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ORIGINAL PAPER

Proximate compositions, nonvolatile taste components and antioxidant capacities of some dried edible mushrooms collected from Thailand

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Abstract Four species of mushrooms are commercially available in Thailand, namely *Lentinus edodes*, *Pleurotus eryngii*, *Pleurotus sajor-caju* and *Pleurotus djamor* and their nutritional compositions, nonvolatile taste components as well as antioxidant capacities were determined. In this research, each mentioned mushrooms were dehydrated by hot air drying prior to analysis. All dried mushrooms were found to be good sources of proteins, with contents varying in the ranges of 21.23–28.23 g/100 g dry weight (dw) while the fat content was very low (1.47–2.57 g/100 g dw). Trehalose (12.97–42.57 mg/g dw) and mannitol (73.27–75.53 mg/g dw) were considered as the major mushroom sugar/polyol. Total soluble sugar contents were in the order: *L. edodes* > *P. sajor-caju* > *P. eryngii* and *P. djamor*. Total content of free amino acids also varied and ranged from 28.46 to 57.09 mg/g dw. Monosodium glutamate (MSG)-like components were the highest in *P. eryngii* (10.72 mg/g dw), and lowest in *L. edodes* (7.16 mg/g dw) and *P. djamor* (7.41 mg/g dw). Equivalent umami concentration values (EUC) in four dried edible mushrooms ranged from 200.28 to 299.60 g MSG/100 g dw, and the highest EUC was found in *P. eryngii*, followed by *P. djamor*, *P. sajor-caju* and *L. edodes*, respectively. In addition, *L. edodes* contained the highest total phenolic contents (26.63 mg/g dw) as well as antioxidant capacities as evaluated by DPPH radical scavenging activity (DPPH-RSA, 7.58 mg/g trolox dw), 2,2′-azino-bis(3-ethylbenzothiazoline-6-sulphonic acid) radical scavenging activity (ABTS-RSA, 2.19 mg/g trolox dw) and Ferric ion reducing *antioxidant* power (FRAP, 18.77 mg/g trolox dw). This result obtained revealed that all dried mushrooms contained a relatively strong umami taste and could be used as functional foods with a palatable umami taste or in the formulation of nutraceuticals.

Keywords Umami · Mushroom · Antioxidant · Taste

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Introduction

Edible mushrooms have long been used as traditionally seasoning materials in soups and sauces, due to their special and subtle flavors. The typical flavor of mushrooms is attributed to either nonvolatile components or volatile compounds. The taste of edible mushrooms is primarily due to the presence of several small water soluble substances, including soluble sugars, free amino acids and 5′-nucleotides. Generally, edible mushrooms are characterized by a short shelf life (1–3 days at room temperature) [1, 2]. Thus, preservation techniques such as drying should be applied to prolong the shelf life. Several drying technologies can be used for the manufacture of mushroom powders, including hot air drying, vacuum drying and freeze drying. Among drying techniques, the most common method is hot air drying.

Mushrooms, particularly *Lentinus edodes* (Shiitake mushroom), *Pleurotus eryngii* (King oyster mushroom), *Pleurotus sajor-caju* (Bhutan oyster mushroom) and *Pleurotus djamor* (pink oyster mushroom), are cultivated widely in Thailand. Shiitake mushrooms are traditional delicacies in Thailand and other Asian countries, due to their desirable complex flavor, and their medicinal properties in preventing heart disease and building resistance against viruses [3]. They are often dried for preservation and to obtain characteristics that differ from those of the

fresh form [4]. The King oyster mushroom (*P. eryngii*) is by far the best tasting oyster mushroom. It contains various compounds such as polysaccharides, polyphenols and flavonoides which have antioxidant activities [5]. This mushroom can be successfully cultivated on many agricultural and agro-industrial wastes [6]. Bhutan oyster mushroom (*P. sajor-caju*) is another edible mushroom that is found growing in tropical and subtropical regions of the world. This mushroom has high nutritional value and is a source of protein, carbohydrates, vitamins, calcium and iron [7]. In addition, the pink oyster mushroom (*P. djamor*) is a species of fungus in the family *Pleurotaceae*. This species owes its popularity mainly to it being relatively simple to cultivate and also high nutritional value [8].

As mentioned previously, the typical flavor substances of mushrooms can be classified into volatile and non-volatile components. Normally, the non-volatile components are responsible for the taste of mushrooms. The taste components and antioxidant activity of Shiitake (*L. edodes*) and King oyster (*P. eryngii*) mushrooms have been reported [1, 3, 9]. However, there is little information available about the non-volatile taste components and antioxidant activities of *P. sajor-caju* and *P. djamor*. Therefore, the aim of this research was to determine the non-volatile taste components and antioxidant activities of some commercial dried mushrooms from Thailand.

Materials and methods

Sample preparation and drying process

Four fresh mushroom samples, *L. edodes* (Shiitake mushroom), *P. eryngii* (King oyster mushroom), *P. sajor-caju* (Bhutan oyster mushroom) and *P. djamor* var. *roseus* (pink oyster mushroom) were collected from the mushroom farm in Nakhon Pathom province, Thailand. After harvesting, each mushroom was first washed with cold tap water to remove surface contamination, drained and immersed in 0.25 % citric acid solution for 15 min and then subjected to drying treatment. After the preparation steps, each mushroom was dried in a cabinet convective air dryer operated at 75 °C until the moisture content was below 10 %. Then all dried mushrooms were ground and sieved (100 mesh) to obtain fine powder.

Proximate analysis

The proximate compositions of four species of mushrooms, including moisture, ash, crude fat, crude fiber and crude protein were determined [10].

Determination of soluble sugar contents

Soluble sugars were measured as described by Mau et al. [11] with some modifications. Each mushroom powder (1 g) was extracted with 50 ml of 80 % aqueous ethanol. This suspension was stirred at room temperature (60 min) 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 filter unit (0.45 μm) prior to injection onto a high-performance liquid chromatography (HPLC; Agilent 1100 series, Palo Alto, CA). The Zorbax carbohydrate column and refractive index detector were used. For the mobile phase, a solution of acetonitrile and water (80:20) was used and pumped at a flow rate of 1.0 ml/min. The calibration curve of each sugar was plotted between peak areas and concentrations.

Determination of free amino acid contents

Free amino acid contents were analyzed according to the method of Bosch et al. [12] with some modifications. Each mushroom powder (1 g) was shaken with 50 ml of 0.1 N HCl for 60 min at ambient temperature and filtered through Whatman No. 4 filter paper. The filtrate was then passed through a filter unit (0.45 μm) to purify it. The purified filtrate was mixed with o-phthalaldehyde reagent, shaken to facilitate derivatisation and then immediately injected onto the HPLC for assessment (Waters Alliance 2695). The HPLC system was fitted with a Hypersil Gold column (C18, 4.6 × 150 mm, 3 μm). The mobile phase was 60 % acetonitrile in sodium acetate buffer (pH 4.9). The fluorescence detector (Ex: 250 nm; Em: 395 nm) was used. Each amino acid was quantified by the calibration curve of the authentic amino acid.

Determination of 5′-nucleotide contents

There were six 5′nucleotides analyzed in this study including 5′-inosine monophosphate (5′-IMP), 5′-guanosine monophosphate (5′-GMP), 5′-xanthosine monophosphate (5′-XMP), 5′-adenosine monophosphate (5′-AMP), 5′-uridine monophosphate (5′-UMP) and 5′-cytosine monophosphate (5′-CMP). All 5′-nucleotides were extracted and analyzed as described by Yang et al. [9]. The mushroom powder (1 g) was extracted with 25 ml of deionized water. This suspension was heated for 1 min (100 °C), cooled, and then centrifuged at 10,000 rpm for 15 min. The residue was further processed to extract three times using 20 ml of deionized water. The combined filtrate was then 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 (0.45 μm) prior to HPLC (HPLC; Agilent 1100 series, Palo Alto, CA) injection in the same manner as in soluble sugar assay. The Prodigy 5 ODS-2 column (4.6 × 250 mm, 5 mm, Phenomenex) and a UV detector were used. The mobile phase was 0.5 M KH_2PO_4/H_3PO_4 (pH 4.0) at a flow rate of 1 ml/min and UV detection at 254 nm. Each 5′-nucleotide was quantified by the calibration curve of the authentic 5′-nucleotide.

Equivalent umami concentration (EUC)

The equivalent umami concentration was calculated by the following addition equation [13]:

$$Y = \Sigma \alpha_i b_j + 1218(\Sigma \alpha_i b_i)(\Sigma \alpha_j b_j)$$

where Y is the EUC of the mixture in terms of g MSG per 100 g dry raw material weight; a_i is the concentration (g/100 g dry raw material weight) of each umami amino acid [aspartic acid (Asp) or glutamic acid (Glu)]; a_j is the concentration (g/100 g dry raw material weight) of each umami 5′-nucleotide [5′-IMP, 5′-GMP, 5′-XMP]; 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 dry raw material weight used.

Determination of total phenolic content (TPC) and antioxidant activity

Total phenolic compound was extracted according to the method described by Lin et al. [6] with some modifications. Each mushroom powder (1 g) was extracted with 50 ml of ethanol (95 %). The mixture was shaken with an orbital shaker for 24 h at ambient temperature. The extract was then separated from the residue by filtration through Whatman No.1 filter paper. The remaining residue was re-extracted (60 min) three times and then all extracts were combined. The ethanolic extract was evaporated to dryness at 40 °C and redissolved in ethanol and used for the determination of total phenolic content (TPC) and antioxidant activities. The TPC in the extracts was determined with Folin–Ciocalteu reagent according to the method of Li and Shah [14] with some modifications using gallic acid as standard. The appropriate diluted sample (0.5 ml) was mixed with 0.5 ml of distilled water. Thereafter, 0.5 ml of Folin–Ciocalteu reagent (1:1 with water) and 2.5 ml of 2 % sodium carbonate solution were added. The mixture was mixed thoroughly and placed in the dark for 40 min. After that, the absorbance was recorded at 725 nm and the TPC was calculated from the standard curve of gallic acid and expressed in term of mg gallic acid (GAE) per g sample (dry weight). The DPPH radical scavenging activity (DPPH-RSA) was analyzed. Briefly, 1.5 ml of sample (appropriate dilution) was added to 1.5 ml solution of DPPH (0.15 mM). The mixture was mixed vigorously and incubated at room temperature in the dark for 30 min and the absorbance of the resulting solution was measured at 517 nm using a UV–Vis spectrophotometer [15]. For the ABTS (2,2′-azino-bis (3-ethylbenzthiazoline-6-sulphonic acid) method, ABTS radical scavenging activity (ABTS-RSA) was also determined as described by Binson et al. [15]. ABTS radical cation was generated by reacting 7.4 mM ABTS with 2.6 mM potassium persulphate at a ratio of 1:1 (v/v). The mixture was stored in the dark for 12 h at room temperature. Prior to assay, the ABTS radical cation was diluted with methanol to obtain an absorbance of 1.1 (±0.02) at 734 nm. Each sample, with appropriate dilution (150 μl), was mixed with 2850 μl of ABTS radical cation and the mixture was left at room temperature for 30 min in the dark. The absorbance was then read at 734 nm. The ferric reducing ability of plasma (FRAP) was assayed according to the method of Benzie and Strain [16]. The stock solutions included 300 mM acetate buffer (pH 3.6), 10 mM TPTZ (2,4,6-tripyridyl-s-triazine) solution in 40 mM HCl, and 20 mM $FeCl_3 \cdot 6H_2O$ solution. A working solution was prepared by mixing 25 ml of acetate buffer, 2.5 ml of TPTZ solution and 2.5 ml of $FeCl_3 \cdot 6H_2O$ solution. The mixed solution was incubated at 37 °C for 30 min and was referred to as FRAP solution. A sample (150 ml) was mixed with 2850 ml of FRAP solution and kept for 30 min in the dark. The ferrous tripyridyltriazine complex (colored product) was measured by reading the absorbance at 593 nm. A standard curve of Trolox was utilized for DPPH-RSA, ABTS-RSA as well as FRAP. The activity was expressed as mg Trolox equivalents (TE)/g sample (dry weight).

Statistical analysis

The experiments were performed in two batches and the measurements were carried out in triplicate per each batch. The mean ± SD values were reported based on six measurements obtained from two batches (three measurements from each batch). All data were subjected to analysis of variance (ANOVA) and the differences between means were run by duncan's multiple range test.

Results and discussion

Proximate compositions

The proximate compositions of all mushroom powders are presented in Table 1. There was no significant difference in

moisture content among all dried mushrooms. The nutritional value of mushrooms is primarily related to their protein content. Mushroom protein is considered to have a higher nutritional quality than that of plant proteins. The protein content of mushroom is not only dependent on environmental factors and stage of fruiting body maturity, but also on species [17]. The protein content of mushroom generally ranges from 19 to 35 g/100 g dw [18]. The protein content of the dried mushrooms was significantly different among samples, and in the order: *L. edodes* > *P. sajor-caju* > *P. eryngii* > *P. djamor*. The highest protein content was found for *L. edodes* (approximately 28 g/100 g dw) which is higher than the hot air dried *L. edodes* (271) (20.5 g/100 g dw) and *L. edodes* (Tainung 1) (19.7 g/100 g dw) collected from Taiwan [9]. In addition, there are several reports related to the protein content of the dried mushrooms in the genus *Pleurotus*. The current data are consistent with the protein level in the hot air dried *P. ostreatus* (23.9 g/100 g dw) [9] and the freeze-dried *P. ostreatus* (24.9 g/100 g dw) [19]. Mushrooms are reported to be a good source of protein, and some investigators have contended that the amino acid composition of mushrooms is comparable to that of animal proteins [3, 17]. The crude fat content of mushrooms is usually low. There was no significant difference in crude fat content for all dried mushrooms in genus *Pleurotus* used in this research while the lowest crude fat content was detected in the dried *L. edodes*. The crude fat content in the mushroom normally ranges from 1.1 to 8.3 g/100 g dw [11]. This result indicated that all dried mushrooms studied contained low fat content. In general, mushrooms are low-calorie foods since they provide low amounts of fat. The results for fat content presented in this research are similar to that in the hot air- and freeze-dried mushrooms in the genus *Pleurotus* [9, 19]. The fat content found in the dried *P. eryngii* was comparable to that detected by Li et al. [2]. Level of fat of *L. edodes* tested in this study was higher compared to corresponding values of the hot air dried *L. edodes* collected from Taiwan; the fat content was 6.34 and 5.71 g/100 g dw for *L. edodes* (271) and *L. edodes* (Tainung 1), respectively [9], but lower in the freeze dried *L. edodes* mushroom collected from Portugal [3]. The ash contents varied among samples. The highest ash content was found in the dried *L. edodes* while there was no significant difference in ash content among all dried mushrooms in genus *Pleurotus* used in this study. The ash content of the dried *L. edodes* was higher than the reports made by Yang et al. [9]. They reported that the ash contents were 5.37 and 5.85 g/100 g dw for the dried *L. edodes* (271) and *L. edodes* (Tainung 1), respectively. In comparison with the previous result for the dried mushrooms in genus *Pleurotus*, a higher ash content of the hot air dried mushrooms in the genus *Pleurotus* (*P.cystidious*, 9.62 g/100 g dw and *P. ostreatus*, 7.59 g/100 g dw) was found compared to the dried mushrooms in genus *Pleurotus* used in this work [9]. Beluhan and Ranogajec [19] also reported a higher ash content (7.62 g/100 g dw) for the same mushroom genus (freeze dried *P. ostreatus*). The crude fiber content was in the order: *P. djamor* > *P. sajor-caju* > *L. edodes* > *P. eryngii*. According to the results, all dried mushrooms could be claimed to be an important source of fiber. A lower crude fiber content was found in the hot air dried *L. edodes* (4.88–5.63 g/100 g dw) collected from Taiwan [9]. Fibers such as the structural polysaccharides β-glucan, hemicellulose, cellulose and pectin substances normally promote beneficial physiological effects. These include relaxation, and/or blood cholesterol attenuation, and/or blood glucose attenuation [17]. Among samples, *P. djamor* seemed to be the best source of fiber.

Soluble sugar

Three categories of sugars were investigated including polyols, reducing sugars and non-reducing sugars. Regarding to the type and concentration of polyols, the four polyols evaluated are xylitol, sorbitol, mannitol and myo-inositol, as shown in Table 2. Among, samples, the highest total polyol contents were found in *P. sajor-caju* followed by *P. djamor*, *P. eryngii* and *L. edodes*, respectively. The polyol which was presented at the largest proportion within the studied was mannitol, followed by myo-inositol in all samples under study. The mannitol content was in the descending order of *P. eryngii* > *P. djamor* > *P. sajor-caju* > *L. edodes*. In addition, there was no significant difference in mannitol content between *P. djamor* and *P. sajor-caju*. Comparing with the previous researches, level of mannitol content reported here for the dried *L. edodes* was higher than the report of Reis et al. [3]

Table 1 Proximate compositions (g/100 g, dry weight) of mushroom powders

Components (g/100 g, dry weight)	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
Protein	28.23 ± 0.42^{a}	22.91 ± 0.15^{c}	24.65 ± 0.41^{b}	21.23 ± 0.15^{d}
Fat	1.47 ± 0.11^{b}	2.24 ± 0.02^{a}	2.37 ± 0.46^{a}	2.57 ± 0.11^{a}
Ash	7.55 ± 0.15^{a}	6.02 ± 0.18^{b}	6.44 ± 0.29^{b}	5.91 ± 0.33^{b}
Moisture	6.86 ± 0.26^{a}	6.36 ± 0.41^{a}	6.42 ± 0.72^{a}	6.91 ± 0.58^{a}
Crude fiber	17.32 ± 0.45^{c}	12.54 ± 0.36^{d}	22.61 ± 0.73^{b}	30.42 ± 0.55^{a}

Means with different letters within a row are significantly different ($P < 0.05$)

Table 2 Soluble sugar content (mg/g, dry weight) of mushroom powders

Categories	Component	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
Polyols	Xylitol	nd	nd	5.57 ± 0.31^{b}	8.50 ± 0.50^{a}
	Sorbitol	$3.03 \pm 0.32^{a,b}$	2.93 ± 0.25^{ab}	2.00 ± 0.36^{bc}	1.63 ± 0.25^{c}
	Mannitol	73.27 ± 0.50^{b}	81.17 ± 2.31^{a}	75.17 ± 0.65^{b}	75.53 ± 0.60^{b}
	Myo-Inositol	10.35 ± 0.22^{b}	5.37 ± 0.35^{d}	13.80 ± 0.36^{a}	7.53 ± 0.50^{c}
	Total Polyols	86.65 ± 0.25^{d}	89.47 ± 0.31^{c}	96.54 ± 0.40^{a}	93.19 ± 0.41^{b}
Reducing sugars (RS)	Ribose	15.70 ± 0.53^{a}	4.23 ± 0.25^{b}	4.90 ± 0.36^{b}	3.83 ± 0.65^{c}
	Xylose	2.90 ± 0.79^{b}	3.63 ± 0.40^{b}	10.13 ± 0.50^{a}	2.00 ± 0.36^{bc}
	Fructose	1.17 ± 0.25^{b}	1.20 ± 0.26^{b}	4.33 ± 0.25^{a}	1.07 ± 0.15^{b}
	Glucose	6.37 ± 0.60^{b}	4.77 ± 0.65^{c}	8.00 ± 0.44^{a}	3.07 ± 0.60^{d}
	Maltose	5.43 ± 0.50^{b}	3.50 ± 0.44^{d}	4.37 ± 0.68^{c}	7.13 ± 0.58^{a}
	Mannose	nd	9.97 ± 0.47^{a}	nd	5.03 ± 0.21^{b}
	Lactose	2.27 ± 0.25^{a}	1.33 ± 0.15^{b}	2.47 ± 0.35^{a}	1.20 ± 0.20^{b}
	Arabinose	3.27 ± 0.31^{b}	2.10 ± 0.17^{c}	8.37 ± 0.35^{a}	1.70 ± 0.30^{d}
	Total RS	37.11 ± 0.35^{b}	30.73 ± 0.68^{c}	42.57 ± 0.71^{a}	24.03 ± 0.54^{d}
Nonreducing sugars (NRS)	Trehalose	42.57 ± 2.20^{a}	30.63 ± 5.23^{b}	20.63 ± 0.50^{c}	12.97 ± 0.60^{d}
	Sucrose	3.47 ± 0.47^{a}	2.40 ± 0.36^{b}	3.53 ± 0.45^{a}	2.13 ± 0.40^{b}
	Total NRS	46.04 ± 0.36^{a}	33.03 ± 0.52^{b}	24.16 ± 0.44^{c}	15.10 ± 0.62^{d}
	Total sugar	169.80 ± 1.65^{a}	153.23 ± 2.23^{c}	163.27 ± 1.91^{b}	132.32 ± 1.32^{d}

Means with different letters within a row are significantly different ($P < 0.05$). *nd* not detected

(0.60 mg/g) but lower than reported by Yang et al. [9] (83.8–134.0 mg/g dw). The latter also noted that mannitol was also found in the hot air dried Shiitake mushroom (*L. edodes* (271), 83.8 mg/g dw and *L. edodes* (Tainung 1), 134 mg/g dw). Comparing the mannitol content among the dried mushrooms in genus *Pleurotus* with the previous works, mannitol content reported here for *P. eryngii*, *P. sajor-caju* and *P. djamor* was higher than the works of Yang et al. [9] (*P.cystidious*, 24.6 mg/g dw and *P. ostreatus*, 3.6 mg/g dw), Reis et al. [3] (*P. eryngii*, 10.01 mg/g dw) and Li et al. [2] (*P.cystidious*, 14.96 mg/g dw and *P. eryngii*, 24.37 mg/g dw). The mannitol is generally reported as a taste-active component in mushroom sugars and polyols. In addition, mannitol could promote a perception of sweetness, which is not a typical mushroom taste [20]. Sorbitol was also detected in all dried mushrooms while xylitol was only detected in *P. sajor-caju* and *P. djamor*. The myo-inositol was the second major soluble polyol in all dried mushrooms. The myo-inositol was also detected for the hot air dried mushroom in the genus *Pleurotus* such as *P. ostreatus* (1.27 mg/g dw) [9]. This was lower than that of the dried mushroom of the genus *Pleurotus* used in this study.

The reducing sugars such as ribose, xylose, fructose, glucose, maltose, mannose, lactose and arabinose were also evaluated in all dried mushrooms (Table 2). In general, the highest total reducing sugar content was observed in *P. sajor-caju* followed by *L. edodes*, *P. eryngii* and *P. djamor*, respectively. All mentioned reducing sugars were detected in all dried mushrooms, but mannose was only observed in *P. eryngii* and *P. djamor*. Compared to the previous researches, Li et al. [21] reported a lower detection of mannose for the hot air dried mushrooms in the genus *Pleurotus* such as *P. cystidious* (0.49 mg/g dw) and *P. eryngii* (0.21 mg/g dw). In addition, the mannose content in the dried *P. eryngii* was lower compared to that reported by Kim et al. [1] (13.58 mg/g dw). Beluhan and Ranogajec [19] found that the reducing sugars detected for the freeze dried mushrooms in the genus *Pleurotus* such as *P. ostreatus* were mannose (111.30 mg/g dw) and glucose (150.10 mg/g dw). Yang et al. [9] reported a higher glucose content for *L. edodes* (271) (28.60 mg/g dw) and *L. edodes* (Tainung 1) (14.20 mg/g dw). Sugars such as ribose and lactose were also found in other dried mushrooms such as *Cordyceps militaris* and *Agaricus bisporus*, respectively [22, 23].

Two non-reducing sugars, sucrose and trehalose, were detected in all dried mushrooms. A higher trehalose content was found in all dried mushrooms compared to the sucrose content (Table 2). Among samples, the highest non-reducing sugar content was observed in *L. edodes* followed by *P. eryngii*, *P. sajor-caju* and *P. djamor*, respectively. Compared to the previous reports, a lower trehalose content was recorded in *L. edodes* (271) (29.20 mg/g dw), *L. edodes* (Tainung 1) (3.47 mg/g dw) dehydrated by hot air drying [9]. Among the dried mushrooms in the genus *Pleurotus*, *P. cystidiosus* (64.90 mg/g dw) [9] and *P. ostreatus* (80.10 mg/g dw) [3] contained a higher trehalose

content than the *P. sajor-caju*, *P. eryngii* and *P. djamor*. However, Beluhan and Ranogajec [19] and Yang et al. [9] reported a lower trehalose content for *P. ostreatus* that was 17.90 and 2.73 mg/g dw, respectively. In addition, the trehalose content in *P. eryngii* was lower compared to those reported by Li et al. [2]. No research has reported the detection of sucrose in the dried *P. eryngii*, *P. djamor* and *P. sajor-caju*, however a lower sucrose content was found in the freeze-dried *L. edodes* (2.33 mg/g dw) as reported by Kim et al. [1]. Additionally, Huang et al. [22] and Tsai et al. [23] revealed that sucrose was detected in *C. militaris* (53.07 mg/g dw) and *A. bisporus* (1.48 mg/g dw) dehydrated by freeze drying, respectively.

The content of total soluble sugars is also shown in Table 2. Our data are consistent with total soluble sugar content found in the hot air dried *L. edodes* collected from Taiwan as noted by Yang et al. [9]. They reported that *L. edodes* (271) and *L. edodes* (Tainung 1) contained total soluble sugar of approximately 141 and 152 mg/g dw, respectively. Compared to the previous researches for the dried mushrooms in genus *Pleurotus*, level of total soluble sugar contents in the hot air dried *P. cystidious* (64.9 mg/g dw) [9], the freeze dried *P. ostreatus* (37.5 mg/g dw) [19] and the hot air dried *P. eryngii* (316.59 mg/g dw) [2] was lower compared to corresponding values found in this work, but higher than that detected by Kim et al. [1] (freeze dried *P. eryngii*, 55.10 mg/g dw). In addition, some reports found that the total soluble sugar content was as follows: 319 mg/g dw for *A. bisporus* [24]; 325 mg/g dw for *Flammulina velutipes* (white) [9]; 151.3 mg/g dw for *P. cystidiosus* [2]; 28.72 mg/g dw for *P. ostreatus* [2]; and 83.89 mg/g dw for *Grifola frondosa* [25]. In addition, Mau et al. [26] found that the medicinal mushrooms of the genus *Ganoderma* spp. contained low amounts of total soluble sugars. Normally, the medical mushrooms have a bitter taste. Soluble sugars and polyols, contained in mushrooms, generally contribute a sweet taste. Thus the results suggest that the four mushrooms tested in this study would give rise to a sweet perception [27, 28]. The utilization of these dried mushrooms as ingredient in the food formulation would enhance the sweet taste. Additionally, several works reported that the mannitol and trehalose are two major sugar and polyol found in the common mushrooms, paddy straw mushrooms and other oyster mushrooms [11, 28, 29].

Amino acid

Amino acids in a free form are important taste activate components found in edible mushrooms, particularly aspartic acid and glutamic acid. Table 3 shows the free amino acid content of each dried mushroom. The total amino acid content was in descending order of *P. djamor*, *P. eryngii*, *P. sajor-caju* and *L. edodes*. The four dried mushroom samples showed notably different in the amino acid profiles. Compared to the previous research, a lower total amino acid content was reported for the hot air dried *L. edodes* (10.5–12.5 mg/g dw) and the hot air dried mushrooms in the genus *Pleurotus* (4.08–7.33 mg/g dw) [9]. In addition, Beluhan and Ranogajec [19] showed that the freeze dried mushrooms in the genus *Pleutrotus* such as *P. ostratus* contained a total free amino acid content of approximately 67.78 mg/g dw. Several authors reported to mushroom as an important source of essential amino acids such as: leucine, valine, threonine, lysine, methionine and tryptophan.

Amino acids in edible mushrooms could be generally classified into four groups based on their taste characteristics [9, 11] (Table 4). The first group is monosodium glutamate-like (MSG-like) or palatable taste amino acids, including aspartic and glutamic acids as mentioned previously. Amino acids such as alanine, glycine, serine and threonine are the second group and responsible for sweet taste. In addition, arginine, histidine, isoleucine, leucine, methionine, phenylalanine, tryptophan and valine are contributed to bitter taste amino acid and finally the tasteless amino acids are lysine, cysteine and tyrosine. Therefore, MSG-like and sweet components could be responsible for the pleasant taste of mushrooms [11, 17, 24, 25].

The highest MSG-like amino acids were observed in *P. eryngii* but small differences in the MSG-like amino acids were found among the other dried mushrooms (*L. edodes*, *P. sajor-caju* and *P. djamor*). The current results correlated well with several publications [1, 19, 22, 28–30] which found that the glutamic content in most edible mushrooms is higher than the aspartic acid content. This establishes that glutamic acid is the main umami amino acid in most edible mushrooms. Yang et al. [6] reported that the contents of MSG-like components could be divided into three ranges: low (<5 mg/g), middle (5–20 mg/g) and high (>20 mg/g). According to the above criteria, the MSG-like components of all dried mushrooms in the current study were in the middle range. This result was in agreement with the reports of Kim et al. [1] who revealed that the content of the MSG-like components of *L. edodes* (17.68 mg/g dw) and *P. eryngii* (8.69 mg/g dw) dehydrated by freeze drying can be also classified as in the middle range. However, Yang et al. [9] reported that the MSG-like components of the dried mushrooms in genus *Lentinula,* such as *L. edodes* (271) (1.71 mg/g dw) and *L. edodes* (Tainung) (1.93 mg/g dw), and genus *Pleurotus,* such as *P. cystidiosus* (1.21 mg/g dw) and *P. ostreatus* (0.84 mg/g dw), were in the low range. The content of MSG-like components were normally found to be 22.7–47.1 mg/g dw in common mushrooms [24], 11.2–26.2 mg/g dw in paddy straw mushrooms, 10.9–11.9 mg/g dw in black poplar

Table 3 Free amino acid content (mg/g, dry weight) of mushroom powders

Amino acids	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
Aspartic acid	1.32 ± 0.11^{c}	3.75 ± 0.04^{a}	1.17 ± 0.03^{c}	2.12 ± 0.21^{b}
Glutamic acid	5.84 ± 0.23^{bc}	6.97 ± 0.05^{ba}	6.24 ± 0.13^{b}	5.90 ± 0.23^{b}
Alanine	4.79 ± 0.03^{d}	7.13 ± 0.08^{b}	8.01 ± 0.08^{a}	5.16 ± 0.13^{c}
Glycine	2.03 ± 0.22^{b}	1.81 ± 0.12^{c}	1.64 ± 0.08^{d}	2.36 ± 0.15^{a}
Serine	1.72 ± 0.13^{c}	2.61 ± 0.11^{b}	3.06 ± 0.22^{a}	3.82 ± 0.12^{a}
Threonine	2.84 ± 0.21^{b}	1.00 ± 0.15^{d}	3.20 ± 0.16^{a}	1.49 ± 0.15^{c}
Arginine	2.19 ± 0.12^{a}	1.49 ± 0.20^{b}	nd	nd
Histidine	1.25 ± 0.11^{b}	1.44 ± 0.13^{a}	0.88 ± 0.17^{c}	1.13 ± 0.21^{b}
Isoleucine	0.74 ± 0.23^{c}	2.23 ± 0.13^{b}	2.22 ± 0.11^{b}	3.19 ± 0.13^{a}
Leucine	1.17 ± 0.21^{d}	3.39 ± 0.21^{b}	2.43 ± 0.25^{e}	5.29 ± 0.14^{a}
Methionine	nd	1.37 ± 0.11^{a}	0.99 ± 0.13^{bc}	1.16 ± 0.21^{b}
Phenylalanine	0.96 ± 0.13^{c}	4.98 ± 0.13^{a}	2.61 ± 0.24^{b}	2.88 ± 0.14^{b}
Valine	1.80 ± 0.17^{d}	2.98 ± 0.11^{b}	2.39 ± 0.14^{c}	5.00 ± 0.31^{a}
Tryptophan	0.24 ± 0.13^{a}	0.43 ± 0.11^{a}	0.25 ± 0.22^{a}	0.22 ± 0.12^{a}
Cysteine	nd	nd	2.70 ± 0.08^{b}	13.25 ± 0.22^{a}
Tyrosine	nd	3.05 ± 0.15^{a}	2.31 ± 0.14^{b}	1.57 ± 0.14^{c}
Lysine	1.57 ± 0.11^{b}	2.37 ± 0.09^{a}	1.47 ± 0.24^{b}	2.55 ± 0.13^{a}
Total	28.46 ± 0.34^{d}	47.00 ± 0.26^{b}	41.57 ± 0.27^{c}	57.09 ± 0.36^{a}

Means with different letters within a row are significantly different ($P < 0.05$). *nd* not detected

Table 4 Content of free amino acids with taste characteristics (mg/g, dry weight) of mushroom powders

Taste characteristics	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
MSG-like	7.16 ± 0.18^{c}	10.72 ± 0.31^{a}	7.41 ± 0.28^{c}	8.02 ± 0.29^{b}
Sweet	11.38 ± 0.35^{c}	12.55 ± 0.27^{b}	15.91 ± 0.44^{a}	12.83 ± 0.34^{b}
Bitter	8.35 ± 0.42^{c}	18.31 ± 0.33^{a}	11.77 ± 0.36^{b}	18.87 ± 0.42^{a}
Tasteless	1.57 ± 0.44^{d}	5.42 ± 0.29^{c}	6.48 ± 0.40^{b}	17.37 ± 0.43^{a}
Total	28.46 ± 0.29^{d}	49.36 ± 0.35^{b}	41.57 ± 0.24^{c}	57.09 ± 0.31^{a}

Means with different letters within a row are significantly different ($P < 0.05$)

MSG-like (Asp + Glu); sweet (Thr + Ser + Gly + Ala); bitter (Arg + His + Leu + Phe + Tyr + Val + Met + Ile); tasteless (Cys + Tyr + Lys)

mushrooms (*Agrocybe cylindracea*), and 0.17-0.50 mg/g dw in medical mushrooms [11, 26].

In addition, the sweet-like amino acids of all dried mushrooms were also determined. Similar results were found in the hot air dried *L. edodes* (7.77 mg/g dw) while a lower content of sweet-like amino acids was observed in the hot air dried mushrooms in genus *Pleurotus* such as *P. cystidiosus* (5.01 mg/g dw) and *P. ostreatus* (2.25 mg/g dw) [9]. Chen [20] conducted a series of sensory evaluations on synthetic mushroom extracts, prepared by omitting and adding soluble components. It was found that sweet amino acids and MSG-like amino acids were responsible for the taste-active amino acids in common mushrooms [28, 31]. The bitter components were not found to be taste-active in the overall perception of taste [2, 22]. Therefore, MSG-like and sweet components would be responsible for the natural taste of mushrooms. In addition, the content of MSG-like and sweet components and total soluble sugars and polyols were considerately higher in the mushrooms. These might be sufficient to suppress and cover the bitter taste arising from the contents of bitter components [23, 29].

5′nucleotides

Table 5 shows the amount of 5′-nucleotides in each dried mushroom. The amounts of total 5′-nucleotides were the highest for *P. djamor* while the lowest was found in *L. edodes*. Compared with other researches, the amount of total 5′-nucleotides was higher in *L.deodes* 271 (24.2 mg/g dw) and *L.deodes* Tainung 1 (9.51 mg/g dw) collected from Taiwan [9]. In addition, a higher content of total 5′-nucleotides was also found for the hot air dried mushrooms in the genus *Pleurotus* such as *P. cystidious* (13.9 mg/g dw) and *P. ostreatus* (15.8 mg/g dw) [9]. The total 5′-nucleotides content recorded for all mushrooms in this

study was higher than the dried mushrooms in the genus *Pleurotus* (*P. cystidiosus*, 1.87 mg/g dw) and *P. eryngii*, 1.68 mg/g dw) reported by Li et al. [2] but lower in *P. ostreatus* (6.04 mg/g dw) compared to the data of Beluan and Ranogajec [19].

Flavor 5′-nucleotides normally consist of 5′-guanosine monophosphate (5′-GMP), 5′-inosine monophosphate (5′-IMP), and 5′-xanthosine monophosphate (5′-XMP) [19, 22, 23, 28, 29]. All these compounds were contributed to the umami or palatable taste [20]. The amount of flavor 5′-nucleotides was high in *P. djamor* but low in *L. edodes*. Comparing with other reports, Yang et al. [9] found that content of flavor 5′-nucleotides in the hot air dried *L. edodes* (271) were 24.2 mg/g dw. This was much higher than in *L. edodes* used in the current study. The hot air dried *L. edodes* (Tainung 1) contained flavor 5′-nucleotides of approximately 1.60 mg/g dw and that was lower than the dried *L. edodes* used in this study. The amount of flavor 5′-nucleotides in the dried mushrooms were found to be 4.19–6.30 mg/g dw in common mushrooms [24], 4.42–9.00 mg/g dw in paddy straw mushrooms [26], and 1.05–13.88 mg/g dw in Croatian wild edible mushroom [19] and 1.63–4.89 mg/g dw in king oyster mushroom [11]. Among the flavor 5′-nucleotides, 5′-XMP was the main constituent while small difference between 5′-GMP and 5′-IMP was found among all dried mushrooms tested. 5′GMP gives the meaty flavor, and is a flavor enhancer much stronger than MSG [22, 23, 27]. In addition, the fourth major 5′-nucleotide was 5′-AMP. 5′-AMP could also provide the sweet taste for mushroom and other food materials, and is also an effective bitter taste inhibitor [21]. According to the classification described by Yang et al. [9], the amount of flavor 5′-nucleotides could be divided into three ranges: low (<1 mg/g), middle (1–5 mg/g) and high (>5 mg/g). Thus the amount of flavor 5′-nucleotides of the dried mushrooms such as *L. edodes, P. eryngii* and *P. sajor-caju* were in the middle range while *P. djamor* contained flavor 5′-nucleotides content in the high range.

Equivalent umani concentration (EUC)

The umami taste or palatable taste was the characteristic taste of MSG and 5′-nucleotide [13]. The synergistic effect of flavor 5′-nucleotides with MSG-like components could greatly increase the umami taste of mushrooms [13, 28, 30]. Thus, the EUC was calculated from the concentration of flavor 5′-nucleotides and MSG-like components. Using the equation derived from sensory evaluation, the EUC values of all dried mushrooms are shown in Table 5. Among samples, the highest EUC values were found in *P. eryngii*, followed by *P. djamor*, *P. sajor-caju* and *L. edodes*, respectively. Level of EUC reported here for the dried mushrooms in genus *Pleurotus* was appreciably higher than *P. cystidiosus* and *P. ostreatus* recorded by Li et al. [2] and Mau et al. [26]. In addition, Mau [26] classified EUC values into four levels: first level of >1000 g MSG/100 g dry matter (>10 g MSG/g dry matter); second level of 100–1000 g MSG/100 g (1–10 g MSG/g); third level of 10–100 g MSG/100 g (0.1–1 g MSG/g); and fourth level of <10 g MSG/100 g (<0.1 g MSG/g). Therefore, the EUC values of four dried mushrooms were all at the second level.

Total phenolic content (TPC) and antioxidant capacity

Mushrooms that contain various kinds of bioactive compounds have been used as food and medicine by humans. It had been reported that the antioxidant activity of plant materials correlates well with their amounts of phenolic compounds [32, 33]. Thus it is important to consider the TPC and antioxidant activity of mushrooms. Among samples, the highest TPC was found in *L. edodes*, followed by *P. eryngii*, *P. sajor-caju* and *P. djamor*, respectively (Table 6). In comparison with the other works, the content of TPC in *L. edodes* was higher compared to that reported by Cheung et al. [32] (1.33 mg/g) and Mujic et al. [33] (11.70 mg/g). The TPC content was higher compared with

Table 5 5′-nucleotides (mg/g, dry weight) and EUC (g/100 g, dry weight) of mushroom powders

Components	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
5′-GMP	0.60 ± 0.03^{b}	0.70 ± 0.10^{a}	0.43 ± 0.11^{c}	0.40 ± 0.07^{d}
5′-XMP	1.00 ± 0.02^{d}	1.52 ± 0.50^{c}	2.31 ± 0.05^{b}	3.80 ± 0.10^{a}
5′-IMP	0.77 ± 0.03^{b}	0.84 ± 0.04^{a}	0.70 ± 0.04^{c}	0.63 ± 0.05^{d}
5′-CMP	0.10 ± 0.02^{b}	0.13 ± 0.02^{b}	0.17 ± 0.02^{a}	0.19 ± 0.02^{a}
5′-AMP	0.12 ± 0.02^{c}	0.47 ± 0.02^{a}	0.53 ± 0.05^{a}	0.21 ± 0.03^{b}
5′-UMP	0.13 ± 0.01^{b}	0.43 ± 0.06^{a}	0.45 ± 0.01^{a}	0.03 ± 0.04^{c}
Total	2.72 ± 0.22^{c}	4.09 ± 0.25^{b}	4.59 ± 0.31^{b}	5.26 ± 0.18^{a}
Flavor 5′-nucleotides	2.37 ± 0.34^{c}	3.06 ± 0.36^{b}	3.44 ± 0.23^{b}	4.83 ± 0.27^{a}
EUC	200.28 ± 1.45^{d}	299.60 ± 1.21^{a}	239.64 ± 0.88^{c}	286.25 ± 1.23^{b}

Means with different letters within a row are significantly different ($P < 0.05$)

Flavor 5′-nucleotides (5′-GMP + 5′-IMP + 5′-XMP)

Table 6 TPC (mg gallic acid/g, dry weight) and antioxidant capacities (mg Trolox/g, dry weight) of mushroom powders

Parameters	*L. edodes*	*P. eryngii*	*P. sajor-caju*	*P. djamor*
TPC	26.63 ± 0.63^{a}	20.60 ± 0.70^{b}	15.95 ± 0.81^{c}	10.29 ± 0.77^{d}
DPPH-RSA	7.58 ± 0.56^{a}	5.14 ± 0.75^{b}	1.47 ± 0.48^{c}	1.56 ± 0.43^{c}
FRAP	18.77 ± 0.78^{a}	18.25 ± 0.69^{a}	5.32 ± 0.61^{b}	2.13 ± 0.67^{c}
ABTS-RSA	2.19 ± 0.49^{a}	1.66 ± 0.50^{b}	0.91 ± 0.56^{c}	0.73 ± 0.48^{c}

Means with different letters within a row are significantly different ($P < 0.05$)

previously reported amounts such as: *P. eryngii* (0.42 mg GAE/g [5] and 21.67 mg tannic acid/g [14]) and *P. sajor-caju* (12 mg tannic acid/g [5]). However, the TPC of *P. djamor* used in the current study was lower than the report of Arbaayah and Umi [8] (18.88 mg tannic acid/g). The difference in TPC in mushrooms among researchers was probably due to the diverse sources of the mushrooms, the extraction conditions, and the drying methods used to prepare the mushroom powders. Regarding to the antioxidant capacities as accessed by DPPH-RSA, FRAP and ABTS-RSA, the samples contained high TPC tended to present high antioxidant capacities. In addition, similar trends were observed in all the antioxidant methods. It is well known that the potential health of bioactive components, especially phenolic compounds, attributed to their antioxidant activities. Normally, high antioxidant capacity can be correlated with the presence of high content of phenolic in the samples [34, 35]. In addition, during thermal processing, brown-colored high molecular weight peptide-bound products known as melanodins are formed which might be responsible for the antioxidant capacity [36, 37]. Among samples, the highest antioxidant capacities were detected in *L. edodes*, followed by *P. eryngii*, *P. sajor-caju* and *P. djamor*, respectively.

Conclusions

All mushrooms tested in this research contained a relatively strong umami taste. This indicated that these four mushrooms are well-flavored foods in their own right. In addition, they might also serve as food flavoring materials or in the formulation of nutraceuticals and as functional foods with a palatable umami taste. This information could be used as a guideline to apply in the production of food flavoring or seasoning powders to enhance the umami taste. Furthermore, the identification and quantification of volatile flavor compound as well as antioxidant compounds in each of the mushroom powders are recommended as subjects for further research.

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