Mushroom Biology and Mushroom Products, Royse (ed.) © 1996 Penn State Univ. ISBN 1-883956-01-3

Mushroom Research and Development — Equality and Mutual Benefit

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ABSTRACT: This conference is about both the basic and applied aspects of mushroom biology because the two can not be separated for any mushroom-based industry; either for mushroom production through the development of mushroom science, or for mushroom products through the evolution of mushroom biotechnology. It is our earnest desire to combine the knowledge of the biological nature of mushrooms with established practical methodology and applications relating to both mushroom production and mushroom products. Academic research and applied development are two aspects with a single purpose — improvement of the mushroom industry. Both features are of equal importance to the industry, and mutually beneficial. Academic researchers and applied growers should respect and enjoy each other's achievements, and try to understand and help resolve and overcome each other's problems. The present status of the mushroom industry is the product of the collaborative efforts of both groups, and the industry's future depends on continued close cooperation. In 1994, world production of cultivated mushrooms was estimated to be 4,909.3 thousand tons. World output was valued at about 9.8 billion dollars while a further 3.6 billion dollars was generated from mushroom products. The concept of an open-minded mushroom society and a new term "mushroom nutriceutical" will also be discussed.

1 INTRODUCTION

Although mushrooms have long been appreciated for their flavor and texture, and some for medicinal and tonic attributes, recognition that they are nutritionally a very good food and physiologically an important potential

source of biologically active compounds of medicinal value is much more recent. It is now known that mushrooms are rich in high quality protein, contain a high proportion of unsaturated fatty acids, and have a nucleic acid content low enough to allow daily use as a form of vegetable (Li and Chang 1982). Moreover, latter-day application of modern analytical techniques has, in a number of cases, provided a scientific basis for assigning medicinal value through the identification of various mushroom-derived compounds including anti-cancer, anti-viral, immunopotentiating, hypocholesterolaemic and hepatoprotective agents (Mizuno *et al.* 1995, Liu *et al.* 1995 and in press, Wang *et al.* 1995a,b).

Sustainable success of mushroom-based industries depends on both research and development. Flegg (1995) has given a simple and clear statement of the relationship between research and development. I quote: "Research is trying to discover information or ideas which have hitherto been unknown or, at most, only vaguely guessed at or imagined. Development is trying to make practical and commercial use of existing information, both new and old. Often it gets quite complicated so that the R and D cannot easily be distinguished. In order to complete the D arising from R, it may be found necessary to do some more R and the two might be carried on at the same time or more or less interlinked."

Regrettably, during an international mushroom science congress held in 1995, some growers commenting about the congress complained that many of the lectures and papers were too scientific and the content not readily understandable. After lengthy discussion of the issue, one grower even suggested that scientific material submitted to the next such congress should be carefully examined to determine if the content was relevant to the mushroom industry and, moreover, readily comprehensible to the mushroom growers.

In my view, if the mushroom science community continues to develop as a single-minded rather than an open-minded society, its potential to become one of the world's important organizations will decline. In this context, a single-minded society is defined as one which attempts to restrict the scientific content of international gatherings to items that are arbitrarily assessed to be comprehensible and of relevance only to growers, and which insists that responsibility for better communication between the growers and scientists rests solely with the latter group. Conversely, an open-minded society advocates no restriction on either scientific or technical papers provided they reach the required academic and practical standards even though this open and more flexible approach may sometimes lead to communication difficulties. In reality, the content of some scientific papers are not always fully appreciated by fellow scientists. Contributors attending international scientific meetings do so in order to obtain and

exchange specific knowledge and techniques, either during formal sessions or informally when participating in associated social activities. Not every paper or activity is appreciated by all participants.

It is my opinion that a mushroom society, when standing at a T-junction with a road sign to the left saying "single-minded" and another to the right indicating "open-minded", should consider carefully the long-term consequences of the route it ultimately elects to take. If it goes along the single-minded road adopted by vocal, self-interested minority groups who believe that the society should show only one side of the coin and emphasize only one aspect of the industry, the end result will be shrinkage and decay. On the other hand, if the society takes the open-minded road along which there will be signposts marked "equality", "mutual benefit", "respect for, and tolerance of, other opinions", it will grow to greatness. It is my strong belief that an international mushroom science society has no option other than to take the open-minded road since this represents the only sensible option for successful future development and expansion. It should be remembered that the society exists not only for mushroom growers but also for mushroom scientists. The relationship between the two groups should be based on equality, harmony, and mutual respect and benefit, not on hostility, discord and hegemony.

In the past, the mushroom industry concentrated mainly on the production of fresh, canned and dried mushrooms for food. Thus, the industry had only one leg. In the present era, due to high-pressure work demands which are considered to cause greater stress to the human body and to result in the weakness of the human immune system, a variety of proprietary products based on mushroom nutriceuticals and mushroom pharmaceuticals have already been produced and marketed. This trend is expected to increase with wider consumer satisfaction and acceptability. This is the second leg of the industry and is soon expected to become the dominant segment of the industry. These two segments of the mushroom-based industry will not compete but will complement each other.

2 RECENT TRENDS IN MUSHROOM PRODUCTION

World production of cultivated edible mushrooms totalled 3,763 thousand tons and 4,909.3 thousand tons in 1990 and 1994, respectively (Table 1). The average price received by growers in the United States in 1990-1991 was reported to be 88.8 cents per pound (NASS 1991, Chang and Miles 1992), and if this figure is used again for estimation purposes, the total world mushroom crop in 1994 is valued at $9.8 billion. In those four years mushroom production increased 30.5%, and annual increase 7.6%.

A comparison of production between 1990 and 1994 reveals that, with the exception of *Pleurotus*, output of all other cultivated mushroom species increased during that period, ranging from 0.5% for *Auricularia* up to 141.6% for *Hypsizygus*. Other large increases were observed in the case of *Lentinula* (110.2%) and *Grifola* (102.8%). This trend of increased production is expected to continue due to advances both in our basic knowledge of mushroom biology and in the practical technology associated with mushroom cultivation.

Table 1. Comparison of 1990 and 1994 world production of cultivated edible mushrooms. (unit: metric tons x 1000).

Species	1990 Fresh wt.	1990 %	1994 Fresh wt.	1994 %	% increase
Agaricus bisporus/bitorquis	1424.0	37.8	1846.0	37.6	29.6
Lentinula edodes	393.0	10.4	826.2	16.8	110.2
Pleurotus spp.	900.0	23.9	797.4	16.3	–11.4
Auricularia spp.	400.0	10.6	420.1	8.5	0.5
Volvariella volvacea	207.0	5.5	298.8	6.1	44.3
Flammulina velutipes	143.0	3.8	229.8	4.7	60.7
Tremella fuciformis	105.0	2.8	156.2	3.2	48.8
Hypsizygus marmoreus	22.6	0.6	54.8	1.1	141.6
Pholiota nameko	22.0	0.6	27.0	0.6	22.7
Grifola frondosa	7.0	0.2	14.2	0.3	102.8
Others	139.4	3.7	238.8	4.8	71.3
Total	3,763.0	100.0	4,909.3	100.0	30.5

The production of edible mushroom species under commercial cultivation in various individual countries in 1994 is shown in Table 2. In percentage terms, output yields of 10 cultivated mushrooms made up 95.1% of the total world production. The big six mushrooms, *Agaricus* (37.6%), *Lentinula* (16.8%), *Pleurotus* (16.3%), *Auricularia* (8.5%), *Volvariella* (6.1%) and *Flammulina* (4.7%) contributed up to 88.9%. It should be noted that amongst these six species, only *Agaricus* and *Pleurotus* are cultivated world-wide. Others are grown either on a national or regional basis, e.g. *Tremella* is cultivated mainly in China, and *Hypsizygus* and *Grifola* in Japan. Since 1988, there has been no production of *Agaricus bisporus* in Japan.

Table 2 also shows that China has become a giant producer of edible mushrooms. Total mushroom production in China in 1994 was 2,640,900 tons which amounted to 53.8% of world output. Production in the U.S. and in Japan made up 7.6% and 7.3%, respectively, of the world total. It is interesting to note here that Japan and South Korea are the

leading producers of *Tricholoma matsutake*, a semi-cultivated mushroom. Annual production in Japan decreased from 349 tons in 1993 to 120 tons fresh weight in 1994, a drop of almost 190%. The highest production figure of the mushroom in Japan was 6,484 tons in 1953. In 1994, S. Korea produced 139 tons which was exported primarily to Japan at a price higher than that from any other country.

Table 2. Estimated production of edible mushroom species under commercial cultivation in some countries in 1994. (fresh wt unit: M.T. x 1000).

Genus	China	Indonesia	Japan	S. Korea	Taiwan	Thailand	U.S.A.	Others	Sub total
Agaricus	359.0	28.0		9.8	7.2	1.3	370.0	1070.7	1846.0
Lentinula	632.0		141.3	20.1	28.1	0.3	2.5	1.9	826.2
Pleurotus	654.0	1.0	20.8	57.9	4.6	15.0	0.9	43.2	797.4
Auricularia	385.0	0.2	0.1		8.8	6.0		20.0	420.1
Volvariella	115.0	89.0			4.5	65.0		25.3	298.8
Flammulina	109.0		101.8	1.7	16.8			0.5	229.8
Tremella	156.0							0.2	156.2
Hypsizygus			54.4		0.3			0.1	54.8
Pholiota	4.3		22.6					0.1	27.0
Grifola			14.0					0.2	14.2
Others	226.6	0.6	5.1	2.5	1.5	2.0	0.5		238.8
Subtotal	2640.9	118.8	360.1	92.0	71.8	89.6	373.9	1162.2	
Grand total									4909.3

Although the cultivation of edible mushrooms dates back many centuries, research in this field is still 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 as a result of aid received from national and international agencies. Mushroom science dealing with mushroom production embodies the principles of mushroom biology, environmental technology, and solid state fermentation in the conversion of domestic agricultural, and industrial organic waste materials into food for humans. The technology for mushroom cultivation can be primitive, as in rural farming in developing countries. In developed countries, it can also be highly industrialized and require an advanced knowledge of biology and technology and the use of sophisticated equipment.

3 RECENT TRENDS IN MUSHROOM PRODUCTS

In addition to possessing highly desirable characteristics as a foodstuff, i.e. (1) mushrooms have remarkable taste and flavor; (2) they are nutritious; (3) they can be easily processed, dried, pickled and canned to facilitate

transportation and long-term storage, many edible mushrooms and medicinal mushrooms have been traditionally used in China, Korea and Japan for their medicinal and tonic properties. There is a saying in China which states "medicines and food have a common origin". Mushrooms are a manifestation of this idea in constituting both a nutritionally functional food and a source of physiologically beneficial and non-invective medicines. Examples include *Auricularia* spp. (wood ear mushrooms), which have traditionally been used to treat piles and various stomach ailments, *Tremella fusiformis* (jelly fungus) for maintaining healthy lung tissue, *Hericium erinceus* (monkey head mushroom) for sufferers of gastric ulcers, *Volvariella volvacea* (straw mushroom) for lowering blood pressure and accelerating the healing of wounds, and *Lentinula edodes* (shiitake) in the prevention of rickets and relief of excess gastric acidity. *Ganoderma lucidum*, an important and leading medicinal mushroom treasured in China for over two thousand years is considered to be a symbol of happy augury, and bespeaking of good fortune, good health, longevity, and even immortality. It has also been variously reported to have multi-beneficial value and concerted medicinal effects in the treatment of various diseases.

The recent application of modern analytical techniques has, in a number of cases, provided a scientific basis for these earlier empirical observations. For example, the pharmacological activities of *Ganoderma lucidum* have been attributed mainly to triterpenes and polysaccharides produced by the mushroom. More than 80 hepatoprotective triterpenoids and over 50 carcinostatic polysaccharides have been isolated from the basidiocarps and mycelia of *G. lucidum* and a related species, *G. tsugae* (Jong and Birmingham 1992, Su *et al.* 1993, Lindequist 1995). The antitumor effects of the polysaccharides are based on the enhancement of the host's immune system and hold considerable potential because of the absence of major side effects. In addition, the mushroom contains other substances which reduce blood pressure and blood sugar levels, eliminate cholesterol, and inhibit platelet aggregation (Liu 1993, Minuno *et al.* 1995, Zhu and Mori 1993). Several polysaccharides and protein-bound polysaccharides with immunomodulatory and antitumor activities have now been isolated from a variety of mushrooms. Notable examples include lentinan (Chihara 1990, 1993), PSK (Sakagami and Takeda 1993), PSP (Yang *et al.* 1993), polysaccharide-proteins extracted from *Coriolus versicolor*, PSPC (Liu *et al.* 1995 and in press; Wang *et al.* 1995a and in press a), a protein-bound polysaccharide complex from *Tricholoma* sp., lectins from *Tricholoma mongolicum* (Wang *et al.* 1995b and in press b), and a glucan material from *Grifola frondosa* (Mizuno and Zhuang 1995). PSK (trade name Krestin) is a protein-bound polysachharide extracted from the mycelium of *C. versicolor* which displays various unique biological activi-

ties including the stimulation of functional maturation of macrophages and an ability to scavenge active oxygen species. PSK is widely prescribed for cancers of the digestive organs (stomach, oesophagus colon) in Japan (Fukushima 1989), while PSP is reported in China (Yang *et al.* 1992, 1993) to eliminate the immunosuppressive function associated with chemo- and radiotherapy in cancer treatments. The production, characterisation and medicinal properties of PSPC are under investigation by a group of researchers from the Department of Biology and Anatomy at The Chinese University of Hong Kong. This polysaccharide-protein complex is derived from a local species of *Tricholoma* and appears to possess immunomodulatory and antitumor activities which are superior to similar products from other mushrooms. Although the precise mechanism of action of these compounds has not yet been elucidated, there is evidence of host-mediated rather than direct cytocidal effects. For example, the inhibitory effects of mushroom polysaccharides and protein-bound polysaccharides on the growth of sarcoma 180 implanted in mice have been attributed to the stimulation of the cell mediated immune response. Immunomodulatory responses are reported to involve several different agents including activated macrophages, natural killer cells, cytotoxic T cells and their secretory products such as tumor necrosis factor, reactive nitrogen and oxygen intermediates and interleukins (Liu *et al.* 1995 and in press).

The recent upsurge of interest in traditional remedies for various physiological disorders and the recognition of numerous biological response modifiers in mushrooms has led to the coining of the term "mushroom nutriceuticals" (Chang and Buswell, to be published). A mushroom nutriceutical is a refined/partially defined mushroom extractive which is consumed in the form of capsules or tablets as a dietary supplement (not a food), and which has potential therapeutic applications. A regular intake may enhance the immune response of the human body thereby increasing resistance to disease and, in some cases, cause regression of a disease state. Although the general public remains cautious and sometimes doubts the effects of these products, there is certainly a greater awareness of and interest in non-drug cures, particularly for *Ganoderma* mushroom extracts, as illustrated by the recent boom in health concern and natural cures. Wong (1996) reported that, in a curious reverse process, Western-trained Asian doctors are being influenced by doctors from the West and Australia where, in recent years, there has been a greater acceptance of non-mainstream medical practices involving the use of herbs, mushrooms and other natural cures. Therefore, enormous potential exists for mushroom biotechnology in developing mushroom products into mushroom nutriceuticals and mushroom pharmaceuticals. Much further research effort is now needed to characterize and standardize the bioactive

ingredients of mushrooms products since good quality and honest products are of paramount importance in earning enduring public credibility and securing an expansive market in the future.

4 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 both of (a) supplementing the nutrition of the majority of humankind through mushroom production, and (b) of alleviating the suffering caused by certain kinds of illness using mushroom products. It is believed that advances in the scientific study of mushroom biology and in the technological development of the mushroom-based industries would be served best if research into both these aspects could be jointly coordinated and were to be supported on a reciprocal basis.

It is important to know how, and to what extent, the benefits of both mushroom production and mushroom products can be maximized. No matter whether you wish to increase mushroom production through the advancement of mushroom science, or the enhance the yield of mushroom products through improvements in mushroom biotechnology, it is important to understand the nature of past benefits and to acknowledge and recognize how those benefits were achieved. Mushroom science and mushroom biotechnology are the two legs of the mushroom industry. In 1994, the value of the world mushroom crop is estimated to be 9.8 billion dollars, whereas mushroom products are assessed to have generated 3.6 billion dollars. Since trends are changing and greater attention is being paid to quality control, it will be no surprise to see mushroom products, the second leg of the industry, developing rapidly during the next decade.With these two strong legs, the mushroom industry will run into the 21st Century.

The major accomplishment of international meetings is the sharing of the latest information relating to research and development — both fundamental and applied. More specifically, the International Conferences on Mushroom Biology and Mushroom Products serve to establish a wider group of mushroom scientists and mushroom industrialists. An important feature of the conferences is the recognition of the nutritional, nutriceutical, and medicinal studies that have been undertaken with mushroom products. Furthermore, these international meetings have served well to integrate basic and applied research. It is recognized by most scientists that these two types of research and development strongly complement one another and are of mutual benefit.

REFERENCES

Chang, S. T. and P. G. Miles 1992. Mushroom biology—A new discipline. The Mycologist 6:64-65.

Chihara, G. 1990. Lentinan and its related polysaccharides as host defense potentiator: their application to infectious diseases and cancer. In: Immunotherapeutic prospects of infectious diseases, pp. 9-18. Edited by K. Noel Masihi and W. Lange. Springer-Verlag, Heidelberg.

Chihara, G. 1993. Medical aspects of lentinan isolated from *Lentinus edodes* (Berk.) Sing. In: Mushroom biology and mushroom products, pp. 261-226. Edited by S.T. Chang, J.A. Buswell & S.W. Chiu. The Chinese University Press, Hong Kong.

Flegg, P. 1995. Research and development. Mush. J. 550:28.

Fukushima, M. 1989. The overdose of drugs in Japan. Nature 342:850-851.

Jong, S. C. and J. M. Birmingham. 1992. Medicinal benefits of the mushroom *Ganoderma*. Adv. Appl. Microbiol. 37:101-134.

Lindequist, U. 1995. Structure and biological activity of triterpens, polysaccharides and other constituents of *Ganoderma lucidum*. In Recent advances in *Ganoderma lucidum* research, pp. 61-73. Edited by B.K. King, I.H. King and Y.S. King. The Pharmaceutical Society of Korea.

Liu, F., V .E. C. Ooi and S. T. Chang. 1995. Anti-tumor components of the culture filtrates from *Tricholoma* sp. World J. Microbiol. Technol. 11:486-490.

Liu, F., V. E. C. Ooi, W. K. Liu and S. T. Chang. In press. Immunomodulation and anti-tumor activity of polysaccharide-protein complex from the culture filtrate of a local mushroom, *Tricholoma* sp. General Pharmacology.

Liu, G. T. 1993. Pharmacology and clinical uses of *Ganoderma*. In: Mushroom biology and mushroom products, pp. 267-273. Edited by S.T. Chang, J.A. Buswell & S.W. Chiu. The Chinese University Press, Hong Kong.

Mizuno, T., G. Wang, J. Zhang, H. Kawagishi, T. Nishitoba and J. Li. 1995. Reiihi, *Ganoderma lucidum* and *G. tsugae*: Bioactive substances and medicinal effects. Fd. Rev. Internat. 11:151-166.

Mizuno, T. and C. Zhuang. 1995. Maitake, *Grifola frondosa*: Pharmacological effects. Fd. Rev. Internat. 11:135-149.

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

Sakagami, H. and M. Takeda. 1993. Diverse biological activity of PSK (Krestin), a protein- bound polysaccharide from *Coriolus versicolor* (Fr.) Quel. In: Mushroom biology and mushroom products, pp. 237-245. Edited by S.T. Chang, J.A. Buswell & S.W. Chiu. The Chinese University Press, Hong Kong.

Su, C. H., M. N. Lai and M. H. Chan. 1993. Gepato-protective triterpenoids from *Ganoderma tsugae murrill*. In: Mushroom biology and mushroom products, pp. 275-283. Edited by S. T. Chang, J. A. Buswell and S. W. Chiu. The Chinese University Press, Hong Kong.

Wang, H. X., W. K. Liu, T. B. Ng, V. E. C. Ooi and S. T. Chang. 1995a. Immunomodulatory and anti-tumor activities of a polysaccharide-peptide complex from a mycelial culture of *Tricholoma* sp., a local edible mushroom. Life Sci. 57:269-281.

Wang, H. X., T. B. Ng, K. W. Liu, V. E. C. Ooi and S. T. Chang. 1995b. Isolation and characterization of two distinct lectins with antiproliferative activity from the cultured mycelium of the edible mushroom *Tricholoma mongolicum*. Intl. J. Peptide Protein Res. 46:508-513.

Wang, H. X., T. B. Ng, V. E. C. Ooi, W. K. Liu and S. T. Chang. In press a. A polysaccharide-peptide complex with immunoenhancing and antitumor activities from cultured mycelia of *Tricholoma mongolicum*. Biochemistry and Cell Biology.

Wang, H. X., K. W. Liu, T. B. Ng, V. E. C. Ooi and S. T. Chang. In press b. The immunomodulatory and antitumor activities of lectins from the mushroom *Tricholoma mongolicum*. Immopharmacology.

Wong, E. 1996. The fungi that spellbound Qin Shi Wang. Asia 21. Feb. 1996:20-24.

Yang, Q. Y., S. C. Jong X. Y. Li, J. X. Zhou, R. T. Chen and L. Z. Xu. 1992. Antitumor and immunomodulating activities of the polysaccharide-peptide (PSP) of *Coriolus versicolor*. EOS-J. Immunology Immunopharmacology 12:29-34.

Yang, Q. Y., Y. J. Hu, X. Y. Li, S. X. Yang, X. J. Liu, T. F. Liu, G. M. Xu and M. L. Liao. 1993. A new biological response modifier—PSP. In: Mushroom biology and mushroom products, pp. 247-259. Edited by S.T. Chang, J.A. Buswell & S.W. Chiu. The Chinese University Press, Hong Kong.

Zhu, S. and M. Mori. 1993. The research on *Ganoderma lucidum* (part one). Shanghai Medical University Press.