aggregatum* in broad leaved forests during autumn.

Hungary: *Marasmius oreades, Boletus aestivalis/edulis, Cantharellus cibarius, Macrolepiota procers, Armillariella mellea.*

Poland: *Boletus edulis* in oak forest, *Catharellus cibariuus, Leccinum versipell* and *Tricholoma flavovirens* in pine and birch forests. All species are collected in autumn when temperature ranges between 7-16°C.

Thailand: *Termitomyces* spp., *Russular* spp., *Astracus hygrometricus* and *Boletus* spp. are collected from forest areas during the rainy season, and *Tricholoma* spp. is found in grassland, again during the rainy season.

South Korea: *Lentinus lepideus* and *Lepista nuda* are collected from summer until autumn in coniferous forests and gardens respectively, and *Volvariella bombycina* in summer from compost heaps or stumps of deciduous trees.

5. Case Study of *Flammulina, Pleurotus* and *Volvariella* Mushrooms in China

Mr. G.L. Yang, Institute of Bioengineering, Hebei University, Baoding, Hebei and Ms. Y.Y. Li, Institute of Microbiology, Hebei Academy of Sciences, Baoding, Hebei, China, reported (personnel communication) that, in recent years, edible mushroom cultivation in Hebei Province has steadily increased. Over 100,000 tonnes of different species of edible mushroom were produced in 1991 throughout 100 counties in the province. Table 16 presents the results of a survey to determine the production of *Pleurotus* spp., *Volvariella volvacea* and *Flammulina velutipes* mushrooms in three of these counties, Xiong County, Qing Yuan County

Table 16. *Pleurotus, Volvariella* and *Flammulina* mushrooms: number of farmers, production, value and profit in Hebei province, China (1989-91).

Species & Place	Items	1989	1990	1991
Pleurotus spp. (Xiong County)[1]	Mushroom farmers	90	120	230
	Cotton seed hull (tonnes)	850	1,500	2,100
	Fresh mushroom (tonnes)	680	1,200	1,680
	Value (US$1,000)	126	222	296
	Profit (US$1,000)	83	148	207
	Average profit per farmer[4] (US$1,000)	0.93	1.24	0.91
Volvariella volvacea (Qing Yuan County)[2]	Mushroom farmers	78	102	180
	Cotton seed hull & wheat straws (tonnes)	425	600	1,000
	Fresh mushrooms (tonnes)	119	174	290
	Value (US$1,000)	110	161	269
	Profit (US$1,000)	75	113	191
	Average profit per farmer[4] (US$1,000)	0.96	1.11	1.06
Flammulina velutipes (Ping Shan County)[3]	Mushroom farmers	41	49	23
	Cotton seed hulls (tonnes)	360	400	23
	Fresh mushrooms (tonnes)	180	200	13.8
	Value (US$1,000)	167	148	77
	Profit (US$1,000)	120	107	56
	Average profit per farmer[4] (US$1,000)	2.93	3.39	1.15

Note: (1) Xiong County is located in the triangle formed by the three major cities of Beijing, Tienjin and Baoding. Therefore, there is a great demand for fresh mushrooms and the latest available figure (1991) for *Pleurotus* production in the county represent a 40% increase compared to 1990 which, in turn, were 76.5% higher than 1989.

(2) Farmers in Qing Yuan County cultivate the *Volvariella* mushroom in plastic shelter trenches (hut trenches) on a compost consisting of spent corn cobs mixed with cotton seed hulls. This mushroom can be grown during the six months from April to September and the product is preserved in brine and exported. Latest available figures (1991) for *Volvariella* production in the county represent a 46% increase compared with 1990 which, in turn, were 66.6% higher than in 1989.

(3) Ping Shan County is located in the Tai Hei Mountains. *Flammulina velutipes* is produced only during winter and is preserved in brine for export to Japan. Due to price fluctuations last year, there was a significant fall in production.

(4) The average profit realized by the mushroom farmers described in this case study ranged from US$900 to US$3,390. This is equivalent to the total annual salaries of 5 to 10 university graduates in China.

and Ping Shan County, respectively.

6. Proposals for Funding An International Centre

It is proposed that funding for the establishment and operation of an International Centre for Mushroom Cultivation Technology and Training be sought from:

(i) governments of participating countries

(ii) donor agencies and international organization (e.g. World Bank, Rockefeller Foundation, United Nations Development Programme)

(iii) private companies involved in mushroom cultivation and waste utilization technology.

7. Rationale for Establishing An International Centre

Huge quantities of lignocellulosic waste materials are generated annually through the activities of the agricultural, forest and food processing industries. This applies particularly to the less leveloped countries whose economies are still largely agriculturally base. Much of this material is either burnt, shredded and/or composted for landfill or improvement of soil quality even though these wastes constitute a potentially valuable resource. There has been a growing recognition in recent years that one of the most economically viable processes for the bioconversion of agricultural and industrial lignocellulosic wastes is the cultivation of edible mushrooms. Since the protein content of mushrooms is relatively high (19-35% on a dry weight basis), they can serve to enrich the human diet in those regions which suffer from a shortage of high quality protein. Mushroom protein can be produced with greater biological efficiency than proteins from animal sources and relatively little is required in terms of large-scale equipment, facilities, capital and land. Production is particularly applicable, therefore, to situations where large-scale capital intensive operations are inappropriate, and harvesting and post-harvest processing requirements are minimal. Perhaps the most compelling consideration is that mushrooms can be cultivated on a wide variety of inexpensive substrates/wastes including such diverse materials as cereal straws, bagasse, banana leaves, coffee grounds, sawdust and cotton wastes from textile factories. This is extremely important in rural areas where there are often available large quantities of agricultural wastes ideally suited for growing different types of edible mushrooms. Of further value is the spent substrate residue left after mushroom harvesting which can be used as an animal feedstock and/or a soil conditioner. In addition, with the growing realization that edible mushrooms represent a source of high-value metabolites (e.g. anti-tumour and immunopotentiating agents, hypocholesterolemic compounds, flavourants), they also hold considerable potential as a future cash crop. This too, holds particular importance for less developed countries where traditional export markets are disappearing, often as a result of alternative commodities produced by utilizing biotechnology in industrialize. countries. thus, in developing countries, properly developed and managed mushroom farms can make important contributions to the nutrition and economic welfare of the people.

To summarize some of the important positive factors associated with mushroom cultivation:

(i) Mushrooms fulfill the three major criteria required of food for human consumption: (a) natural food - will become more important as more exphasis is placed on this aspect in the future, (b) highly nutritive food, and (c) healthy food,

(ii) mushrooms cultivation utilises and upgrades a wide variety of waste materials,

(iii) mushroom cultivation represents a low technology industy,

(iv) mushroom cultivation offers a short-term return compared with many other crops important to the economics of developing countries, e.g. palms, fruit trees, etc.

Despite these obvious benefits, especially to developing countries, mushroom cultivation has not been as successful or as widely adopted as might have been expected. To understand the reasons for this and how best to address the problems, three basic questions may be asked.

7.1. Is the concept and the technology of mushroom cultivation appropriate for less-developed countries?

The answer to this question is yes and no. The techniques involved in mushroom cultivation (*Agaricus*) are well-developed and have been successfully exploited in several countries such as Taiwan, Korea and China. Since the introduction of the *Agaricus* mushroom into these countries, in the 1950's, 1960's and 1970 respectively, the industry has seen a remarkable and sustained increase in production levels. On the other hands, in other developing countries, the picture is very different although perhaps for different reasons. In bangladesh and Nepal, the slow progress in developing a viable mushroom-growing industry is due largely to problems associated with social barriers and infrastructure deficiencies within these countries. However, this is not the case in other developing countries where mushroom cultivation has failed to fluorish. For example, India, which introduced *Agaricus* cultivation at the same time as China (1970), had a total output in 1991 of only 6,000 tonnes compared to 150,000 tonnes in China.

7.2. Why have previous efforts to introduce mushroom cultivation into certain developing countries proved generally unsuccessful?

(a) In some countries there is no appreciation among the general populace that the mushroom represents a delicious and highly nutritive food source, or of the mushroom's heath and tonic qualities.

(b) Mushooms are unpopular in some developing countries for a variety of generally minor social and religious reasons. A traditional association with poisonous species (toadstools) still exists in many regions and consequently there is a lack of trust in the safety of mushrooms as a food source even though they are widely cultivated and consumed elsewhere. Others regard mushrooms as an unsavoury foodstuff because they are grown on manure and are therefore 'dirty'. In Bangladesh, there is a traditional association between the mushroom and the toadstool and, since the toad is regarded as an ugly species,, extrapolation of this association is expressed in the form of a distaste for cultivated mushrooms.

(c) The absence of systematic government support for, and promotion of, mushroom growers appears to be responsible in part for the failure of some countries to sustain a viable mushroom cultivation programme. In countries with thriving mushroom cultivation industries (e.g. Korea/Taiwan), a coordinated government policy allots production quotas for each grower and provides price guarantees for those quotas thereby reducing some of the financial uncertainly assocated with the enterprise. In countries where no such coordinated government policy exists, the lack of confidence created by inadequate government involvement dissuades potential growers from entering into the business.

(d) Lack of access to good quality spawn represents a major problem for mushroom growers in developing countries. Quality controls may be non-existent and there is no 'in-house' testing of spawn by the spawn producers to ensure the character and condition of their product. Spawn cultures are normally obtained from outside the region concerned. The spawn may be well-suited to the climatic conditions and the cultivation procedures adopted in the source region but totally unsuited to the circumstances prevailing in the importing country. No special attention is given to the particular requirements of the local conditions. Thus, while top quality spawn imported from Holland and France will be well-suited to the sophisticated and highly-automated controlled cultivation systems adopted in these developed countries, the same spawn may be completely impractical for use in developing countries where growth conditions are nothing like as tightly controlled and where the nature of the locally available growth substrates may be quite different. Although a single spawn producer may supply spawn to large number of growers scattered over a wide regions, spawn producing operations are frequently located large distances away from the rural environment of the growers. Therefore, the spawn producers often have little or no knowledge of the broad range of local climatic conditions and cultivation procedures to which their spawn will be exposed. Furthermore, the grower receives no guarantee of spawn quality, or financial restitution should the spawn prove defective or inappropriate, leaving him/her to carry the full burden of an unsuccessful harvest.

(e) Of paramount importance is the failure to appreciate the importance of the composting process of efficient mushroom production. Composting is a highly sophisticated operation which is designed to proved a **selective** medium which is favourable to the growth of the mushroom but inhibitory to competing microorganisms. In developing countries where attempts to develop viable mushroom growing industries have misfired due to technical difficulties, the lack of success can usually be traced back to poor quality compost most often due to the exclusion of a Phase II (pasteurization) stage. This, in turn, frequently stems from an incomplete or mistaken understanding of the precise conditions necessary for pasteurization.

(f) Although mushroom researchers in most developing countries have access to the production technology, there is often a serious lack of liason between the researcher and the grower. Research institutes may offer in-house training courses but fail to augment these with appropriate follow-up exercises. Thus, while training courses may educate the grower on the general concepts of good mushroom house management, the mushroom scientist rarely ventures out into the field to demonstrate to the grower how to manipulate key environmental parameter such as temperature, oxygen, carbon dioxide, light, moisture, etc., during the different segments of mushroom development **within the confines of the individual grower's own operation.** This is essential also if the effects of local environmental conditions on mushroom production are to be fully appreciated, or if the manifold problems regularly faced by the growers (e.g. poor yields, pest control) are to receive the scientific analysis necessary to correctly identify the underlying casues.

(g) Lack of appropriate production technology and poor observance of the correct cultivation procedures means that mushroom prices are very high. Therefore, mushrooms are beyond the reach of the large majority of potential end-users in many developing countries. For the development and survival of a viable mushroom industry, it is essential to produce mushrooms more cheaply while maintaining a satisfactory return on the grower's investment. This is readiy achieveable as exemplified by *Pleurotus* production in China which, in recent years, has increased to the point where the mushroom has acquired the status a common vegetable.

7.3. What are the remedies?

Some of the technical remedies which need to be investigated are:

7.3.1. Quality and reproduciability of spawn:

(i) Introduction of a system of registered spawn producers (eg. government and/or commercial laboratories) to produce high quality spawn.

(ii) Introduction of a partial payment scheme whereby 50% of the cost of the spawn in paid on acquisition and the remainder after harvesting.

The onus is then on both parties to carry out their part of process responsibility.

(iii) It is important to stress that spawn should be appropriate to the local prevailing climatic conditions, available substrates, etc. A 'robust' spawn able to tolerate the more demanding cultivation conditions which previal in the more 'low tech' mushroom growing operations in developing countries may by preferable to using spawn more suited to the highly sophisticated 'high tech', capital intensive systems found in developed countries.

(iv) Introduction of the concept of 'local' cooperative spawn producers with sufficient expertise to produce good quality spawn suited to the climate and substrates of the local region.

7.3.2. Adoption of correct composting techniques:

Introduction of a system of commercial compost suppliers or 'compost cooperatives' whereby groups of farmers produce communal compost with each producer taking out a proportion based on imput.

7.3.3. Quality control:

Introduction of systems to guarantee the quality of product; e.g. a system of communal centres for the processing (eg. canning) of mushrooms prior to export at which stage the appropriate quality controls can be applied.

7.3.4. Field Technical Service (FTS)

Introduction of a Field Technical Service to bridge the gap between, on the one hand, the researchers and the spawn producers, and on the other the growers/farmers. The FTS would ensure that the cultivation techniques courses are properly applied, and that the spawn suppliers and researchers are receiving feedback on the success or otherwise of their spawn material and mushroom cultivation techniques at the grass-roots level under the prevailing local conditions. Responsibility for providing the FTS should probably lie with the spawn suppliers (i.e. government laboratories, private spawn companies, spawn suppliers to cooperatives) since the improved expertise, increased yields and subsequent expansion of the mushroom growing industry in the particular country will inevitably lead to higher spawn sales.

8. Objectives of An International Centre

The objectives of the proposed International Centre for Mushroom Research and Training are as follows:

8.1. Centre for basic research

The Centre would conduct research into:

(i) all aspects mushroom biology including taxonomy, development, physiuology, genetics, cultivation (including diseases and pests), pathology, medicinal and tonic attributes, organoleptic qualities toxicity, post-harvest technology, etc.

(ii) The development of systems for coupling edible mushroom production with the total utilization of the manifold organic wastes generated by the agricultural, forest, food processing and textile industries.

8.2. Training of personnel

The Centre would conduct basic and advance training programmes in mushroom biology and cultivation, and waste utilization technology. It should also consider the provision of social education on the advantages and desirability of mushrooms, and the alleviation of traditional prejudices and social barriers against consuming mushrooms.

At some stage, the Centre might confer internationally recognized accreditation for various forms of expertise associated with mushroom cultivation.

8.3. Refresher and remedial courses

The Centre would also conduct refresher and remedical courses, the former to update on more recent developments and the latter to provide a forum for analysing specific problems experiences by growers.

8.4. Provision of a Field Training Service

The Centre would provide a Field Taining Service, the functions of which would include:

(i) liason between the researchers/spawn producers and the mushroom growers,

(ii) to provide advice and information on mushroom cultivation techniques to growers in the field, and to undertake field inspections to ensure that procedures described in training courses are carried out correctly,

(iii) to feed back detailed information following field inspections on problems which arise in the field so that these can be analysed and resolved.

The FTS would be operated by professionally qualified Field Training

Service agents who themselves would be trained at the Centre.

8.5. Data Depostition and Coordination

The Centre would serve as a repository for information on such matters as production levels, developments in cultivation methods, disease and pest control problems, quality control problems, etc., feed back from the growers. This information, together with scientific advances achieved at the Centre itself and at national mushroom research institutes would be stored in a data bank to which free access would be guaranteed.

8.6. Centre for matters relating to quality control

The Centre would participate in the development of international quality control standards, and would minitoi and maintain the quality of exports. It would also act as a consultative agency on measures to be undertaken when a breakdown in quality occurs.

8.7. Mushroom gene bank

The Centre would be the site of an international repository of mushroom germplasm for the preservation of biological diversity.

8.8. Consultative body

The Centre would act as a consultative body to government departments, private companies, etc on matters relating to mushroom cultivation and waste utilization technology.

8.9. Affiliated consultative network

The Centre would operate an affiliated network of individual consutltants with expertise in highly specialised areas of mushrooms cultivation to deal with particular problems beyond the expertise of the permanent staff of the Centre.

S.10. Internaional arbitration

The Centre might, at some future stage, act as an international arbitrator on matters relating to strain identification/history/ownership, etc. Such a role would require international acceptance and would largely depend upon the level of resources at the Centre's disposal.

9. Porposed Organization of An International Centre

9.1 Organization

An outline of the organization and function of the proposed International Centre for Mushroom Research and Training (ICMRT) is shown in Figure 7. It is recommended that the Centre would consist of five functional units, namely the Research, Training, Culture Collection and Service Divisions and the Experimental Station.

The Centre would include the following facilities:

(i) laboratories for conducting research and training on all aspects of mushroom biology, mushroom-derived products and bioconversion technology involving edible mushrooms,
(ii) an experimental station for pilot-scale and large-scale mushroom cultivation,
(iii) a depository for mushroom germplasm
(iv) office facilities for permanent and contracted visiting scientists/trainees, and associated administrative staff, working at the Centre,
(v) Living accommodation for upto 20-30 overseas research scientists/trainees plus appropriate dining and recreational facilities normally associated with an international centre,
(vi) a maintenance workshop,
(vii) conference facilities suitable for convening international meetings.

9.2. Location

It is proposed that the Centre be located in a country of Southeast Asia with interests in mushroom cultivation and waste bioconversion technology. Suitable candidates include China, Hong Kong, Indonesia and Malaysia. The host country should be prepared to allocate an acceptable piece of land up to 3.0 hectares in area; 0.6 hectares for research buildings and living accommodation, and 2.4 hectares for facilities associated with mushroom cultivation (i.e. composting yards, mushroom houses, etc.), and recreational areas. In addition, the host country should provide the necessary electricity and water supply systems, and appropriate communication and transportation infrastructure to ensure the optimum development of the Centre.

9.3. Budget

It is estimated that the cost of establishing the Centre would be in the region of US$4 million with funding of the same magnitude, in the form of an endowment or continued direct support, required for on-going recurrent expenses.

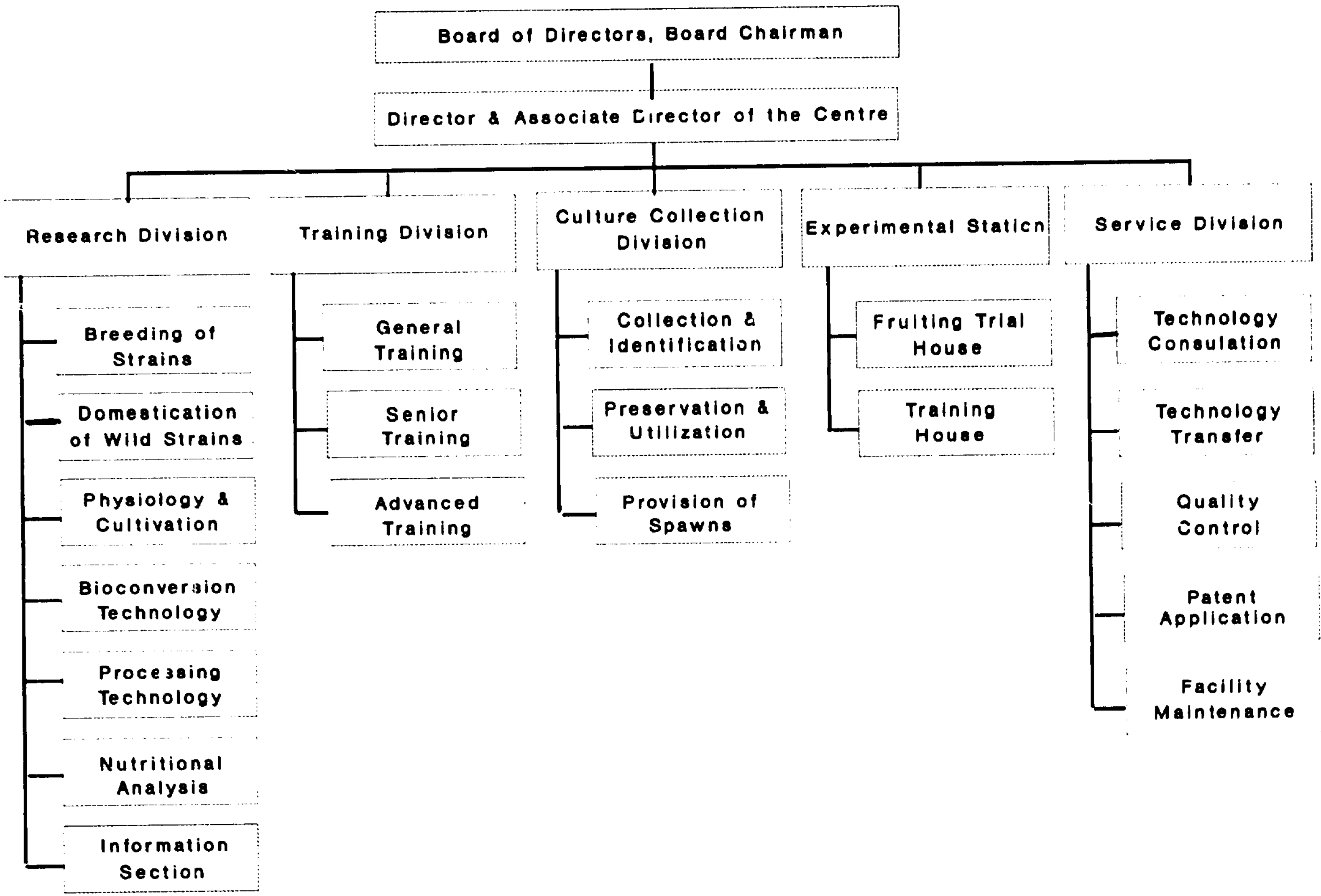

Fig. 7 Organization and Function of the Proposed International Centre for Mushroom Research and Training.

Only general proposals can be made at this state. Subject to acceptance of the recommendation that an international centre be established, it is suggested that an Implementation Committe, consisting of a panel (3-5 persons) of relevant experts, be created in order to undertake the detailed planning for the institution of the centre and its future operation.

10. Concluding Remarks

As the population of the world continues to increase, so the amount of food and the level of medical care available to each individual, especially those living in less developed countries, decreases. Mushrooms, with their great variety of species, constitute a cost-effective means of supplementing the nutrition of the majority of humankind and of alleviating the suffering caused by certain kinds of illness. Furthermore, with proper training and supervision, mushroom cultivation can be introduced to the small farmer in different regions of the world as a means of generating income, thereby raising the economic and social status of the rural population in less developed countries. It is based on these sincere beliefs, and in support of UNIDO and other international agencies, that we have undertaken this feasibility study which we hope will lead to the establishment of the International Centre for Mushroom Research and Training (ICMRT).

The Centre has three key roles in developing mushroom science and the mushroom industry: to conduct scientific research, the transfer of the fruits of this research to the private sector, and the training of the labour pool necessary to meet the demands of the industry in both the more developed and the less developed countries. Another important activity of the Centre will be to organize international lectures, workshops and symposia to increase public awareness of mushrooms as a good source of human food. Through these activities, the Centre will aim to achieve its overall goal of maximizing mushroom production per unit area with minimum outlay in order to provide a low cost source of high quality food protein from waste materials for the people of the developing world.

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