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Non-volatile taste components of *Agaricus blazei*, *Agrocybe cylindracea* and *Boletus edulis*

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Abstract

Three species of dried mushrooms are commercially available in Taiwan, namely *Agaricus blazei* (Brazilian mushroom), *Agrocybe cylindracea* (black popular mushroom) and *Boletus edulis* (king bolete), and their non-volatile taste components were studied. All mushrooms were high in contents of carbohydrate, crude fiber and protein but low in contents of crude ash and fat. Arabitol, myo-inositol, mannitol and trehalose were detected in these three mushrooms, whereas glucose was not found in *B. edulis*. Contents of total soluble sugars and polyols ranged from 150.33 to 225.08 mg/g. Total free amino acid contents were low in these three mushrooms and ranged from 8.97 to 14.91 mg/g. The contents of MSG-like components ranged from 1.24 to 4.40 mg/g were in the descending order of the *A. blazei*, *A. cylindracea* and *B. edulis*. Total 5′-nucleotides contents of *A. blazei* and *A. cylindracea* were higher than that of *B. edulis* whereas flavor 5′-nucleotides content of *A. blazei* was higher than those of *A. cylindracea* and *B. edulis*. Equivalent umami concentrations values in three mushrooms ranged from 10.46 to 135.90 g per 100 g. Overall, these three mushrooms possessed highly umami taste.
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Keywords: *Agaricus blazei*; *Agrocybe cylindracea*; *Boletus edulis*; Soluble sugars; Free amino acids; 5′-Nucleotides; Equivalent umami concentration

1. Introduction

Mushrooms are health foods with relatively low in calories and fat but rich in vegetable proteins, chitin, vitamins, and minerals. Furthermore, it is suggested that they constitute an increasing share in the world diet (Manzi, Gambelli, Marconi, Vivanti, & Pizzoferrato, 1999). Mushrooms are also thought to be beneficial for such diseases as hypertension, hypercholesterolemia, and cancer (Bobek & Galbavy, 1999; Borchers, Stern, Hackman, Keen, & Gershwin, 1999). Mushrooms have been used as foods and food flavoring materials in soups and sauces for centuries, due to their unique and subtle flavor.

Agaricus blazei Murrill (Agariaceae), Brazilian mushroom, was reported to possess antitumour and immunomodulating activities (Kawagishi et al., 1989). Its isolated polysaccharides could stimulate lymphocyte T-cells in mice (Mizuno, Morimoto, Minate, & Tsuchida, 1998). Recently, *A. blazei* is used for the prevention of cancer and/or as an adjuvant with cancer chemotherapy drugs after the removal of a malignant tumor (Ishihara, 1999). *Agrocybe cylindracea* (DC: Fr.) Mre. [syn. *Agrocybe aegerita* (Briganti) Singer] (Bolbitiaceae) also called black poplar mushroom (Leu, 1992). Fruit bodies of this mushroom are found to be medically active in several therapeutic effects such as antitumor, antifungal, nerve tonic, hypercholesterolemia and hyperlipidemia (Wasser & Weis, 1999). Extracts from *A. cylindracea* possessed antimutagenic activities and might play a role in the prevention of cancer (Shon & Nam, 2001). Furthermore, two new indole derivatives isolated from its methanolic extract inhibited lipid peroxidation in rat liver microsomes (Kim et al., 1997).

Boletus edulis Bull.: Fr. (Boletaceae), king bolete, was a popular edible mushroom in Europe, North America, and Asia (Arora, 1986). Fresh and dried king bolete may be

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marketed in oriental restaurants and oriental, gourmet, and health food stores. The flavor of this dried king bolete including odor and taste is marvelous-nutty, earthy, and meaty all at once.

Currently, these three tasty mushrooms are available in Taiwan in dried forms. However, the chemical composition and the profile of taste components of these mushrooms were not known. Accordingly, our objective was to examine the non-volatile taste components in the three dried mushrooms, including their proximate compositions, soluble sugars, free amino acids and 5′-nucleotides. Equivalent umami concentrations (EUC) of these mushrooms were also evaluated.

2. Materials and methods

2.1. Mushrooms

Air-dried mushrooms of *A. blazei*, *A. cylindracea* (golden strain) and *B. edulis* were purchased from Save & Safe Hypermarket, Tali City, Taichung County, Taiwan. For each mushroom, three dried samples (~50 g each) were randomly selected and ground using a mill (Retsch ultra-centrifugal mill and sieving machine, Haan, Germany) to obtain fine powder (60 mesh).

2.2. Proximate analysis

The proximate compositions of the three species of mushroom, including moisture, crude ash, crude fat, crude fiber and crude protein, were determined according to the methods of AOAC (1990). The nitrogen factor used for crude protein calculation was 4.38 (Crisan & Sands, 1978). The carbohydrate content (%) was calculated by subtracting the contents of crude ash, fat, fiber and protein from 100% of dry matter. Total reducing sugars were determination using the 3,5-dinitrosalicylic acid (DNS) method as described by James (1995). The absorbance of each sample solution was measured at 540 nm on a Hitachi 2001 spectrophotometer. Total reducing sugars were calculated based on a calibration curve of glucose.

2.3. Soluble sugar and polyol assay

Soluble sugars and polyols were extracted and analyzed as described by Ajlouni, Beelman, Thompson, and Mau (1995). Mushroom power (600 mg) was extracted with 50 ml of 80% aqueous ethanol (95% pure, Taiwan Tobacco & Wine Monopoly Bureau, Taipei). This suspension was shaken for 45 min at room temperature and filtered through Whatman No. 4 filter paper. The residue was washed five times with additional 25-ml portions of 80% ethanol. The combined filtrate was then rotary evaporated at 40 °C and redissolved in deionized water to a final volume of 10 ml. The aqueous extract was passed through a Millex-HV filter unit (13 mm, Millipore, Billerica, MA), and filtered using a 0.45-μm PVDF filter (Millipore) prior to injection onto high-performance liquid chromatograph (HPLC).

The HPLC system consisted of a Shimadzu LC-10AT *VP* pump, a Rheodyne 7725i injector, a 20-μl sample loop, a Shimadzu RID-10A detector, and a Phase Sep-NH_2 column (4.6 × 250 mm, 5 μm, Phase Separation Inc., Norwalk, CT). The mobile phase was acetonitrile (LC grade, Tedia Co., Fairfield, OH)/deionized water, 85:15 (v/v) at a flow rate of 1.0 ml/min. Each sugar or polyol was identified using the authentic sugar or polyol (Sigma Chemical Co., St. Louis, MO) and quantified by the calibration curve of the authentic compound.

2.4. Free amino acid assay

Mushroom power (500 mg) was shaken with 50 ml of 0.1 N HCl (Union Chemical Co., Hsinchu, Taiwan) for 45 min at ambient temperature and filtered through Whatman No. 4 filter paper. The filtrate was then passed through a Millex-HV filter unit (13 mm), and filtered using a 0.45-μm PVDF filter. This filtrate was mixed with *o*-phthalaldehyde reagent (Sigma) in an eppendorf tube, shaken to facilitate derivatisation and then immediately injected onto HPLC.

The HPLC system was the same as for sugar and polyol analysis but included a Hitachi L-7485 fluorescence detector with fluorescence excitation at 340 nm and emission at 450 nm, and a LiChrospher 100 RP-18 column (4.6 × 250 mm, 5 μm, Merck, Darmstadt, Germany). The mobile phases were A, 50 mM sodium acetate (pH 5.7) containing 0.5% tetrahydofuran; B, deionized water; and C, methanol. The gradient was A:B:C 80:0:20 (v/v/v) to 33:0:67 for 0–38 min, 0:33:67 for 38–40 min, and 0:100:0 for 40–43 min. The flow rate was 1.2 ml/min (Mau, Chyau, Li, & Tseng, 1997). Each amino acid was identified using the authentic amino acid (Sigma) and quantified by the calibration curve of the authentic compound.

2.5. 5′-Nucleotide assay

5′-nucleotides were extracted and analyzed as described by Taylor et al. (1981). Mushroom power (500 mg) was extracted with 25 ml of deionized water. This suspension was heated to boiling for 1 min, cooled, and then centrifuged at 11,800*g* for 15 min. The extraction was repeated once with 20 ml of deionized water. The combined filtrate was then evaporated, and filtered prior to HPLC injection in the same manner as in soluble sugar or polyol assay.

The HPLC system was the same as for sugar and polyol analysis but included a Shimadzu UV detector and a LiChrospher 100 RP-18 column (4.6 × 250 mm, 5 μm, Merck). The mobile phase was 0.5 M KH_2PO_4/H_3PO_4 (pH 4.3, Wako Pure Chemical Co., Osaka, Japan) at a flow rate of 1 ml/min and UV detection at 254 nm. Each 5′-nucleotide was identified using the authentic 5′-nucleotide (Sigma) and quantified by the calibration curve of the authentic compound.

2.6. Equivalent umami concentration

The equivalent umami concentration [EUC, mg monosodium glutamate (MSG) per 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 (Yamaguchi, Yoshikawa, Ikeda, & Ninomiya, 1971):

$$Y = \Sigma a_i b_i + 1.218(\Sigma a_i b_i)(\Sigma a_j b_j)$$

where Y is the EUC of the mixture in terms of mg MSG per 100 g; a_i is the concentration (mg per 100 g) of each umami amino acid [aspartic acid (Asp) or glutamic acid (Glu)]; a_j is the concentration (mg per 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 1.218 is a synergistic constant based on the concentration of mg per 100 g used.

2.7. Statistical analysis

For each mushroom, three samples were used for the determination of every quality attribute. The experimental data were subjected to an analysis of variance for a completely random design to determine the least significant difference among means at the level of 0.05.

3. Results and discussion

The moisture contents ranged from 8.75% to 11.97%, and in the descending order of *B. edulis*, *A. cylindracea* and *A. blazei* (Table 1). Generally, all mushrooms were high in contents of carbohydrate, crude fiber and protein but low in contents of crude ash and fat. The carbohydrate contents ranged from 45.52% to 56.16% and in the descending order of *B. edulis*, *A. cylindracea* and *A. blazei*. However, the reducing sugar contents ranged from 7.88% to 10.71% and in the descending order of *A. blazei*, *B. edulis* and *A. cylindracea*. The difference between carbohydrate and reducing sugar contents was the content of soluble polysaccharides. Soluble polysaccharides were thought to the biologically active component in mushrooms, and their contents were 34.81%, 45.83% and 47.85% for *A. blazei*, *A. cylindracea* and *B. edulis*, respectively.

Table 1
Proximate composition of *A. blazei*, *A. cylindracea* and *B. edulis*

Components	Content[a] (%)		
	A. blazei	*A. cylindracea*	*B. edulis*
Moisture	10.86 ± 0.11 B[b]	8.75 ± 0.16 C	11.97 ± 0.18 A
Dry matter	89.14 ± 0.11 B	91.26 ± 0.16 A	88.03 ± 0.18 C
Carbohydrate	45.52 ± 0.40 C	53.71 ± 0.08 B	56.16 ± 0.23 A
Reducing sugar	10.71 ± 0.03 A	7.88 ± 0.16 C	8.31 ± 0.08 B
Crude ash	6.81 ± 0.21 A	6.65 ± 0.09 A	5.84 ± 0.12 B
Crude fat	2.62 ± 0.16 C	3.63 ± 0.21 B	5.76 ± 0.19 A
Crude fiber	18.31 ± 0.08 B	19.54 ± 0.26 A	13.70 ± 0.25 C
Crude protein	26.74 ± 0.40 A	16.47 ± 0.34 C	18.54 ± 0.35 B

[a] Moisture and dry matter were presented based on air-dried weight, others were presented based on dry weight.

[b] Each value is expressed as mean ± standard deviation ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).

Generally, carbohydrate contents of fruit bodies were in the range of 44.0%–74.3% (Crisan & Sands, 1978). Furthermore, the pattern was consistent with the findings of *A. blazei* (45.47%; Huang, 2000). However, Mau and Tseng (1998) reported that contents of carbohydrate in those three strains of *A. cylindracea* (strains B, M and W) ranged from 27.06% to 39.54%. The carbohydrate content of *A. cylindracea* golden strain in Table 1 was high as compared with those in Mau and Tseng (1998). The discrepancy in carbohydrate contents of *A. cylindracea* is mainly due to the difference in the strains used.

With regard to ash content, *A. blazei* and *A. cylindracea* (6.81% and 6.65%, respectively) were slightly higher that *B. edulis* (5.84%). However, ash contents were low in *Ganoderma* spp. (0.72–1.77%; Mau, Lin, & Chen, 2001). The crude fat contents ranged from 2.62% to 5.76% and were in the descending order of *B. edulis*, *A. cylindracea* and *A. blazei*. Crisan and Sands (1978) reported that most fruit bodies contained 1.1%–8.3% of fat with the mean being ~4.0%. Apparently, the fat contents of these three mushrooms were within the normal range.

The crude fiber contents were low in *B. edulis* (13.70%), but high in *A. blazei* and *A. cylindracea* (18.31% and 19.54%, respectively). These fiber contents were within the range of 3–32% (Crisan & Sands, 1978). The crude protein content of *A. blazei* (26.74%) was significantly higher than those in *A. cylindracea* and *B. edulis* (16.47% and 18.54%, respectively). Generally, mushrooms are a good source of protein, and their protein contents range from 19% to 35% of dry weight (Crisan & Sands, 1978). However, protein contents of these three mushrooms were comparable to those of several medicinal (14.6–22.3%; Mau et al., 2001) and of commercial mushrooms (15.4–26.7%; Yang, Lin, & Mau, 2001).

Huang (2000) reported that *A. blazei* contained higher ash (8.85%) and protein (35.86%) but lower fat (1.85%) and fiber (7.98%) than those found in Table 1. In addition, those three strains of *A. cylindracea* in Mau and Tseng (1998) contained lower carbohydrate (27.06–39.54%), fat (2.18–2.71%) and fiber (16.15–16.70%) but higher protein (34.17–44.94%) and ash (7.66–8.59%). The discrepancy in the profiles of proximate compositions might be mainly due to the difference in the strains used.

Arabitol, myo-inositol, mannitol and trehalose were detected in these three mushrooms whereas glucose was not found in *B. edulis* (Table 2). Contents of total soluble sugars and polyols ranged from 150.33 to 225.08 mg/g and in the descending order of *A. cylindracea*, *A. blazei*

Table 2
Content of soluble sugars and polyols of *A. blazei, A. cylindracea* and *B. edulis*

Sugar or polyol	Content (mg/g)		
	A. blazei	*A. cylindracea*	*B. edulis*
Arabitol	25.23 ± 2.88 A[a]	14.48 ± 3.38 B	29.24 ± 2.20 A
Glucose	27.59 ± 2.43 A	17.28 ± 4.36 B	nd[b]
myo-Inositol	23.22 ± 0.06 B	85.95 ± 3.12 A	29.54 ± 4.98 B
Mannitol	79.43 ± 0.87 A	5.70 ± 0.24 C	58.81 ± 2.35 B
Trehalose	29.76 ± 3.08 B	101.67 ± 2.73 A	32.74 ± 2.02 B
Total	185.23 ± 1.43 B	225.08 ± 0.81 A	150.33 ± 7.15 C

[a] Each value is expressed as mean ± SD ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).
[b] Not detected.

and *B. edulis*. Mannitol and trehalose, which were major mushroom polyol and sugar, respectively (Bano & Rajarathnam, 1988; Hammond & Nichols, 1976; Mau et al., 1997), were found in these three mushrooms. High amounts of mannitol were found in *A. blazei* and *B. edulis* (79.43 and 58.81 mg/g, respectively) whereas that in *A. cylindracea* was relatively low (5.70 mg/g). Interestingly, the myo-inositol content of *A. cylindracea* was 3-fold higher than those of *A. blazei* and *B. edulis*. However, the first two highest amounts of sugars or polyols found in *A. cylindracea* were myo-inositol and trehalose (85.95 and 101.67 mg/g, respectively).

As compared with other mushrooms, contents of total soluble sugars or polyols were found to be 349–457 mg/g in *Volvariella volvacea* (Mau et al., 1997), 205–320 mg/g in *Agaricus bisporus* (Tseng & Mau, 1999), 98.7–316.4 mg/g in *Auricularia* spp. and *Tremella fuciformis* (Mau & Tseng, 1998), 6.96–20.8 mg/g in *Pleurotus eryngii* (Mau, Lin, Chen, Wu, & Peng, 1998), 169 mg/g in *Pleurotus citrinopileatus* (Huang, 2003) and 40.2 mg/g in *Hypsizigus marmoreus* (Lee, 2003). It seems that the contents of sugars and polyols in these three mushrooms were in the middle range. However, Mau and Tseng (1998) found that those three strains of *A. cylindracea* contained extremely low amounts of total soluble sugars, ranged from 56.00 to 86.14 mg/g. Soluble sugars contained in the mushroom contributed a sweet taste (Litchfield, 1967). Therefore, the high contents of sugars and polyols would give rise to a moderately sweet taste perception.

Total free amino acid contents were low in these three mushrooms and ranged from 8.97 to 14.91 mg/g (Table 3). The highest amount of total free amino acids was found in *A. blazei* whereas those contents in *A. cylindracea* and *B. edulis* were similar. The amino acids with contents of more than 2 mg/g were glutamic acid for *A. blazei* and *A. cylindracea*, and lysine for *B. edulis*. However, three mushrooms were considerably different in the profiles of free amino acids. Surprisingly, γ-aminobutyric acid (GABA), a hypotensive agent (Kohama et al., 1987; Kushiro et al., 1996), was found in these three mushrooms. The GABA contents ranged from 0.11 to 0.36 mg/g and were in the descending order of *A. blazei*, *A. cylindracea* and *B. edulis*. Furthermore, Tsai (2004) found that the content of GABA in *Coprinus comatus* was 0.63 mg/g. Since GABA is a biologically active compound, the presence of GABA in these three mushrooms would be beneficial to humans in addition to their palatable taste and other therapeutic effects.

Table 3
Content of free amino acids of *A. blazei*, *A. cylindracea* and *B. edulis*

Amino acid	Content (mg/g dry weight)		
	A. blazei	*A. cylindracea*	*B. edulis*
L-Alanine	1.09 ± 0.01 A[c]	0.31 ± 0.02 C	0.63 ± 0.05 B
L-Arginine	0.65 ± 0.01 A	0.57 ± 0.01 B	0.54 ± 0.02 B
L-Aspartic acid	1.11 ± 0.13 A	0.94 ± 0.07 AB	0.65 ± 0.01 B
L-Cystine	nd[d]	nd	nd
GABA[a]	0.36 ± 0.02 A	0.21 ± 0.03 B	0.11 ± 0.05 C
L-Glutamic acid	3.29 ± 0.18 A	2.18 ± 0.04 B	0.59 ± 0.01 C
Glycine	0.44 ± 0.01 A	0.25 ± 0.01 B	0.18 ± 0.04 C
L-Histidine	1.63 ± 0.04 A	0.44 ± 0.01 B	0.44 ± 0.12 B
L-Isoleucine[b]	0.49 ± 0.03 A	0.54 ± 0.07 A	0.48 ± 0.01 A
L-Leucine[b]	0.76 ± 0.02 A	0.69 ± 0.03 B	0.58 ± 0.02 C
L-Lysine[b]	1.19 ± 0.01 B	1.05 ± 0.08 B	2.17 ± 0.25 A
L-Methionine[b]	0.32 ± 0.01 A	nd	0.41 ± 0.05 A
L-Phenylalanine[b]	0.42 ± 0.02 B	1.01 ± 0.05 A	1.04 ± 0.04 A
L-Proline	nd	nd	nd
L-Serine	0.82 ± 0.08 A	0.56 ± 0.03 B	0.35 ± 0.01 C
L-Threonine[b]	0.27 ± 0.01 A	nd	0.19 ± 0.01 B
L-Tryptophan[b]	nd	nd	nd
L-Tyrosine	1.61 ± 0.01 A	0.79 ± 0.05 B	0.61 ± 0.06 C
L-Valine[b]	0.46 ± 0.01 A	nd	nd
Total	14.91 ± 0.05 A	9.54 ± 0.26 B	8.97 ± 0.49 B

[a] GABA, γ-aminobutyric acid.
[b] Essential amino acid.
[c] Each value is expressed as mean ± SD ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).
[d] Not detected.

Table 4 divides the free amino acids into several classes on the basis of their taste characteristics, as described by Komata (1969). Aspartic and glutamic acids were monosodium glutamate-like (MSG-like) components, which gave the most typical mushroom taste, the umami taste or palatable taste that was the characteristic taste of MSG and 5′-nucleotides (Yamaguchi, 1979). The contents of MSG-like components ranged from 1.24 to 4.40 mg/g were in the descending order of the *A. blazei*, *A. cylindracea* and

Table 4
Content of taste components of free amino acids of *A. blazei*, *A. cylindracea* and *B. edulis*

Taste component[a]	Content (mg/g dry weight)		
	A. blazei	*A. cylindracea*	*B. edulis*
Bitter	4.73 ± 0.02 A[b]	3.25 ± 0.17 B	3.49 ± 0.01 B
MSG-like	4.40 ± 0.05 A	3.12 ± 0.04 B	1.24 ± 0.03 C
Sweet	2.62 ± 0.07 A	1.13 ± 0.05 B	1.35 ± 0.09 B
Tasteless	3.16 ± 0.05 A	2.04 ± 0.17 B	2.89 ± 0.37 A
Total	14.91 ± 0.05 A	9.54 ± 0.26 B	8.97 ± 0.49 B

[a] MSG-like, monosodium glutamate-like, Asp + Glu; sweet, Ala + Gly + Ser + Thr; bitter; Arg + His + Ile + Leu + Met + Phe + Try + Val; tasteless, Lys + Tyr + GABA.
[b] Each value is expressed as mean ± SD ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).

B. edulis. For *A. blazei* and *A. cylindracea*, contents of bitter components were comparable to contents of MSG-like components but for *B. edulis*, content of bitter components was significantly higher than content of MSG-like components.

Chen (1986) conducted a series of sensory evaluations on synthetic mushroom extracts prepared by omitting and adding soluble components and found that alanine, glycine and threonine (sweet), and aspartic and glutamic acids (MSG-like) were taste-active amino acids in common mushrooms, whereas none of the bitter components was found to be taste-active. The bitterness from the bitter components in three mushrooms could probably be masked by the sweetness from sweet components and mainly the high amount of soluble sugars and polyols. Therefore, MSG-like and sweet components would be responsible for the nature taste of these three mushrooms.

With regard to contents of MSG-like components in other mushrooms, including common mushrooms (22.67–47.12 mg/g; Tseng & Mau, 1999), *Lentinula edodes* (3.75–9.06 mg/g; Lin, 1999), *P. citrinopileatus* (16.12 mg/g; Huang, 2003) and *H. marmoreus* (14.26 mg/g; Lee, 2003), these three mushrooms possessed the low content of MSG-like components. Furthermore, Mau, Lin, Ma, and Song (2001) found that contents of MSG-like components in four specialty mushrooms, including *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum* ranged from 0.68 to 1.09 mg/g. Yang et al. (2001) found that contents of MSG-like components in several commercial mushrooms, including *L. edodes*, *Flammulina velutipes* strain white, *Pleurotus cystidiosus* and *P. ostreatus*), ranged from 0.84 to 1.93 mg/g. Yang et al. (2001) also found that that in the strain yellow of *F. velutipes* was 7.06 mg/g. However, Mau et al. (2001) found that contents of MSG-like components in medicinal mushrooms, including *G. lucidum*, *G. tsugae* and *Coriolus versicolor* were in the range of 0.17–0.50 mg/g. Mau and Tseng (1998) reported that contents of MSG-like components in three strains of *A. cylindracea* ranged from 10.85 to 11.89 mg/g, higher to the of *A. cylindracea*. Yang et al. (2001) divided contents of MSG-like components into three ranges: low (<5 mg/g), middle (5–20 mg/g) and high (>20 mg/g). Based on the previous results, the contents of MSG-like components in these three mushrooms were in the low range.

Contents of total 5′-nucleotides were significantly higher in *A. blazei* and *A. cylindracea* (8.00 and 8.56 mg/g, respectively) than in *B. edulis* (2.76 mg/g) (Table 5). Flavor 5′-nucleotides, which also gave the umami or palatable taste, were found to be 5′-guanosine monophosphate (5′-GMP), 5′-inosine monophosphate (5′-IMP) and 5′-xanthosine monophosphate (5′-XMP) (Chen, 1986). Contents of flavor 5′-nucleotides were higher in *A. blazei* (5.15 mg/g) but lower in *A. cylindracea* and *B. edulis* (2.44 and 2.01 mg/g, respectively).

Contents of flavor 5′-nucleotides were found to be 4.19–6.13 mg/g in *A. bisporus* (Tseng & Mau, 1999), 1.63–4.89 mg/g in *P. eryngii* (Mau et al., 1998), 1.51 mg/g in *P. citrinopileatus* (Huang, 2003) and 1.47 mg/g in *H. marmoreus* (Lee, 2003). In addition, Yang et al. (2001) found that contents of flavor 5′-nucleotides in several commercial mushrooms, including *F. velutipes* strain white, *P. cystidiosus* and *P. ostreatus*, ranged from 5.52 to 8.60 mg/g. Mau et al. (2001) found that contents of flavor 5′-nucleotides in *D. indusiata*, *G. frondosa*, *H. erinaceus* and *T. giganteum* were 9.04, 0.64, 0.62 and 13.6 mg/g, respectively. Contents of flavor 5′-nucleotides in medicinal mushrooms, including *G. lucidum*, *G. tsugae* and *C. versicolor*, were in the range 1.18–5.65 mg/g (Mau et al., 2001). Yang et al. (2001) reported that contents of flavor 5′-nucleotides could be divided three ranges: low (<1 mg/g), middle (1–5 mg/g) and high (>5 mg/g). Therefore, the content of flavor 5′-nucleotides in *A. blazei* was in the high range whereas those in *A. cylindracea* and *B. edulis* were in the middle range.

Table 5
Content of 5′-nucleotide of *A. blazei*, *A. cylindracea* and *B. edulis*

5′-Nucleotide[a]	Content (mg/g dry weight)		
	A. blazei	*A. cylindracea*	*B. edulis*
5′-AMP	0.15 ± 0.01 A[c]	0.03 ± 0.01 C	0.09 ± 0.02 B
5′-CMP	1.27 ± 0.06 A	1.12 ± 0.01 B	0.66 ± 0.04 C
5′-GMP	0.06 ± 0.02 B	0.11 ± 0.02 A	0.04 ± 0.01 C
5′-IMP	0.07 ± 0.01 A	0.04 ± 0.01 B	0.06 ± 0.01 A
5′-UMP	1.43 ± 0.01 B	4.97 ± 0.01 A	nd[d]
5′-XMP	5.02 ± 0.46 A	2.29 ± 0.38 B	1.91 ± 0.13 C
Flavor 5′-nucleotide[b]	5.15 ± 0.43 A	2.44 ± 0.05 B	2.01 ± 0.09 B
Total	8.00 ± 0.55 A	8.56 ± 0.07 A	2.76 ± 0.12 B

[a] 5′-AMP, 5′-adenosine monophosphate; 5′-CMP, 5′-cytosine monophosphate; 5′-GMP, 5′-guanosine monophosphate; 5′-IMP, 5′-inosine monophosphate; 5′-UMP, 5′-uridine monophosphate; 5′-XMP, 5′-xanthosine monophosphate.
[b] Flavor 5′-nucleotide, 5′-GMP + 5′-IMP + 5′-XMP.
[c] Each value is expressed as mean ± SD ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).
[d] Not detected.

5′-GMP gave the meaty flavor, and is a flavor enhancer much stronger than MSG (Litchfield, 1967). The synergistic effect of flavor 5′-nucleotides with MSG-like components might greatly increase the umami taste of mushrooms (Yamaguchi et al., 1971). Using the equation derived from sensory evaluation (Yamaguchi et al., 1971), the EUC values were much higher in *A. blazei* (135.90 g per 100 g), moderate in *A. cylindracea* (46.73 g per 100 g), and low in *B. edulis* (10.46 g per 100 g) (Table 6). The results of three strains of *A. cylindracea* in Mau and Tseng (1998) were calculated to show a EUC value of 68.1–164 g per 100 g, higher than that of the golden strain in Table 6.

Mau (2005) reported that EUC values could be grouped into four levels: first level of >1000 g per100 g dry matter (>10 g MSG/g dry matter), second level of 100–1000 g per 100 g (1–10 g MSG/g), third level of 10–100 g per 100 g (0.1–1 g MSG/g), and fourth level of <10 g per 100 g (<0.1 g MSG/g). Therefore, the EUC value of *A. blazei* was at the second level, and *A. cylindracea* and

Table 6
Equivalent umami concentration of *A. blazei*, *A. cylindracea* and *B. edulis*

	EUC[a] (g per 100 g dry weight)
A. blazei	135.90 ± 8.49 A[b]
A. cylindracea	46.73 ± 1.95 B
B. edulis	10.46 ± 0.80 C

[a] Calculated based on the equation: $Y = \Sigma a_i b_i + 1218\ (\Sigma a_i b_i)(\Sigma a_j b_j)$ (Yamaguchi et al., 1971) Where Y is the EUC of the mixture in terms of g MSG per 100 g; a_i is the concentration (g per 100 g) of each umami amino acids (Asp or Glu); a_j is the concentration (g per 100 g) of each umami 5′-nucleotides (5′-IMP, 5′-GMP, 5′-XMP or 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 g per 100 g used.

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

B. edulis were at the third level. In other words, the umami intensity of one gram of *A. blazei*; *A. cylindracea* and *B. edulis* were equivalent to the umami intensity given by 1.36, 0.47 and 0.10 g of MSG.

Based on the results obtained, *A. blazei*, *A. cylindracea* and *B. edulis* possessed highly intense umami taste in addition to its pharmacological properties. The sensory EUC values of these three mushrooms might be beneficial for its use as foods or food flavoring materials or in the formulation of nutraceuticals and functional foods with a palatable umami taste.

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