

## NUTRICEUTICALS FROM MUSHROOMS

### **S.T. Chang**

*Department of Biology and Centre for International Services to Mushroom Biotechnology, The Chinese University of Hong Kong, Hong Kong SAR, China;*

### **J. A. Buswell**

*Institute of Edible Fungi, Shanghai Academy of Agricultural Sciences, Shanghai, China.*

**Keywords:** dietary supplements, nutraceuticals, mushroom nutraceuticals, polysaccharide, immunomodulatory agents, antitumour effects, antioxidants, genoprotection, anti-diabetic activity, antibiotics, quality control.

### **Contents**

1. Introduction
  2. Nutritional value of mushrooms
  3. Nature of bioactive components of mushrooms
  4. Biological effects of mushrooms and mushroom products
    - 4.1. Antitumour/anticancer effects
    - 4.2. Antioxidant-genoprotective effects
    - 4.3. Hypoglycaemic/antidiabetic effects
    - 4.4. Hypocholesterolaemic effects
    - 4.4. Antibiotic effects
    - 4.5. Other effects
  5. Mushroom nutraceuticals
  6. A protocol for quality mushroom nutraceuticals
- Glossary  
Bibliography  
Biographical Sketches

### **Summary**

The perception of mushrooms as a highly nutritional foodstuff is well founded. Compositional analyses of the main cultivated varieties have revealed that, on a dry weight basis, mushrooms normally contain between 19 and 35 percent protein. The low total fat content, and the high proportion of polyunsaturated fatty acids (72 to 85 percent) relative to total fatty acids, is considered a significant contributor to the health value of mushrooms. The recent application of modern analytical techniques has provided a scientific basis for their medicinal properties. The multi-functional effects of mushroom nutraceuticals/dietary supplements are based on the enhancement of the host's immune system and hold considerable potential benefit to health care because of the absence of major side effects.

There is no doubt that mushroom-based products, mushroom nutraceuticals, can serve as superior dietary supplements to improve biological functions and contribute to human fitness and health. Commercialisation of these products is a rapidly expanding industry

with the current market value of medicinal mushroom/ dietary supplement products worldwide estimated to be in excess of US\$12 billion per year. Precisely how mushroom nutraceuticals exert their effects is still a matter of conjecture, but numerous laboratory and human trials have shown many of them to function mainly through their immunomodulating properties. However, mushroom-based dietary supplements are highly diverse, and a major problem faced by the industry is the current lack of standard production protocols and critical testing procedures for guaranteeing product quality and safety. The establishment of standard production protocols, strict adherence to these protocols, and appropriate monitoring and control is essential both to increase and maintain consumer confidence, and to meet the current and future standards set by the regulatory authorities.

## 1. Introduction

Humankind has constantly searched for new substances that can improve biological functions and thereby make people fitter and healthier. Recently, Western society has placed greater emphasis on plants, herbs and foods as sources of these enhancers. About 3.5 billion people worldwide rely on plant-based medicines/dietary supplements for their primary health care. These products have variously been called: vitamins, dietary supplements, functional foods, phytochemicals, nutraceuticals and nutraceuticals. Dietary supplements are ingredients extracted from foods, herbs and plants that are taken without further modification outside of foods for their presumed health-enhancing benefits. During the past decade, there has been a major expansion in the industries involved in providing these substances, especially in the United States. In 1990, US diet-supplement sales were valued at US\$3.3 billion; in 1992, US\$3.7 billion; in 1994, US\$5.0 billion; in 1996, US\$6.5 billion; in 1998, US\$12.0 billion; and in the year 2000, it was estimated to have reached US\$14.0 billion.

In 1994, worldwide sales of medicinal mushrooms, mushroom extracts and various derived products were estimated at US\$3.8 billion. By 1999, this figure had risen to US\$6.0 billion. In regional terms, Asia and Europe accounted for approximately 99% of this market with North America contributing less than 0.1% to the overall total. In 2002, mushroom products (mushroom derivatives from medicinal, edible and wild mushrooms) used mainly for dietary supplements (mushroom nutraceuticals) was assessed to have generated about US\$11 billion. In 1994, the US market for mushroom-based dietary supplements had an estimated value of US\$35 million. However, since that time, demand in North America for medicinal mushrooms and derived products has increased by between 20-40% annually depending upon the species.

Mushrooms have long been appreciated for their flavour and texture, and some for medicinal and tonic attributes. However, recognition that they represent a nutritious food and an important source of biologically active compounds of medicinal value has been much more recent. Mushrooms are now known to be rich in high quality protein, to contain a high proportion of unsaturated fatty acids, and to have nucleic acid contents low enough to allow them to be eaten on a regular basis as a form of vegetable. Moreover, the 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, eg., polysaccharides, triterpenoids, lectins, steroids, proteins and protein-bound-polysaccharides, which may constitute anti-cancer, anti-viral, immunomodulatory, hypocholesterolaemic and hepatoprotective agents. These compounds, which can be consumed daily as a form of dietary supplement, are called mushroom nutraceuticals. For the last two decades, derivatives from *Ganoderma lucidum* (Cur.:Fr.) Karst., *Coriolus versicolor* (L.:Fr.) Pat. and *Lentinula edodes* (Berk.) Pegler, perhaps the best-known and most extensively studied medicinal mushrooms, have received intense scrutiny in terms of their ability to improve biological functions and thereby make people fitter and healthier. In some cases, these dietary supplements have been used for the prevention and treatment of various human diseases, and are without the troublesome side effects that frequently accompany treatments involving synthetic drugs. As an example, the severe pain that may often be experienced by cancer patients following radiotherapy or chemotherapy can be reduced or eliminated by the regular intake of good quality mushrooms. Furthermore, the reported enhancement of the immune system (eg. increases in macrophage and killer T-cell activity) by mushroom nutraceuticals may help reduce the likelihood of contracting infectious diseases.

The current market value of mushroom nutraceuticals/dietary supplement products worldwide is estimated to be in excess of US\$14 billion per year. In 1995, the market value of *Ganoderma*-based dietary supplements alone was estimated to be US\$1,628.4 million, and the value of equivalent products derived from *L. edodes* was probably of the same order. More recently, *Hericium erinaceus* (Bull.:Fr.) Pers., *Agaricus blazei* Murr, *Cordyceps sinensis* (Berk.) Sacc., *Flammulina velutipes* (Curt.:Fr.) Sing., *Grifola frondosa* (Fr.) S. F. Gray, and *Tremella fuciformis* Berk. have been the subject of intensive research and development as potential sources of immunotherapeutic agents. It has been proposed that mushroom nutraceuticals should be regulated as a special intermediate class of compounds between pharmaceuticals and healthy foods. Furthermore, in view of the large expansion this sector is currently experiencing, there is a serious need to improve the quality control of these products. A trustworthy and good quality product is essential in order to protect public health, to maintain and increase consumer confidence, and to meet current and future standards set by the regulatory authorities.

## 2. Nutritional value of mushrooms

The source of energy food -- carbohydrates, -- accessory food factors, vitamins, and inorganic compounds, together with water, are indispensable to good health. However, the greatest difficulty in meeting human nutritional requirements is to supply a sufficient amount of the body-building material -- protein.

The moisture content of fresh mushrooms varies within the range 70- 95 percent, depending upon the time of harvest and the environmental conditions, and between 10- 13 percent in dried mushrooms. The protein content of the major cultivated species ranges from 1.75 to 5.9 percent of their fresh weight although it has been estimated that an average value of 3.5 to 4.0 percent would be more representative. Therefore, the protein content of edible mushrooms is, in general, about twice that of onion (1.4 percent) and cabbage (1.4 percent), four times that of oranges, and 12 times higher than

apples (0.3 percent). In comparison, the protein contents of common meats are as follows: pork, 9-16 percent; beef, 12-20 percent; chicken, 18-20 percent; fish, 18-20 percent; and milk, 2.9-3.3 percent. On a dry weight basis, mushrooms normally contain 19-35 percent protein, as compared to 7.3 percent in rice, 12.7 percent in wheat, 38.1 percent in soybean, and 9.4 percent in corn. Consequently, in terms of crude protein content, mushrooms rank below animal meats, but well above most other foods, including milk. Furthermore, mushroom protein contains all nine essential amino acids required by humans.

Quantitative data relating to the nutritive value of mushrooms are sparse. In the absence of feeding trials, alternative methods have been used to determine or predict the nutritional value of foods based on their content of essential amino acids. The Essential Amino Acid Index (EAA Index) rates dietary protein in terms of an essential amino acid pattern based on known adult human dietary requirements. The Amino Acid Score (Chemical Score) is the amount of the most limiting amino acid in the food protein expressed as a percentage of the same amino acid present in the reference protein. In an attempt to resolve the difficulties inherent in comparisons between those mushrooms containing small amounts of high quality protein with those containing larger amounts of a protein of lesser nutritional quality, Crisan & Sands proposed in 1987 the use of a Nutritional Index calculated as follows:

$$\text{Nutritional Index} = \frac{(\text{EAA Index} \times \text{percentage protein})}{100}$$

The EAA Indexes, Amino Acid Scores and Nutritional Indexes for various mushrooms and other foods are shown in Table 1. In terms of EAA Indexes and Amino Acid Scores, the most nutritive mushrooms (highest values) rank alongside meat and milk in potential nutritive value and considerably higher than most legumes and vegetables. The least nutritive mushrooms rank appreciably lower but are still comparable to some common vegetables.

In addition to their high quality protein, mushrooms are a relatively good source of the following individual nutrients: fat, phosphorus, iron, and vitamins including thiamine, riboflavin, ascorbic acid, ergosterol and niacin. Fruit bodies are low in calories, carbohydrates and calcium, and the commonly cultivated mushrooms are reported to have a total lipid content between 0.6 and 3.1 % on a dry weight basis. Unsaturated fatty acids, essential and significant to our diet and to our health, constitute at least 70 percent of the total fatty acid content.

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 <i>V. diplasia</i>	89 mushrooms (high)	31 pork
91 potatoes; kidney beans <i>P. ostreatus</i>	71 <i>V. diplasia</i>	28 mushroom (high)

88 corn	63 cabbage	27 <i>V. diplasia</i>
87 <i>A. bisporus</i>	59 potatoes <i>P. ostreatus</i>	26 spinach
86 cucumbers	53 peanuts	25 milk
79 peanuts	50 corn	22 <i>A. bisporus</i>
76 spinach; soybeans	46 kidney beans	21 kidney beans
74 <i>L. edodes</i>	42 cucumbers	20 peanuts
72 mushrooms	40 <i>L. edodes</i>	17 cabbage
69 turnips	33 turnips	15 <i>P. ostreatus</i>
53 carrots	32 mushrooms (low)	14 cucumbers
44 tomatoes	31 carrots	11 corn
	28 spinach	10 turnips
	23 soybeans	9 potatoes
	18 tomatoes	8 potatoes
		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). Data from Crisan & Sands (1978).

Table 1: Comparison of nutritive value of mushrooms with various foods

The desirability of a food product is not necessarily correlated to its nutritional value. However, appearance, taste, and aroma are often important in stimulating the appetite. Thus, in addition to nutritional value, edible mushrooms possess unique characteristics in terms of colour, taste, aroma and texture that make them attractive for human consumption.

TO ACCESS ALL THE 21 PAGES OF THIS CHAPTER,  
Visit: <http://www.eolss.net/Eolss-sampleAllChapter.aspx>

### Bibliography

- Brower V. (1988). Nutraceuticals: Poised for a healthy slice of the healthcare market? *Nature Biotechnology* **16**, 728-731. [This paper presents some definitions for different types of nutraceutical].
- Chang S. T. and Buswell J. A. (1996). Mushroom nutraceuticals. *World J. Microb. Biotechnol.* **12**, 473-476. [A summary of the main features of functional foods/nutraceuticals, nutraceuticals and pharmaceuticals].
- Chang S. T. and Buswell J. A. (1999). *Ganoderma lucidum* (Curt.:Fr.) P. Karst. (Aphyllophoromycetidae) – A mushrooming medicinal mushroom. *Intl. J. Medicinal Mushrooms*

1,139-146. [This article describes various bioactive compounds obtained from *Ganoderma lucidum* and their medicinal value, and the market value of *Ganoderma lucidum*-based products].

Chang, S.T. and Buswell, J.A. (2003). Mushrooms – A prominent source of nutraceuticals for the 21<sup>st</sup> Century. *Curr.Topics in NutraceuticalRes.* **1**:257-280. [This article is a comprehensive account of the different compounds that have been identified in mushrooms and their associated bioactivities].

Crisan E. V. and Sands A. (1978). Nutritional value. In “ The Biology and Cultivation of Edible Mushrooms” edited by S.T. Chang and W.A. Hayes . Academic Press, New York. [An overall review of the nutritional value of mushrooms].

Miles P. G. and Chang S. T. (1997). Mushroom Biology-Concise Basics and Current Developments, 194 pp. World Scientific:Singapore. [Describes the potential development of mushroom biology discipline as a discipline and commercial enterprises based on mushroom products].

Reshetnikov, S.V, Wasser, S.P. and Tan, K.K. (2001). Higher Basidiomycota as a source of antitumor and immunostimulating polysaccharides. *Intl. J. Medicinal Mushrooms*, **3**, 361-394. [Provides a comprehensive list of higher basidiomycetes identified as sources of bioactive polysaccharides].

Shi Y.S., James, A.E., Benzie, I.F.F. and Buswell, J.A. (2002). Mushroom-derived preparations in the prevention of H<sub>2</sub>O<sub>2</sub>-induced oxidative damage to cellular DNA. *Teratogenesis, Carcinogenesis, and Mutagenesis.* **22**, 103-111. [This study demonstrates the genoprotective activity of certain mushrooms].

Wachtel-Galor S, Benzie IFF, Tomlinson B. & Buswell JA. (2004). Lingzhi (*Ganoderma lucidum*): Molecular Aspects of Health Effects. In Herbal Medicines. L Packer, B Halliwell, CN Ong eds. Marcel Dekker Inc.:New York. [This article is a comprehensive coverage of the medicinal properties of *Ganoderma lucidum*].

Wang H. X., Ng T. B; Ooi V. E. C; Liu W. K. and Chang S. T. (1997). Actions of lectins from the mushroom *Tricholoma mongolicum* on macrophages, splenocytes and life-span of sarcoma-bearing mice. *Anticancer Res.* **17**, 415-420. [This article provides evidence that lectins isolated from mushrooms serve as potential preventive agents of cancer metastases and as therapeutic drugs].

Wasser S. P. (2002). Medicinal Mushrooms as a source of anti-tumor and immunomodulating polysaccharides. *Appl. Microbiol. Biotechnol.* **60**, 258-274. [This article focuses on the structure and bioactivity of mushroom polysaccharides].

Wasser P. S; Nevo E; Sokolov D; Reshetnikov S and Timor-Tismenetsky M. (2000). Dietary supplements from medicinal mushrooms: Diversity of types and variety of regulations. *Intl. J. Medicinal Mushrooms*, **2**, 1-19. [Proposes forms of regulation of dietary supplements from medicinal mushrooms].

Yao Q. Z., Yu M. M; Ooi L. S. M; Ng T. B; Chang S. T; Sun S.S.M. and Ooi V. E.C. (1998). Isolation and characterization of a Type I ribosome-inactivating protein from fruiting bodies of the edible mushroom (*Volvarella volvacea*). *J. Agri. Food Chem.* **46**, 788-792. [The study demonstrates the existence of a RIP with rRNA N-glycosidase activity in the fruiting bodies of the mushroom *V. volvacea*].

Zeisel S. H. (1999). Regulation of “Nutraceuticals”. *Science* **285**, 1853-1855. [Proposes forms of regulation relating to the preparation of dietary supplements, nutraceuticals, and functional foods].

### Biographical Sketches

**Professor Shu-Ting Chang**, Emeritus Professor of Biology, The Chinese University of Hong Kong, is the Vice-President of the World Society for Mushroom Biology and Mushroom Science; and Director of Hong Kong MIRCEN for Mushroom Science, which is sponsored by Unesco. He is also the Director of the Centre for International Services to Mushroom Biotechnology under the aegis of UNIDO, and Editor of the International Journal of Medicinal Mushrooms.

Professor Chang received a BS degree from the National Taiwan University in 1953 and earned MS and PhD degrees in 1958 and 1960 respectively from the University of Wisconsin. He was awarded a post-doctoral fellow at Harvard University during 1966-67, a Visiting Fellow at the University of Tokyo in 1969 and at the same time a Visiting Fellow of the Australian National University (ANU) and the CSIRO during 1972-73 and 1978-79. Other Honours include:

- Elected Fellow of the World Academy of Art and Science (1989)
- Fellow of the International Institute of Biotechnology (1990)
- Fellow of the World Academy of Productivity Science (1992)
- International Cooperation Award for Light Industry, China (1990)
- Honorary Life Member of the British Mycological Society (1990)
- Honorary Life Member of the International Society for Mushroom Science (1993)
- An Officer of the Most Excellent Order of the British Empire (OBE) in 1994

Prof. Chang has authored or co-authored over 200 articles in scientific journals and 22 books.

Professor Chang and his family have moved to Canberra (Australia) after his retirement in 1995.

**J.A. Buswell** gained a BSc in Bacteriology at the University of Birmingham, England in 1963, followed by a PhD in 1966 on “Microbial degradation of methoxylated phenolic compounds”. He was the Rosalie B. Hite Postdoctoral Fellow at the Department of Microbiology, University of Texas, Austin, Texas from 1996-7.

*Employment History:*

- |              |   |
|--------------|---|
| 1967-68      | Research Scientist, University of Texas, USA.   |
| 1968-71      | Assistant Professor, Department of Microbiology, University of Southwestern Louisiana, USA                                    |
| 1971-72      | Science Research Council Postdoctoral Fellow, Biological Laboratories, University of Kent, UK                                 |
| 1972-89      | Lecturer I, Lecturer II and Senior Lecturer (Microbiology), Department of Biology, Paisley College of Technology, Paisley, UK |
| 1989-90      | Associate Research Microbiologist, University of Georgia, Athens, Georgia, USA  |
| 1990-2003    | Lecturer/Senior Lecturer/Reader, Department of Biology, The Chinese University of Hong Kong.                                  |
| 2003-present | Guest Professor, Institute of Edible Fungi, Shanghai Academy of Agricultural Sciences.  |
| 1978-80      | Visiting Researcher, Swedish Forest Products Laboratory, Stockholm, Sweden.   |
| 1984-85      | Visiting Researcher, Institut National Agronomique, Paris, France.  |

His major research interests are the fungal mediated biodegradation and bioconversion of lignocellulose, microbial degradation of xenobiotics, and mushroom nutraceuticals (i.e. mushroom-derived bioactive compounds). He has also been: Co-Director, Hong Kong MIRCEN (Microbial Resource Centre); Hong Kong Representative and General Secretary, International Mycological Association Committee for Asia; Deputy Director, UNIDO-Chinese University of Hong Kong Centre for International Services to Mushroom Biotechnology; Secretary/Treasurer, World Society for Mushroom Biology and Mushroom Products; and Committee and Founding Member of the Mycological Association of Hong Kong. He is a Past Member of the Editorial Board of the Journal of General Microbiology, and Past Member of the Editorial Boards of the World Journal of Microbiology and Biotechnology and Letters in Applied Microbiology. He has published 82 scientific papers and edited two books.