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Non-volatile taste components of several speciality mushrooms

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Abstract

Four speciality mushrooms are commercially available in Taiwan, including *Dictyophora indusiata* (basket stinkhorn), *Grifola frondosa* (maitake), *Hericium erinaceus* (lion's mane), and *Tricholoma giganteum* (white matsutake). Protein contents ranged from 14.6 to 22.3%. Carbohydrate contents were high in basket stinkhorn and white matsutake (67.0 and 70.1%) and low in maitake and lion's mane (58.8 and 57.2%, respectively). Contents of total soluble sugars showed two distinct levels, white matsutake (349 mg g^{-1}) and other mushrooms (153–188 mg g^{-1}). Total free amino acid contents ranged from 7.41 to 12.3 mg g^{-1}. Contents of monosodium glutamate-like components ranged from 0.68 to 1.09 mg g^{-1}. Contents of flavor 5′-nucleotides were high in white matsutake, moderate in basket stinkhorn, and low in lion's mane and maitake. In this study, the four speciality mushrooms, in addition to their characteristic appearances, were distinctly different in both their proximate compositions and their taste components.

Keywords: Mushrooms; *Dictyophora indusiata*; *Grifola frondosa*; *Hericium erinaceus*; *Tricholoma giganteum*; Soluble sugars; Free amino acids; 5′-Nucleotides

1. Introduction

Four species of speciality mushrooms are commercially available in Taiwan. Mature basket stinkhorn (*Dictyophora indusiata*) consists of a conical to bell-shaped cap on a stipe, with a large lace-like veil flaring out from beneath the cap (Arora, 1986). Maitake (*Grifola frondosa* [Dickson: Fries] Gray) is also called the king of mushrooms, and the hen of the woods (Stamets, 1993). Its fruiting body is composed of multiple, overlapping caps of 2–10 cm diameter, arising from branching stipes, eccentrically attached, and sharing a common base. Lion's mane (*Hericium erinaceus* [Bulliard: Fries] Persoon) is composed of downward, cascading, non-forking spines (Stamets, 1993). The giant mushroom (*Tricholoma giganteum* Massee), also called white matsutake in Japan, is remarkably large compared to other edible mushrooms. Currently, these rare mushrooms are highly valued as a centerpiece of Taiwanese cooking. However, the nutritional values and taste components of these four speciality mushrooms are not clearly understood. Our objective was to examine the non-volatile taste components in the four mushrooms, including their proximate compositions, soluble sugars, free amino acids and 5′-nucleotides.

2. Materials and methods

2.1. Mushrooms

Maitake and white matsutake were harvested from the mushroom farm of the Taiwan Agricultural Research Institute, Taichung County, Taiwan. Fresh mushrooms from each species were randomly selected as three samples, ~500 g each. Fresh mushrooms were air-dried in an oven at 60°C before analysis. Dried basket stinkhorn and lion's mane were purchased at a local market in Taichung City, Taiwan. Dried mushrooms were also randomly selected as three samples, ~50 g each.

2.2. Proximate analysis

The proximate compositions of four speciality mushrooms, including moisture, ash, carbohydrate, crude fat,

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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).

2.3. Soluble sugar assay

Soluble sugars were extracted and analyzed as described by Ajlouni, Beelman, Thompson and Mau (1995). Air-dried mushroom powder (600 mg) was extracted with 50 ml of 80% aqueous ethanol (95% pure, Taiwan Tobacco & Wine Monopoly Bureau, Taipei) and xylose (50 mg, Sigma Chemical Co., St. Louis, MO) was added as an internal standard. This suspension was shaken for 45 min at room temperature and filtered through Whatman No. 4 filter paper. The residue was washed 5 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 filter unit (13 mm, Lida, Corp., Kenosha, WI), and filtered using 0.45-μm CA non-sterile filter (Lida) prior to injection onto a high-performance liquid chromatograph (HPLC).

The HPLC system consisted of a Hitachi L-6000 pump, a Rheodyne 7161 injector, a 20-μm sample loop, a Hitachi D-2500 chromato-integrator, a Bischoff RI 8110 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, 17:3 (v/v) at a flow rate of 2 ml min^{-1}. Each sugar was quantified by comparing the peak area of the sugar to that of the internal standard.

2.4. Free amino acid assay

Air-dried mushroom powder (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 filter unit (13 mm, Lida), and filtered using a 0.45 μm CA non-sterile filter (Lida). The purified filtrate was mixed with *o*-phthalaldehyde reagent (Sigma) in an Eppendorf tube, shaken to facilitate derivatization and then immediately injected onto a HPLC.

The HPLC system was the same as for sugar analysis but included a Hitachi F-1050 fluorescence detector with fluorescence excitation at 340 nm and emission at 450 nm, and a Prodigy 5 ODS-2 column (4.6×250 mm, 5 μm, Phenomenex Inc., Torrance, CA). The mobile phases and gradient conditions were the same as described in Mau, Chyau, Li and Tseng (1997). Each amino acid was quantified by the calibration curve of the authentic amino acid.

2.5. 5′-Nucleotide assay

5′-Nucleotides were extracted and analyzed as described by Taylor, Hershey, Levine, Coy and Olivelle (1981). Air-dried mushroom powder (500 mg) was extracted with 25 ml of deionized water. This suspension was heated to boiling for 1 min, cooled, and then centrifuged at 22,200 ***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 assay.

The HPLC system was the same as for sugar assay except for a Hitachi L-4000 UV detector and a Prodigy 5 ODS-2 column (4.6×250 mm, 5 μm, Phenomenex). The mobile phase was 0.5 M KH_2PO_4/H_3PO_4 (pH 4.0, Wako Pure Chemical Co., Osaka, Japan) at a flow rate of 1 ml min^{-1} and UV detection at 254 nm. Each 5′-nucleotide was quantified by the calibration curve of the authentic 5′-nucleotide.

2.6. 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 as described by Steel, Torrie and Dickey (1997), to determine the least significant difference among means at the level of 0.05.

3. Results and discussion

Fresh maitake and white matsutake contained 86.06 and 89.11% moisture, respectively (Table 1). Crisan and Sands (1978) reported that most fresh mushrooms contained ~90% moisture. Maitake seemed to be less moist and denser. Ash content varied among mushrooms and

Table 1
Proximate compositions of *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum*

Component[a]	Content[b] (%)			
	D. indusiata	*G. frondosa*	*H. erinaceus*	*T. giganteum*
Moisture	9.05±0.10	86.06±0.25	4.31±0.46	89.11±0.75
Dry matter	90.95±0.10	13.94±0.25	95.69±0.46	10.89±0.75
Ash	6.25±0.08c	6.99±0.03b	9.35±0.12a	5.03±0.18d
Carbohydrate	67.0±1.06a	58.8±0.70b	57.0±0.63b	70.1±2.83a
Crude fat	2.98±0.02c	3.10±0.25bc	3.52±0.16b	4.28±0.06a
Crude fiber	9.16±0.44b	10.1±0.07a	7.81±0.07c	4.50±0.08d
Crude protein	14.6±1.37c	21.1±0.90ab	22.3±0.71a	16.1±2.71bc

[a] Moisture and dry matter in *D. indusiata* and *H. erinaceus* were based on air-dried weight, and moisture and dry matter in *G. frondosa* and *T. giganteum* were based on fresh weight, others were presented based on dry weight.

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

ranged from 5.03 to 9.35% of dry weight. Generally, mushrooms are a good source of protein, and their proteins range from 19 to 35% of dry weight (Crisan & Sands, 1978). Protein contents ranged from 14.6 to 22.3% and were in the order of basket stinkhorn, white matsutake, maitake and lion's mane. Carbohydrate contents were high in basket stinkhorn and white matsutake (67.0 and 70.1%) and low in maitake and lion's mane (58.8 and 57.0%, respectively). Carbohydrate contents were in the range of 44.0 to 74.3% (Crisan & Sands, 1978). The crude fat ranged from 2.98 to 4.28% and was in the range of 1.1 to 8.3% (Crisan & Sands, 1978). Fiber contents ranged from 4.50 to 10.1% and were in the order of white matsutake, lion's mane, basket stinkhorn and maitake. From the results shown in Table 1, these four mushrooms were considerately different in the profile of proximate composition.

The lion's mane contained a high amount of arabitol (127 mg g^{-1} dry weight) (Table 2). However, this sugar alcohol was not found in other mushrooms. Glucose and trehalose were found in mushrooms, whereas mannitol was not found in white matsutake. Inositol was found in mushrooms excluding basket stinkhorn. Mannitol and trehalose were two major components of common mushrooms (*Agaricus bisporus*; Hammond & Nichols, 1976), paddy straw mushrooms (*Volvariella volvacea*; Mau et al., 1997) and oyster mushrooms (*Pleurotus* spp.; Bano & Rajarathnam, 1988). White matsutake and maitake contained relatively high amounts of trehalose (341 and 162 mg g^{-1}, respectively). Glucose, mannitol and trehalose were found in comparable amounts in basket stinkhorn. Surprisingly, contents of total soluble sugars showed two distinct levels, white matsutake (349 mg g^{-1}) and other mushrooms (153–188 mg g^{-1}). However, their profiles of soluble sugars were extremely different.

Total free amino acid contents were low in these four mushrooms and ranged from 7.41 to 12.3 mg g^{-1} dry weight (Table 3). Maitake contained the highest amount of total free amino acids whereas white matsutake contained the least amount. Four speciality mushrooms were considerably different in the profiles of free amino acids. Two major amino acids found were isoleucine and lysine in basket stinkhorn, alanine and threonine in maitake, alanine and leucine in lion's mane, and threonine and methionine in white matsutake.

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). Contents of MSG-like components in four mushrooms were relatively low and ranged from 0.68 to 1.09 mg g^{-1} dry weight. Contents of sweet components ranged from 0.36 to 8.71 mg g^{-1} and were in the order of basket stinkhorn, white matsutake, lion's mane and maitake. However, contents of bitter components were significantly high in total free amino acid contents of four speciality mushrooms.

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 were found to be taste-active. Therefore, MSG-like and sweet components would be responsible for the natural taste of mushrooms. Additionally, the bitterness from the bitter components in four speciality mushrooms could be unequivocally masked by sweet components and mainly total soluble sugars.

Contents of MSG-like components were found to be 22.7–47.1 mg g^{-1} dry weight in common mushrooms (Tseng & Mau, 1999), 11.2–26.2 mg g^{-1} in paddy straw mushrooms (Mau et al., 1997), 10.9–11.9 mg g^{-1} in black poplar mushrooms (*Agrocybe cylindracea*; Mau & Tseng, 1998), 3.75–9.06 mg g^{-1} in shiitake (*Lentinula edodes*; Lin, 1988), 1.01–1.77 mg g^{-1} in king oyster mushrooms (*P. eryngii* ; Mau, Lin, Chen, Wu & Peng, 1998), and 0.05–0.34 mg g^{-1} in ear mushrooms (*Auricularia* spp. and *Tremella fuciformis*; Mau, Wu, Wu & Lin, 1998). In addition, Yang, Lin and Mau (2001) found that contents of MSG-like components in several

Table 2
Content of soluble sugars at polyols of *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum*

Sugar or polysyl	Content[a] (mg g^{-1} dry wt.)			
	D. indusiata	*G. frondosa*	*H. erinaceus*	*T. giganteum*
Arabitol	nd[b]	nd	127.17±8.45	nd
Glucose	39.41±0.76a	14.02±0.28b	11.35±1.74b	4.91±0.30c
Mannitol	50.89±1.05a	9.36±0.76c	12.98±1.76b	nd
myo-Inositol	nd	3.20±0.36a	1.43±0.12b	2.48±0.46a
Trehalose	62.48±6.76c	161.83±2.59b	9.71±1.06d	341.19±17.31a
Total	152.78±8.21c	188.41±2.64b	162.64±6.85bc	348.58±17.41a

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

Table 3
Contents of free amino acids of *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum*

Amino acid	Content[a] (mg g^{-1} dry wt.)			
	D. indusiata	*G. frondosa*	*H. erinaceus*	*T. giganteum*
L-Alanine	0.32±0.01b	2.77±0.36a	2.43±0.21a	0.73±0.28b
L-Arginine	0.05± < 0.01b	0.64±0.16a	0.47±0.04a	nd[b]
L-Aspartic acid	0.31±0.01a	0.42±0.08a	0.50±0.06a	0.34±0.14a
L-Glutamic acid	0.54±0.04ab	0.67±0.10a	0.50±0.06ab	0.34±0.06b
Glycine	nd	0.57±0.12b	1.03±0.07a	0.47±0.15b
L-Histidine[c]	0.04±0.01c	0.59±0.06a	0.34±0.09b	0.13±0.05c
L-Isoleucine[c]	2.88±0.09a	0.33±0.03b	nd	0.51±0.09b
L-Leucine[c]	0.52±0.06b	0.35±0.04b	2.38±0.41a	0.19±0.05b
L-Lysine[c]	4.58±0.06a	1.11±0.14b	0.47±0.02c	0.43±0.11c
L-Methionine[c]	1.24±0.11ab	1.40±0.07a	1.08±0.10ab	0.98±0.14b
L-Phenylalanine[c]	0.60±0.02a	0.80±0.11a	0.20±0.01b	0.30±0.09b
L-Serine	0.04± < 0.01c	0.97±0.12a	0.35±0.04b	0.34±0.07b
L-Threonine[c]	nd	4.40±0.12a	0.78±0.05c	1.54±0.17b
L-Tryptophan[c]	0.10±0.01b	0.27±0.03a	0.10±0.02b	0.26±0.07a
L-Tyrosine	nd	nd	nd	0.85±0.08
L-Valine[c]	1.03±0.03a	0.60±0.05b	0.30±0.05c	nd
Total	12.3±0.38b	15.9±0.97a	10.93±0.60b	7.41±0.65c

[a] Each value is expressed as mean±S.E. ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).
[b] nd, not detected.
[c] Essential amino acid.

Table 4
Content of taste characteristics of free amino acids in *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum*

Taste characteristic[a]	Content[b] (mg g^{-1} dry wt.)			
	D. indusiata	*G. frondosa*	*H. erinaceus*	*T. giganteum*
MSG-like	0.85±0.05ab	1.09±0.12a	1.00±0.11ab	0.68±0.19b
Sweet	0.36± < 0.01d	8.71±0.67a	4.59±0.25b	3.08±0.28c
Bitter	6.46±0.30a	4.98±0.09b	4.87±0.44b	2.37±0.17c
Tasteless	4.58±0.06a	1.11±0.14b	0.47±0.02c	1.28±0.15b
Total	12.3±0.38b	15.9±0.97a	10.93±0.60b	7.41±0.65c

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

commercial mushrooms, including shiitake, winter (*Flammulina velutipes* strain white), abalone (*P. cystidiosus*) and tree oyster mushrooms (*P. ostreatus*), ranged from 0.84 to 1.93 mg g^{-1}. Yang et al. (2001) also found that in strain yellow of winter mushrooms was 7.06 mg g^{-1}. Furthermore, contents of MSG-like components in medicinal mushrooms, including *Ganoderma lucidum*, *G. tsugae* and *Coriolus versicolor*, were in the range of 0.17–0.50 mg g^{-1} (Mau et al., 2000). Based on the previous results, the contents of MSG-like components in four speciality mushrooms were in the low range (< 5 mg g^{-1}).

Flavor 5′-nucleotides were found to be 5′-guanosine monophosphate (5′-GMP), 5′-inosine monophosphate (5′-IMP) and 5′-xanthosine monophosphate (5′-XMP) (Chen, 1986). Contents of total 5′-nucleotides were high in white matsutake (31.9 mg g^{-1} dry wt.), moderate in basket stinkhorn and lion's mane (15.9 and 14.1 mg g^{-1}, respectively), and low in maitake (7.43 mg g^{-1}; Table 5). However, contents of flavor 5′-nucleotides were high in white matsutake (13.6 mg g^{-1}), moderate in basket stinkhorn (9.04 mg g^{-1}), and relatively low in lion's mane and maitake (0.62 and 0.64 mg g^{-1}, respectively).

Contents of flavor 5′-nucleotides were found to be 4.19-6.30 mg g^{-1} dry weight in common mushrooms (Tseng & Mau, 1999), 4.42–9.00 mg g^{-1} in paddy straw mushrooms (Mau et al., 1997), 1.63–4.89 mg g^{-1} in king oyster mushrooms (Mau, Lin, et al., 1998), 1.73–3.67 mg g^{-1} in shiitake (Lin, 1988), 0.39–2.17 mg g^{-1} in ear mushrooms (Mau, Wu, et al., 1998), and 0.21–0.63 mg g^{-1} in black poplar mushrooms (Mau & Tseng, 1998). In addition, Yang et al. (2001) found that contents of

Table 5
Content of 5′-nucleotides of *Dictyophora indusiata*, *Grifola frondosa*, *Hericium erinaceus* and *Tricholoma giganteum*

5′-Nucleotide[a]	Content[b] (mg g^{-1} dry wt.)			
	D. indusiata	*G. frondosa*	*H. erinaceus*	*T. giganteum*
5′-AMP	0.21±0.01b	0.60±0.09a	nd[c]	0.26±0.01b
5′-CMP	5.88±0.14c	5.33±0.48c	13.3±0.40b	17.1±0.43a
5′-GMP	2.97±0.13a	0.56±0.02b	0.04±0.01c	0.10±0.01c
5′-IMP	0.02±0.01c	0.08±0.01b	0.01± < 0.01c	0.29± < 0.01a
5′-UMP	0.75±0.02a	0.86±0.02a	0.13±0.01b	0.94±0.15a
5′-XMP	6.05±0.30b	nd	0.57±0.08c	13.3±2.46a
Flavor 5′-nucleotides[d]	9.04±0.42b	0.64±0.03c	0.62±0.07c	13.6±2.46a
Total	15.9±0.59b	7.43±0.52c	14.1±0.43b	31.9±2.03a

[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] Each value is expressed as mean±S.E. ($n = 3$). Means with different letters within a row are significantly different ($P < 0.05$).
[c] nd, not detected.
[d] Flavor 5′-nucleotide: 5′-GMP + 5′-IMP + 5′-XMP.

flavor 5′-nucleotides in several commercial mushrooms, including, winter, abalone and tree oyster mushrooms, ranged from 5.52 to 8.60 mg g^{-1}. Yang et al. (2001) also found that the content of flavor 5′-nucleotides in strain 271 of shiitake was 11.6 mg g^{-1} and that in strain Tainung 1 was only 1.60 mg g^{-1}. Furthermore, contents of flavor 5′-nucleotides in medicinal mushrooms, including *Ganoderma lucidum*, *G. tsugae* and *Coriolus versicolor*, were in the range of 1.18 to 5.65 mg g^{-1} (Mau et al., 2000). Based on the previous results, the contents of flavor 5′-nucleotides in basket stinkhorn and white matsutake were in the high range (> 5 mg g^{-1}), whereas there in maitake and lion's mane were in the low range (< 1 mg g^{-1}).

5′-GMP gave a 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, Yoshikawa, Ikeda & Ninomiya. 1971). Due to their low contents of MSG-like components, the umami taste, or palatable taste of these four mushrooms mainly depends on contents of flavor 5′-nucleotides. Therefore, based on the contents of MSG-like components and flavor 5′-nucleotides, the umami intensities of the four speciality mushrooms were expected to be in the order of white matsutake, basket stinkhorn, maitake and lion's mane. In addition, based on their contents of total soluble sugars and sweet components, it anticipated that the sweet intensities would be in the order of white matsutake, maitake, lion's mane and basket stinkhorn. In this study, the four speciality mushrooms, in addition to their characteristic appearances, were distinctly different in both their proximate compositions and their taste components. To determine the relationship of the palatability of these mushrooms to their taste compounds, and to determine the taste threshold of these components, further sensory evaluation is needed.

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