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# Phenolic Compound Concentration and Antioxidant Activities of Edible and Medicinal Mushrooms from Korea

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A study was conducted to determine the content of phenolic compounds and the antioxidative activity of five edible and five medicinal mushrooms commonly cultivated in Korea. Phenolic compounds were analyzed using high performance liquid chromatography, and antioxidant activity was evaluated by 1,1-diphenyl-2-picrylhydrazyl radical scavenging activity and superoxide dismutase activity. A total of 28 phenolic compounds were detected in the mushrooms studied. The average total concentration of phenolic compounds was 326 $\mu$g/g, the average being of 174 $\mu$g/g in edible mushrooms and 477 $\mu$g/g in medicinal mushrooms. The average total flavonoids concentration was 49 $\mu$g/g, with averages of 22 and 76 $\mu$g/g in edible and medicinal mushrooms, respectively. The DPPH radical scavenging activities ranged between 15 (*Pleurotus eryngii*) and 70% (*Ganoderma lucidum*) when reaction time was for 1 min. When reaction time was 30 min, the values ranged between 5 (*Pleurotus eryngii*) and 78% (*Agaricus bisporus*). The SOD activity averaged 28% among the 10 mushroom species, averages for edible and medicinal mushrooms being comparable. DPPH activities was significantly correlated ($p < 0.01$) with total content of phenolic compounds in edible mushrooms, while in medicinal mushrooms there was a significant correlation ($p < 0.01$) between SOD activity and total concentration of phenolic compounds. Numerous significant positive correlations were observed between phenolic compounds detected and antioxidative potential.

**KEYWORDS: Edible and medicinal mushrooms; high performance liquid chromatography (HPLC); phenolic compounds; antioxidant activity; SOD; DPPH**

## INTRODUCTION

Mushrooms have been used for centuries in Korea both as food and medicine. In general, cultivated mushrooms contain little fat and digestible carbohydrates, but have higher protein contents than most vegetables. They are also rich in vitamins B, D, and K, and sometimes vitamins A and C, making them suitable for low calorie diets (*1–4*). Mushrooms also have been reported to have antioxidant properties (*5*). For example, Fu et al. (*6*) reported that several cultivated edible mushrooms such as *Agaricus bisporus*, *Hericium erinaceus*, *Flammulina velutipes*, *Lentinus edodes*, *Pleurotus eryngii*, and *Pleurotus ostreatus* have significant antioxidant and free radical scavenging activities. Such properties have also been reported in medicinal mushrooms, including *Agaricus blazei*, *Sparassis crispa*, *Phellinus linteus*, *Ganoderma lucidum*, and *Inonotus obliquus* (*7*).

Phenolic compounds can be classified as simple phenols and phenolic acids such as gallic acid, benzoic acid, syringic acid, chlorogenic acid, and other associates, and polyphenols, which are classified into many groups such as flavonoids, tannins, stilbenes, and so on. Flavonoids are a group of polyphenolic compounds with known health-beneficial properties, which include free radical scavenging, inhibition of hydrolytic and oxidative enzymes, and anti-inflammatory action (*8*). Some evidence suggest that the biological actions of these compounds

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are related to their antioxidant activity (*9*). Phenolic compounds have significant biological and pharmacological properties, and some have demonstrated remarkable ability to alter sulfate conjugation. The bioactivity of phenolics may be related to their ability to chelate metals, inhibit lipoxygenase, and scavenge free radicals (*10*).

Oxidation is necessary to many living organisms for the production of energy to fuel biological processes (*11*). However, numerous physiological processes and external factors including many environmental factors occasionally produce oxygen-centered free radicals and other reactive oxygen species (ROS), which may contribute to diseases including atherosclerosis, diabetes, cancer, and cirrhosis (*12*). Most organisms have evolved antioxidant defense and repair systems to protect them against oxidative damage; however, these systems are insufficient to prevent the damage entirely (*13*). So, the search for antioxidants in food is a very active field of research. An easy, rapid, and sensitive method for antioxidant screening of plant extracts is the free radical scavenging assay, spectrophotometrically using the 1,1-diphenyl-2-picrylhydrazyl (DPPH) stable radical. In the presence of an antioxidant, the DPPH radical obtains one more electron, and the absorbance decreases (*14*). Superoxide dismutase (SOD) is a metalloenzyme whose active center is occupied by copper and zinc, occasionally manganese or iron. SOD plays an important role in the protection of all aerobic life systems against oxygen toxicity and the free radicals derived from oxygen. As an enzyme, SOD has particular value as an antioxidant that can help to protect against cell destruction. It has the clear ability to neutralize superoxide, one of the most damaging free radical substances in nature.

The objective of the present study was to determine contents of phenolic compounds in edible and medicinal mushrooms commonly cultivated in Korea as well as to give basic information about their antioxidative properties. The relationship between phenolic compound content and antioxidative activity in edible and medicinal mushrooms was also investigated.

## MATERIALS AND METHODS

**Sample Collection and Preparation.** Fresh fruiting bodies of edible mushrooms, *Pleurotus ostreatus* (strain No. KKU-01, Chunchoo No. 2), *Agaricus bisporus* (strain No. KKU-02, Brown), *Flammulina velutipes* (strain No. KKU-03, White), *Pleurotus eryngii* (strain No. KKU-04, Seasongi), and *Lentinus edodes* (strain No. KKU-05, Hwago), were purchased in a local supermarket in Seoul, Korea. Other medicinal mushrooms, *Agaricus blazei* (strain No. CL-01, Sinryeong), *Sparassis crispa* (strain No. CL-02, Kkotsongi), *Phellinus linteus* (strain No. CL-03, Jangsoo), *Ganoderma lucidum* (strain No. CL-04, Bulmyeong), and *Inonotus obliquus* (strain No. CL-05, Chaga), were collected from the Cheonglyang mushroom farm in Hongcheongun, Gangwondo, Korea. After collection, each mushroom was isolated and identified to confirm correct species, and the fresh fruiting body of each mushroom was freeze-dried and then ground.

**Analysis of Phenolic Compounds.** Thirty phenolic compound standards, flavonoids as catechin, naringin, naringenin, myricetin, quercetin, biochanin A, formononetin, hesperetin, kaempferol, and rutin, and phenolic acids as gallic acid, pyrogallol, homogentisic acid, 5-sulfosalicylic acid, protocatechuic acid, gentisic acid, *p*-hydroxybenzoic acid, chlorogenic acid, vanillic acid, caffeic acid, syringic acid, vanillin, cinnamic acid, *p*-coumaric acid, ferulic acid, veratric acid, salicylic acid, benzoic acid, *o*-coumaric acid, and resveratrol were purchased from Sigma Aldrich (MO, USA) and Extrasynthese (Gernay, France) and used for calibration curves. The standard stock solutions (50, 100, 250, and 500 ppm) were made with dimethylsulfoxide (DMSO). All standard calibration curves showed high degrees of linearity ($r^2 > 0.99$) (data not shown). Sample compounds were identified on the basis of the retention times of standard materials and were quantified by comparing their peak areas with those of standard curves.

Samples preparation for analysis of phenolic compounds followed Kim et al. (*15*). Two grams of freeze-dried mushroom powder were mixed with 10 mL of acetonitrile and 2 mL of 0.1 N hydrochloric acid and stirred for 2 h at room temperature. The suspension was filtered through No. 42 Whatman filter paper. The extract was freeze-dried below −40 °C, and the residues were redissolved in 10 mL of 80% aqueous methanol (HPLC grade) (J. T. Baker, NJ, USA), filtered through a 0.45 μm nylon membrane filter (TITAN, TN, USA). The 20 μL filtrate was loaded on the HPLC system, a Shimadzu SPD-M10A HPLC system with a photodiode array detector (Tokyo, Japan) equipped with a Midas autoinjector. Separation was achieved on a 250 mm × 4.6 mm i.d., 5 μm, YMC-Pack ODS AM-303 (YMC, Kyoto, Japan) column. The absorbance of each sample solution was measured at 280 nm. The mobile phase was distilled water with 0.1% glacial acetic acid (solvent A) and acetonitrile with 0.1% glacial acetic acid (solvent B). The gradient was 0 min, 92% A; 0−2 min, 90% A;2−27 min, 70% A; 27−50 min, 10% A;50−51 min, 0% A; 51−60 min, 0% A; 60−63 min, 92% A. Run time was 60 min using a flow rate of 1 mL/min. The 30 standards and all solvents used (J. T. Baker, NJ, USA) were of HPLC grade.

**Determination of Antioxidant Activities.** *Measurement of Radical Scavenging Activity by DPPH.* Five grams of freeze-dried mushroom powder were mixed with 100 mL of 80% aqueous methanol and stirred for 24 h at 24 °C. The suspension was filtered through Whatman No. 42 filter paper. The extract was evaporated at temperatures below 30 °C, and the concentrated extract was then freeze-dried. Residues were redissolved in 80% aqueous methanol to make 1% solution (w/v), and filtered through a 0.45 μm nylon membrane filter (TITAN, TN, USA). The free radical scavenging activity was measured using 1,1-diphenyl-2-picrylhydrazyl (DPPH) (Sigma Aldrich, MO, USA) following the protocols of Chung et al. (*16*) and Oh et al. (*17*). Then 0.25 mL of each sample solution and 2.5 mL of reacting solution (0.35 mM DPPH in 50% ethanol) were mixed. The mixtures were left for 1 and 30 min at room temperature in the dark. Absorbencies were measured with a UV−vis spectrophotometer (Hitachi, Tokyo, Japan) at 517 nm. DPPH activity was calculated as an inhibition percentage based on the following equation:

$$\text{Free radical scavenging activity (\%)} = (1 - \text{Abs}_{\text{sample}}/\text{Abs}_{\text{control}}) \times 100 \quad (1)$$

**Determination of SOD Activity.** Freeze-dried mushroom powder (0.2 g) was mixed with 0.4 g of poly(vinylpyrrolidone)-iodine complex (PVP)(Sigma Aldrich, MO, USA) and 2 mL of extraction buffer (pH 7.0) including 100 mM potassium phosphate, 10 mM sodium ascorbate, and 5 mM EDTA. Following centrifugation of the homogenate at 15,000 rpm for 20 min, the collected supernatant was separated using a PD-10 Sephadex G-25 column, and the eluate was used to determine SOD activities. The SOD activity of mushrooms was determined using the nitro blue tetrazolium (NBT) (Sigma Aldrich, MO, USA) reduction method following Beyer and Fridovich (*18*). Test tubes containing the reacting solution with 3 mL of assay buffer, 60 μL of crude enzyme, and 30 μL of riboflavin were illuminated for 7 min in an aluminum foil lined box containing two 20-W Sylvania Grolux fluorescent lamps at 25 °C. The absorbance of the control and the reacting solution were measured with an UV−vis spectrophotometer (Hitachi, Tokyo, Japan) at 560 nm. SOD activities were calculated using the following equation:

$$\text{SOD activity (\%)} = (1 - \text{Abs}_{\text{sample}}/\text{Abs}_{\text{control}}) \times 100 \quad (2)$$

**Statistical Analyses.** Analysis of variance was performed using the general linear model (GLM) of the SAS program (*19*). All measurements were repeated three times. Differences between treatment means were determined using the least significant difference (LSD) test at a probability level of 0.05.

## RESULTS AND DISCUSSION

**Phenolic Compound Concentration in Edible and Medicinal Mushrooms.** Twenty-eight of the 30 phenolic compounds monitored were detected; only rutin and salicylic acid were not detected in the mushrooms studied (**Figure 1**, **Table**

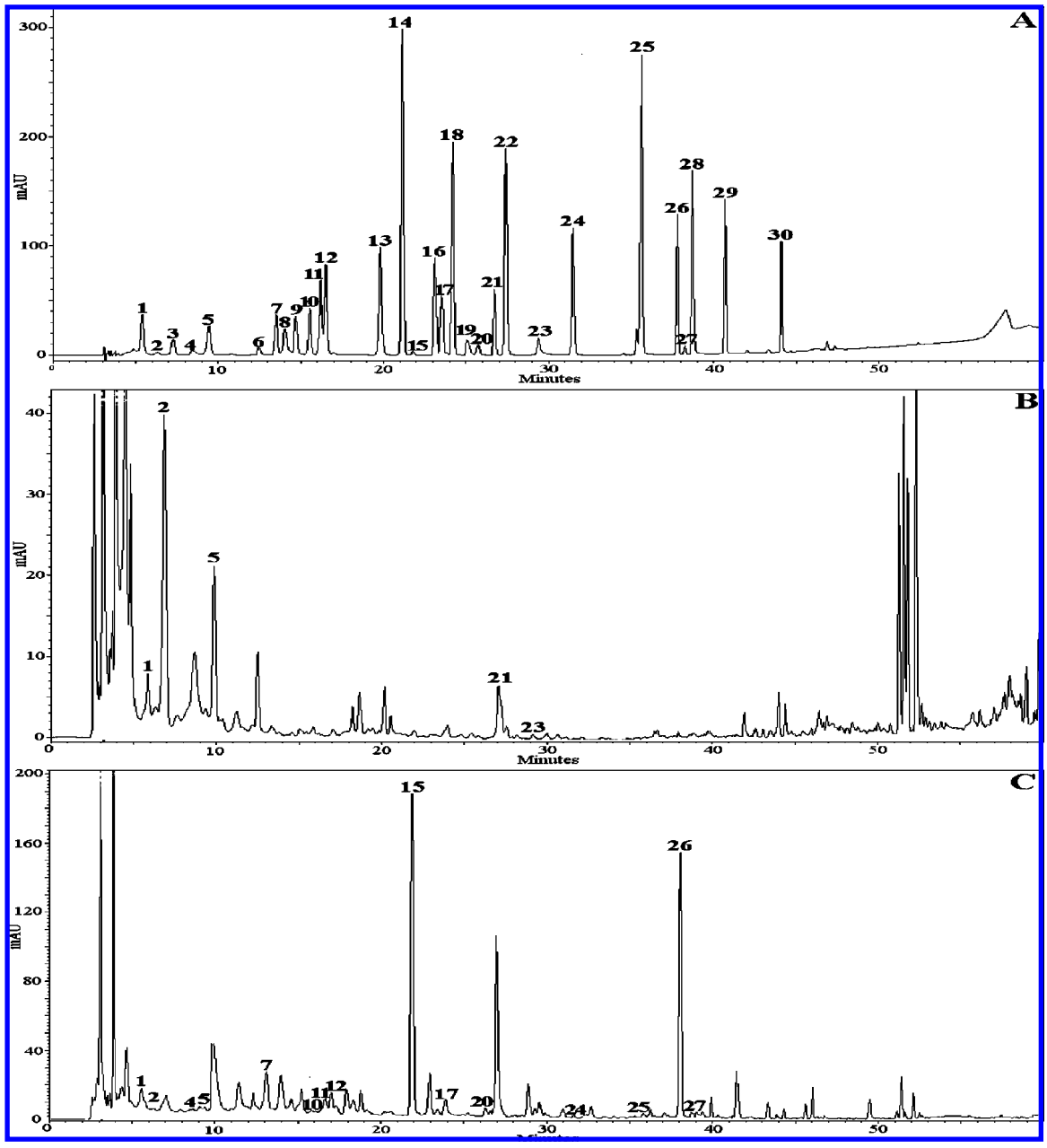


**Figure 1.** Chromatogram of phenolic compound analysis by HPLC. (**A**) Standard mixture of 30 phenolic compounds. (**B**) Edible mushroom *Agaricus bisporus*. (**C**) Medicinal mushroom *Sparassis crispa*. 1, gallic acid; 2, pyrogallol; 3, homogentisic acid; 4, 5-sulfosalicylic acid; 5, protocatechuic acid; 6, gentisic acid; 7, *p*-hydroxybenzoic acid; 8, (+) catechin; 9, chlorogenic acid; 10, vanillic acid; 11, caffeic acid; 12, syringic acid; 13, vanillin; 14, cinnamic acid; 15, *p*-coumaric acid; 16, ferulic acid; 17, veratric acid; 18, rutin; 19, salicylic acid; 20, benzoic acid; 21, naringin; 22, *o*-coumaric acid; 23, myricetin; 24, resveratrol; 25, quercetin; 26, naringenin; 27, kaempferol; 28, hesperetin; 29, formononetin; 30, biochanin A.

**1**). Overall, phenolic compounds concentration was greater in medicinal mushrooms than edible mushrooms (**Figure 2**, **Table 1**). Total average concentration of phenolic compounds was 174 and 477 $\mu$g/g in edible and medicinal mushrooms, respectively, with an overall average of 326 $\mu$g/g among all 10 mushrooms. Only one phenolic compound (i.e., protocatechuic acid) was detected in all 10 mushroom species. More phenolics were detected overall in medicinal than in edible mushrooms (i.e., 28 vs 12). Mushroom species also contained different types of phenolic compounds in varying numbers, ranging from 3 to 15. Eleven phenolic compounds were detected in only one species (e.g., gentisic acid, vanillic acid, and vanillin). The mushroom species that contained the least number of phenolic compounds were *Lentinus edodes* and *Pleurotus eryngii*, which had only three phenolic compounds each, while *Sparassis crispa* contained 15 among the 30 phenolic compounds. *S. crispa*, a medicinal mushroom contained the largest total concentration of phenolic compounds (i.e., 764 $\mu$g/g), while *Agaricus bisporus* was the edible species with the most phenolics (i.e., 543 $\mu$g/g) (**Figure 2**, **Table 1**). In each of these species, one phenolic compound contributed to more than half of the total concentration (i.e., benzoic acid and pyragallol).

Differences in total flavonoid content were also observed between mushroom species (**Figure 2**). Flavonoids detected included catechin, naringin, naringenin, myricetin, quercetin, biochanin A, formononetin, hesperetin, kaempferol, and rutin. *Inonotus obliquus* contained the largest total concentration of flavonoids (i.e., 143 $\mu$g/g) while *Phellinus linteus* had no flavonoids. The average total flavonoids concentration was 49 $\mu$g/g in the 10 mushroom species. Greater concentrations were

**Table 1.** Concentration of Phenolic Compounds in Five Edible and Five Medicinal Mushrooms From Korea

| | edible mushrooms (E) | | | | medicinal mushrooms (M) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Pleurotus ostreatus* | *Agaricus bisporus* | *Flammulina velutipes* | *Lentinus edodes* | *Pleurotus eryngii* | *Agaricus blazei* | *Sparassis crispa* | *Ganoderma lucidum* | *Inonotus obliquus* | *Phellinus linteus* | $LSD_{0.05}$ | ContrastE vs M[c] |
| | | | | | $\mu g\ g^{-1}$ | | | | | | | |
| 1[a] | 7 | 16 | 21 | 13 | 5 | 17 | 19 | 8 | nd | 9 | 2.86 | NS[d] |
| 2 | nd[b] | 464 | 15 | nd | nd | 20 | 66 | 18 | nd | 67 | 31.31 | NS |
| 3 | 16 | nd | 15 | nd | nd | nd | nd | nd | 51 | 30 | 1.60 | NS |
| 4 | nd | nd | 15 | nd | nd | nd | 53 | 17 | nd | 27 | 13.27 | *[e] |
| 5 | 18 | 32 | 21 | 16 | 14 | 25 | 96 | 19 | 50 | 18 | 4.58 | * |
| 6 | nd | nd | nd | nd | nd | 53 | nd | nd | nd | nd | 15.81 | NS |
| 7 | nd | nd | nd | nd | nd | nd | 34 | nd | 263 | 6 | 3.87 | NS |
| 8 | nd | nd | nd | 3 | nd | 22 | nd | 14 | nd | nd | 4.40 | NS |
| 9 | 19 | nd | 26 | nd | nd | nd | nd | nd | nd | 23 | 2.06 | NS |
| 10 | nd | nd | nd | nd | nd | nd | 5 | nd | nd | nd | 0.83 | NS |
| 11 | nd | nd | 17 | nd | nd | nd | 18 | nd | nd | 13 | 1.38 | NS |
| 12 | nd | nd | nd | nd | nd | 22 | 5 | nd | nd | nd | 1.20 | NS |
| 13 | nd | nd | nd | nd | nd | nd | nd | nd | 5 | nd | 1.99 | NS |
| 14 | nd | nd | nd | nd | nd | 1 | nd | nd | nd | nd | 0.55 | NS |
| 15 | nd | nd | nd | nd | nd | nd | 37 | nd | nd | nd | 1.17 | NS |
| 16 | nd | nd | 9 | nd | nd | nd | nd | nd | 22 | nd | 0.54 | NS |
| 17 | nd | nd | nd | nd | nd | nd | 12 | nd | nd | nd | 4.43 | NS |
| 18 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | | |
| 19 | nd | nd | nd | nd | nd | nd | nd | nd | nd | nd | | |
| 20 | nd | nd | nd | nd | nd | 490 | 348 | nd | nd | 19 | 15.80 | * |
| 21 | 9 | 13 | nd | nd | 8 | nd | nd | 9 | 38 | nd | 2.16 | NS |
| 22 | nd | nd | nd | nd | nd | nd | nd | nd | 1 | nd | 0.08 | NS |
| 23 | 21 | 19 | nd | nd | nd | 26 | nd | 21 | nd | nd | 0.50 | NS |
| 24 | nd | nd | nd | nd | nd | nd | 1 | nd | 12 | nd | 2.33 | NS |
| 25 | nd | nd | 35 | nd | nd | 26 | 24 | 26 | 52 | nd | 1.49 | * |
| 26 | nd | nd | nd | nd | nd | nd | 36 | nd | nd | nd | 0.64 | NS |
| 27 | nd | nd | nd | nd | nd | nd | 7 | 25 | 53 | nd | 3.91 | * |
| 28 | nd | nd | nd | nd | nd | nd | nd | 3 | nd | nd | 0.06 | NS |
| 29 | nd | nd | nd | nd | nd | nd | nd | 1 | nd | nd | 1.18 | NS |
| 30 | nd | nd | nd | nd | nd | nd | nd | 3 | nd | nd | 0.04 | NS |
| total | 90 | 543 | 174 | 32 | 28 | 702 | 764 | 162 | 547 | 213 | 57.05 | ** |
| $LSD_{0.05}$ | 1.51 | 2.60 | 3.13 | 1.77 | 1.04 | 8.60 | 8.42 | 5.34 | 3.37 | 16.04 | | |

[a] 1, gallic acid; 2, pyrogallol; 3, homogentisic acid; 4, 5-sulfosalicylic acid; 5, protocatechuic acid; 6, gentisic acid; 7, *p*-hydroxybenzoic acid; 8, (+) catechin; 9, chlorogenic acid; 10, vanillic acid; 11, caffeic acid; 12, syringic acid; 13, vanillin; 14, cinnamic acid; 15, *p*-coumaric acid; 16, ferulic acid; 17, veratric acid; 18, rutin; 19, salicylic acid; 20, benzoic acid; 21, naringin; 22, *o*-coumaric acid; 23, myricetin; 24, resveratrol; 25, quercetin; 26, naringenin; 27, kaempferol; 28, hesperetin; 29, formononetin; 30, biochanin A. [b] Not detected. [c] Contrast *P* values of edible vs medicinal mushrooms. [d] Not significantly different. [e] ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$.

observed in medicinal (77 $\mu$g/g) than in edible (22 $\mu$g/g) mushrooms, and the greatest concentrations were observed in *Ganoderma lucidum*.

Valentão et al. (*20*) studied phenolic compounds of *Cantharellus cibarius*. Three phenolic compounds (i.e., caffeic acid, *p*-coumaric acid, and rutin) were studied in both Valentão et al. (*20*) and the present study. Caffeic acid was found in highest concentration among these three phenolic compunds in *C. cibarius*, while *p*-coumaric acid was dominant among all mushrooms in our research. *S. crispa* contained large concentrations of caffeic acid (18 $\mu$g/g) and *p*-coumaric acid (38 $\mu$g/g); however, rutin was not detected in any of the mushrooms we studied, while *C. cibarius* had concentrations of 2 $\mu$g/g.

Many studies have reported on the contents of phenolic compounds in a range of plants including rice, soybean, and various fruits. For example, Zhou et al. (*21*) reported six phenolic compounds in rice (i.e., gallic acid, vanillic acid, caffeic acid, syringic acid, *p*-coumaric acid, and ferulic acid). While ferulic acid was reported as the dominant phenolic compound in rice, the 10 mushrooms studied herein only had limited contents of ferulic acid. However, gallic acid, which is a strong antioxidant, was detected in much greater concentrations in the 10 species of mushrooms in our study.

**Antioxidant Activities of Edible and Medicinal Mushrooms.** *Free Radical Scavenging Activity.* The 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity tests we conducted followed the methods of Chung et al. (*16*) and Oh et al. (*17*), which checked activity at different time periods. The average total DPPH radical scavenging activities for the 10 mushrooms species ranged between 10 and 72% (**Table 2**). When the reaction time was for 1 min, DPPH activity ranged between 15 (*Pleurotus eryngii*) and 70% (*Ganoderma lucidum*); while with a reaction time of 30 min, DPPH activity ranged between 5 (*Pleurotus eryngii*) and 78% (*Agaricus bisporus*). Overall, medicinal mushrooms had a higher DPPH activity than edible mushrooms (46 vs 34%). Except for one species (i.e., *Pleurotus eryngii*), a longer reaction time resulted in greater DPPH activity (i.e., increase of 5 and 11% for edible and medicinal mushrooms, respectively). Mau et al. (*22*) reported antioxidant activities of 68−74% for *Ganoderma lucidum*, while Cheung et al. (*23*), who evaluated the scavenging activity of DPPH radical of the methanol and water crude extracts of mushrooms at different concentrations, reported an antioxidant activity of 29% for a methanol extract (9 mg/mL) of *Lentinus edodes*.

*Superoxide Dismutase (SOD) Activity.* Results obtained using this assay differed from those observed for both DPPH assays. The enzyme SOD catalyzes the dismutation of superoxide into oxygen and hydrogen peroxide. As such, it is an important antioxidant defense in nearly all cells exposed to oxygen. But SOD is unstable at high temperatures and pH (*25*). The average total SOD activity was 28% for all 10 mushroom species, edible and medicinal mushrooms presenting similar average SOD activity (**Table 2**). *Sparassis crispa*, *Agaricus blazei*, *Agaricus*

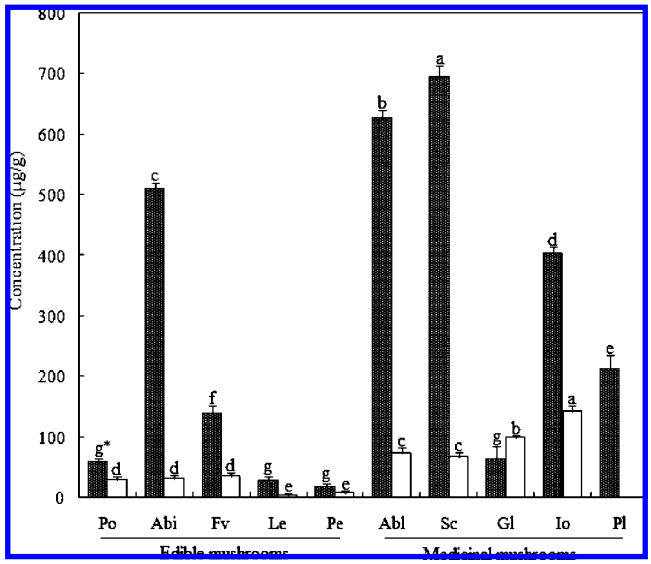


**Figure 2.** Concentrations of flavonoids (white) and phenolic acids (black) in five edible and five medicinal mushrooms from Korea. Po, *Pleurotus ostreatus*; Abi, *Agaricus bisporus*; Fv, *Flammulina velutipes*; Le, *Lentinus edodes*; Pe, *Pleurotus eryngii*; Abl, *Agaricus blazei*; Sc, *Sparassis crispa*; Gl, *Ganoderma lucidum*; Io, *Inonotus obliquus*; Pl, *Phellinus linteus.* *Means with a different letter are significantly different ($p < 0.05$). Vertical bars indicate standard deviation.

**Table 2.** Timed 1,1-Diphenyl-2-picrylhydrazyl (DPPH) Free Radical Scavenging Activity and Superoxide Dismutase (SOD) Activity in Five Edible and Five Medicinal Mushrooms From Korea

| | DPPH % | | |
|---|---|---|---|
| species | 1 min | 30 min | SOD |
| Edible Mushrooms | | | |
| *Pleurotus ostreatus* | 44 | 51 | 18 |
| *Agaricus bisporus* | 61 | 78 | 47 |
| *Flammulina velutipes* | 17 | 19 | 0* |
| *Pleurotus eryngii* | 15 | 5 | 25 |
| *Lentinus edodes* | 20 | 31 | 49 |
| Medicinal Mushrooms | | | |
| *Agaricus blazei* | 54 | 67 | 48 |
| *Sparassis crispa* | 37 | 55 | 50 |
| *Phellinus Linteus* | 29 | 36 | 24 |
| *Ganoderma lucidum* | 70 | 74 | 8 |
| *Inonotus obliquus* | 44 | 56 | 13 |
| $LSD_{0.05}$ | 7.11 | 5.50 | 9.62 |
| contrast edible vs medicinal (*P* value) | *[a] | * | NS |

[a] ***$P < 0.001$, **$P < 0.01$, *$P < 0.05$. NS, not significantly different. *, no effect.

*biporus*, and *Lentinus edodes* had the greatest SOD activity (i.e., average of 48%). In contrast, *Ganoderma lucidum*, which had greatest DPPH activities, had the lowest detected SOD activity (i.e., 8%) among all mushrooms, with *Flammulina velutipes* not exhibiting any SOD activity. Chung et al. (*24*) published antioxidative activities of a range of mushrooms using various assays. They reported that *Inonotus obliquus* and *Agaricus blazei* had SOD activities of 15 and 21%, respectively, compared to 13 and 48% in our study for these same two species.

**Correlations between Antioxidant Activities and Phenolic Compounds in Edible and Medicinal Mushrooms.** The correlations between antioxidant activities and total concentration of individual phenolic compounds in the edible mushrooms *Pleurotus ostreatus*, *Agaricus bisporus*, *Flammulina velutipes*, *Pleurotus eryngii*, and *Lentinus edodes* and those for the medicinal mushrooms *Agaricus blazei, Sparassis crispa, Phellinus linteus, Ganoderma lucidum and Inonotus obliquus* are presented in **Tables 1** and **2**. In edible mushrooms, DPPH radical scavenging activities and SOD activity were positively correlated with gallic acid, pyrogallol, homogentisic acid, protocatechuic acid, catechin, caffeic acid, ferulic acid, naringin, myricetin, quercetin, and total phenolic compounds. Among the phenolic compounds, caffeic acid ($r = 0.99$***) and naringin ($r = 0.99$***) presented the strongest correlations with total phenolic compounds. Only chlorogenic acid did not show any positive correlations with SOD activity and total phenolic compounds. In medicinal mushrooms, gallic acid, homogentisic acid, 5-sulfosalicylic acid, catechin, caffeic acid, syringic acid, *p*-coumaric acid, benzoic acid, myricetin, resveratrol, kaempferol, and total phenolic compounds were positively correlated with both DPPH radical scavenging activities and SOD activity. All phenolic compounds that were detected in medicinal mushrooms exhibited positive correlation with total phenolic compounds except vanillin and *o*-coumaric acid. Gallic acid ($r = 0.99$***), caffeic acid ($r = 0.99$***), *p*-coumaric acid ($r = 0.99$***), benzoic acid ($r = 0.99$***), and myricetin ($r = 0.99$***) displayed high positive correlation with total phenolic compounds.

Chi (*26*) studied DPPH inhibition by phenolic standard compounds, including catechin, hesperidin, syringic acid, and kaempferol. She reported that catechin and syringic acid both exhibited 81% DPPH inhibition. Our results also suggest that catechin and syringic acid were related to antioxidant properties. Velioglu et al. (*27*) also reported that the antioxidant activity of plant materials is well correlated with their phenolic compound concentration.

On the basis of the results of our study, medicinal mushrooms had various phenolic compounds that have shown limitless potential in functional foods and medicinal industries. Also, we confirmed that the phenolic content of mushrooms could make a significant contribution to the antioxidant properties and that it could explain the relationship between phenolic compounds and antioxidant activities. Overall, our report from the present analysis should be ground data for undertaking further study, and it is useful information for investigating new mushroom materials for food additives and human health.

## NOTE ADDED AFTER ASAP PUBLICATION

There were errors in the author affiliation and in footnote of Table 2 in the version published ASAP July 11, 2008; the corrected version was published ASAP July 18, 2008.

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