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Development of the Culinary-Medicinal Mushrooms Industry in China: Past, Present, and Future

Shu-Ting Chang

Emeritus Professor of Biology and Director of Centre for International Services to Mushroom Biotechnology, The Chinese University of Hong Kong; Honorary Visiting Professor, Department of Biological Sciences, University of Wollongong, Australia; scha6507@bigpond.net.au

ABSTRACT: In 1978, I was invited to conduct the first Mushroom Training Workshop in China. At that time, the production of cultivated edible mushrooms in China was only 60,000 tons, which accounted for only 5.7% of total world production. However, in 2002, China's mushroom production was over 8.6 million tons and accounted for about 70% of the total world output. The year 1990 can be considered the turning point in mushroom production in China. It was the year in which, for the first time, China produced more than 1 million tons of cultivated edible mushrooms, accounting for more than 28% of world mushroom production. The number of species of both edible and medicinal mushrooms cultivated has also been increasing over the years. Whereas the dynamics of production have been maintained for quite a few years, recent data indicate that the buoyant development is far from reaching a peak. China is now the largest mushroom producer, consumer, and exporter in the world. The reasons underlying China's success in the development of its mushroom industry during the past two and half decades can be broadly summarized as follows: (1) the vision, strong leadership, and initiative of central and local governments in grasping the immense potential benefits of mushroom cultivation; (2) strong scientific support from academic institutions; (3) manifold innovations in mushroom cultivation technology by talented mushroom farmers; and (4) the growth of the domestic market as a result of a strong national economy, which has been a key factor in the expansion of mushroom cultivation in China. The complementary major challenges now facing the mushroom industry in China are entry into an era of improved management, marketing, and quality control of its mushrooms and mushroom products and further promotion of research. In particular, improvements in communication technology are vital for modern business transactions. Advancement of the Chinese mushroom community's standing internationally should also be encouraged by hosting more international conferences, producing and publishing more high-quality scientific articles in international journals, and even establishing a home-based international journal for mushroom sciences. This will then further contribute to, and have a great impact on, the development of the mushroom industry at national and international levels.

KEY WORDS: mushroom industry, mushroom production, mushroom cultivation technology, China, innovation, medicinal mushrooms

INTRODUCTION

China, with its vast territories, complex topographical features, and diverse climates, is home to numerous mushroom species. At present, there are about 950 species of domesticated mushrooms, among which approximately 50 species have been cultivated successfully (Mao, 2004). China can boast that it was the first country to cultivate successfully many popular mushrooms species—for example, *Auricularia auricula-judae* (Bull.) Wettst. (estimated date, 600 A.D.), *Flammulina velutipes* (W.Curt.:Fr.) P.Karst. (800–900 A.D.), *Lentinus edodes* (Berk.) Singer (1000–1100 A.D.), *Vol-*

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TABLE 1. Average Production of Cereal Grains and Their Straws for 2000–2002 in China

Cereal	Grain (×1000 MT)	Conversion factor*	Straw (×1000 MT)
Wheat	94,934	1.8	170,881
Rice	181,891	1.0	181,891
Maize	114,536	7.4	847,566
Other coarse grain	11,213	2.4	26,911
Total			1,227,249

* See Chang (1980). Source: *FAO Production Year Book*, 2002.

variela volvacea (Bull.:Fr.) Singer (1700 A.D.), and *Tremela fuciformis* Berk. (1800 A.D.). Therefore, prior to the 1900s, *Agaricus bisporus* (J. Lge) Imbach (1650 A.D.) was the only major mushroom species that was not first cultivated in China (Chang and Miles, 1987).

China is one of the largest agricultural countries in the world, producing huge amounts of inedible crops, crop residues, and forest and agro-industrial solid organic wastes, which can be used as substrates for mushroom cultivation. It is estimated that China produces 1.2 billion tons of cereal straw and 3.6 million tons of cottonseed hull waste each year. In 2002, using some of its huge lignocellulosic wastes as substrates, China produced 8.6 million tons of mushrooms, accounting for over 70% of total world mushroom production. China is now the largest producer, consumer, and exporter of edible mushrooms in the world. China's share of the total mushroom export volume is 80% for Asia, and 40% of the total mushroom export volume worldwide (The Secretariat of Sub-Chamber of Fungi, 2004). Thus, China can be seen as the new powerhouse for the world mushroom industry.

Although China's mushroom industry has a long history, it has flourished and developed rapidly only during the past 25 years. In 1978, China produced only 60,000 tons, contributing to less than 6% of world production. The year 1978 was also the first year of China's economic reform program. Twenty-five years of reform have transformed China from a centrally planned and closed system for agriculture, particularly in the mushroom industry, to one that is predominantly market-driven and openly competitive. The progress of the mushroom industry over these years has made a great contribution to developing the Chinese rural economy. The total population directly engaged in the mushroom industry is now over 30 million, many having been raised from poverty as a result.

The mushroom industry has also improved people's general well-being by introducing new food and new nutritional and medicinal resources. I was fortunate enough to be involved in this miraculous development, from the time I was invited by the Ministry of Light Industry to conduct the first Mushroom Training Workshop in China in 1978 and, subsequently, as a result of further invitations by different levels of government to visit China up to five times every year. In total, these visits have involved about 120 counties in 20 provinces and cities. I am pleased to have this opportunity to share some of my experiences of the development of China's mushroom industry.

RESOURCES FOR THE MUSHROOM INDUSTRY

China has some unique and complex geological structures. Its diversified climatic conditions are particularly suitable for nourishing mushrooms. For example, Yunnan Province has been considered to be the richest place for the wild mushrooms in the world. According to the estimate by Zhang (2004), 850 edible mushroom species have been described in Yunnan. Wild edible mushrooms are widely distributed and are estimated at about 500,000 tons. At present, over 50 species have been developed in commercial scale, and over 10 of them are exported in large quantity. The annual export of those wild mushrooms has exceeded 100,000 tons. For example, the export of the matsu-

take mushroom *(Tricholoma matsutake)* has reached 1000 tons annually in recent years, which accounts for over 70% of the international market of this delicious and high-priced wild mushroom.

China is one of the largest producers of agricultural products in the world. There are two or three harvests annually in the East and Southeast provinces of China. China produces over 1 billion tons of cereal straw (Table 1), 3.6 millions tons of cottonseed hulls, and 1.8 million tons of sunflower seed hulls. The figure for forestry byproducts would also certainly stand at several hundred million tons. In addition, there are abundant wild grasses, from which 33 species have been selected to cultivate 43 species of edible and medicinal mushrooms. More-over, there are clearly still many wild grass resources yet to be developed. These lignocellulosic wastes are the main materials used as substrates for mushroom cultivation.

China also has a huge labor force available in rural areas, particularly during the off seasons for agricultural activities. In 2002, the total population directly engaged in the mushroom industry numbered over 30 million. In addition, several thousand mushroom scientists work closely with mushroom growers to conduct experiments and monitor the results of mushroom technology development in the field.

WITNESSING THE DEVELOPMENT OF THE INDUSTRY

Conducting Mushroom Training Workshops/Courses

In 1978, I was invited by the Ministry of Light Industry to conduct the first Mushroom Training Workshop in Beijing, China. This was closely followed by a second workshop held in Fuzhou, Fujian Province, the following year. The main theme of the workshops was the cultivation of *A. bisporus,* particularly emphasizing Phase II fermentation technology. Two distinguished mushroom scientists were participants at these workshops: Prof. X. C. Wang (former Director of Fujian Light Industry Research Institute, Fuzhou) and Prof. N. L. Huang (Director of Sanming Mycological Institute, Fujian) (Fig. 1). Both have contributed greatly to the development of the mushroom industry in China.

Since 1978, I have been invited more than ten times by the Ministry to conduct workshops/courses and discuss various subjects relating to the development of the mushroom industry—in 1979 (Fuzhou, Fujian), 1981 (Hangzhou, Zhejiang), 1983 (Chengdu, Sichuan), 1984 (Beijing), 1985 (Beijing), 1986 (Beijing), 1989 (Hangzhou), 1989 (Beijing), 1990 (Beijing), 1993 (Mianyang, Sichuan), and 1995 (Beijing).

During the past 25 years, I have also been invited by other ministries and local governments to conduct more than 80 mushroom training courses/workshops/seminars in 20 provinces and cities. I have had opportunities to visit rural villages to guide, learn, and discuss mushroom cultivation problems with mushroom farmers in over 140 counties located in 22 provinces and cities. The biggest and longest training course was held in Shijiazhuang, capital of Hebei province. It was held over 3 weeks, July 3–23, 1983. A total of 230 mushroom scientists, researchers, and farmers from 25 provinces and autonomous regions attended the course, which consisted of lectures in the mornings and practical demonstrations and discussions in the afternoon sessions. The contents of the training course have been published in a small booklet (141 pages) in Chi-

FIGURE 1. (R-L) Prof. X. C. Wang, Prof. S.-T. Chang, and Prof. N. L. Huang (2004). Prof. Wang and Prof. Huang participated in the first two mushroom workshops held in China in 1978 and 1979. Prof. Wang attended in Beijing and Prof Huang in Fuzhou. Courtesy of Prof. Z.S. Wang.

TABLE 2. Production Growth of *Agaricus bisporus* in China (1975–2003)

Year	Production (×1000 MT)	Year	Production (×1000 MT)
1975	30.0	1989	139.4
1978	45.0	1994	359.0
1980	100.0	1997	180.5
1983	140.0	1998	426.0
1984	167.0	1999	600.0
1985	184.0	2002	923.0
1986	185.0	2003	1330.4

Courtesy of J. W. Wu (Former Senior Engineer, China National Research Institute of Food and Fermentation Industries, Beijing, 2004) and of the Chinese Mushroom Association (CMA).

nese, entitled, *The Genetics and Breeding of Edible Mushrooms.*

MUSHROOM PRODUCTION

In 1978, the production of *Agaricus bisporus* in China was only 45,000 tons (Table 2), and the production of all cultivated edible mushrooms was a mere 60,000 tons (Table 3). However, in 2002, China's mushroom production was over 8.7 million tons. Now China is a leading producer and consumer of both edible and medicinal mushrooms. Production growths of Chinese mushrooms have increased sharply in the years 2000–2003. National total outputs for this period were 6.6 million tons in 2000, 7.8 million tons in 2001, 8.7 million tons in 2002, and 10.4 million tons in 2003 (Table 4). It should be noted that the contributions to this steady growth are not only from traditional species—for instance, *Lentinus edodes, Agaricus bisporus,* and *Pleurotus ostreatus* (Jacq.:Fr.) P. Kumm.—but also from newly developed species such as *Pleurotus eryngii* (DC.:Fr.) Quél., P. *nebrodensis* (Inzenga) Sacc., *Coprinus comatus* (Müll.:Fr.) S.F.Gray, and *Ganoderma lucidum* (W.Curt.:Fr.) P. Karst. (Fig. 2). China has also greatly increased the number of cultivated mushroom species from 5 in 1950 to 50 in 2002 (Table 5). It has been estimated that China has about 1500–2000 edible mushroom species, and, at present, there are 981 known edible species (Mao 2004).

TABLE 3. Growth in Production of Mushrooms in China (1978–2003)

Year	Production (×1000 MT)	Year	Production (×1000 MT)
1978	60.0	1997	3918.3
1986	586.0	2000	6638.0
1990	1083.0	2001	7818.0
1994	2600.0	2002	8764.0
1996	3500.0	2003	10,386.9

Sources: Chang (1999); Huang (2000); Lin (2002).

In 1978, China's production of edible mushrooms accounted for only 5.7% of total world production. However, as shown later in Table 6, the percentage contribution made by China to total world mushroom output has increased steadily over the years. The production of mushrooms in China increased to 174,500 tons in 1983 (Chang, 1990), which accounted for 12% of the world output. In 1986, the total output of mushrooms in China increased to 585,000 tons, which represented 27% of the total world production, which by then had reached 2.18 million tons.

However, the turning point in mushroom production in China occurred in 1990. That was the year when, for the first time, China produced more than 1 million tons of cultivated edible mushrooms, accounting for more than 28% of world mushroom production. Since then, the output of China has been growing steadily at a rate of 18–20% per annum. Total production of cultivated edible mushrooms in 1994 was 2.6 million tons, or 54% of the world output, and it has been estimated that the production of cultivated edible mushrooms in China in 2002 exceeded 8.7 million tons, which accounted for approximately 70% of total world output. In addition, the number of species of edible mushrooms cultivated in China has also been increasing (Table 5). Whereas the dynamics of production have been maintained for quite a few years, recent data indicate that the buoyant development is far from reaching a peak.

Before 1983, the main mushroom industry in China was based on *Agaricus bisporus*. This mushroom was first introduced into Shanghai in 1928. However, cultivation was disrupted during World War II. Following the trend of production,

first in Taiwan in the 1950s, then in South Korea in the 1960s, China resumed cultivation of this mushroom in the 1970s. However, at that time, yields per unit were generally and comparatively low. Since the introduction of the Phase II composting technology into China during the Mushroom Training Workshop in Beijing in 1978, the following 4 years saw a major increase in production capacity of *A. bisporus* (Table 2).

Subsequently, improvements in production capacity continued as a result of familiarization with, and improvements of, the new composting technology, and also as a result of the later introduction of selected high-yield and more adaptive strains. In 1983, the production of *A. bisporus* in China was already gaining world prominence. The world out-put of *A. bisporus* mushrooms in 1983 was 1 million tons, and production of the mushroom in China was 140,000 tons, or 14% of the total.

Production of the mushroom in Fujian reached 45,000 tons, representing about 31% of the national production. This province became the leading producer of the mushroom in China from that year onward. However, production of other mushroom species in China was still at the infant stage. For example, production of *Lentinus edodes* in 1983 was only 19,500 tons, which represented about 9.4% of the total world production of 206,700 tons (Royse et al., 1985). In that year, Japan produced 171,200 tons of this mushroom, which contributed 82.8% of the world output. However, 14 years later, the production situation of *L. edodes* had seen a drastic change. In 1997, China produced 1,125,000 tons of *L. edodes,* and its share of the total output worldwide had risen to 85.1% (Table 7). Production of this mushroom reached 2 million tons in 2000 and has remained

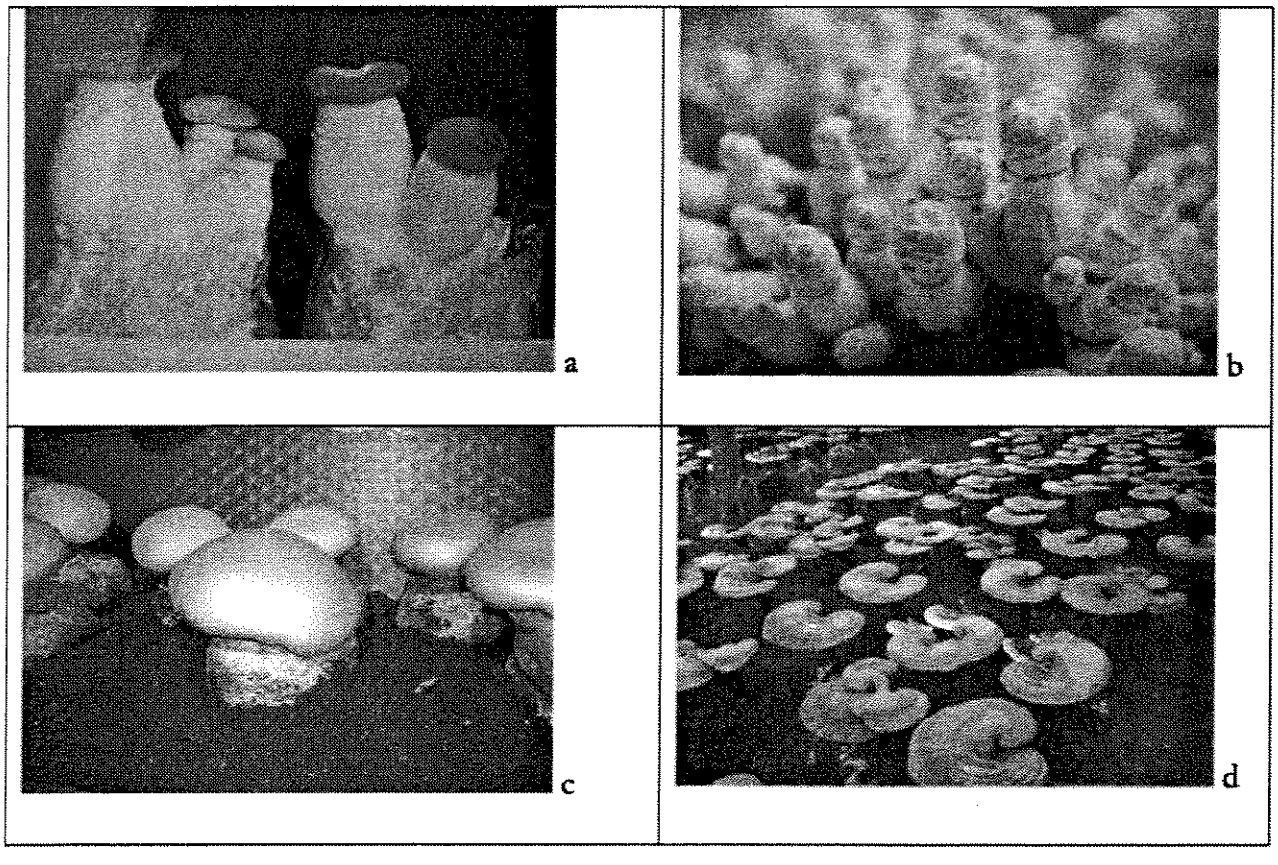

FIGURE 2. (a) *Pleurotus eryngii*; **(b)** *Coprinus comatus*; **(c)** *Pleurotus nebrodensis*; **(d)** *Ganodermna lucidum.*

TABLE 4. Production of Major Cultivated Edible and Medicinal Mushrooms in China (1986–2003)

Species	1986	1998	2000	2001	2002	2003[a]
Pleurotus spp.	100.0	1020.0	1700.0	2590.0	2647.0	2488.0
Lentinus edodes	120.0	1388.0	2205.0	2072.0	2214.0	2228.0
Agaricus bisporus	185.0	426.0	637.0	743.0	923.0	1330.4
Auricularia spp.	80.0	491.0	968.0	1124.0	1242.0	1654.8
Volvariella volvacea	38.0	32.0	112.0	116.0	151.0	197.4
Flammulina velutipes	10.0	189.0	299.0	389.0	505.5	557.7
Tremella spp.	50.0	100.0	103.0	114.0	138.0	183.3
Hericium erinaceus	-	28.0	6.0	9.5	12.6	30.5
Hypsizygus spp.	-	21.0	84.0	120.0	189.6	242.5
Pholiota nameko	-	31.0	48.0	51.0	84.6	171.5
Grifola frondosa	-	10.0	6.0	15.0	36.6	24.9
Coprinus comatus	-	-	-	38.9	156.8	177.8
Pleurotus nebrodensis	-	-	-	7.3	34.3	52.2
Pleurotus eryngii	-	-	-	21.0	72.4	114.1
Agrocybe chaxinggu	-	-	-	-	48.4	92.9
Dictyophora spp.	-	-	-	10.1	13.2	32.2
Agaricus brasiliensis	-	-	-	-	14.7	42.0
Ganoderma spp.	-	-	13.5	21.8	36.7	49.1
Wolfiporia cocos	-	-	-	-	74.0	145.9
Others[b]	2.0	664.0	456.4	376.1	170.4	571.7
Total	585.0	4400.0	6,637.9	7818.7	8764.8	10,386.9

Source: Chang (1987), Chang and Miles (1993), Huang (2000).

[a] Estimated figures, courtesy of the Chinese Mushroom Association (CMA).

[b] There are several new species of mushrooms that have been cultivated recently on a small commercial scale in China but have great potential for further expansion. These include *Lepista nuda, Agrocybe aegerita, Tricholoma giganteum, Auricularia fuscosuccinea, Tremella cinnabarina, Pleurotus citrinopileatus, P. sapidus Stropharia rugosoannulata,* and *Lentinus giganteus.*

at this level ever since (Table 7).

On the other hand, the percentage of *L. edodes* contribution from Japan dropped from 82.8% in 1983 to 10% in 1997. A comparison of *L. edodes* production in 1985 and 1995 indicates that during the those 10 years, China increased her production by 1060%, while production in Japan, Korea, and Taiwan decreased by 46.5, 23.2, and 82.2%, respectively. China has now become the world's largest producer, exporter, and consumer of *L. edodes* mushrooms. Although normally regarded as a mushroom from Northeast Asia, cultivation of this mushroom is now rapidly spreading to other parts of the world. It is expected that cultivation of this mushroom, which can be used for both food and medicinal purposes, and which is already spreading faster than any other species, will continue to expand. The average biological efficiency using synthetic sawdust is about 60–80% over a period of 6 months. With an extended cropping period, 100% yields are not unusual.

The National Mushroom Conference held in Sanming Fungi Research Institute in 1983 had a long lasting influence on Chinese mushroom research and development. Because most of the leading Chinese mushroom scientists of that time were active participants, it provided a new vision and drive for the Chinese mushroom industry. This was the beginning of more focused attention upon the more exotic mushrooms, particularly *L. edodes.* Since then, the mushroom industry in China has rapidly developed in all aspects, not only in the

TABLE 5. Number of Known Edible, Domesticated, and Commercially Cultivated Mushroom Species in China (1950–2002)

	1950	1951–1960	1961–1970	1971–1980	1981–1990	1991–2000	2001–2002
Edible mushroom species	50	100	200–260	300–350	360–655	720–838	981
Domesticated species	5	7	10	16	50	86	92
Commercially cultivated species	5	5	7	9	16	26	50
Exported species, including wild mushrooms	4–5	5	6	6–7	8–18	33	35

Source: Mao (2004).

application of cultivation technology but also in basic academic research, particularly into the genetics and breeding of mushrooms. The number of commercially cultivated mushroom species steadily rose from 16 in the early 1980s to 50 in 2002 (Table 5). Nowadays, China has become a "mushroom kingdom," where more mushrooms are being cultivated and more mushroom restaurants are being operated than anywhere else in the world. More than 20 species are produced on an industrial scale, and *L. edodes* in particular has become the leading mushroom in China, as well as worldwide.

In the 1980s, the production of mushrooms still took place on a small scale, mainly in rural areas. In recent years, the structure of mushroom production has gradually transformed to urban areas, with production taking place on an industrial scale. For example, there are now six companies producing *Flammulina velutipes* with a capacity of 5–10 tons per day. There are four companies producing 2–4 tons of *Pleurotus nebrodensis* per day. Furthermore, there is one company capable of producing 5–8 tons of *Agaricus bisporus,* and another company producing up to 5 tons per day of *Hypsizygus* spp. Finally, there is one company able to produce 3 tons of *Pleurotus eryngii* per day. These companies are located mainly in Beijing, Shanghai, Guangdong, and Shandong, the more populated and economically developed cities in China, and have better quality control as a result of more advanced equipment and better corporate management Furthermore, there are several big companies with sophisticated equipment and technology capable of scrutinizing the production process and detecting heavy metals and other impurities that may be present in any contaminated dried or fresh mushrooms.

Since China joined the WTO in 2001, the country is gradually standardizing its industrial and regulatory practices in order to be consistent and complementary with international levels, and China's mushroom industry is certainly heading toward this goal.

CASE STUDIES

The successful implementation of a mushroom farming strategy has the possibility of engaging

TABLE 6. China's Contribution to World Mushroom Production Since 1978

Year	World production (×1000*t*)	China production (×1000*t*)	Contribution by China (%)
1978	1060.0	60.0	5.7
1983	1453.0	174.5	12.0
1986	2176.0	585.0	26.8
1990	3763.0	1083.0	28.8
1994	4909.3	2640.0	53.8
1997	6158.4	3918.0	63.6
2002	12,250.0*	8760.0	71.5

*Author's own estimation (estimated from previous historical record).
Source: Miles and Chang (1986), Chang (1991, 1992, 1999), Huang (2000).

TABLE 7. Production of *Lentinus edodes* in China Compared to the World

Year	China's production (×1000MT)	World's production (×1000)	China's contribution to world production (%)
1983	19.5	206.7	9.4
1985	50.0	359.1	13.9
1991	380.0	628.2	60.5
1992	450.0	704.0	63.9
1993	550.0	798.6	68.9
1994	626.0	850.4	73.6
1995	580.0	799.1	72.6
1996	670.0	879.3	76.2
1997	1125.0	1321.6	85.1
2000	2205.2	—	—
2001	2072.2	—	—
2002	2214.4	—	—
2003	2227.6	—	—

Sources: Royse et al. (1985); Chang (1996, 1999, 2002); Yao (1998). Courtesy of the Chinese Mushroom Association (CMA).

thousands, if not millions, of farmers in the industry. The production of mushrooms in China is highly decentralized. However, over 35 counties in 10 provinces have each produced edible mushrooms valued in excess of 200 million Yuan (US $25 million) per annum. In recent years, the mushroom industry has gradually moved to the northern provinces, in particular Henan and Shandong, which have now become two of the top five provinces for mushroom production in China. Here I select four case studies that have provided special contributions to the development of China's mushroom industry: Gutian, Qingyuan, Biyan, and Pan'an.

Gutian in Fujian Province

Gutian is in the north central part of Fujian province and is the home of edible mushrooms in China. It is a mountainous area, and its environment is most suitable for growing many edible mushrooms. Gutian is home to many new innovations relating to the cultivation of a variety of edible mushrooms. Traditionally, *Tremela fuciformis* was cultivated using wood logs. Gutian was the first to boost the yield of *T. fuciformis* by switching in the 1970s to the bottle method and then to the plastic bag method. Later, in the 1980s, the plastic bag method was adapted to create the widely used synthetic log method for growing *Lentinus edodes*. In the late 1980s, *Dictyophora* spp. were also successfully cultivated on unsterilized substrates. Since 1990, the total output of edible fresh mushrooms in the county has exceeded 100,000 tons, of which *Tremela fuciformis* accounts for more than 90%.

In recent years, production of edible mushrooms has increased 10% annually. In 2003, total production of cultivated edible mushrooms in the county reached 275,000 tons, consisting of 128,000 tons of *T. fuciformis*, 48,000 tons of *Lentinus edodes*, 40,000 tons of *Agrocybe chaxinggu*, and 59,000 tons of other species. The total production value is close to US $100 million, which accounts for 41.3% of the value of total agricultural output.

Qingyuan in Zhejiang Province

Qingyuan is the birthplace of artificial cultivation of *Lentinus edodes*, dating back almost 1000 years. The county of Qingyuan is located in a tropical monsoon climatic region that is considered ideal for the production of *L. edodes*. The production of mushrooms in Qingyuan has grown from a mere 2765 tons fresh weight in 1986 to 48,202 in 1993, and to over 106,500 tons in 1997. Presently, only 20% of the production comes from cultivation on

wood logs; the remaining 80% is obtained by using the synthetic sawdust log technique. The overharvesting of wood has impelled the government to encourage farmers to abandon the traditional log technique. The imminent environmental damage of logging wood for mushroom cultivation has spurred new technological breakthroughs, including improving the average biological efficiency to approximately 100%.In 1993, this efficient production of one county represented 10% of the world production and one-fifth of the Chinese output. This was one of the main reasons why, in 1994, the Chinese Government officially named the county as the "*Lentinula* Mushroom Town of China."

It is interesting to note that the total population of the county is slightly less than 200,000, of which, in 1994, 120,000 were directly engaged in mushroom cultivation. Thus, 60% of the total population was engaged in mushroom production and management. In terms of jobs, the mushroom industry in 1997 employed an additional 4000 persons in the trading and marketing of mushroom, and about 2000 were engaged in manufacturing plastics for bagging substrates, sales, production and maintenance of machinery, printing of labels and packaging, and related businesses. The total value of mushroom production in 1997 was US $46.3 million. It is the main source of revenue for the local government, and, in recent years, the economic status of the population of Qingyuan ranks among the 100 richest counties out of some 3000 in China.This improvement is due solely to the cultivation and marketing of *Lentinus edodes* mushrooms.

Prior to 1991, trading in *L. edodes* was conducted at numerous stores. However, the regional government decided to invest in a trading floor, which has since been expanded. Today, there are some 280 active traders each day, except during the Chinese New Year Festival. Each trader employs up to 8 people, most of them women. The success of the trading is reflected by the fact that, in 1999, there was need for an expansion consisting of an additional 137 trading stalls. The market system and support services, such as banking, hotels, and restaurants, now employ 15,000 people, of whom 3000 are paid directly by the traders. There are 60 traders who export as many as 50 tons dry weight of mushrooms per annum.

The county is also producing medicinal extracts from *L. edodes* and *Grifola frondosa* for sale to the Chinese herbal communities worldwide. The spent substrate is now under study for its use as a medium for earthworm cultivation, which is a source of natural enzymes. In this way, the county expects to continue increasing its level of well-being.

Biyang in Henan Province

Biyang is the home of the Flower (Cracked) Mushroom. Biyang County is located about 400 km southwest of Zhengzhou, the provincial capital of inland Henan. Zhengzhou was the cradle of Chinese civilization at the start of the Shang dynasty, nearly 4000 years ago. These days, Zhengzhou is best known as an inland transport hub, a crossroad for train and highway. The county is surrounded by two mountain ranges that are rich in oak trees. Forests cover approximately half the county, and only 40% is farmland. The county has a population of 910,000, of which 800,000 are engaged in farming. There is no industry in the county, and therefore it enjoys the advantage of not being burdened by air or water pollution. In 1992, it was decided to proceed with the economic development of the county based on the creation of "The *Lentinula* Mushroom Economy." Within 5 years (in 1997), the value of mushroom production reached US $81 million, which represents 32% of the total value of agricultural production in the county.

Since the small rushy/plastic shed and big bag method of Biyang was developed and adopted, the average income of the farmer increased 5.5 times between 1991 and 1997. In the mountain ranges of the county, the cultivation of *Lentinus edodes* mushrooms, along with other mushrooms, has permitted the government to eliminate poverty in only a few years. Now the Biyang method has been introduced to 120 counties in 15 provinces. In 1997, 300 million mushroom bags had been planted, for a total production value of US $375 million. As a result of the influence of this new technique, many farmers

TABLE 8. Distinguished Mushroom Biologists Who Have Made Great Contributions to Mushroom Research, Cultivation, and Development in China

Name	Affiliation	Brief remarks
Chen, Meipeng (1902–1968)	Edible Fungi Institute, Shanghai Academy of Agriculture	Dr. Chen was the founding director of the Institute (1960), the first mushroom research institute in China. In 1928, he successfully introduced *Agaricus bisporus* from France to China. One of the scientists who contributed to the artificial cultivation of *Tremella fuciformis.*
Yang, Xinmei (1911–)	Huazhong Agricultural University, Wuhan, Hubei	Professor Yang advocated the establishment of the Applied Mycology Research Institute at the University (1978), which has become a leading institute for mushroom research and training in China. He adapted the germinated oidiospore as spawn for growing *Tremella fuciformis* (1941). His numerous students and large number of publications are testaments of his great influence in the mushroom industry of China.
Huang, Nianlai (1939–)	Sanming Mycological Institute, Sanming, Fujian	Professor Huang devoted much of his academic career to studying the life cycle of *Tremella fuciformis.* During a career already spanning more than 40 years, he has selected and adapted more than 20 mushroom species, many of which are cultivated commercially. His research and publications have contributed greatly to all aspects of the development of the mushroom industry in China.

can now produce high quality (flower/cracked) *Lentinula* mushrooms using sawdust mixed with other lignocellulosic biomass materials, and thereby are lifted from the poverty they had suffered for many years. I was very touched when a visit was arranged for me to see the *Lentinula* villages and composed a poem in order to express my emotions:

"*If we begin to look at what they have in their life today, what they did not have for many years, we begin to see what they will have more due to the blessing of a small creature, a Lentinula mushroom, which may change their life forever*" (Chang, 1999).

Pan'an in Zhejiang Province

Pan'an, the home of fresh *Lentinus edodes* mushrooms, is a mountainous county located in the middle of Zhejiang Province. It consists of 20 administrative villages and has a population of about 200,000 people. Mushroom cultivation has become a pillar of agro-economic development in the county. There are several special characteristics of mushroom cultivation and development in the county:

1. *L. edodes* is the main mushroom species cultivated in this county. Traditionally, it is only harvested in autumn and winter. However, Pan'an has developed several new varieties of the mushroom that can be cultivated all year round. Therefore, Pan'an can continually supply this fresh mushroom to the markets, amounting to a production of 40,000 tons annually.
2. Pan'an not only sells its locally produced fresh mushrooms, but it has also become a marketing hub for fresh *L. edodes* mushrooms from other counties. Many fresh *L. edodes* mush-rooms exchange hands in Pan'an markets en route to other destinations, either in China or overseas. These sales and exchanges are valued at approximately US $53 million. In addition, some are exported, and the exports account for approximately US $27 million. This accounts for one-third of the national export of fresh *L. edodes* mushrooms. There are 35 export companies in the county dedicated to these fresh *L. edodes* mushrooms.Together, these companies have a total of 50 cold rooms especially for the

TABLE 9. Innovative Mushroom Farmers Who Have Contributed to the Development of the Mushroom Industry in China

Name	Home County, province	Innovation
PAN, Zhaowan (1940–)	Gutian, Fujian	Invented the synthetic log method for the cultivation of *Lentinus edodes* (1982-1984). The basic technique of this invention was quickly adopted by other provinces, spurring the development of the *L. edodes* mushroom industry in China. This innovation is one of the reasons that China became the leading producer of *L. edodes* mushrooms in 1987 and has dominated the world market for this mushroom ever since.
DAI, Wenhau (1952–)	Gutian, Fujian	Invented the plastic bag method for the cultivation of *Tremella fuciformis* (1979). This important breakthrough, away from the bottle method, has led to higher yields and enhanced the mass production of this mushroom commercially. This has led to Gutian becoming the capital of *T. fuciformis* mushroom production in China.
QI, Jianxun (1962–)	Biyang, Henan	Inventor of the Biyang Flower (cracked) *Lentinus edodes* (early 1970s). Following the use of the small rushlike/plastic shed and the introduction of the big bag method, the average income of farmers in Biyang has increased 5.5 fold (between 1991 and 1997). The key feature of this innovation is using fluctuations in temperature, as well as moisture content, to generate the "cracking" of the mushroom skin.

storage of their fresh mushrooms.

3. Pan'an is now one of the leading producers of high-temperature mushroom strains in China, so the *L. edodes* mushroom can be grown in summer. In 1992, production of this summer strain of *L. edodes* was valued at approximately US $6.25 million.
4. Because China is a now a member of the World Trade Organization (WTO), all products for export now face great challenges with respect to safety and quality control. Pan'an has also taken up this challenge in relation to its exports of fresh *L. edodes* mushrooms by imposing high standard regulations with regard to the safety and quality of the mushrooms. In 2003, the Pan'an government published a document setting out various codes and rules to be observed by companies and farmers.
5. In recent years, Pan'an has evolved from a producer of a singe mushroom species—that is, *L. edodes*—to a producer of multiple cultivated mushroom species, including *Auricularia auricula, Grifola frondosa, Flammulina velutipes, Hericium erinaceus, Coprinus comatus, Pleurotus eryngii, P. nebrodensis, P. ostreatus,* and *Agrocybe aegerita.* However *Lentinus edodes* mushrooms still account for 80% of the county's total mushroom production.

THE CHINESE EXPERIENCE—SOME REASONS BEHIND THE SUCCESS

This dramatic expansion in mushroom production in China during the last 13 years (1990–2003), from 1 to 8.6 million tons, is due mainly to the following seven reasons.

1. Strong leadership and initiative of provincial and county governments in adopting new cultivation techniques and promoting production. Under these governments, there is usually a special section called the "Office of Mushroom Production," which bears responsibility for mushroom research, production and training. This office frequently organizes mushroom farming training courses for farmers.
2. Strong scientific support from the academic

institutions in China. The Edible Fungi Institute at the Shanghai Academy of Agricultural Sciences; the Institute of Applied Mycology at the Huazhong Agricultural University in Wuhan, Hubei Province; the Sanming Mycological Research Institute in Sanming, Fujian Province; China National Research Institute of Food and Fermentation in Beijing; Guangdong Microbiology Research Institute in Guangzhou, Guangdong Province; Fujian Light Industry Research Institute in Fuzhou, Fujian Province; and the Kunming Edible Fungi Research Institute in Kunming, Yunnan Province, are the leading institutes for various aspects of mushroom research.

3. Proliferation of mushroom scientists and scholars with, among others, the China Agricultural University in Beijing, the Huazhong

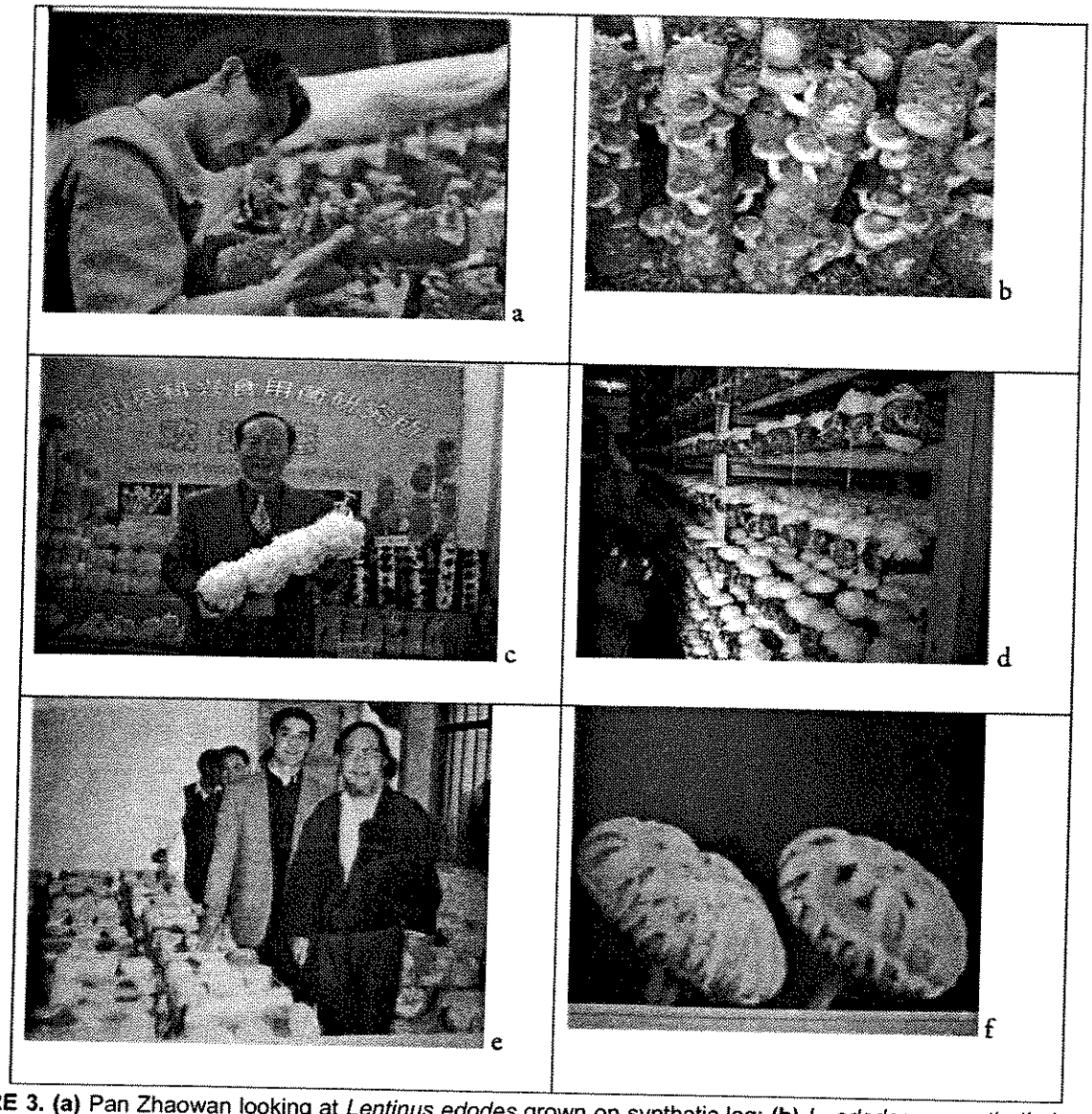

FIGURE 3. (a) Pan Zhaowan looking at *Lentinus edodes* grown on synthetic log; **(b)** *L. edodes* on synthetic logs laid in the field; **(c)** Dai Wenhau holding four *Tremella fuciformis* "flowers" in a plastic bag; **(d)** plastic bags of *T. fuciformis* mushrooms laid on shelves; **(e)** Qi Jianxun (second from the front) with big bags with three inoculums laid on the floor; **(f)** Biyang Flower (cracked) *Lentinus edodes.*

TABLE 10. Notable Mushroom Journals in China

Name	Year and place of initiation	Founder/first Editor-in-Chief	Frequency	Main features (language)
Edible Fungi	1979, Shanghai	Zhang, Puan	Bimonthly	Promoting practical mushroom cultivation techniques (Chinese)
Edible Fungi of China	1982, Kunming, Yunnan	Zhang, Guangya	Bimonthly	Basic scientific mushroom papers (Chinese with English summaries)
Acta Edulis Fungi	1994, Shanghai	Xu, Chongjing	Quarterly	Academic papers (Chinese with English summaries)
Mushroom Market	2001, Shenzhen (now Beijing)	Li, Yuchun	Monthly	Marketing information (Chinese)

Agricultural University in Wuhan,the Nanjing Agricultural University in Nanjing, and the Fujian Agricultural and Forestry University in Fuzhou, offering MSc and PhD degree programs in mushroom-related areas.

4. Many devoted mushroom biologists who have made extraordinary contributions to mushroom research, cultivation, and development in China. Three of the most distinguished are cited in Table 8. There are also several new mushroom stars (young mushroom scientists) emerging on the industry's horizon.
5. Many innovations in mushroom cultivation technology by talented mushroom farmers. For example, the synthetic log method for the cultivation of *Lentinus edodes* was invented by Mr. Pan Zhaowan, the plastic bag method for cultivation of Tremella fuciformis by Dai Wenhau, and the technology of the Biyang Flower (cracked) *Lentinus edodes* by Qi Jianxun (Table 9 and Fig. 3). These technologies alone have done much to raise the living standards of the farmers.
6. Notable mushroom journals (Table 10, Fig. 4) that have not only communicated valuable knowledge of mushroom biology to mushroom researchers but also disseminated the latest, newly developed cultivation technology and marketing information to mushroom farmers.
7. Expansion of the domestic market, which is also a key factor in the increased scale of cultivation of edible mushrooms in China as a result of improvements in the national economy. China has been a rapidly growing economy since economic reform began in 1978, having an estimated 9.2% GDP growth last year and maintaining an average annual growth rate of 9% for the past 25 years (Hutzler, 2005). Accordingly, living standards have soared over the past 25 years, with GDP per capita having increased about 600% between 1978 and 2003 (Fig. 5). This is a highly commendable result, especially when compared to growth rates of industrialized countries (Fig. 6). Many of the mushrooms produced are finally reaching consumers in China's domestic market. This will be a key area for expansion of the mushroom industry. It is estimated that it is possible for China to maintain an annual growth of 7–8% for the next 10 years. At that rate, China's GDP, measured at PPP (purchasing power parity), could overtake that of the United States by 2020 (*The Economist,* 2004).

Indeed, historically, China has been ahead of most of the world (Cox and Koo, 2003) However, to-

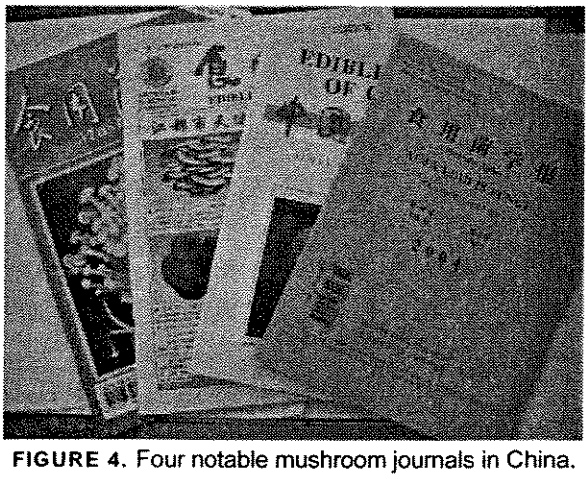

FIGURE 4. Four notable mushroom journals in China.

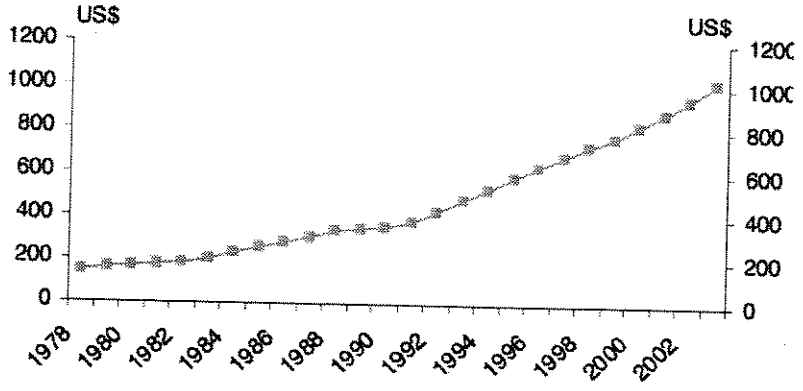

FIGURE 5. GDP per capita (1978–2003). Source: World Development Indicators, World Bank, 2004.

ward the end of the Ming Dynasty (1368–1644) and throughout the Qing dynasty (1644–1912), China's GDP per capita was virtually unchanged for more than 300 years. China's recent rapid increase in GDP per capita is reminiscent of Western Europe's period of industrial revolution in the nineteenth century, which sent European economies soaring. The resulting benefits for Europe are clearly evident today, and it is to be hoped that China will reap further rewards from its current reforms in the years to come. Currently, China is the sixth largest economy in the world, in terms of GDP (Fig. 7). However, using PPP measurements, China is actually the second largest economy, after the US (*The Economist*, 2004).

THE CHINESE EXPERIENCE: STILL ROOM FOR IMPROVEMENT

The mushroom industry in China has proved its production capacity to the world. However, it must now also prove its commitment in other areas.

1. Quality control is important in securing consumer confidence and, consequently, creating a solid and stable market. This involves producing higher quality mushrooms on a regular and reliable basis through closer scrutiny of sources of mushroom production. A verifiable source is of paramount importance. Growing mushrooms under more ecologically friendly environmental conditions characterized, for example, by clean air and clean water, as well as an absence of insect pests and harmful chemicals, is vital for attracting consumers.
2. Breeding and selection of desirable strains that should have incorporated local germ plasma will mean mushrooms are more adaptive to local growing conditions and will generate more predictable and reliable yields. Knowledge and ability to harvest mushrooms during optimal maturity will ensure higher grade mushrooms. Furthermore, development of grading

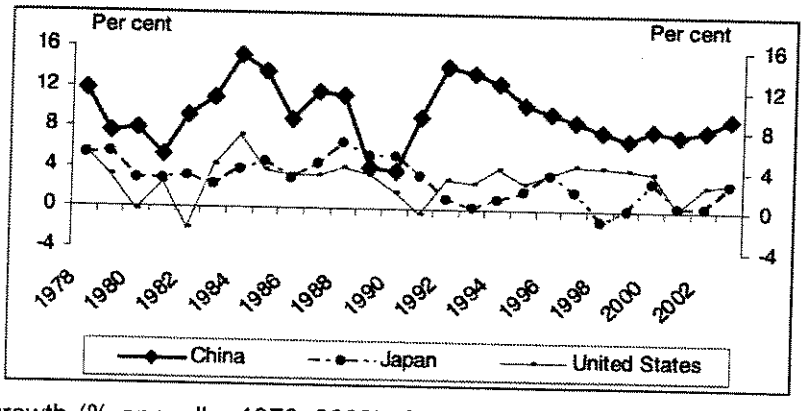

FIGURE 6. GDP growth (% annually, 1978–2003). Source: World Development Indicators, World Bank, 2004.

protocols for identifying low- through high-quality mushrooms and pricing accordingly will present clearer choices to consumers and, ultimately, generate more profits for farmers and merchants.

3. Further technological development strategies are needed that focus on the market-driven generation of value-added goods. These should include improvement in the freshness of the harvested mushrooms, extending present shelf lives of 1 week to at least 2 weeks, and the introduction of precut and premixed mushroom and vegetable packages. These actions will dramatically increase the value of the mushrooms and in turn generate more income for the farmers.
4. A complementary major challenge to the mushroom industry in China is to enter the era of management, marketing, and further promotion of research. In particular, improvements in communication technology are vital for modern business transactions.
5. Increases in international contact should be stressed—for example, by encouraging attendance at international mushroom conferences overseas. Improvement in the standing of the Chinese mushroom community internationally should also be encouraged by hosting international conferences, producing and publishing more good quality scientific articles in international journals, and even establishing a home-based international journal for mushroom sciences.
6. The establishment of a national/international mushroom school is desirable, because it can serve to provide a reference point for all mushroom-related matters and provide coherent and systemic training. Fostering greater theoretical knowledge of mushroom biology, developing practical cultivation skills, and improving marketing strategies can be core functions of such an institution. Through this, mushrooms and mushroom products will naturally be granted greater attention.

THE CHINESE EXPERIENCE: POSSIBILITIES FOR DEVELOPING COUNTRIES

China's success in the development of its mushroom industry during the past two and half decades should serve as an example for what is possible in other developing countries. We should make a concerted effort to lobby government and industrial organizations, reminding them that research and development in the mushroom industry is not a luxury but a national necessity for human welfare.

Strategies that could be followed by less developed mushroom production industries in various developing countries could include:

- Initially, a strategy not based on the use of highly mechanized technologies (as in large farms located in industrialized countries), but the promotion of cottage style enterprises for the rural poor, in thousands of small mushrooms sheds, constructed using locally avail-

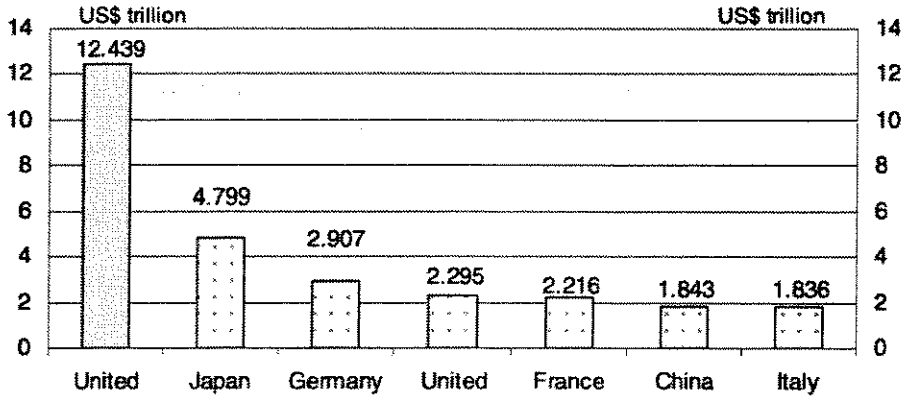

FIGURE 7. The seven largest economies in the World, by GDP (2005). Source: IMF World Economic Outlook database, April 2005.

able materials (such as those used in China at the beginning of its mushroom industry).
- A subsequent move toward the gradual introduction and familiarization of the art of large-scale commercial cultivation techniques. This was the path China followed from its humble beginnings to its current status as the world's leading mushroom production powerhouse.
- Selection of appropriate target strains of different mushrooms grown on a seasonal basis.
- Use of existing lignocellulosic residues and waste from agricultural activities and agro-industries.
- Creation of employment opportunities, particularly for women and the youth in rural areas, and control of pollution.
- Emphasis on rapid-investment-return mushrooms and selection of relatively fast growing species that can be harvested within 3–4 weeks after spawning, thus generating immediate benefits.
- Promotion of mushroom species that have been demonstrated to generate potent nutriceuticals with superior immune-enhancing attributes—that is, species whose natural products include unique bioactive compounds that can make people healthier and fitter.

CONCLUDING REMARKS

The mushroom industry in China, like every science, has two aspects: theoretical (academic) and practical applications. It is like the two faces of a coin: inseparable and yet distinct. Knowledge of one is bound to enhance that of the other. The two are invariably complementary to each other, and only by combining the knowledge of academic research and the practical experience of the farmer to achieve a common goal (continual improvements in the mushroom industry) will there be mutual benefits for researchers and growers. Furthermore, it is the combination of the factors set out above that has led to improved cultivation technologies and the introduction of a broader variety of species at both the small-scale and industry-scale farming levels.

It is important to emphasize that, although science and farming practices have led to the development of some universal or general concepts concerning mushroom cultivation, the diverse biological nature of the process (in which large numbers of mushroom species and natural organic substrates are involved) also means that a wide spectrum of variations in farming methods must be employed. Thus the transfer of mushrooms from one region or country to another cannot be treated in the same way as the transfer of nonbiological industrial technology, such as that of a complete complex of factory equipment for textile or chemical fertilizer industries. Because the cultivation of mushrooms deals with living organisms, one should consider not only the unique attributes of the mushroom itself and of the various microorganisms growing with it (both harmful and beneficial), but also the biochemical nature of the substrates. Specific methods must be tailored in accordance with the prevailing unique natural resources heritage, local climate, and socio-economic conditions of the farming community. All these considerations call for a critical mass of well-trained mushroom scientists.

It should be emphasized that both mushroom crops (the mushrooms themselves) and mushroom products (mushroom derivatives) should be of good quality and free from potentially harmful substances. Reproducible quality, recognized grade, and trustworthy products are of paramount importance in earning enduring public credibility and in securing an expanding and stable market. However, as the market develops and mushroom-based products assume more functional food and mushroom nutriceutical (dietary supplement) roles, regulatory controls will inevitably become more stringent. Three levels of control should be considered: (1) control of the raw materials, (2) control of the cultivation and manufacturing process, and (3) control of the final product.

The bright long-term future of the Chinese mush-room industry can be maintained by virtue of the comparative advantage that lies in its huge domestic market. This is despite enormous commercial challenges posed by other developing countries striving to develop their own mushroom industries. China's steady GDP growth rates of around

9% over the last two and half decades, and predictions of continued high rates of growth, mean that the highest potential for China's mushroom industry is its own domestic market. Although external trade has contributed much to the rise of China's mushroom industry and will remain important, the next big opening for China's mushroom industry is China itself. Of great importance will be the ability to persuade people to eat more of the mushrooms that are being produced. The marketing strategy should be based on scientific data showing the beneficial characteristics of the mushrooms and their products—low fat and carbohydrate content, high content of vitamins and trace elements, and health-related attributes, such as possible immunopotentiating, antitumor, and anticancer properties.

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