# Nutritional and medicinal value of mushrooms

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## Introduction

Mushrooms, the edible species of a large group of the higher fungi, are produced with high quality and high economic value. Mushrooms have been used as foods and food flavoring materials in soups and sauces for centuries, due to their unique and subtle flavor. Generally, mushrooms possess all four functionalities of food -- nutritional, tasty, physiological and cultural. For the first functionality of nutritional values, mushrooms are rich in polysaccharides, proteins, chitin, vitamin $D_2$ and minerals and low in fat, calories and contain no cholesterols. Secondly, the functionality of tasty properties features mushrooms as delicious food and contain food flavoring substances due to their unique flavor. In addition to the volatile eight-carbon compounds such as 1-octen-3-ol and 1-octen-3-one, the typical mushroom flavor consists of water soluble taste components including free amino acids and 5'-nucleotides. For the third functionality of physiological effects, as several physiologically active substances contained therein, mushrooms become a valuable health food. Mushrooms are thought to be beneficial for such diseases as hypertension, hypercholesterolemia, and cancer. Fourthly, take exemplified cases to show the functionality of mushrooms in cultural aspect; truffle is related to French cuisine and matsutake is famous in Japan, while Chang-chih (*Antrodia camphorata*) is only found in Taiwan.

Edible mushroom products are always available in fruiting body forms as food sources or as food additives for cooking whereas medicinal mushrooms are always available in mycelia due to their rare and expensive nature. Nevertheless, some are consumed in the form of sclerotia such as truffle while some species of mushroom spores are made into broken products for use in pharmaceutical formulation such as Lingzi (*Ganoderma lucium*). Due to increased health awareness for human life, it appears mushroom production and consumption is increasing in recent years.

Currently, there are many mushroom products/fruiting bodies available in market either produced domestically or imported from other countries and some mycelia produced via submerged fermentation mainly used as an ingredient for pharmaceutical formulations in Taiwan. These mushrooms are common mushroom [*Agaricus bisporus* (Lange) Imbach], hot mushroom [*Agaricus bitorquis* (Quelet) Saccardo], shiitake [*Lentinula edodes* (Berkeley) Pegler], paddy straw mushroom [*Volvariella volvacea* (Bulliard: Fries) Singer], winter mushroom [*Flammulina velutipes* (Curtis: Fries) Singer], willow-pine mushroom [*Agrocybe cylindracea* (de Candolle: Fries) Maire], summer oyster (*Pleurotus cystidiosus* Miller), mini oyster [*Pleurotus ostreatus* (Jacquin: Fries) Kummer], king oyster [*Pleurotus eryngii* (de Candolle: Fries) Quelet], golden oyster (*Pleurotus citrinopileatus* Singer), ferulae mushroom [*Pleurotus ferulae* (DC.: Fr) Quel.], big cup mushroom (*Clitocybe maxima* Gaertn. et G. Mey.: Fr.), black ear [*Auricularia mesenterica* (Dickson) Persoon], red ear [*Auricularia polytricha* (Montagne) Sacchardo], jin ear[ *Auricularia fuscosuccinea* (Montagne) Farlow], silver ear (*Tremella fuciformis* Berkeley), hon-shimeji [*Hypsizigus marmoreus* (Peck.) Bigelow], lion's mane mushroom [*Hericium erinaceus* (Bulliard: Fries) Persoon], basket stinkhorn (*Dictyophora indusiata* Fischer), king bolete (*Boletus edulis* Bull.: Fr.), maitake [*Grifola frondosa* (Dickson: Fries) Gray], white matsutake (*Tricholoma giganteum* Massee), wood blewit (*Lepista nuda* Bulliard ex Fries), Chaga [*Inonotus obliquus* (Fr.) Pilat], Ling-chih [*Ganoderma lucidum* (Curtis: Fries) Karsten], Tsuga Ling-chih (*Ganoderma tsugae* Murrill), Yun-chih [*Coriolus versicolor* (Fries) Quelet], Brazilian mushroom (*Agaricus blazei* Murrill), Chang-chih [*Antrodia camphorata* (Chang & Chou) Wu, Ryvarden & Chang], shiang-shan-chih (*Antrodia salmonea* Chang & Chou), caterpillar fungus [*Cordyceps sinensis* (Berk.) Sacc.], Northern caterpillar fungus [*Cordyceps militaris* (L.) Link], san-huang [*Phellinus linteus* (Berkeley & Curtis) Teng], termite fungus [*Termitomyces albuminosus* (Berkeley & Broome) Heim], and chicken-leg mushroom [*Coprinus comatus* (Muller: Fries) S.F. Gray].

This paper focuses on nutrition and medicinal values of edible and medicinal mushrooms including proximate composition, taste components and bioactive components.

- **Proximate composition**

Table 1 shows the proximate composition of some mushroom fruiting bodies available in Taiwan. In order to show the consistent comparison on the same basis, the data were calculated based on the dry matter. The composition of mushrooms can vary considerably from species to species and strains to strains. In addition, the cultivation techniques including use of different substrates, maturity at harvest and methods of analysis also result in different composition. However, the results can provide basic information about several important mushrooms.

Most fresh mushrooms contained 85% to 93% of moisture and generally around 90%. Therefore, upon the conversion of the dry basis to the fresh basis, the moisture content of mushrooms was arbitrarily assigned to be 90%. The ash, carbohydrate, fat, fiber and protein contents shown in Table 1 can be converted into fresh basis by a factor of 0.1, i.e., one log reduction or one decimal reduction.

Generally, mushrooms are a good source of protein. Mushroom protein is of good quality in vegetable in addition to legume protein. However, in Table 1, protein contents range from 4.2% to 44.94%.

*Agrocybe* and *Agaricus* provide high amount of protein (30-40%), *Lentinula* and *Pleurotus* provide middle amount (10-30%) and *Auricularia*, *Tremella*, *Ganoderma* and *Antrodia* are poor source of protein.

Usually, mushrooms are low in fat. However, the fat content in *Antrodia* is high (32.23-37.23%). Besides, the fat contents in other mushrooms are lower than 10%. The fat contents in *Auricularia* are even lower than 1%. *Agaricus* contained high amount of ash (12.6%). The ash contents in other mushrooms are lower than 10%. The fat contents in *Antrodia* and *Ganoderma* are around 1-2%.

The carbohydrate content (%) was calculated by subtracting the contents of crude ash, fat, fiber and protein from 100% of dry matter. Carbohydrate contents in Table 1 widely range from 10.41% to 88.14%. However, carbohydrate content can be subdivided into total reducing sugar (TRS) and non-reducing sugar (NRS) contents. TRS is the energy of mushrooms whereas NRS is so called soluble polysaccharide, which is another kind of dietary fiber in addition to insoluble polysaccharide. In Table 1, *Tremella* and *Auricularia* are rich in soluble polysaccharides. Nevertheless, *Ganoderma* is not rich in TRS or NRS.

The fiber contents in *Ganoderma* and *Lentinula edodes* stipe are high (59-73% and 32-47%). The fiber contents in *Pleurotus*, *Auricularia* and *Tremella* are lower than 10% and those in other mushrooms are between 10-30%. The fiber is acid-, alkali- and alcohol-insoluble polysaccharide and is ineffective in taste. The major component of crude fiber in mushrooms is chitin, which is an important structural polysaccharide found in the cell wall. The fiber and NRS contents together are called dietary fiber. Generally, mushrooms are rich in dietary fiber and some mushrooms are rich in soluble polysaccharides and other mushrooms are rich in insoluble polysaccharides. Both dietary fiber and polysaccharides are good for health-care.

- **Vitamins**

Mushrooms are known to be a good dietary source of B-complex vitamins. Besides, mushrooms are a good source of vitamin $D_2$, ergocalciferol and the only non-animal fresh food source of vitamin D. Also, mushrooms contain high amount of ergosterol, provitamin $D_2$, which can be converted to vitamin $D_2$ by ultraviolet (UV) irradiation. The enrichment of vitamin D in foods provides the advantage that calcium in foods can be more available for children, senior and postmenopausal women.

Further research on mushrooms and UV light is being conducted in the America and Australia. Tables 2 and 3 shows the effect of ultraviolet-C and ultraviolet-B irradiation on vitamin $D_2$ contents, respectively. After UV-C irradiation for 2 h, vitamin $D_2$ contents in *Agaricus bisporus* and *A. bitorquis* increased from 2.20 μg /g dry weight and 4.01 to 7.30 and 5.32, respectively. After UV-B irradiation for 2 h, the vitamin $D_2$ content in *A. bisporus* reached 12.48 μg/g. Mushrooms received UV-B irradiation resulted in higher vitamin $D_2$ conversion for *A. bisporus*. After UV-B irradiation for 2 h, vitamin $D_2$ contents in shiitake and straw mushrooms increased from 2.16 μg/g and 3.86 to 6.58 and 7.58, respectively. The increase rates in shiitake and straw mushrooms were not as high as that of *A. bisporus*.

- **Minerals**

Mushrooms contain high amount of potassium, copper and other minerals. Also, mushrooms are a good source of selenium (Se). Selenium is an essential micronutrient in human nutrition and it is incorporated into the antioxidant enzymes as glutathione peroxidase in the form of selenocysteine. These selenoproteins function in the prevention of cellular damage caused by free radicals. In addition, health benefits attributed to Se include anti-inflammatory and anti-carcinogenic properties. This element is found in soil where it is absorbed by plants and fungi and later accumulated in animals. Important sources of Se in foods are plants, meats, seafood and nuts.

Selenium can be accumulated in mushrooms through cultivation practice, when Se is supplied in the form of sodium selenite. This research is currently being conducted in the America.

- **Taste components**

Taste components present in mushrooms are soluble sugars and polyols, organic acids, free amino acids and 5'-nucleotides. Via a series of sensory evaluations on synthetic mushroom extracts prepared by the omission and addition of soluble components, major taste-active components in *A. bisporus* are found to be mannitol, oxalic, malic, citric, aspartic, glutamic acids, glycine, threonine, alanine, 5'-inosine monophosphate (5'-IMP), 5'-guanosine monophosphate (5'-GMP), and 5'-xanthosine monophosphate (5'-XMP). Mannitol and organic acids contribute most to the sweet and sour tastes, respectively. However, they are not the taste characteristic of mushroom flavor.

The predominant flavor of mushrooms is the umami taste, also called the palatable taste or the perception of satisfaction, which is an overall food flavor induced or enhanced by monosodium glutamate (MSG). In addition to four basic tastes such as sour, sweet, bitter and salty tastes as well as hot taste, the umami taste is the sixth taste in mouth perception. MSG can alleviate on salty, sour and bitter tastes, enhance the perception of sweet taste, and lower the sharp irritation of onion, the raw odor of meat and earthy note of potatoes. As a result of the properties of MSG, mushrooms can be widely used in most foods such as meat, seafood, soup, stew and cooked vegetables. Nevertheless, mushrooms cannot improve the taste of fruits, juices, desserts and cooked cereals.

Mushrooms contain considerably high amounts of free amino acids that impart the food taste with smooth feeling and thereby, compromising a sharp taste from some substances. Therefore, the combination of free amino acids always gives rise to a unique natural flavor. On the basis of their flavor characteristics, free amino acids are grouped into four classes of taste components, including MSG-like, sweet, bitter and tasteless components. Besides, sweet components (alanine, glycine, and threonine) and MSG-like components (Aspartic (Asp) and glutamic acids (Glu)) were taste-active amino acids in mushrooms, whereas none of the bitter components were found to be taste-active. The bitter taste from bitter components might be eliminated or suppressed by the soluble sugars and polyols and sweet components.

Since they give the most typical mushroom taste, MSG-like components, Asp and Glu, are also called umami amino acids. Six 5'-nucleotides are usually detected in mushrooms, including 5'-adenosine monophosphate (5'-AMP), 5'-cytosine monophosphate (5'-CMP), 5'-GMP, 5'-IMP, 5'-uridine monophosphate (5'-UMP), and 5'-XMP. Among these 5'-nucleotides, four 5'-nucleotides including 5'-AMP, 5'-IMP, 5'-GMP and 5'-XMP are also called umami 5'-nucleotides. 5'-GMP gives a meaty flavor and is a much stronger flavor enhancer than MSG. In addition, the synergistic effect of umami 5'-nucleotides and umami amino acids may greatly increase the umami taste of mushrooms.

The equivalent umami concentration [EUC, mg monosodium glutamate (MSG)/100 g] is the concentration of MSG equivalent to the umami intensity of that given by the mixture of MSG and the 5'-nucleotide and is represented by the following addition equation:

$$Y = \Sigma a_i b_i + 1218\ (\Sigma a_i b_i)\ (\Sigma a_j b_j),$$

where $Y$ is the EUC of the mixture in terms of mg MSG/100 g; $a_i$ is the concentration (mg/100 g) of each umami amino acid [aspartic acid (Asp) or glutamic acid (Glu)]; $a_j$ is the concentration (mg/100 g) of each umami 5'-nucleotide [5'-inosine monophosphate (5'-IMP), 5'-guanosine monophosphate (5'-GMP), 5'-xanthosine monophosphate (5'-XMP) or 5'-adenosine monophosphate (5'-AMP)]; $b_i$ is the relative umami concentration (RUC) for each umami amino acid to MSG (Glu, 1 and Asp, 0.077); $b_j$ is the RUC for each umami 5'-nucleotide to 5'-IMP (5'-IMP, 1; 5'-GMP, 2.3; 5'-XMP, 0.61 and

5'-AMP, 0.18); and 1218 is a synergistic constant based on the concentration of mg/100 g used.

Currently there are all varieties of fresh and dried mushrooms available in Taiwan. This paper summarized the results of mushroom taste components from a decade research, and calculated the EUC values of the fruit bodies and mycelia for each mushroom studied using the above additive equation, which are show in Tables 4 and 5, respectively. The EUC value is expressed as the percentages of dry matter by weight. An EUC value of 100% represents that the umami intensity of this fruit bodies or mycelia per 1 g dry matter is equivalent to the umami intensity given by 1 g of MSG and; in other words for short, 1 g MSG/g dry matter. EUC values are grouped into 4 levels: first level of > 1000% (> 10 g MSG/g dry matter), second level of 100-1000% (1-10 g MSG/g), third level of 10-100% (0.1-1 g MSG/g), and fourth level of 10% (<0.1 g MSG/g).

The EUC values at the first level are *V. volvacea* (paddy straw mushrooms) and *A. bisporus*. The EUC values of *V. volvacea* dramatically increased with cap opened. The EUC values of fruit bodies at the second and third levels are commercial mushroom products, including fresh or imported dried products. These mushrooms are famous not exclusively due to their umami taste, and rather partially due to different type of culinary quality such as unique flavor, consistency and texture. The EUC values of fruit bodies at the fourth level were mainly medicinal and ear mushrooms. Ear mushrooms for use in foods are dried products, and they provide bite and chew texture instead of the umami taste after dehydration and cooking.

As shown in Table 5, the EUC values of mycelia also varied and ranged from the highest value of 460% (*Termitomyces albuminosus*) to the lowest value of (*Agaricus blazei*). There are five species of mycelia at the second level, three species at the third level and one species at the fourth level. The EUC values of commercially available mushroom fruit bodies and mycelia summarized herein are valuable for their further use as foods or food-flavoring materials or in the formulation of health foods.

- **Bioactive components**

In addition to the bitter triterpenoids well-known in *Ganoderma*, there are several biologically active components found in mushrooms including Lovastatin, γ–aminobutyric acid (GABA) and ergothioneine. Lovastatin, GABA and ergothioneine are secondary metabolites from fungal growth.

Lovastatin, also known as monacolin K, mevinolin or mevacor, is a kind of statins (3-hydroxy-3-methylglutaryl coenzyme A reductase inhibitors), which inhibit the rate-limiting enzyme in the production of cholesterol, lowering total and LDL cholesterol levels and have been proven to reduce the risk of coronary *heart disease*. This class of statins has a well-studied lipid-lowering impact on serum cholesterol levels benefit. They have been shown to have effectively anti-inflammatory, antioxidant and pro-fibrinolytic properties and to prevent acute coronary syndromes and atherosclerotic disease.

GABA is a hypotensive agent, which is known to be produced by edible, medicinal mushrooms and *Monascus* species. In spontaneously hypertensive rats, GABA has an antihypertensive effect. Furthermore, the protection and hypotensive actions of some food products containing GABA were shown in hypertensive patients.

Ergothioneine is a thiol compound and a naturally occurring antioxidant of biological origin. In animals, ergothioneine provides several physiological benefits such as enhancement of metabolic energy, protection against formation of cataracts and molecular regulation of anti-inflammatory mechanisms in lungs. Synthesis of ergothioneine in nature is restricted to fungi and Mycobacterium. Ergothioneine synthesized by these organisms is taken up by plants from the soil and then passed to animals and humans where it accumulates at different concentrations in tissues and blood. In addition, ergothioneine is effective intrinsic anti-hydroxyl, anti-peroxyl and anti-peroxynitrite radical antioxidant activity, as compared to classic molecules with antioxidant capacity as reduced glutathione, uric acid and trolox.

Tables 6 and 7 show Lovastatin, GABA and ergothioneine contents in fruiting bodies and mycelia, respectively. *Agaricus bisporus* and *B. edulis* contained high amount of Lovastatin (565 and 327 mg/kg, respectively) in 20 kinds of fruiting bodies. However, Lovastatin was not detected in mycelia of *G. frondosa*, and fruiting bodies of *L. edodes*, *G. frondosa* and *A. mesenterica*. However, *C. sinensis*, *A. salmonea* and *A. blazei* contained high amount of Lovastatin (1365, 1032 and 770 mg/kg, respectively) in 20 kinds of mycelia. Lovastatin contents can be grouped into four levels: first level of >1000 mg/kg dry matter, second level of 500–1000 mg/kg, third level of 100–500 mg/kg, and fourth level of < 100 mg/kg. Therefore, Lovastatin content in mycelia of *C. sinensis* and *A. salmonea* were at the first level, and those in *A. blazei*, *P. ostreatus* (Japan) and *A. camphorata* were at the second level. In addition, Lovastatin content in fruiting body of *A. bisporus* was at the second level. It seems that Lovastatin content in mycelia has high level than that in fruiting body. Furthermore, the result demonstrated the Lovastatin value in medicinal mushrooms was more than that in edible mushrooms.

Lovastatin and the HMG-CoA reductase activity are produced by fruiting bodies and mycelia liquid cultures of edible mushroom, especially in *Pleurotus* spp. The hypocholesterolemic influence of oyster mushroom (*Pleurotus* spp.), combined with inhibition of lipid peroxidation was shown in rats and rabbits. Oyster mushroom diet considerably reduced the numbers and size of atherosclerotic plaques in rabbits. Lovastatin could be detected in this species and was equally responsible for the observed effects.

*Flammulina velutipes*, *B. edulis* and *A. bisporus* contained high amount of GABA (230, 202 and 125 mg/kg, respectively) in 20 kinds of fruiting bodies. *Cordyceps cicadae*, *C. sinensis* and *A. blazei* contained high amount of GABA (255, 221 and 200 mg/kg, respectively) in 20 kinds of mycelia. However, Lovastatin was not detected in mycelia of *G. frondosa* and *C. comatus*, and fruiting bodies of *A. mesenterica*, *I. obliquus*, *P. eryngii* (foot), *P. ostreatus* and *P. salmoneostramineus*. That GABA contents can be grouped into four levels: first level of > 200 mg/kg dry matter, second level of 100–200 mg/kg, third level of 10–100 mg/kg, and fourth level of < 10 mg/kg. Therefore, the values in mycelia of *C. cicadae*, *C. sinensis* and *A. blazei* were at the first level, and *A. salmonea*, *H. marmoreus* (white), *A. cylindracea*, *C. versicolor* and *H. marmoreus* were at the second level. GABA value in fruiting bodies of *F. velutipes* and *B. edulis* were at the first level, and *A. bisporus* and *H. marmoreus* were at the second level. Similarly, GABA content in mycelia is higher than that in fruiting body. Furthermore, the result demonstrated the GABA contents in medicinal mushrooms were more than those in edible mushrooms.

*Pleurotus citrinopileatus* contained the highest amount of ergothioneine (2850.7 mg/kg) in fruiting body. *Pleurotus eryngii* shows higher ergothioneine content in mycelia (1514.6 mg/kg) than fruiting body (840.4 mg/kg). This result shows that higher amount of ergothioneine are found in *Pleurotus* spp. Ergothioneine values can be grouped into four levels: first level of > 2000 mg/kg dry matter, second level of 1000–2000 mg/kg, third level of 200–1000 mg/kg, and fourth level of < 200 mg/kg. Therefore, ergothioneine value in mycelia of *P. eryngii* was at the second level. The ergothioneine value in fruiting bodies of *P. citrinopileatus* was at the first level, and *P. ostreatus* (korea), *P. ostreatus and P. salmoneostramineus* were at the second level. Generally, the ergothioneine values in fruiting bodies are higher than those in mycelial. Interestingly, the result demonstrated that ergothioneine contents in edible mushrooms are higher than those in medicinal mushrooms.

## Conclusion

Mushrooms are not vegetables and are not even plants. Mushrooms are higher fungi which evolved between plants and animals. As a result of this, mushrooms have a much different nutritional profile from those of plants and animals. Mushrooms are known to be high in antioxidants and are in the top five highest antioxidant foods when compared to common vegetables. To know more information about their nutritional and medicinal values will facilitate the expansion and consumption of mushrooms.

Table 1. Proximate composition (% dry wt) of mushroom fruiting bodies

| Fruit body | Ash | Carbohydrate (TRS + NRS) | Fat | Fiber | Protein |
|---|---|---|---|---|---|
| *Agaricus bisporus* | 12.57 | 53.44 | 2.10 | 16.68 | 15.21 |
| *Agaricus bisporus* Tainung 3 | 8.54 | 33.98 (14.48 + 19.50) | 2.90 | 11.00 | 43.58 |
| *Agaricus blazei* | 8.85 | 45.47 | 1.87 | 7.95 | 35.86 |
| *Agaricus blazei* | 6.81 | 45.52 (10.71 + 34.81) | 2.62 | 18.31 | 26.74 |
| *Agrocybe cylindracea* B | 8.19 | 29.02 | 2.18 | 16.37 | 44.24 |
| *Agrocybe cylindracea* B | 7.90 | 43.58 (14.73 + 28.85) | 3.54 | 22.80 | 22.18 |
| *Agrocybe cylindracea* B | 6.06 | 23.00 | 4.26 | 26.55 | 40.13 |
| *Agrocybe cylindracea* M | 7.66 | 39.54 | 2.48 | 16.15 | 34.17 |
| *Agrocybe cylindracea* W | 8.59 | 27.06 | 2.71 | 16.70 | 44.94 |
| *Agrocybe cylindracea* yellow | 6.65 | 53.71 (7.88 + 45.83) | 3.63 | 19.54 | 16.47 |
| *Antrodia camphorata* | 1.04 | 31.76 | 37.23 | 22.68 | 7.29 |
| *Antrodia camphorata* | 1.73 | 36.91 | 32.23 | 22.53 | 6.60 |
| *Auricularia fuscosuccinea* brown | 4.02 | 71.19 (9.87 + 61.32) | 4.48 | 11.69 | 8.62 |
| *Auricularia fuscosuccinea* white | 5.54 | 68.88 (10.90 + 57.98) | 4.54 | 8.51 | 12.53 |
| *Auricularia mesenterica* | 3.29 | 76.53 (17.81 + 58.72) | 0.80 | 3.92 | 15.46 |

Table 1. continued

| | | | | | |
|---|---|---|---|---|---|
| *Auricularia polytricha* | 2.05 | 88.14 (17.62 + 70.52) | 0.48 | 3.63 | 5.70 |
| *Boletus edulis* | 5.84 | 56.16 (8.31 + 47.85) | 5.76 | 13.70 | 18.54 |
| *Clitocybe maxima* cap | 5.28 | 43.65 (22.21 + 21.44) | 2.70 | 26.78 | 21.59 |
| *Clitocybe maxima* stipe | 3.67 | 50.92 (31.47 + 19.45) | 1.24 | 31.76 | 12.41 |
| *Coprinus comatus* | 8.44 | 58.37 (15.91 + 42.46) | 3.11 | 12.48 | 17.60 |
| *Cordyceps militaris* | 5.94 | 28.04 (14.03 + 14.01) | 10.09 | 19.57 | 36.36 |
| *Coriolus versicolor* | 6.37 | 65.09 (28.27 + 36.82) | 1.10 | 23.24 | 4.20 |
| *Dictyophora indusiata* | 6.25 | 67.02 (20.11 + 46.91) | 2.98 | 9.16 | 14.59 |
| *Flammulina velutipes* white | 6.93 | 48.19 (13.88 + 34.31) | 8.89 | 15.99 | 20.00 |
| *Flammulina velutipes* white | 7.84 | 48.02 | 10.08 | 11.40 | 22.66 |
| *Flammulina velutipes* yellow | 7.51 | 39.63 (12.03 + 27.60) | 9.23 | 16.98 | 26.65 |
| *Flammulina velutipes* yellow | 9.41 | 45.82 (14.07 + 31.75) | 3.90 | 23.98 | 16.89 |
| *Ganoderma lucidum* | 1.77 | 26.02 (15.12 + 10.90) | 5.13 | 59.16 | 7.92 |
| *Ganoderma lucidum* antler | 1.70 | 27.78 (15.56 + 12.22) | 3.85 | 59.49 | 7.18 |
| *Ganoderma tsugae* | 0.72 | 21.83 (15.81 + 6.02) | 4.62 | 65.29 | 7.54 |

Table 1. continued

| | | | | | |
|---|---|---|---|---|---|
| *Ganoderma tsugae* | 1.69 | 10.41 (5.35 + 5.06) | 5.72 | 73.37 | 8.81 |
| *Ganoderma tsugae* baby | 2.62 | 17.17 (5.86 + 11.31) | 6.50 | 59.93 | 13.78 |
| *Grifola frondosa* | 6.99 | 58.78 (10.71 + 48.07) | 3.10 | 10.05 | 21.08 |
| *Grifola frondosa* | 6.15 | 33.53 (20.11 + 13.42) | 6.51 | 32.81 | 21.00 |
| *Hericium erinaceus* | 9.35 | 57.02 (17.39 + 39.63) | 3.52 | 7.81 | 22.30 |
| *Hypsizigus marmoreus* | 6.85 | 47.45 (13.87 + 33.58) | 3.62 | 24.75 | 17.33 |
| *Lentinula edodes* 271 | 5.27 | 62.30 (25.81 + 36.49) | 6.34 | 5.63 | 20.46 |
| *Lentinula edodes* stipe | 3.50 | 47.06 (36.14 + 10.92) | 2.89 | 35.99 | 10.56 |
| *Lentinula edodes* stipe | 3.78 | 37.65 (19.68 + 17.97) | 1.32 | 46.99 | 10.26 |
| *Lentinula edodes* stipe | 3.87 | 36.06 (11.11 + 24.95) | 1.74 | 45.73 | 12.60 |
| *Lentinula edodes* stipe | 3.04 | 37.34 | 6.21 | 32.51 | 20.90 |
| *Lentinula edodes* Tainung 1 | 5.85 | 63.90 (21.91 + 41.99) | 5.71 | 4.88 | 19.66 |
| *Pleurotus citrinopileatus* | 6.72 | 45.82 (17.90 + 27.92) | 3.44 | 18.03 | 25.99 |
| *Pleurotus cystidiosus* | 9.62 | 63.13 (21.00 + 42.13) | 3.10 | 8.74 | 15.41 |
| *Pleurotus eryngii* | 4.96 | 66.21 | 2.65 | 7.42 | 18.76 |
| *Pleurotus eryngii* base | 5.15 | 77.33 | 0.81 | 7.59 | 9.12 |

Table 1. continued

| | | | | | |
|---|---|---|---|---|---|
| *Pleurotus eryngii* large | 5.76 | 64.55 | 1.57 | 5.97 | 22.15 |
| *Pleurotus eryngii* small | 7.21 | 61.12 | 1.81 | 9.15 | 20.71 |
| *Pleurotus ferulae* | 6.60 | 61.13 | 3.01 | 12.98 | 16.28 |
| *Pleurotus ostreatus* | 7.59 | 61.07 (19.65 + 41.42) | 2.16 | 5.33 | 23.85 |
| *Pleurotus ostreatus* gray | 5.90 | 64.20 | 3.76 | 9.82 | 16.32 |
| *Tremella fuciformis* | 6.14 | 81.72 (31.64 + 50.08) | 0.93 | 2.91 | 8.30 |
| *Tremella fuciformis* | 6.48 | 80.74 (29.73 + 51.01) | 2.74 | 2.51 | 7.53 |
| *Tremella fuciformis* | 7.36 | 81.43 | 2.57 | 1.53 | 7.11 |
| *Tricholoma giganteum* | 5.03 | 70.07 ( 37.95 + 32.12) | 4.28 | 4.50 | 16.12 |

TRS, Total reducing sugar; NRS, non-reducing sugar

Table 2. Effect of ultraviolet-C irradiation on contents of vitamin $D_2$ and ergosterol in *Agaricus bisporus* and *A. bitorquis*

| | Content (μg/g dry mushroom) [relative %][a] | | | |
|---|---|---|---|---|
| | 0 h[b] | 0.5 h | 1 h | 2 h |
| *Agaricus bisporus* | | | | |
| Vitamin $D_2$ | 2.20d[c] | 4.49c | 6.00b | 7.30a |
| | [100] | [204] | [273] | [332] |
| Ergosterol | 273.97a | 165.62b | 91.47c | 33.93d |
| | [100] | [60] | [33] | [12] |
| *Agaricus bitorquis* | | | | |
| Vitamin $D_2$ | 4.01c | 4.59b | 5.62a | 5.32a |
| | [100] | [114] | [140] | [133] |
| Ergosterol | 50.78c | 43.53c | 78.57b | 254.88a |
| | [100] | [86] | [155] | [502] |

[a]Based on the control (0 hr).

[b]Irradiation intensity: 0.2 mW/cm$^2$.

[c]Means with different letters within the same row are significantly different ($p < 0.05$).

Table 3. Effect of ultraviolet-B irradiation on contents of vitamin $D_2$ and ergosterol in *Agaricus bisporus*, *Lentinula edodes* and *Volvaria volvacea*

| | Content (μg/g dry mushroom) [relative %][a] | | | |
|---|---|---|---|---|
| | 0 h[b] | 0.5 h | 1 h | 2 h |
| *Agaricus bisporus* | | | | |
| Vitamin $D_2$ | 2.20d[c] | 5.74c | 8.51b | 12.48a |
| | [100] | [261] | [387] | [567] |
| Ergosterol | 273.97a | 21.61b | 40.39b | 56.69b |
| | [100] | [8] | [15] | [21] |
| *Lentinula edodes* | | | | |
| Vitamin $D_2$ | 2.16d | 3.71c | 4.69b | 6.58a |
| | [100] | [172] | [217] | [305] |
| Ergosterol | 297.09b | 316.61b | 373.15a | 286.16b |
| | [100] | [107] | [126] | [96] |
| *Volvariella volvacea* | | | | |
| Vitamin $D_2$ | 3.86d | 4.98c | 6.28b | 7.58a |
| | [100] | [129] | [163] | [196] |
| Ergosterol | 185.89b | 96.92c | 233.56a | 215.81a |
| | [100] | [52] | [126] | [116] |

[a]Based on the control (0 hr).

[b]Irradiation intensity: 0.14 mW/cm$^2$.

[c]Means with different letters within the same row are significantly different ($p < 0.05$).

Table 4. Equivalent umami concentration (EUC) for fruit bodies

| Fruitnig body | EUC (% dry wt) |
| --- | --- |
| *Volvariella volvacea* (flat cap) | 4465.00 |
| *Volvariella volvacea* (stipe elongated) | 2593.00 |
| *Volvariella volvacea* (volva broken) | 2198.00 |
| *Volvariella volvacea* (egg shape) | 1181.00 |
| *Agaricus bisporus* (Tainung 3) | 1144.00 |
| *Volvariella volvacea* (bell shape) | 1048.00 |
| *Pleurotus citrinopileatus* | 511.00 |
| *Flammulina velutipes* (yellow) | 363.00 |
| *Hypsizigus marmoreus* | 272.00 |
| *Agrocybe cylindracea* (Brown) | 164.00 |
| *Flammulina velutipes* (white) | 139.00 |
| *Agaricus blazei* | 136.00 |
| *Lentinula edodes* (271) | 132.00 |
| *Coprinus comatus* | 103.00 |
| *Agrocybe cylindracea* (golden) | 100.00 |
| *Pleurotus eryngii* (small fruit body) | 97.90 |
| *Pleurotus cystidiosus* | 85.20 |
| *Dictyophora indusiata* | 72.70 |
| *Pleurotus eryngii* (large fruit body) | 68.70 |
| *Agrocybe cylindracea* (white) | 68.10 |
| *Pleurotus ostreatus* | 48.00 |
| *Agrocybe cylindracea* (yellow) | 46.70 |
| *Tricholoma giganteum* | 38.70 |
| *Pleurotus eryngii* (fruit body base) | 32.10 |
| *Lentinula edodes* (Tainung 1) | 23.40 |
| *Grifola frondosa* | 12.70 |
| *Boletus edulis* | 10.50 |
| *Ganoderma lucidum* | 7.92 |
| *Coriolus versicolor* | 7.70 |
| *Ganoderma tsugae* (baby Ling chih) | 5.43 |

Table 4. continued

| | |
|---|---|
| *Auricularia fuscosuccinea* (white) | 4.11 |
| *Hericium erinaceus* | 3.00 |
| *Ganoderma lucidum* (antler) | 2.58 |
| *Auricularia fuscosuccinea* (brown) | 2.38 |
| *Auricularia mesenterica* | 1.52 |
| *Ganoderma tsugae* | 0.97 |
| *Ganoderma tsugae* | 0.66 |
| *Tremella fuciformis* | 0.49 |
| *Auricularia polytricha* | 0.12 |

Table 5. Equivalent umami concentration (EUC) for mycelia

| Mycelia | EUC (% dry wt) |
|---|---|
| *Termitomyces albuminosus* | 460.00 |
| *Grifola frondosa* | 375.00 |
| *Morchella esculenta* | 363.00 |
| *Hypsizigus marmoreus* | 128.00 |
| *Cordyceps militaris* | 124.00 |
| *Pleurotus citrinopileatus* | 37.10 |
| *Antrodia camphorata* | 21.20 |
| *Ganoderma tsugae* | 19.40 |
| *Agaricus blazei* | 1.92 |

Table 6. The Lovastatin, GABA and ergothioneine contents (mg/kg dry weight) of fruiting bodies

| Fruit body | Lovastatin | GABA | Ergothioneine |
|---|---|---|---|
| *Agaricus bisporus* | 565.4±18.5B | 125.4±8.8C | 932.7±5.0E |
| *Auricularia mesenterica* | ND | ND | 149.4±1.0L |
| *Boletus edulis* | 327.3±10.3C | 202.1±4.9B | 494.4±1.0HI |
| *Clitocybe maxima* (cap) | 155.8±5.2GH | 17.3±0.7EF | 991.2±29.8E |
| *Clitocybe maxima* (stipe) | 239.9±5.7D | 22.7±0.7EF | 664.4±3.6G |
| *Flammulia velutipes* | 90.8±2.0J | 229.7±13.3A | 454.5±2.4IJ |
| *Grifola frondosa* | ND | 17.8±2.4EF | 553.2±1.3H |
| *Hypsizigus marmoreus* | 257.9±8.9D | 114.1±14.7C | 409.5±15.0J |
| *Inonotus obliquus* | 22.0±0.3K | ND | 47.7±0.6M |
| *Lentinula edodes* | ND | 15.4±1.2F | 412.3±9.2J |
| *Pholiota nameko* | 185.5±3.6F | 8.2±0.3F | 228.8±7.8K |
| *Pleurotus citrinopileatus* | 118.0±2.7I | 17.8±3.3EF | 2850.7±10.6A |
| *Pleurotus cystidiosus* | 101.1±1.5IJ | 37.1±1.5DE | 258.9±12.4K |
| *Pleurotus eryngii* (foot) | 151.8±3.2GH | ND | 624.5±30.3G |
| *Pleurotus eryngii* | 119.9±2.3I | 25.5±0.9EF | 840.4±19.7F |
| *Pleurotus ferulae* | 142.2±2.5H | 46.7±5.7D | 464.1±6.9IJ |
| *Pleurotus ostreatus* (Japan) | 606.5±5.6A | 6.1±1.3F | 944.1±43.1E |
| *Pleurotus ostreatus* (Korea) | 165.3±3.8G | 23.6±2.9EF | 1829.4±49.9B |
| *Pleurotus ostreatus* | 216.4±9.9E | ND | 1458.4±35.3C |
| *Pleurotus salmoneostramineus* | ND | ND | 1245.0±48.7D |

Each value is expressed as mean ± standard error ($n$ = 3). Means with different letters within a column are significantly different ($P < 0.05$).

ND, Not detected.

Table 7. The Lovastatin, GABA and ergothioneine contents (mg/kg dry weight) of mycelia

| Fruit body | Lovastatin | GABA | Ergothioneine |
|---|---|---|---|
| *Agaricus blazei* | 769.9±7.2C | 200.4±21.0BC | 79.6±7.3KLM |
| *Agrocybe cylindracea* | 417.8±7.5F | 123.0±10.3DE | 279.4±7.3FG |
| *Antrodia camphorata* | 543.6±6.5D | 38.4±2.7G | 281.6±13.8FG |
| *Antrodia salmonea* | 1032.3±8.6B | 133.0±9.1D | 7.6±0.5M |
| *Armillariella mellea* | 253.2±10.7G | 34.2±3.4GH | 219.6±9.3FGH |
| *Coprinus comatus* | 109.6±5.4K | ND | 399.0±4.6D |
| *Cordyceps cicadae* | 134.3±4.2J | 254.9±9.6A | 588.0±42.3C |
| *Cordyceps militaris* (cm1) | 37.7±0.7L | 70.6±6.5F | 215.0±10.5FGH |
| *Cordyceps militaris* (cm5) | 47.9±3.5LM | 68.6±5.4F | 785.1±9.4B |
| *Cordyceps militaris* | 57.3±3.2LM | 180.1±8.4C | 123.4±12.7JKL |
| *Cordyceps sinensis* | 1365.3±7.9A | 220.5±10.2B | 142.0±38.5IJK |
| *Coriolus versicolor* | 207.0±7.1H | 115.8±4.2DE | 13.0±1.9M |
| *Ganoderma lucidum* | 10.6±0.3N | 7.0±0.6I | 16.5±2.0M |
| *Grifola frondosa* | ND | ND | 296.2±25.1EF |
| *Hericium erinaceus* | 187.5±7.3HI | 6.2±0.7I | 376.2±36.7DE |

Table 7. continued

| | | | |
|---|---|---|---|
| *Hypsizigus marmoreus* (white) | 455.2±15.9E | 125.3±1.8DE | 221.4±4.6FGH |
| *Hypsizigus marmoreus* | 424.3±13.6F | 101.1±4.8E | 206.7±12.6GHI |
| *Inonotus obliquus* | 25.6±1.5MN | 12.1±0.8HI | 252.1±5.5FGH |
| *Phellinus linteus* | 168.3±4.5I | 67.8±4.8F | 181.8±16.7HIJ |
| *Pleurotus eryngii* | 44.5±0.9LM | ND | 1514.6±15.7A |

Each value is expressed as mean ± standard error ($n$ = 3). Means with different letters within a column are significantly different ($P < 0.05$).

ND, Not detected.