Journal of Medicinal Plants Research Vol. 6(39), pp. 5228-5239, 10 October, 2012
Available online at http://www.academicjournals.org/JMPR
DOI: 10.5897/JMPR12.135
ISSN 1996-0875 ©2012 Academic Journals

Full Length Research Paper

Comparison of phenolic compounds content in indeciduous *Quercus* species

Jong Jin Kim[1], Bimal Kumar Ghimire[2], Hyeun Cheul Shin[3], Kyung Jae Lee[4], Ki Sun Song[1], Young Suk Chung[5], Taek Seong Yoon[6], Ye-Ji Lee[7], Eun-Hye Kim[7] and Ill-Min Chung[7]*

[1]Department of Environmental Science, Konkuk University, Seoul 143-701, Korea.
[2]Department of Ethnobotany and Social Medicine, Sikkim University, Gangtok- 737 102, Sikkim, India.
[3]Southern Forest Research Center, Korea Forest Research Institute, Jinju 660-300, Korea.
[4]Forest Practice Research Center, Korea Forest Research Institute, Pocheon 487-821, Korea.
[5]Institute of Life and Environment, Konkuk University, Seoul 143-701, Korea.
[6]Suppro Plant Environment Research Center, AT Center, Seoul 137-787, Korea.
[7]Department of Applied Bioscience, Konkuk University, Seoul 143-701, Korea.

Accepted 4 May, 2012

Indeciduous *Quercus* species have been used in Korean folk medicine, having effects on various diseases such as dysentery, diarrhea, hemorrhagia and dermatitis. In this study, five *Quercus* species were used for determination of phenolic compounds. In particular, phenolic compounds content in *Quercus salicina* Blume was compared between its leaf and shoot. Results indicated that the concentration of phenolic compounds in the leaf (25702.13 µg g^{-1}) was higher than in the shoot (16461.82 µg g^{-1}). Among the five *Quercus* species, the average concentration of phenolic compounds in their leaves ranged from 900.91 to 25702.13 µg g^{-1}, with the *Q. salicina* Blume leaf showing the highest concentration of total phenolic compounds. *Quercus* species have long been medicinally important, but there have been no previous reports about their functional ingredients.

Key words: *Quercus salicina* Blume, *Quercus acuta* Thunberg, *Quercus phillyraeoides* A. Gray, *Quercus glauca* Thunberg, *Quercus myrsinaefolia* Blume, phenolic compounds.

INTRODUCTION

Leaves of indeciduous *Quercus* species have been used in Korean folk medicine for dysentery, diarrhea, hemorrhagia, dermatitis, and exclusion of extravasated blood (Kim et al., 2008). The species *Quercus salicina* Blume, which is distributed in the southern part of Korea and in Japan, has especially been used for anti-inflammatory, diuretic and litholytic remedies (Elliott, 2001; Walters et al., 2001; Redwane et al., 2002; Goun et al., 2002).

Oxidative stress (oxygen free radical injury, lipid peroxidation) has been named as the major cause of aging, cancer and various diseases in humans such as heart disease and cataracts (Pietta, 2000; Katalinic et al., 2006; Halliwell and Gutteridge, 1998). Phenolics are secondary plant metabolites, mainly synthesized by the pentose phosphate pathway and skimate and phenylpropanoid pathways (Randhir and Shetty, 2005). Phenolic compounds have shown antioxidant effects on lipid oxidation (Kaarina et al., 2004; Heinonen et al., 1998; Hopia et al., 1999; Kähkönen and Heinonen, 2003) and a wide range of anti-allergenic, anti-atherogenic, anti-inflammatory, anti-microbial, anti-thrombotic and cardioprotective effects (Wei et al., 1990; Pietta, 2000; Middleton et al., 2000). Phenolic compounds have been associated with the health benefits of edible plants, and could be a major determining factor on antioxidant capacity (Balasundram et al., 2006). In addition, phenolic

*Corresponding author. E-mail: imcim@konkuk.ac.kr. Tel: +82-2-450-3730. Fax: +82-2-446-7856.

compounds contain an aromatic ring bearing hydroxyl substituent. Phenolic acids and flavonoids are the major class of phenolic compounds, widely distributed in plants (Cai et al., 2004). In phenolic compounds, phenolic acids consist of two kinds of subgroups of hydroxybenzoic and hydroxycinnamic acids (Bravo, 1998). Flavonoids constitute the largest group of plant phenols and naturally generating phenolic compounds (Harbone et al., 1999) and have the basic skeleton of diphenylpropanes.

Numerous quantitative studies on phenolic compounds have been conducted with various methods (Häkkinen et al., 1998; Kawaii et al., 1999; Christopher et al., 2006). In this study, high performance liquid chromatography (HPLC) was used for the determination of phenolic acids and flavonoids in *Quercus* species used in Korean folk medicine. It is of interest to investigate the functional components of *Quercus* species traditionally used in Korean folk medicine. The aim of this study was to determine the concentrations of phenolic compounds in *Quercus* species as medicinal plants. In particular, we determined the concentration of phenolic compounds in *Q. salicina* Blume leaves and shoots, and in the leaves of four other *Quercus* species.

MATERIALS AND METHODS

Plant description

The indeciduous *Quercus* species studied were *Q. salicina* Blume, *Quercus acuta* Thunberg, *Quercus phillyraeoides* A. Gray, *Quercus glauca* Thunberg and *Quercus myrsinaefolia* Blume, which were collected from southern coast and southern Island of Korea. The collection of shoots and leaves from this tree species was conducted from May 10, 2009 to May 15, 2009. In particular, those from *Q. salicina* Blume were collected from an experimental forest in the Warm-Temperate Research Center of the Korea Forest Research Institute in Jeju Island. Other species were collected from an experimental forest in the Southern Forest Center of Korea.

Preparation of samples

Leaves from five *Quercus* species were freeze-dried and then ground. Sample extractions were prepared as per the method described by Kim et al. (2006). Two grams of ground samples were extracted in 10 ml of acetonitrile (ACN) and 2 ml of 0.1 N hydrochloric acid, and stirred for 2 h at room temperature. The extract was filtered through a No. 42 Whatman filter paper (125 mm Dia x 100 circles, England) and concentrated by a vacuum evaporator. Residues were re-dissolved in 10 ml of 80% aqueous methanol (HPLC grade, J.T. Baker, USA) and filtered through a 0.45 µM syringe filter (TITAN, Nylon; Sun Sri, USA) and then transferred to 2-ml vials. These samples were used for phenolic compounds analyses.

Phenolic compounds analyses

The HPLC system used was an Agilent 1100 series with PDA detector (Germany). Separation was conducted on a YMC-Pack ODS-AM-303 (5 µM, 250 mm × 4.6 mm I.D.) column. The sample preparation for analysis of phenolic compounds in the HPLC system followed the protocol of Kim et al. (2006). Briefly, 20 µL of filtrate were injected into the HPLC system; the same system and column were used for all phenolic compounds analyses. Compounds were detected at a wavelength of 280 nm. The mobile phase consisted of distilled water with 0.1% glacial acetic acid (solvent A) and acetonitrile (ACN) with 0.1% glacial acetic acid (solvent B). The gradient was as follows: 0 min, 92% A:8% B; 0 to 2 min, 90% A:10% B; 2 to 27 min, 70% A:30% B; 27 to 50 min, 10% A:90% B; 50 to 51 min, 0% A:100% B; 51 to 60 min, 0% A:100% B; 60 to 63 min, 92% A:8% B. Run time was 60 min, using a flow rate of 1 ml min^{-1}.

Thirty one phenolic compounds standards (gallic acid, pyrogallol, homogentisic acid, protocatechuic acid, gentisic acid, chlorogenic acid, (+)-catechin, *p*-hydroxybenzoic acid, *ß*–resorcyclic acid, vanillic acid, caffeic acid, vanillin, *p*-coumaric acid, rutin, ferulic acid, veratric acid, *m*-coumaric acid, syringic acid, naringin, hesperedin, benzoic acid, *o*-coumaric acid, myricetin, resveratrol, quercetin, *t*-cinnamic acid, naringenin, kaempferol, hesperetin, formononetin, and biochanin A) were purchased from Sigma Aldrich (St. Louis, USA) and Extrasynthese (Germany, France) and used to establish calibration curves. The standard stock solutions (1, 25, 50, 75 and 100 µg g^{-1}) were made with dimethyl sulfoxide (DMSO). All standard calibration curves showed high degrees of linearity (r^2> 0.99) (Table 1). Phenolic compounds in the samples were determined based on the retention times of the standards, and their concentrations were calculated by calibration curves (Table 2).

Statistical analyses

Statistical analyses were conducted using the general linear model procedure (GLM) of the SAS program (SAS Institute, Inc., 2000). The experimental design was a completely randomized design with three replicates. Means separation was performed using the least significant difference (LSD) test at the 0.05 probability level.

RESULTS

Comparison of phenolic compounds contents between the leaf and shoot of *Q. salicina* Blume

The total concentrations of phenolic compounds in *Q. salicina* Blume showed differences between leaf and shoot (Figure 1). The average total phenolic compounds in *Q. salicina* Blume leaves and shoots were 21081.98 µg g^{-1}. The total amount of phenols in leaves and shoots were 25702.13 µg g^{-1} and 16461.82 µg g^{-1} respectively. Thus, the amount of phenolic compounds in leaves was about 1.56 times than shoots. Among the individual phenolic compounds, gentisic acid was the highest, especially in leaves (9587.50 µg g^{-1}). Also, the leaves had higher chlorogenic acid (6081.11 µg g^{-1}) and pyrogallol (3708.30 µg g^{-1}) content than other substances. The vanillic acid and *m*-coumaric acid were only detected in leaves. However, (+)-catechin (576.43 µg g^{-1}) was only detected in the *Q. salicina* Blume shoot.

The proportions of phenolic acids and flavonoids are shown in Figure 2. The proportion of phenolic acids among the *Q. salicina* Blume leaves and shoots varied from 87.86 to 94.08%. The flavonoid proportion in shoots (12.14%) was higher than leaves (5.92%).

Table 1. Calibration curve equation for the 31 phenolic compounds standards.

Phenolic compounds	Equation	R^2
Gallic acid	y = 47.638x + 144.05	0.994
Pyrogallol	y = 2.2087x - 2.1338	0.998
Homogentisic acid	y = 9.8339x + 23.401	0.996
Protocatechuic acid	y = 25.447x - 2.2837	0.999
Gentisic acid	y = 3.3267x + 11.674	0.994
Chlorogenic acid	y = 4.8652x - 12.034	0.998
p-Hydroxybenzoic acid	y = 32.158x + 4.2742	0.999
(+)-Catechin	y = 11.682x - 3.9961	0.999
Vanillic acid	y = 29.469x + 11.278	0.999
Syringic acid	y = 55.324x – 27.508	0.999
Caffeic acid	y = 14.737x - 26.154	0.999
Vanillin	y = 78.013x - 8.6281	0.999
p-Coumaric acid	y = 39.421x + 14.495	0.999
Rutin	y = 14.096x - 9.1985	0.999
Ferulic acid	y = 18.57x - 3.1248	0.999
m-Coumaric acid	y = 104.83x – 177.01	0.999
Hesperedin	y = 33.61x – 13.632	0.999
Caffeic acid	y = 14.737x – 26.154	0.999
o-Coumaric acid	y = 147.58x – 310.61	0.998
Myricetin	y = 23.69x – 85.77	0.999
Resveratrol	y = 26.775x – 12.57	0.999
Quercetin	y = 20.767x – 65.419	0.996
t-Cinnamic acid	y = 160.71x + 1.8274	0.999
Naringenin	y = 45.344x – 36.433	0.999
Hesperetin	y = 49.722x + 7.4397	0.999
Formononetin	y = 46.158x – 10.95	0.999
Biochanin A	y = 43.437x – 9.0737	0.999
ß-Resorcylic acid	y = 24.161x – 11.12	0.999
Naringin	y = 21.468x – 16.187	0.999
Kaempferol	y = 26.652x – 24.209	0.999
Veratric acid	y = 38.525x – 32.961	0.998

Table 2. Phenolic compounds content of the *Quercus salicina* Blume leaf and shoot.

Compounds	Leaf	Shoot	$LSD_{(0.05)}$
	($\mu g\ g^{-1}$)		
Phenolic acids			
Gallic acid	47.57	128.31	32.12
Pyrogallol	3708.30	3006.20	742.06
Homogentisic acid	856.48	1435.63	91.58
Protocatechuic acid	1199.60	541.50	925.86
Gentisic acid	9587.50	4452.30	275.82
Chlorogenic acid	6081.11	3401.00	189.91
p-Hydroxybenzoic acid	317.92	247.00	25.05
Vanillic acid	197.04	ND	3.18
Syringic acid	130.02	69.56	15.81
Caffeic acid	394.50	587.53	81.22
Vanillin	12.06	13.58	51.90
p-Coumaric acid	162.81	39.68	104.21

Table 2. Cont.

Ferulic acid	297.11	39.38	46.19
m-Coumaric acid	11.86	ND	2.60
Salicylic acid	553.11	137.18	35.92
o-Coumaric acid	16.08	22.00	1.34
Resveratrol	35.27	6.55	127.88
t-Cinnamic acid	3.84	1.87	7.63
Veratric acid	166.31	55.09	37.92
ß-Resorcylic acid	403.26	279.64	379.24
Average	1209.09	723.20	
Flavonoids			
(+)Catechin	ND	576.43	85.48
Rutin	167.40	397.20	44.11
Quercetin	26.00	312.30	809.42
Naringenin	7.05	6.08	30.72
Hesperetin	5.05	5.02	17.14
Formononetin	2.37	8.20	1.22
Biochanin A	14.52	11.33	1.01
Naringin	1023.00	261.30	8.85
Kaempferol	11.63	11.16	8.56
Myricetin	199.56	308.09	25.97
Hesperedin	63.85	100.83	6.24
Average	138.22	181.63	
TOTAL	25702.13	16461.82	

ND, Not detected.

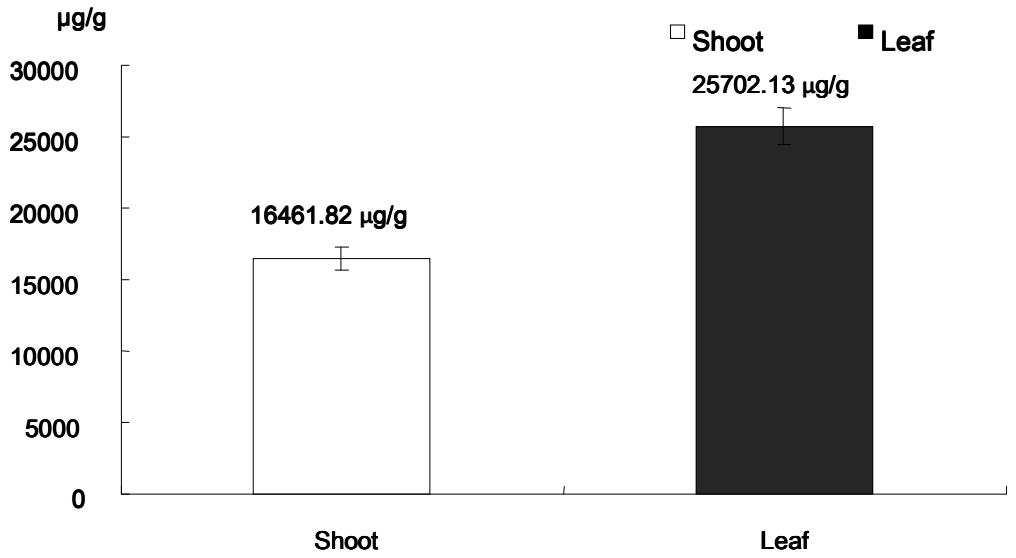

Figure 1. Comparison of total phenolic compounds in *Quercus salicina* Blume leaf and shoot.

Comparison of phenolic compounds contents between leaves of the five *Quercus* species

We compared the amounts of phenolic compounds in leaf extracts from five *Quercus* species. Estimation and identification of individual phenolic compounds in extracts was performed by associating the HPLC peak (Figure 3A-C). The average total phenolic compounds in leaves

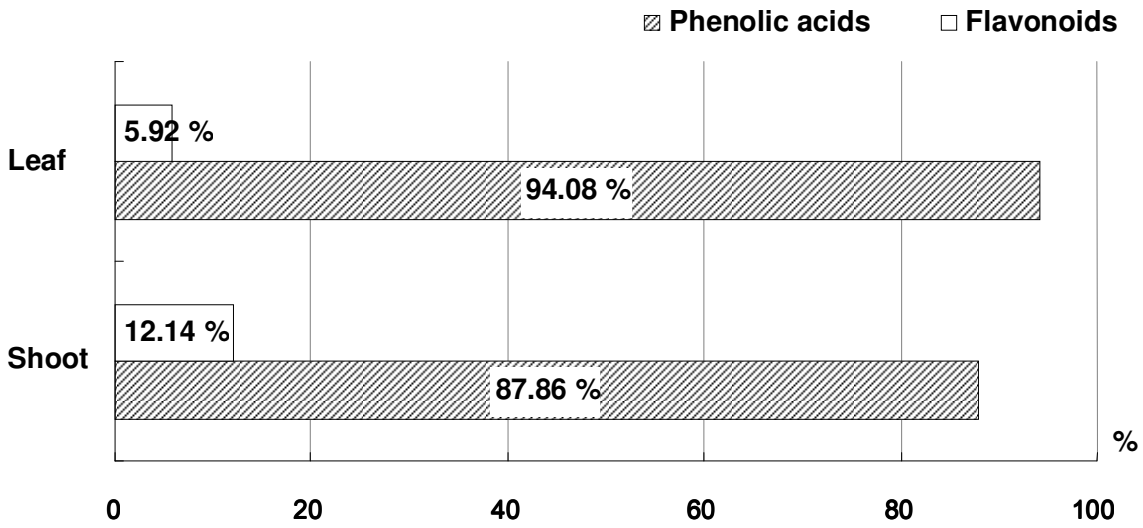

Figure 2. Proportions of phenolic acids and flavonoids in *Quercus salicina* Blume leaf and shoot.

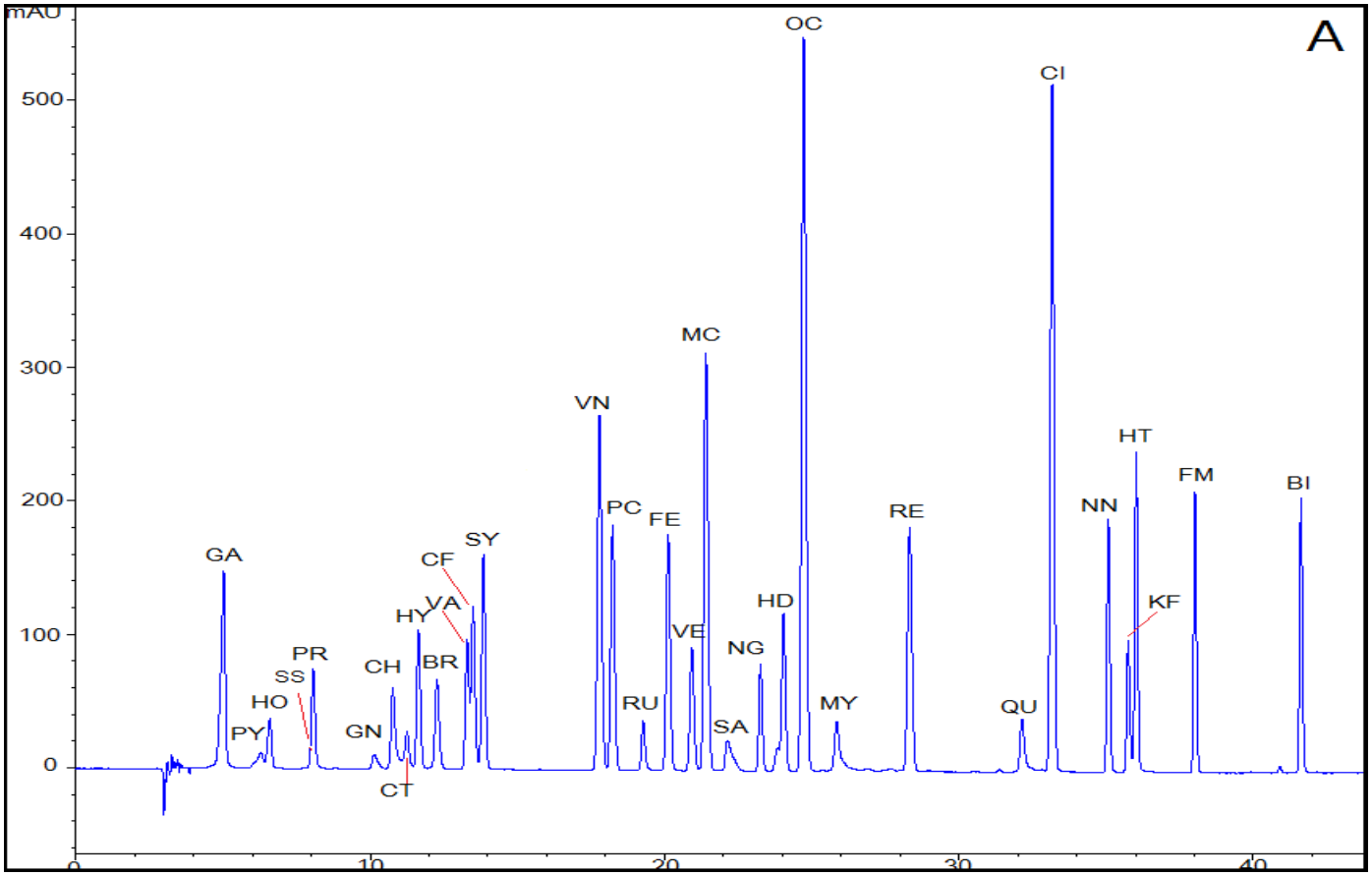

Figure 3. HPLC chromatogram of phenolic compounds on *Quercus* species. A, 32 Standard phenolic compounds; B, *Quercus salicina* Blume; C, *Quercus acuta* Thunberg. GA, Gallic acid; PY, Pyrogallol; HO, Homogentisic acid; SS, 5-sulfosalicylic acid; PR, Protocatechuic acid; GN, Gentisic acid; HY, *p*-Hydroxybenzoic acid; BR, *β*-Resorcylic acid; CT, (+) Catechin; CH, Chlorogenic acid; VA, Vanillic acid; CF, Caffeic acid; SY, Syringic acid; VN, Vanillin; PC, *p*-Coumaric acid; RU, Rutin; FE, Ferulic acid; VE, Veratric acid; MC, *m*-Coumaric acid; SA, Salicylic acid; BZ; Benzoic acid, NR; Naringin, OC; *o*-Coumaric acid, MY; Myricetin, RE; Resveratrol, QU; Quercetin, CI; *t*-Cinnamic acid, NN; Naringenin, KF; Kaempferol, HT; Hesperetin, FM; Formononetin, BI; Biochanin A.

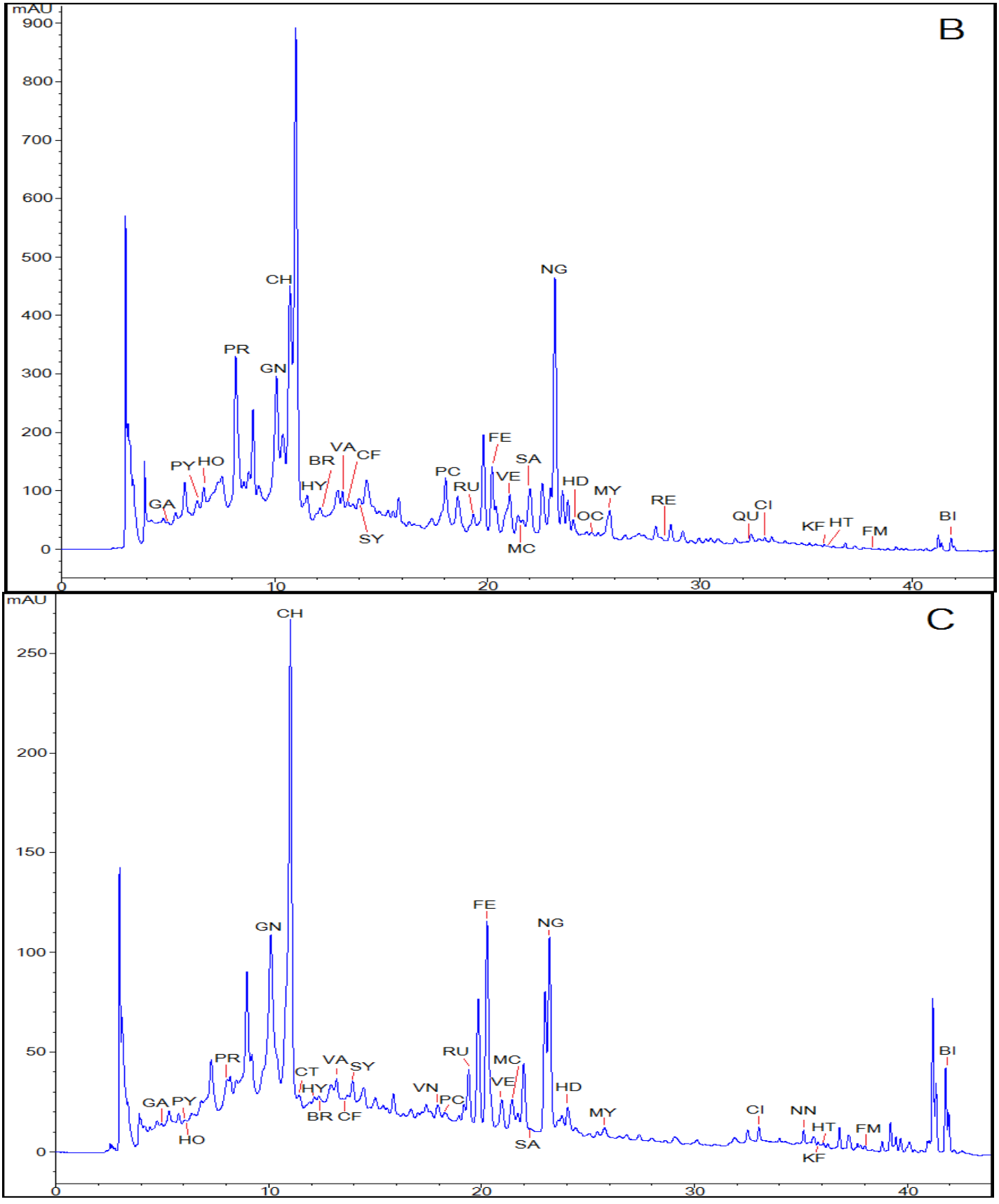

Figure 3. Cont.

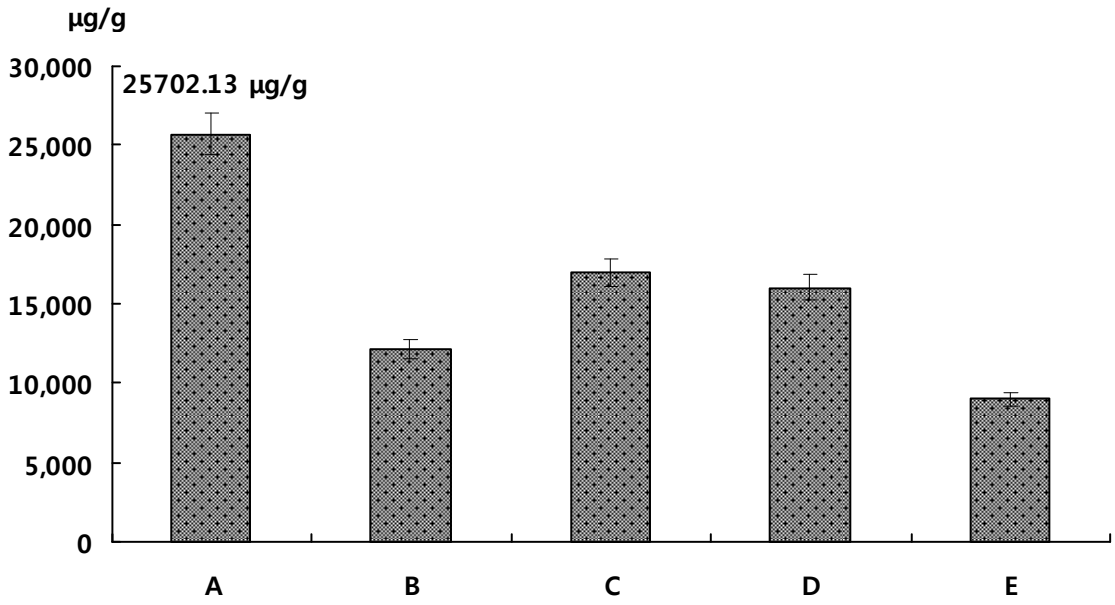

Figure 4. Comparison of total phenolic compounds in leaves of five *Quercus* species. A, *Quercus salicina* Blume; B, *Quercus acuta* Thunberg; C, *Quercus phillyraeoides* A. Gray; D, *Quercus glauca* Thunberg; E, *Quercus myrsinaefolia* Blume.

among the five *Quercus* species was 15960.59 μg g^{-1}. Among them, *Q. salicina* Blume (25702.13 μg g^{-1}), *Q. phillyraeoides* A. Gray (16988.82 μg g^{-1}), and *Q. glauca* Thunberg (16003.35 μg g^{-1}) had higher than average concentration total phenolic compounds (Table 2, Figure 4). The total of phenolic compounds concentration in the leaves of the five *Quercus* species leaves ranged from 900.91 μg g^{-1} in *Q. myrsinaefolia* Blume to 25702.13 μg g^{-1} in *Q. salicina* Blume. The highest total phenolic compounds content was found in *Q. salicina* Blume, which contained 25702.13 μg g^{-1}. The plant with the second highest content was *Q. phillyraeoides* A. Gray, with 16988.82 μg g^{-1}. Moreover, *Q. myrsinaefolia* Blume (900.91 μg g^{-1}) showed the lowest concentrations of total phenolic compounds.

Among the 31 individual phenolic compounds, the average content of gentisic acid (5382. 0 μg g^{-1}) was highest, and chlorogenic acid (3608.64 μg g^{-1}) and the second highest was estimated as chlorogenic acid (3608.64 μg g^{-1}). Hesperetin showed the lowest levels (1.86 μg g^{-1}) in the leaves of *Quercus* species. Most of the phenolic compounds of *Q. salicina* Blume occurred at higher concentrations than in other species. Gentisic acid (9587.50 μg g^{-1}) and naringin (1023.00 μg g^{-1}) occurred in especially higher concentrations (Figures 5 and 6). Figure 7 shows the variations in chlorogenic acid and gentisic acid content among five *Quercus* species. Three *Quercus* species (*Q. salicina* Blume, *Q. acuta* Thunberg, *Q. phillyraeoides* A. Gray) showed higher gentisic acid than chlorogenic acid content. *Q. salicina* Blume leaf had the highest concentration of both gentisic acid and chlorogenic acid, while gentisic acid was not detected in *Q. myrsinaefolia* Blume, and chlorogenic acid was not detected in *Q. glauca* Thunberg. Among the individual compounds, the leaves of *Q. salicina* Blume had the highest contents of 16 kinds of phenolic compounds (Table 3). Ferulic acid (304.47 μg g^{-1}) was highest in *Q. acuta* Thunberg, whereas *p*-coumaric acid (794.34 μg g^{-1}), rutin (6524.50 μg g^{-1}) and biochanin A (40.82 μg g^{-1}) were highest in *Q. phillyraeoides* A. Gray. Gallic acid (180.68 μg g^{-1}) was the highest in *Q. myrsinaefolia* Blume. Furthermore, *Q. glauca* Thunberg contained the highest levels of vanillic acid (278.42 μg g^{-1}), syringic acid (333.89 μg g^{-1}), (+)-catechin (3134.69 μg g^{-1}), quercetin (192.30 μg g^{-1}), and hesperedin (132.49 μg g^{-1}).

The proportions of phenolic acids and flavonoids in *Quercus* species are shown in Figure 8. The proportion of phenolic acids among the five species of *Quercus* leaf varied from 57.75 to 94.56%, and flavonoids varied from 5.44 and 42.25%. In particular, *Q. acuta* Thunberg (94.56%) and *Q. salicina* Blume (94.08%) had high phenolic acid content, while *Q. phillyraeoides* A. Gray contained a high percentage of flavonoids (42.25%).

DISCUSSION

Phenolic compounds are secondary metabolites with high antioxidative, anti-cancer, and anti-aging effects (Kähkönen et al., 1999; Aaby et al., 2004).

Their activities are related to the number of hydroxyl functional groups in their structures (Middleton et al., 2000; Balasundram et al., 2006). *Q. salicina* Blume has been used as a folk medicine for various diseases, with

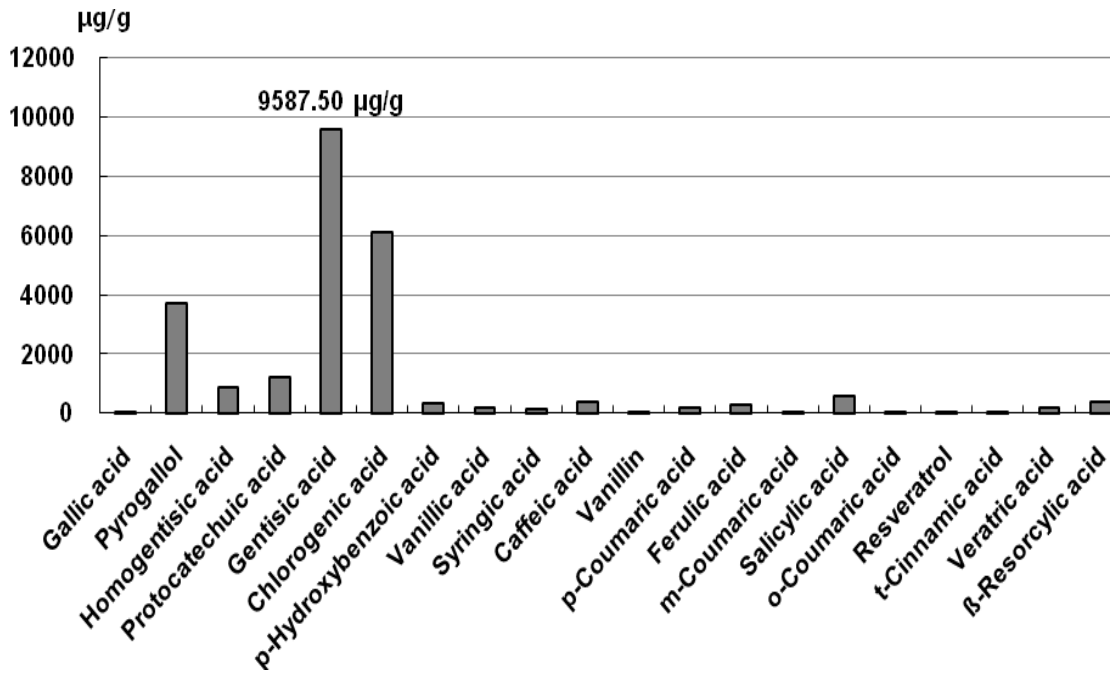

Figure 5. Comparison of 20 phenolic acids contents in leaves of *Quercus salicina* Blume.

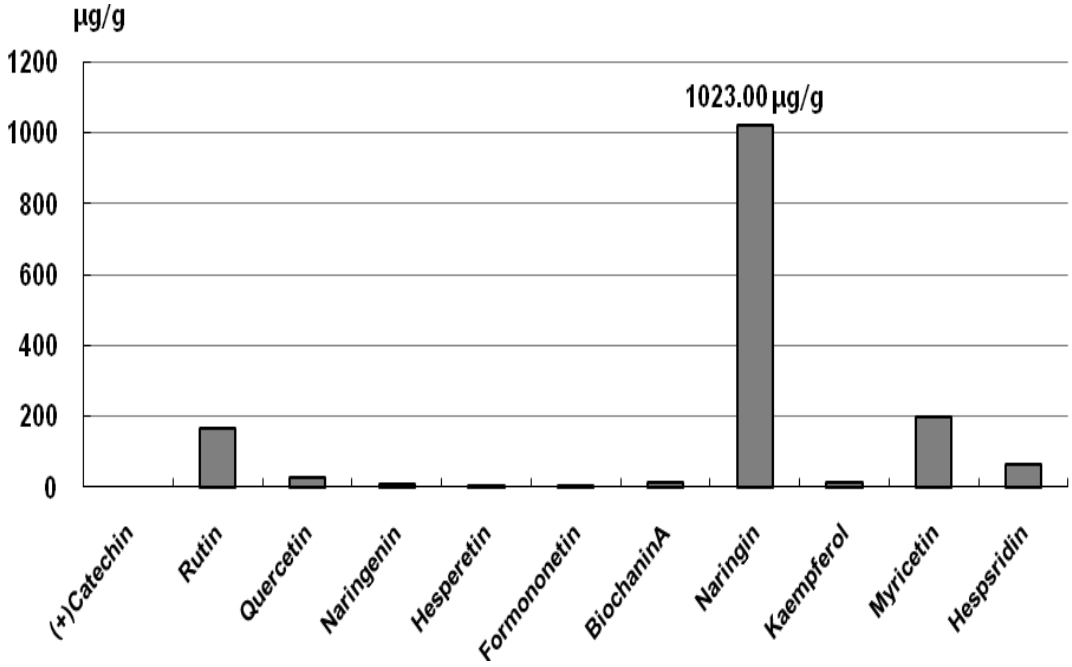

Figure 6. Comparison of 11 flavonoids contents in leaves of *Quercus salicina* Blume.

proven effects.

A previous study reported the antioxidative compounds of *Q. salicina* Blume shoot (Kim et al., 2008), but there have been no reports on the different functional substances such as phenolic acids and flavonoids. In this study, the total concentrations of phenolic compounds varied in leaf and shoot extract of *Q. salicina* Blume. Among 31 kinds of phenolic compounds, the shoots had higher content of

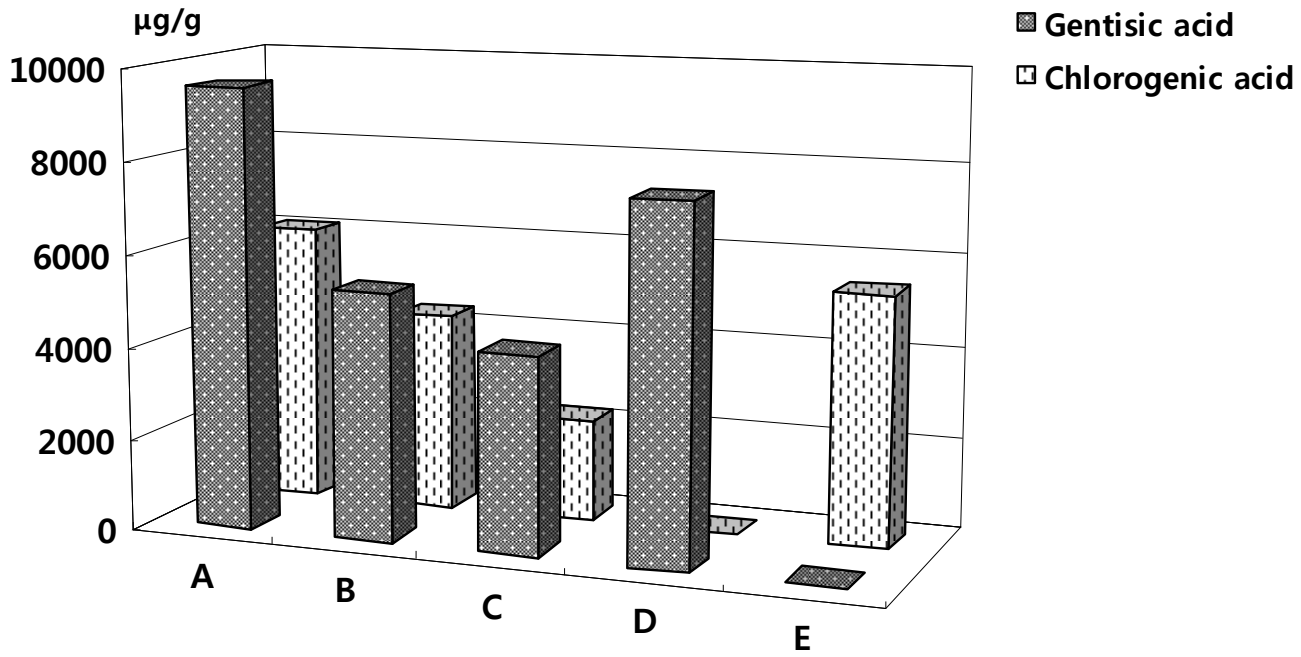

Figure 7. Variation between gentisic acid and chlorogenic acid in leaves of five *Quercus* species. A, *Quercus salicina* Blume; B, *Quercus acuta* Thunberg; C, *Quercus phillyraeoides* A. Gray; D, *Quercus glauca* Thunberg; E, *Quercus myrsinaefolia* Blume.

Table 3. Phenolic compounds content of the *Quercus* species.

Compounds	A	B	C	D	E	$LSD_{(0.05)}$
			(µg g^{-1})			
Phenolic acids						
Gallic acid	47.57	1.89	19.77	89.30	180.68	4.05
Pyrogallol	3708.30	692.70	590.10	2054.30	151.00	249.05
Homogentisic acid	856.48	91.71	281.65	ND	573.82	81.04
Protocatechuic acid	1199.60	122.30	126.80	393.00	483.40	88.07
Gentisic acid	9587.50	5370.00	4277.60	7647.90	ND	472.62
Chlorogenic acid	6081.11	4334.91	2207.93	ND	5419.26	75.68
ρ-Hydroxybenzoic acid	317.92	83.79	58.73	152.03	ND	8.44
Vanillic acid	197.04	102.86	98.02	278.42	144.90	7.86
Syringic acid	130.02	52.32	299.33	333.89	128.43	36.32
Caffeic acid	394.50	108.69	252.88	ND	77.97	127.46
Vanillin	12.06	7.27	ND	63.35	41.60	19.68
ρ-Coumaric acid	162.81	7.53	794.34	16.47	26.84	46.52
Ferulic acid	297.11	304.47	238.96	284.03	147.33	3.59
m-Coumaric acid	11.86	0.45	ND	ND	ND	1.12
Salicylic acid	553.11	2.84	297.40	94.73	36.22	59.86
o-Coumaric acid	16.08	5.65	ND	12.59	11.71	9.19
Resveratrol	35.27	2.01	7.71	2.95	5.60	48.67
t-Cinnamic acid	3.84	2.23	2.72	10.00	6.61	2.18
Veratric acid	166.31	25.95	16.53	88.32	17.22	2.57
ß-Resorcylic acid	403.26	124.42	240.11	256.75	264.25	138.52
Average	1209.09	572.20	490.53	588.90	385.84	
Flavonoids						
(+)-Catechin	ND	215.45	420.10	3134.69	884.68	24.25

Table 3. Cont.

Rutin	167.40	101.20	6524.50	659.50	163.50	319.49
Quercetin	26.00	ND	31.70	192.30	27.20	5.12
Naringenin	7.05	10.57	9.76	9.54	12.07	11.62
Hesperetin	5.05	0.90	0.49	0.26	2.63	7.57
Formononetin	2.37	2.45	4.39	5.01	5.06	1.63
Biochanin A	14.52	29.03	40.82	6.17	8.84	2.16
Naringin	1023.00	232.14	79.91	ND	120.75	2.29
Kaempferol	11.63	6.95	12.00	9.38	23.30	10.26
Myricetin	199.56	32.58	43.21	49.02	32.37	5.60
Hesperedin	63.85	26.53	11.42	132.49	9.70	23.81
Average	138.22	59.08	652.57	381.67	117.28	
TOTAL	25702.13	12101.75	16988.82	16003.35	9006.91	

A, *Quercus salicina* Blume; B, *Quercus acuta* Thunberg; C, *Quercus phillyraeoides* A. Gray; D, *Quercus glauca* Thunberg; E, *Quercus myrsinaefolia* Blume; ND, not detected.

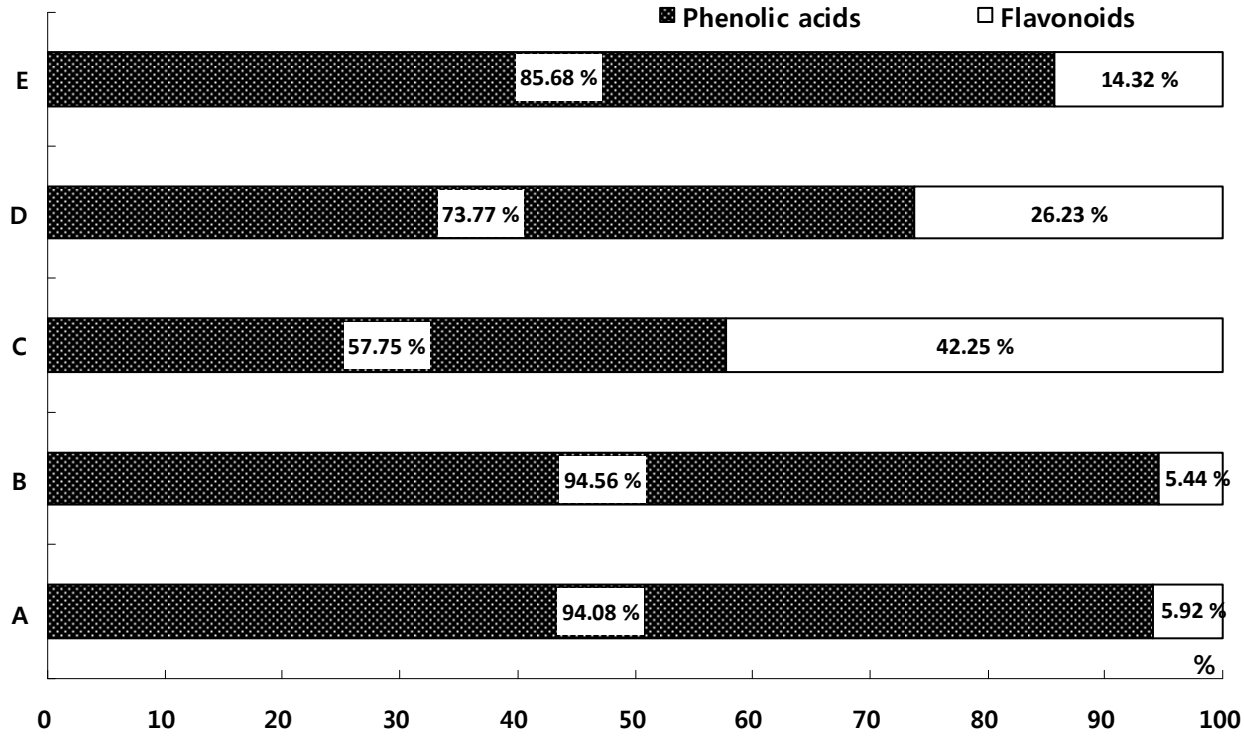

Figure 8. Proportions of phenolic acids and flavonoids in leaves of five *Quercus* species. A, *Quercus salicina* Blume; B, *Quercus acuta* Thunberg; C, *Quercus phillyraeoides* A. Gray; D, *Quercus glauca* Thunberg; E, *Quercus myrsinaefolia* Blume.

gallic acid and other 10 phenolic compounds (homogentisic acid, catechin, caffeic acid, vanillin, rutin, hesperedin, *o*-coumaric acid, myricetin, quercetin and formononetin) than leaves. On the other hand, *Q. salicina* Blume leaves were higher in 20 other phenolic compounds.

Thus, this study demonstrated differences in phenolic compounds content in different parts of plants. Several studies have also showed the presence of various phenolic compounds in different tissues of the leaf (Jahne et al., 1993; Weissenbock et al., 1986). Variation in phenolic compounds at different stages of maturity have been reported in *Quercus* species (Makkar et al., 1991). Moreover, seasonal variation of phenolic compounds composition of *Quercus* species has also been reported by Brossa et al. (2009).

In addition, we compared the amounts of phenolic compounds in leaf extracts from five *Quercus* species. The quantitative analyses of 31 phenolic compounds were done using HPLC. In this analyses, *Q. salicina* Blume leaves showed higher concentration of phenolic compounds than other *Quercus* species. Three *Quercus* species (*Q. salicina* Blume, *Q. acuta* Thunberg and *Q. phillyraeoides* A. Gray) showed higher gentisic acid than chlorogenic acid content. *Q. salicina* Blume leaf had the highest concentration of both gentisic acid and chlorogenic acid, while gentisic acid was not detected in *Q. myrsinaefolia* Blume, and chlorogenic acid was not detected in *Q. glauca* Thunberg. On the other hand, *Q. glauca* Thunberg contained the highest levels of vanillic acid, syringic acid, (+)-catechin, quercetin, and hesperedin.

The presence of major phenolic compounds such as catechin, epicatechin, gallocatechin, epigallocatechin, procyanidin B-4, catechin-3-O-rhamnoside, rutin, querglanin and isoquerglanin has been reported in *Q. glauca* (Sheu et al., 1997). A number of studies have demonstrated that the levels of individual and total flavonoids in food are influenced by genetic and environmental factors (Chu et al., 2000; Yarnes et al., 2006), excess photochemical energy (Close and McArthur 2002), microbes and pathogens (Latte and Kolodzeij, 2000).

In summary, the *Q. salicina* Blume leaf contained the highest concentration of phenolic compounds. Phenolic compounds have important anticancer and anti-aging properties.

In this study, we found differences between *Quercus* species in the amounts of different phenolic compounds. Overall, *Quercus* species are useful sources of anti-oxidants. Future studies are needed for the determination of various *Quercus* germplasms as useful folk medicines.

ACKNOWLEDGEMENT

This study was carried out with the support of 'Forest Science and Technology Projects (Project No. SI20909L080000)' provided by Korea Forest Service.

REFERENCES

Aaby K, Hvattum E, Skrede G (2004). Analysis of flavonoids and other phenolic compounds using high-performance liquid chromatography with colometric array detection: Relationship to antioxidant activity. J. Agric. Food Chem. 52:4595-4603.

Balasundram N, Sundram K, Samman S (2006). Phenolic compounds in plants and agri-industrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chem. 99:191-203.

Bravo L (1998). Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. Nutr. Rev. 56:317-333.

Brossa R, Casals I, Pintó-Marijuan M, Fleck I (2009). Leaf flavonoid content in *Quercus ilex* L. resprouts and its seasonal variation. Trees 23:401-408.

Cai Y, Luo Q, Sun M, Corke H (2004). Antioxidant activity and phenolic compounds of 112 traditional Chinese medicinal plants associated with anticancer. Life Sci. 74:2157-2184.

Christopher TY, William JB, Kati T, Juha-Pekka S (2006). Defining phytochemical phenotypes: size and shape analysis of phenolic compounds in oaks (Fagaceae, *Quercus*) of the Chihuahuan Desert. Can. J. Bot. 8:1233-1248.

Chu YH, Chang CL, Hsu HF (2000). Flavonoids content of several vegetables and their antioxidant activity. J. Sci. Food Agric. 80:561-566.

Close D, McArthur C (2002). Rethinking the role of many plant phenolics-protection from photodamage not herbivores. Oikos 99: 166-172.

Elliott M (2001). Cushing's disease: a new approach to theraphy in equine and canine patients. Br. Homeopathic J. 90:33-36.

Goun EA, Petrichenko VM, Solodnikov SU, Suhinina TV, Kline MA, Cunningham G, Nguyen C, Miles H (2002). Anticancer and antithrombin activity of Russian plants. J. Ethnopharmacol. 81:337-342.

Häkkinen SH, Kärenlampi SO, Heinonen IM, Mykkänen HM, Törrönen AR (1998). HPLC method for screening of flavonoids and phenolic acids in berries. J. Sci. Food Agric. 77:543-551.

Halliwell B, Gutteridge JMC (1998). In free radicals in biology and medicine; Oxford University Press Oxford.

Harbone JB, Baxter H, Moss GP (1999). Phytochemical dictionary: Handbook of bioactive compounds from plants. (2nd ed.). London: Taylor and Francis.

Heinonen M, Rein D, Satue-Gracia MT, Huang SW, German JB, Frankel EN (1998). Effect of protein on the antioxidant activity of phenolic compounds in a lecithin-liposome oxidation system. J. Agric. Food Chem. 46:917-922.

Hopia A, Heinonen M (1999). Antioxidant activity of flavonolaglycones and their glycoside in methyl linolate. J. Am. Oil Chem. Soc. 76:139-144.

Jahne A, Fritzen C, Weissenbock G (1993). Chalcone synthase and flavonoid products in primary-leaf tissues of rye and maize. Planta 189:39-46.

Kaarina V, Riitta K, Marina H (2004). Protein-Lipid interactions during liposome oxidation with added anthocyanin other phenolic compounds. J. Agric. Food Chem. 52:1104-1111.

Kähkönen MP, Heinonen M (2003). Antioxidant activity of anthocyanins and their aglycones. J. Agric. Food Chem. 51:628-633.

Kähkönen MP, Hopia AI, Vuorela HJ, Rauha JP, Pihlaja K, Kujala TS, Heinonen M (1999). Antioxidant activity of plant extracts containing phenolic compounds. J. Agric. Food Chem. 47:3954-3962.

Katalinic V, Milos M, Kulisic T, Jukic M (2006). Screening of 70 medicinal plant extracts for antioxidant capacity and total phenols. Food Chem. 94:550-557.

Kawaii S, Tomono Y, Katase E, Ogawa K, Yano M (1999). Quantitation of flavonoids constituents in *Citrus* fruits. J. Agric. Food Chem. 47: 3565-3571.

Kim EH, Kim SH, Chung JI, Chi HY, Kim JA, Chung IM (2006). Analysis of phenolic compounds and isoflavones in soybean seeds [*Glycine max* (L.) Merill] and sprouts under different conditions. Eur. Food Res. Technol. 222:201-208.

Kim JI, Kim HY, Kim SG, Lee KT, Ham IH, Whang WK (2008). Antioxidant compounds from *Quercus salicina* Blume stem. Arch. Pharm. Res. 31:274-278.

Latte KP, Kolodzeij H (2000). Antifungal effects of hydrolysable tannins and related compounds on dermatophytes, mould, fungi, and yeasts. PMID: 10928561. Z. Naturforsch. 55:467-472.

Makkar HPS, Dawra RK, Singh B (1991). Tannin levels in leaves of some oak species at different stages of maturity. J. Sci. Food Agric. 54:513-519.

Middleton E, Kandaswami C, Theoharides TC (2000). The effects of plant flavonoids on mammalian cells: implications for inflammation, heart disease and cancer. Pharmacol. Rev. 52:673-751.

Pietta PG (2000). Flavonoids as antioxidants. J. Nat. Prod. 63:1035-1042.

Randhir R, Shetty K (2005). Developmental stimulation of total phenolics and related antioxidant activity in light- and dark-germinated corn by natural elicitors.Proc. Biochem. 40:1721-1732.

Redwane A, Lazrek HB, Bouallam S, Markoik M, Amarouch H, Jane M (2002). Larvicidal activity of extracts from *Quercus Lusitania* var.

infectioria galls (Oliv). J. Ethnopharmacol. 79:261-263.
Sheu S, Yang-Hwei T, Feng-Lin H, Fung-Jou L, Hsuch-Ching C (1997). Superoxide anion scavenge effect of *Quercus glauca* Thunb. in whole blood of patients with ankylosing spondylitis. Am. J. Chinese Med. (AJCM) 25:307-315.
Walters D, Meurer-Grimes B, Rovira I (2001). Antifungal activity of three spermidine conjugates. FEMS Microbiol. Lett. 201:255-258.
Wei H, Tye L, Brensnick E, Birt DF (1990). Inhibitory effect of apigenin, a plant flavonoid, on epidermal ornithine decarboxylase and skin tumor promotion in mice. Cancer Res. 50:499-506.
Weissenbock G, Hedrich R, Sachs G (1986). Secondary phenolic products in isolated guard cell, epidermal cell and mesophyll cell protoplasts from pea (*Pisum sativum* L.) leaves: distribution and determination. Protoplasma 134:141-148.