Edible and medicinal mushrooms for sub-health intervention and prevention of lifestyle diseases

Technology Trends

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Abstract

Mushrooms are growing in importance as numerous nutritional and therapeutic benefits are noted in them. Mushroom cultivation can be a zero-waste activity whereby lignocellulosic agro-residues are converted to food, feed for animals and fertilizers for plants. Mushrooms as functional food can help in the intervention of subhealth states in humans and may prevent the 'full blown consequences' of life threatening diseases. The discovery of mushrooms for human well-being hinges on the traditional knowledge of mushrooms used as food and medicine by the indigenous people of a nation. Wild medicinal and culinary mushrooms have been successfully tamed, domesticated and brought to commercial scale. The mushroom industry has grown from a cottage industry to supplement the income of a household to medium and mega-sized industrial ventures. Mushrooms produced are not only food but are raw material for development of functional food (nutraceuticals) and dietary supplements (nutriceuticals) for health and quality life of humans.

Introduction

Humankind is plagued by a number of diseases many of which are life-threatening. The aging population are prone to many diseases including neurodegenerative diseases — Alzheimer and dementia; cardiovascular diseases; cancer and diabetes that affect the kidney and the eyes. These days not only are the aged prone to diseases but also very young individuals are reported to die from cardiac arrests, diabetes and cancer. What is perplexing is that a number of these diseases are a result of our lifestyle — the food we eat and the habits — smoking and consuming alcoholic drinks contribute to the onset of these diseases. Further, the exposure to the polluted environment contributed by industrialization can cause a number of human illnesses. Although many drugs are available, the quality of life is jeopardized in many cases. To add to the burden is the rising cost of health care. The strategy now is subhealth intervention and prevention rather than cure of life threatening diseases by reverting to traditional knowledge as a source of chemopreventive food and nutraceuticals. Further, the quality of life of those who are ill and on lifelong therapeutic drugs may be enhanced by using functional molecules from plants and fungi, too. A number of these natural resources are used and curative claims can be obtained from ethnobotanical and ethnomycological studies.

The fungi and, in particular, the mushroom have components that can contribute to human wellness and mitigate threats and assaults that render the human body vulnerable to several life threatening diseases including cardiovascular ailments, cancer, metabolitic disorders (diabesity) and neurodegenerative disorders. Mushrooms have been used as medicines by humans for 5000 years or more (Halpern, 2007). Mushrooms — an unexploited resource of numerous bioactive components including polysaccharides, terpenes, flavonoids, alkaloid, nucleotides, lipids, vitamins, protein, amino acid and minerals can have many beneficial effects on human systems (Wasser & Weis, 1999). It was found that mushrooms and their extracts can benefit the central nervous system, heart and liver. They can be exploited for their chemopreventive activities against many of the life threatening or debilitating diseases such as metabolic syndromes — diabesity (Kanagasabapathy *et al*., 2012); cardiovascular diseases and neurodegenerative diseases (Wong et al., 2012). The main culprits triggering these human ailments are reactive oxygen species and inflammation. These two factors are responsible for subhealth states leading to pre-disease conditions and poor quality of life.

Mushrooms packed with a wide array of bioactive components are excellent antioxidants and anti-inflammatory agents. Secondary metabolites of mushroom that may have therapeutic potentials are alkaloids, antibiotics, lectins, lactones and terpenoids (Wasser, 2010). Primary metabolites such as enzymes — glucose oxidase, superoxide dismutase, peroxidases and laccases may prevent oxidative stress (Wasser, 2010, Chang and Wasser, 2012). Further, humans have learnt to tame these mushrooms

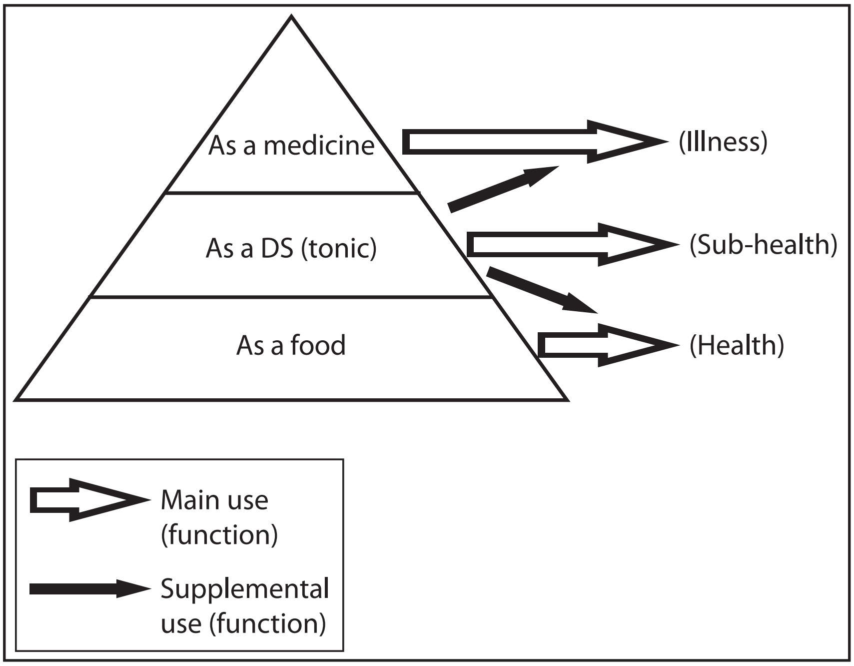

Figure 1: A pyramid model of mushroom uses (Chang and Wasser 2012)

via. modern biotechnology tools and processing them for food and nutraceuticals (Vikineswary *et al*., 2013).

In this paper, we highlight the importance of mushrooms in healthy lifestyle and the technologies that are being developed to realize the goal that "mushrooms can be on every human being's table". This is for early intervention of subhealth states and to ensure that the population ages gracefully and in good health.

Why mushrooms as food and dietary supplements for preventive health

It is well aware that we live in an age of human health crises, especially when considering the leading killer diseases of our time, such as HIV/AIDS pandemic, cancer and diabetes that could lead to the possibility of developing other serious health complications including heart attack, stroke, kidney disease, blindness and limb amputation. This is where the role of edible and medicinal mushrooms with their products has become important. They are increasingly becoming a vital component of the human diet as well as dietary supplements (Chang and Buswell 2003, Cheung 2008). Actually, a variety of mushrooms have been used traditionally in many different cultures for the maintenance of health and in the prevention and treatment of various diseases. Mushrooms themselves can be mainly used as food for a healthy state, pure refined products can mainly used as a medicine for ill state, and crude extract products mainly used as dietary supplements for a subhealthy state as well as for both healthy and ill states as reported recently (Chang and Wasser, 2012) and as shown in Figure 1.

Mushrooms according to the definition given by Chang and Miles (1992), particularly the edible species of a large group of the macrofungi, are produce of high quality of food with high economic value. Nutritional analyses have revealed that edible mushrooms possess all three properties of food — nutrition, tastes, and physiological functions (Chang and Buswell 2003). For the first property of nutritional value, mushrooms are rich in relatively high contents of good quality protein (Tables 1 and 2), a low total fat content but a high percentage of polyunsaturated fatty acids (Table 3), as well as significant amounts of vitamins, minerals and fiber. Mushrooms have a low energy level that is beneficial for weight reduction, have a low glucose level, more mannitol, that is especially suitable for diabetics and have a very low sodium concentration that is good for persons suffering from high blood pressure. They have a high content of several vitamins particularly of Bs and D, minerals (potassium, phosphorus), and also a high content of some trace elements, especially of selenium which is regarded as an excellent antioxidant. They contain no cholesterols. For the second property of taste, mushrooms become delicious food and food flavoring substances because of their unique flavor. In addition to the volatile eight-carbon compounds, the typical mushroom flavor consists of water-soluble taste components including soluble

Table 1: Proximate composition of the 3 mushroom species (Chang and Miles, 2004)

	A. bisporus	*L. edodes*	*Pleurotus spp*
Moisture	78.3–90.5	90.0–91.8	73.7–90.8
Crude protein	23.9–34.8	13.4–17.5	10.5–30.4
Crude fat	1.7–8.0	4.9–8.0	1.6–2.2
Total carbohydrate	51.3–62.5	67.5–78.0	57.6–81.8
N-free carbohydrate	44.0–53.5	59.5–70.7	48.9–74.3
Total dietary fiber	8.0–10.4	7.3–8.0	7.5–8.7
Ash	7.7–12.0	3.7–7.0	6.1–9.8
Energy value	328–368	387–392	345–367

Note: All data are presented as percentage of dry weight, except moisture (percentage of fresh weight) and energy value (Kcal per 100g dry weight).

sugars and polyols, organic acids and free amino acids and 5-nucleotides.

Thus, in addition to nutritional value, edible mushrooms possess unique characteristics in terms of color, taste, aroma and texture, which make them attractive for human consumption. For the third property of physiological effects, with several physiologically active substances including high molecular weight polysaccharides (mainly ß-D-glucans), heteroglucans, chitinous substances, peptidoglucans, proteoglucans, lectins, RNA components, dietary fiber; and low molecular weight organic substances, such as terpenoids, steroids, novel phenols. Many varieties of mushrooms are valued greatly as nutritious food sources, as tonic foods, and as important sources of medicinal compounds — anti-tumour/anti-viral agents and other pharmaceutically active components. A number of proprietary products, including cosmetics, beverages and health foods, are marketed currently and the demand for such products is expected to increase. Numerous studies have shown that regularly consumption of certain mushroom species as either a regular food or as extracted compound (nutriceuticals) is effective in both preventing and treating specific diseases, mainly through immune-stimulating polysaccharides. The term "mushroom nutriceuticals" has been coined to embody both the nutritional and medicinal features of these biological response modifiers extractable from either the mushroom mycelium or mycelium culture fluids, or mushroom fruiting bodies (Chang and Buswell 1996). Mushroom extracts, nutriceuticals, compared with other drugs, as noted, show a very low toxicity when regularly consumed, even in high dosages. Therefore, mushrooms become a valuable health food and also a dietary supplement in modern society.

Current world status and demand for mushrooms, China's story

Overall, world mushroom production has steadily increased (Table 4), mainly due to contributions from countries with developing economies including China, India, Poland and Hungary. In contrast,

Table 2: Essential amino acid contents of the mushrooms* (Beelman *et al.*, 2003)

	A. bisporus	*L. edodes*	*Pleurotus spp*
Cystine	23	24	28
Methionine	33	29	35
Threonine	111	98	106
Valine	121	124	112
Isoleucine	91	79	82
Leucine	153	133	139
Lysine	143	122	126
Tyrosine	283	265	219
Phenylalanine	107	91	111

*mg/100 g FW

Table 3: Fatty acid content of the mushrooms (Huang *et al.*, 1989)

Mushroom	% of Saturated fatty acids	% of Unsaturated fatty acids
Agaricus bisporus	19.5	80.5
Auricularia auricula	25.8	74.2
Pleurotus sajor-caju	20.7	79.3
Lentinula edodes	19.9	80.1
Tremella fuciformis	22.8	77.2
Volvariella volvacea	14.6	85.4

Table 4: World mushroom production (1960–2011)

Year	Total production (x1,000 tonnes)
1960	170
1965	301
1970	484
1975	922
1978	1,060
1981	1,257
1983	1,453
1986	2,182
1990	3,763
1994	4,909
1997	6,158
2002	12,250
2009	24,000
2011	Est. 29,000

Table 5: The production of farmed mushrooms in China during the period, 1978 to 2011

Year	Production (x1000 MT)	Growth rate (%)	Avg. annual increase (%)
1978	60.0	—	—
1986	586.0	876.7	109.6
1990	1,000.0	70.6	17.6
1994	2,600.0	160.0	40.0
1996	3,500.0	34.6	17.3
1997	3,918.3	12.0	12.0
2000	6,630.0	69.2	23.1
2001	7,818.0	17.9	17.9
2003	10,387.0	32.8	16.4
2005	13,346.0	28.5	14.2
2007	16,822.0	26.0	13.0
2009	20,200.0	20.0	10.0
2011	25,717.4	27.3	13.6

Courtesy: China Edible Fungi Association.

mushroom production in Western European countries, the United States and Japan, has remained unchanged or even fallen (Chang 2006a). Although China's mushroom industry has a long history, it has flourished and developed rapidly only during the past 35 years. In 1978, China produced only 60,000 tonnes, contributing to less than 6% of world production. The year 1978 was also the first year of China's economic reform program. Thirty-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 of them having been divorced 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. China's production of cultivated mushrooms over a number of years (1978–2011) is shown in Table 5. 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 one million tonnes of cultivated edible mushrooms, accounting for more than 28.0% of world mushroom production. Since then, the output of China has been growing steadily at a rate of more than 10% per annum. The total production of cultivated edible mushrooms in 1994 was 2.6 million tonnes, which amounted to 54.0% of the world output. In 2002, the production of cultivated edible mushrooms in China was over 8.6 million tonnes which accounted for about 70.0% of the world total output. In 2011, the production was 25.70 million tonnes and contributed over 85% to the world production (Table 6) and the productive value was estimated about USD 2,400 billion.

It should be noted that the production of mushrooms in China is highly decentralized. However, 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 29 companies producing edible mushrooms with a capacity of over 20 tonnes daily. These companies are mainly located in Jiangsu province with nine companies, Shanghai having seven and then Beijing, Guangdong, Hubei, Shandong each having two, and Gansu, Liaoning, Fujian, Sichuan and Jiangxi each having one. In 2011, those companies produced about 347,845 tonnes that accounted for about 14% of the national production. In 2012, there are two companies to produce fresh mushrooms over 100 tonnes daily: Shanghai Xuerong Biotechnology 260 tonnes and Gunsu Tianshui biotechnology 118 tonnes. They have better quality control due to more advanced equipment

Table 6: China's contribution to worldwide mushroom production since 1978

Year	Total production (x1,000 tonnes)	China's production (x1,000 tonnes)	China's contribution (%)
1978	1,060.0	60.0	5.7
1983	1,453.0	174.5	12.0
1990	3,763.0	1,083.0	28.8
1994	4,909.3	2,640.0	53.8
1997	6,158.4	3,918.0	63.6
2002	12,250.0	8,650.0	70.6
2006	NA	14,000.0	NA
2009	24,000	20,200.0	More than 80
2011	Est. 29,000	25,717.5	More than 85

NA: Not available

Courtesy: Communications with the China Edible Fungi Association.

and better corporate management. Furthermore, there are several big companies with sophisticated equipments and technology capable of scrutinizing the production process as well as detecting heavy metals and other impurities that may be present in any contaminated dried and 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 towards this goal.

At the same time, it has been estimated that there are more than 200 research institutes/units engaged in edible and medicinal mushroom research and development and over 300 industrial-scale companies engaged in production of edible and medicinal products in China. Over 35 species of mushrooms are used to produce commercial products through solid and liquid fermentation technologies. Uptil now, only about 150,000 species of fungi on Earth have been validly named by taxonomists and we currently know about 15,000 mushroom species which would account only for about 10% of the estimated mushroom species. Of these, about 2,000 are safe species including about 700 with some pharmaceutical activities (Wasser, 2010). In China, more than 300 species of medicinal mushrooms have been estimated to be adopted in folk remedies. Reliable techniques for fruiting body cultivation are known for only about 65 mushroom species. The benefits of mushrooms in human nutrition are growing as more research is undertaken to validate traditional claims (Vikineswary *et al.*, 2007). Further, the research has shown that efforts to domesticate the wild culinary and medicinal mushrooms to commercial scales are possible as many mushrooms (with their powerful enzymes systems) only need lignocellulosic materials as their main carbon source.

Bioconversion of lignocellulosic agricultural residues to dietary and functional food

Mushrooms are saprophytic fungi and have a wide array of enzymes including the lignin degrading enzymes that enable them to utilize substrates rich in carbohydrates including lignocellulosic agroresidues that are generated by agricultural industries (Stamets, 2000). Mushroom cultivation, a zero waste system, is the utilization of lignocellulosic agroindustrial wastes into culinary and medicinal mushrooms (Figure 2). The lignocellulosic components of plants (generated via. photosynthesis) comprise 60–80% of an agroindustry. For example, in paddy cultivation only 40% reaches the table as the rice we eat. The

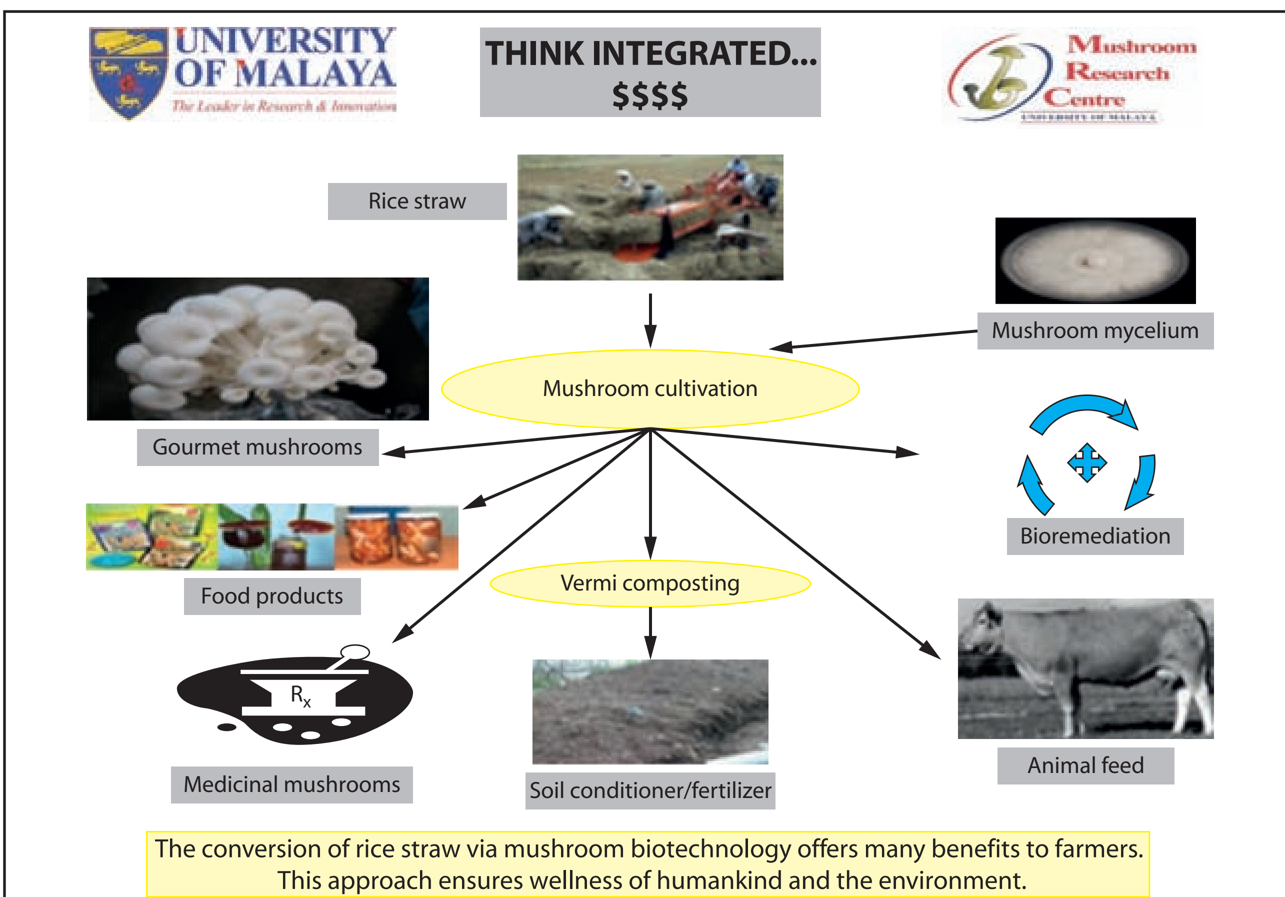

Figure 2: Waste-to-wealth via mushroom biotechnology

remaining 60% is rice straw and husks — lignocellulosic renewable resources that can be converted via. mushroom biotechnology to value-added mushrooms. This process offers many benefits to farmers. This approach reduces open burning and ensures wellness of the environment. Mushroom industry is a zero-waste industry whereby the misplaced resources — agroindustrial wastes are converted to food, feed and fertilizer. Mushroom cultivation is one of the most economical processes to convert wastes to wealth (Figure 2). Starting with superior hybrids, the mushrooms produced are high quality protein rich food which can be converted to functional food (nutraceuticals) and dietary supplements (nutriceuticals) (Chang and Buswell, 2003). The spent substrate can be converted to feed, seed medium and fertilizer for soil amendment. Thus, mushroom cultivation is a profitable agribusiness.

For each metric tonne of mushrooms produced, at least an equivalent amount of spent mushroom substrates is generated. Spent mushroom substrates, because of its high mineral content, phosphate content, and high porosity, is a good soil conditioner and soil fertilizer for stimulating seed germination (Phan and Vikineswary, 2012). Spent mushroom substrate will be the base medium to cultivate sprout vegetables and then the spent medium can be vermicomposted to organic fertilizer for horticulture crops.

Benefits of mushroom cultivation in developing countries

Developing countries are predominantly agriculture-based growing not only rice as a staple but other short term crops that results in lignocellulosic byproducts. Mushroom cultivation is viewed as a zero-waste technology and there are numerous technologies available to economically the agricultural by-products to dollars (Chang, 2006a). These technologies for edible and medicinal mushroom cultivation, however, need to be adapted to the country. The growing substrates availability preferably throughout the year and the costs of these substrates, the variety of mushroom to be cultivated, the weather conditions and the consumers acceptance of mushrooms are of utmost importance.

Mushroom cultivation can be a cottage industry providing an additional income for the family or a high technology facility that generates huge income for the industry. The basic premise is the bioconversion of agricultural residues to value-added mushrooms (Chang, 2006a). Selected technologies available to cultivate culinary and medicinal mushrooms as food or nutraceuticals can contribute to wellness and quality life — and reduction or prevention of subhealth status and life threatening diseases as one ages. This is explained below as 'Technologies/Case studies'. In this paper, the detailed cultivation protocols are not provided (contact emails are provided or contact the corresponding author).

Technologies/Case studies

(a) Domestication of wild medicinal mushroom: LignoBiotech — *Lignosus rhincerotis* — traditional knowledge from forest to factory (ngszuteng@gmail.com)

Malaysia is home to a diversity of cultures, traditions and is an ecological treasure trove in its ancient rainforests. These rainforests, located far away from the large cities, are still pristine and pollution free where the many species of medicinal mushrooms have long been a source of medicine for the indigenous people living there. Today, these medicinal mushrooms traditionally used by indigenous folks are radically changing the way we treat diseases in the modern world. One such treasure is *Lignosus rhinocerotis* — the 'Tiger Milk Mushroom' — the mushroom that sprouted from the tigress' milk — at least, that's what legends say!

The 'Orang Asli' (or aborigines) of Malaysia, also believed that this mushroom is rare and difficult to find, and only they, the aborigines, are able to find it. *Lignosus rhinocerotis*, hailed as Malaysia's national treasure, has been recognized by indigenous community as an indispensable medicinal mushroom with the ability to cure more than 15 ailments (Lee *et al*., 2009) In the 1950s–1960s, the Tiger Milk mushroom was widely used by local people as a medicine to treat fever, cough, vomiting, cuts and to boost their energy. The Tiger Milk mushroom has been used by the people of Malaysia long before European traders and Western colonists arrived (Tan *et al*., 2010).

Despite its curative properties, the increased difficulty in locating these mushrooms and the advent of the popularity and accessibility of western medicine from the 60s, the use of Tiger Milk Mushroom started to decline. Further, the traditional use of this mushroom was not common knowledge and many people do not know about the existence of this medicinal mushroom. Today, considered a threatened species, there is a progressive depletion of the mushroom from the wild due to over harvesting. To add to this dilemma, the underground fungus tuber or *sclerotia* — the part that contains the rich nutritional and medicinal components (Figure 3) can remain below the ground for months, years or decades. The fruit body of the mushroom will only sprout from the ground when natural conditions are right. The *sclerotium* can only be found when the fruit body (cap and stipe) of the mushroom sprout from the ground, making the wild Tiger Milk mushroom scarce and difficult to be located. Other factors contributing to the loss of this precious mushroom will be the encroachment of deforestation, modern development, and pollution.

In a bid to conserve this precious mushroom, two researchers from LiGNO™ Biotech Sdn. Bhd (a Malaysian Biotech company) embarked on the project, 'Bringing Back the Lost Treasure — Cultivation Technology'. Now, Malaysia is the first country in the world to have successfully pioneered a high yield cultivation of this mushroom — making it a commercially viable product. With specially formulated culture medium and biotechnology, it is possible to produce high quality Tiger Milk mushroom similar to wild — type sclerotia and in shorter time. LiGNO™ Biotech Sdn. Bhd. is the world's first producer of the Tiger Milk mushroom. Combining the highly precise and proprietary cultivation and processing technologies, LiGNO™ Biotech is now poised to offer the demanding market a commercially viable product-freeze-dried cultivated Tiger Milk mushroom *sclerotia*. Commercial ventures and partnerships are possible to exploit this mushroom as a supplement for quality life of humans. As the mushroom is now readily available, researchers are actively validating the traditional claims (Eik *et al*., 2012; Yap *et al*., 2013, Lee *et al*., 2013). Besides employing bioprocessing technologies (LiGNO™ Biotech), attempts to cultivate Tiger Milk mushrooms in a condition similar to the wild, have been successful (Noorlidah *et al*., 2013).

(b) Story of milky mushroom Calocybe indica var. APK2: From wild to table (milkmush@rediffmail.com/ milkmushapk2@gmail.com)

Milky mushroom (*Calocybe indica* var. APK 2) is a tropical edible mushroom and is relatively new to the world mushroom lovers (Figure 4). It is of Indian origin. The technology for commercial cultivation and the new variety has been introduced first from Tamil Nadu Agricultural University, Coimbatore, India (Krishnamoorthy *et al*., 1998).

A new edible mushroom which has not been commercially exploited anywhere in the world except in India. Milky mushroom is a high temperature tolerant mushroom (30–35ºC), robust, fleshy with very good market appeal. The mushrooms are milky white, compact, flexible in shape and size; sometimes exactly resembling button mushrooms.

The cultivation technology is very simple and involves less cost as compared to button mushroom cultivation. It grows well in paddy straw substrate and no special compost is needed for the cultivation of milky mushroom. The mushroom is highly tropical in nature and loves to grow at 30–35°C and increased humidity (>80% RH). Average production efficiency is 145–200% (which means the total yield per 1000 kg of paddy straw (dry weight basis) will be around 1450–2000 kg (fresh weight), which is far better as compared to any other commercially cultivated mushroom. Short duration: Mushrooms could be harvested within 24–28 days of bed

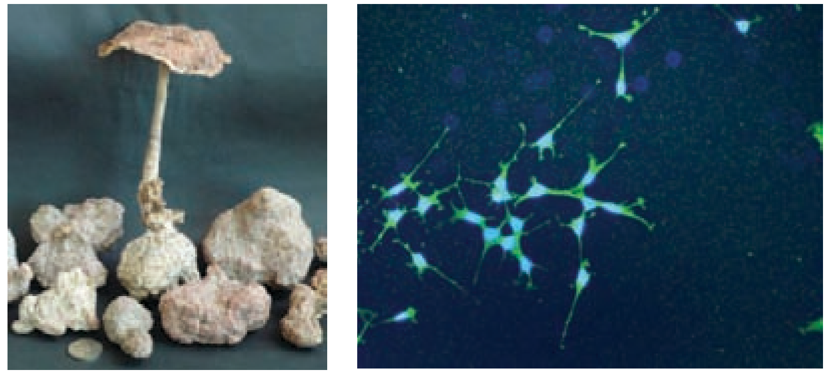

Figure 3: PC-12 in response to treatment of aqueous extracts of *L.rhinocerotis sclerotium* (Eik *et al.,* 2012)

preparation. Total crop cycle will be in 3 or 4 flushes in 50–60 days. Hence, money flow on investment will be very quick. Average weight of single mushroom will be 55–60 g.

Under normal room temperature (28 ± 20ºC) without any extra care, the mushrooms can be stored even up to one week. Under cold storage/modified atmospheric package, the shelf life can be extended well extended up to one month or more. Canning, drying, pickling and other methods of value additions of milky mushrooms are also possible. Protein content of milky mushroom is 32.3% and the crude fiber content is up to 41%. Increased protein and fiber content speak better about milky mushroom with reference to its nutritional value.

With less investment for establishing the production unit, the cost of production per kg is comparatively less than that of button mushroom. In Indian market, milky mushroom fetches price equal to that of button mushroom (approx. INR 100 to 120 per kg). This variety is yet to be introduced in international markets.

Calocybe (popularly known as milky mushroom in India) is the genera with large, pale tricholomatoid basidiocarp. Approximately 20 species of *Calocybe* have been described worldwide (Pegler, 1983; Singer, 1986). Milky mushroom normally grows on humus soil on road side and forest areas. Almost about three decades ago, *Calocybe indica* was a wild edible mushroom in India and was first described by Purkayastha and Chandra (1974). This species is very close to *C. gambosa* (Fr.) Sing. However, the basidiocarps of *Calocybe indica* are robust, fleshy, pure white slightly larger and broadly ellipsoid.

Although success was achieved in the induction of fruit bodies of *Calocybe indica* in culture (Purkayastha, 1981); only limited attempts were made on its cultivation

Figure 4: *Calocybe indica* var. APK2 — World's first commercial Milky mushroom variety from Tamil Nadu Agricultural University, Coimbatore, India (Krishnamoorthy *et al.,* 1998)

until 1998. Krishnamoorthy (1992–1998) collected an isolate of *Calocybe indica* near a coconut (*Cocos nucifera*) tree adjacent to a sugarcane field near Coimbatore, Tamil Nadu, India. Pure cultures of the specimen were made and the perfect cultivation technology was standardized for the first time in the world. This isolate was found to outyield hither to known cultivated mushrooms around the globe (with an average bio-efficiency of 142% in paddy straw). After thorough field testing under University Adoptive Research Trials (ART) and Multi Location Trials (MLT) with mushroom growers in the region the first ever variety of milky mushroom *Calocybe indica* var. APK2 was released for commercial cultivation during 1998 by Tamil Nadu Agricultural University, Coimbatore, India (Krishnamoorthy, 2004). Its milky white color and robust nature are appealing to all. Hence, it is known as "milky mushroom".

Market scope

The scenario of mushroom industry in India has witnessed a tremendous change after the introduction of *Calocybe indica* var. APK 2. A visible shift has been noticed among oyster mushroom growers to produce milky mushroom. Simple production techniques, wide adaptability, substantial and sustainable yield, attractive milky white color, the most preferable shape have all attracted the mushroom growers in India. The fungus prefers to grow at an optimum temperature of about 30–35ºC and increased relative humidity (>85%). In addition *Calocybe indica* var. APK2 is known for its prolonged shelf life, rapid growth on a variety of substrates, increased productivity and all the more high B:C ratio as compared to any other cultivated mushroom in the world. Certainly it could revolutionize mushroom industry in the tropical and subtropical regions of the world. Currently, three more selections viz., WCi 2, WCi 6 and WCi 19 have shown the best performance with respect to yield, uniform size, uniform flushing pattern and more consumer appeal. Large scale growing experiments are underway.

This mushroom is easily grown and on cheap available substrate such as rice straw. It can be a high protein food in diets contributing to the overall wellness of humans. Mushrooms, in general, are rich in polysaccharides and other bioactive secondary metabolites may contribute to prevention or reduction of life-threatening diseases. However, these potentials have to be validated via experimental studies.

(c) Domestication of low temperature/highland mushrooms: Hericium erinaceus — temperate to tropical and still potent (viki@um.edu.my)

Hericium erinaceus is an edible mushroom widely consumed in the Orient and highly reputed for its medicinal values (Figure 5). The discovery of NGF-stimulating compounds in this mushroom has attracted great attention in research as it holds promise as a cure for Alzheimer's disease and management of neurodegenerative diseases. A double-blind placebo-controlled clinical trial showed signs of improvement in subjects with cognitive impairment after consumption of *H.erinaceus* (Mori *et al*., 2009).

Hericium erinaceus (Bull.: Fr.) Pers. also known as Lion's Mane, Monkey's Head, Hedgehog Mushroom, Satyr's Beard, Pom Pom Blanc, Igelstachelbart, and Yamabushitake is one of the edible and medicinal mushrooms distributed in Asia, Europe, and North America It is a temperate mushroom that requires cool temperatures of 18–24°C to produce fruit bodies. The nutritional and medicinal properties of *Hericium erinaceus* grown in low temperature conditions are well known and documented in Europe, China, and Japan. Since 2000, it has been successfully domesticated via. adaptation to tropical climate in Malaysia. This mushroom grows and produces fruit bodies in lowlands of tropical temperature (Figure 5). This domestication/taming of temperate mushrooms to grow and fruit in tropical mushrooms is an advantage as it can be grown throughout the year. In addition, though the mushroom was cultivated at higher temperature (27–30ºC) did not affect its known medicinal properties.

Studies have shown that the mushroom though cultivated at higher temperatures retained its signature properties — neurite-stimulating activity (Wong *et al*., 2007) and gastric ulcer and prevention healing (Abdulla *et al.*, 2008). Further, the extracts enhanced peripheral nerve regeneration in vivo (Wong *et al*., 2011, 2012). These studies show that the mushroom can be grown in tropical countries like Malaysia and India and its medicinal properties are not lost. This medicinal mushroom has great potential to be developed as functional foods or nutraceuticals for boosting brain and nerve health (Vikineswary *et al*., 2013) and in intervention of subhealth states related to aging and delaying neurodegeneration.

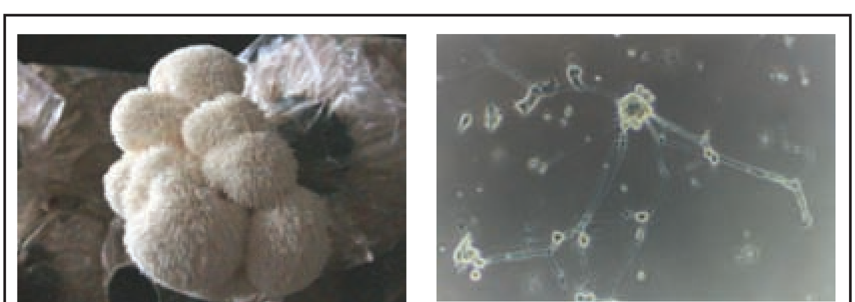

Figure 5: Response by NG108 cells to aqueous extract of *Hericium erinaceus* grown in lowland conditions (Wong *et al.*, 2012).

Challenges facing mushroom industries

It should be noted that any science or industry, just like building a house, does not start from the roof down. That would be a recipe for disaster. We need a foundation. The principle of mushroom biology is considered as the foundation of mushroom biotechnology and mushroom industry. Mushroom biology includes not only cultivation, but it deals with any aspect of mushrooms, such as taxonomy, development, nutrition, physiology, genetics, pathology, medicinal and tonic attributes edibility, toxicity, etc. In addition to the basic researches in mushroom biology, there also have great challenges in applied aspects of mushroom industries which have been reported in details in "development of the world mushroom industry: applied mushroom biology and international mushroom organizations" (Chang and Buswell 2008).

In addition, the complementary major challenge of mushroom industry is to enter the promotion of marketing and quality control. Particularly, communication technology improvements are vital for modern academic activities and business transactions. Increases in international contact should be stressed, for example, encouraging attendances of international mushroom conferences and producing and publishing more good quality scientific papers in international journals and even establishing a home-based international journal of mushroom biology and mushroom products. We should make a concerted effort to lobby the government and industrial organizations, reminding them that research and development of mushroom industry is not a luxury but a human health necessity.

Challenges in developing mushrooms as dietary supplements for preventive health

There is an old Chinese saying that says: "HEALTH IS MORE IMPORTANT THAN WEALTH", or "WITHOUT HEALTH, YOU HAVE NOTHING". As we disseminate the notion that "prevention is better than cure" to the benefit of everyone, what human health problems are we facing? A major health problem increasingly affecting humans is the increased number of infectious diseases. This may be due, in part, to the natural decline of the body's immune system due to the constant stress and worry of the modern world. Another causal possibility may be the ever-increasing levels of pollution in our environment.

The products of medicinal mushrooms can help to enhance the immune system and promote the human's natural defense system. It is also good for patients who have received treatment of radiotherapy or chemotherapy, as it may help to reduce the side effects from such therapies. This mushroom has wide range of positive pharmacological effects for patients having undergone such therapies. These include: (a) increased number of leucocytes in the blood, and enhancing the immune functions. It has been known that chemotherapy treatment can markedly deplete the number of platelets in the blood and put patients at risk of excessive bruising, internal bleeding, brain haemorrhage and sometimes death, (b) increased/improved appetite, (c) reduced pain, (d) anti-emetic properties, (e) reduced or no hair loss, (f) reduced tumor regression; (g) potential anti-oxidant/genoprotective properties, and (h) general health improving effects. Furthermore, it should be noted, in some cases, that prevention of diseases might be more beneficial rather than curing of diseases. This does not only have positive financial and social impacts but also can maintain or even improve an individual's quality of life and human dignity.

The growing global dietary supplement for healthcare aids industries has prompted the need for international governance in establishing regulatory and standard benchmarks for the expanding world market. However, a major problem associated with mushroom-based dietary supplements/nutriceuticals is their wide variability and the current lack of standards for production and testing protocols necessary to guarantee product quality. The active ingredient components of the majority of present commercial products have not been indicated. Improvements in both areas are essential in order to increase and maintain consumer confidence, protect public health, and to meet current and future quality demands and safety-criteria set by regulatory authorities. This is especially important given that progress achieved during the past two decades in both research and production is clearly documentary evidence of the benefits medicinal mushrooms have to offer the human healthcare system. Modern medicines may not always provide the remedies required and mushroom products (nutriceuticals) are likely to prove extremely useful in both alleviating and preventing human disease conditions. The scientific validation of mushroom products can help boost the credibility of mushroom products (Chang 2006b). The key of the rational use of mushroom nutriceuticals, and for such products to fulfill their huge potential as part of an international market, is dependent upon interested governments formulating this regulatory framework.

Conclusion

The progress achieved during the past two decades in both research and production is clear documentary evidence of the benefits medicinal mushrooms have to offer human health-care systems in the 21st Century. Modern medicines may not always provide the remedies required and mushrooms and their nutriceuticals are likely to prove extremely useful in both alleviating and preventing human disease conditions. Disease prevention is particularly desirable, not only in having positive financial and social impacts, but also in maintaining/improving the quality of life and human dignity. Edible and medicinal mushrooms represent promising and relatively untapped sources of materials with potential nutritional and medicinal applications. However, many of the medicinal properties attributed to mushroom nutriceuticals or nutraceuticals are based on data obtained from *in-vitro* and animal-based experiments. Much more basic science is required to demonstrate that claims of enhanced function and reduced disease risks are also applicable in the human context.

As the world population is expected to continue to increase in the 21st century, so the amount of food and the level of medical care available to each individual, especially those living in less developed countries, may decrease. It is time that humans should make every endeavor to maximize the use of their limited natural resources including mushrooms that make it possible to convert agro-residues to value-added food, feed, fertilizer and fuel. We should thus make a concerted effort in research and development of applied mushroom industry to maximize mushroom production, thus generating a new cheap source of food protein from waste materials. Mushroom products, thus provide health enhancing dietary supplements for healthy and subhealth status people and enhancing the quality of life.

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