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RESEARCH NOTE

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Analysis of Aroma Components from *Zanthoxylum*

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Abstract *Zanthoxylum schinifolium* and *Zanthoxylum piperitum* A.P. DC. belong to the Rutaceae family and are perennial, aromatic, and medicinal herbaceous plants. In this study, their aroma compounds were isolated by steam distillation extraction using a Clevenger-type apparatus, and then further analyzed by gas chromatography (GC) and gas chromatograph/mass spectrometry (GC/MS). The yields of the essential oils from *Z. schinifolium* and *Z. piperitum* A.P. DC. were 2.5 and 2.0%(w/w), respectively, and the color of their oils was quite similar, a pale yellow. From the distilled oil of *Z. schinifolium*, 60 volatile compounds which make up 87.24% of the total composition were tentatively identified, with monoterpenes predominating. β-Phellandrene (22.54%), citronellal (16.48%), and geranyl acetate (11.39%) were the predominantly abundant components of *Z. schinifolium*. In the essential oil of *Z. piperitum* A.P. DC., 60 volatile flavor components constituted 94.78% of the total peak area were tentatively characterized. Limonene (18.04%), geranyl acetate (15.33%), and cryptone (8.52%) were the major volatile flavor compounds of *Z. piperitum* A.P. DC.

Keywords: *Zanthoxylum schinifolium*, *Zanthoxylum piperitum* A.P. DC., Rutaceae, aroma compound

Introduction

Zanthoxylum is a member of the Rutaceae family, and *Zanthoxylum schinifolium* and *Zanthoxylum piperitum* A.P. DC. are two representative species of *Zanthoxylum* found in Korea (1,2). *Z. schinifolium* and *Z. piperitum* A.P. DC. generally bloom from April to August, with light greenish yellow-colored flowers, and each bears fruit and black colored seeds from October to early November. *Z. schinifolium* and *Z. piperitum* A.P. DC. are widely used as spices to mask fishy and meaty odors, and have also been used for medicinal purposes. Since ancient times, these plants have been employed as folk medicines in Korea and other East Asian countries, including China, Taiwan, and Japan, for the treatment of neurological problems, headache, hypotension, anti-inflammatory diseases, ulcers, and stomach problems (3-5). Furthermore, it was recently reported that *Z. schinifolium* has anti-HBV DNA replication, anti-platelet aggregation, and monoamine oxidase inhibitory activities; and the essential oil of *Z. piperitum* A.P. DC. possesses antioxidative and 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical-scavenging activity (4-6). The essential aromatic oils of plants are a complex mixture of volatile flavor compounds consisting of terpenes and their oxygenated derivatives such as alcohols, aldehydes, esters, ethers, ketones, phenols, and oxides, and may possess antioxidant, antimicrobial, and anti-inflammatory activities (7-9). Studies that analyzed the essential oils of *Zanthoxylum* have been reported by several researchers (10-13). There are various extraction methods for essential plant oils, such as simultaneous steam distillation extraction (SDE), hydro-distillation, the headspace method, etc. SDE is a useful method for extracting abundant volatile flavor components; however it has several limitations such as using an organic solvent, boiling off-flavor, and a long experimental time. Recently, headspace solid phase micro extraction (HS-SPME) has been substituted in place of SDE for plant aroma compound analysis; however, it has limitations for cell experiments and is difficult when testing bioactivity. In this study, a modified SDE method was implemented that did not use an organic solvent capable of contaminating the plant aroma. The aim of this study was to compare the chemical variability of essential oils from *Zanthoxylum* species produced in Korea, and to perform additional studies on them.

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Material and Methods

Plant materials *Z. schinifolium* and *Z. piperitum* A.P. DC. were purchased at Gyungdong herbal market (Seoul, Korea) in the spring of 2007. These plants had been harvested in the fall of 2006 from Namwon (Jeonbuk) province in western Korea and Youngju (Gyeongbuk) province in eastern Korea, respectively. The samples were kept at −70°C in airtight bags until analysis was carried out.

Isolation of essential oils The dried *Z. schinifolium* and *Z. piperitum* A.P. DC. were crushed for 10 sec using a blender (HMC-400T; Hanil Electronics, Seoul, Korea), and 1 kg samples were extracted by steam distillation for 3 hr using a Clevenger-type apparatus (Hanil Lab Tech Ltd., Incheon, Korea). The obtained essential oils were dried over anhydrous sodium sulfate overnight, measured, and stored in hermetically sealed dark glass containers in a freezer at −4°C until they were tested and analyzed by GC and GC/MS.

Gas chromatograph (GC) analysis GC analysis was performed using a Hewlett-Packard 6890 (Agilent Technologies, Palo Alto, CA, USA) gas chromatographer equipped with a flame ionization detector (FID), along with an HP-5MS capillary column (30 m length×0.25 mm i.d.×0.25 μm film thickness; Agilent Co.) and micro syringe. Nitrogen was used as a carrier gas at a flow rate of 1.0 mL/min. The oven temperature was maintained at 40°C for 5 min and then programmed to increased as follows: from 40 to 150°C at a rate of 3°C/min, and holding at 150°C for 5 min; and then from 150 to 220°C at a rate of 7°C/min, and holding at 220°C for 5 min. The temperatures of the injector and detector were 250 and 280°C, respectively. A 10^{-1} μL sample, previously dissolved in methylene chloride, was injected in split mode with a split ratio of 10:1.

GC-mass spectrometry (MS) analysis An Agilent 6890 gas chromatograph/5973 mass selective detector (Agilent Co.) was employed. The same conditions, capillary column, and programmed temperatures as used in the GC-FID technique were employed. Helium was used as a carrier gas at a flow rate of 1.0 mL/min. The MS conditions were as follows: ionization energy of 70 eV for the mass selective detector, scanning interval of 0.5 sec, and a detector voltage of 1.2 kV. The mass scanning range was recorded at *m/z* 33-330.

Identification of chemical compounds The volatile flavor components were identified by comparing the mass spectra with those from an online computer library (Wiley 275: Agilent Co.). Alkanes were used as reference points in the calculation of relative retention indices (RI). The RIs were experimentally determined using the standard method involving the retention times of an *n*-alkane series [alkane standard solution (04070, 04071), (C_8-$C_{20,}$ $C_{21\text{-}40}$), standard for GC, Fluka, Buchs, Switzerland] injected after the essential oil under the same chromatographic conditions. The RIs of the compounds, determined using C_8-C_{22} as external references (14), were compared with published data (15,16). Several compounds identified with those in the literature (17-19). The relative amounts of individual components from the oils are expressed as the peak area % relative to the total peak area based on the ratio of the peaks obtained from the mass total ion chromatogram, and also the marked quality percentages of the identified volatile flavor compounds from the MS data.

Results and Discussion

The list of detected compounds in the steam distilled oils of *Z. schinifolium* and *Z. piperitum* A.P. DC. are given in Table 1 and 2, presenting their retention times, retention indices, relative peak area percentages, quality percentages, and percentage amounts for each compound class. Some composition differences were observed in the essential oils of the 2 Korean *Zanthoxylum* species.

Volatile compounds in *Z. schinifolium* The yield of the essential oil from *Z. schinifolium* was 2.5%(w/w) (25 g of the oil/1 kg of the materials, d.w.), and the color of the oil was pale yellow. As shown in Table 1 and 2, 60 volatile flavor compounds were tentatively identified from the essential oil of *Z. schinifolium*, consisting of 41 terpenes, 4 hydrocarbons, 2 alcohols, 5 aldehydes, 5 ketones, 1 ester, and 2 carboxylic acids. There were 41 terpene compounds (79.53%, more than in *Z. piperitum* A.P. DC) in the *Z. schinifolium* oil with 29 monotperpenes [α-pinene, sabinene, β-myrcene, α-phellandrene, β-phellandrene, *(E)*-β-ocimene, γ-terpinene, *cis*-linlool oxide, linalool, α-terpinolene, *cis*-sabinene hydrate, terpinen-1-ol, isopulegol, citronellal, β-thujone, terpinen-4-ol, β-fenchyl alcohol, terpinen-3-ol, *cis*-piperitol, citronellol, linalyl acetate, geraniol, geranial, cuminol, α-terpinyl acetate, citronellyl acetate, cinnamyl acetate, geranic acid, and geranyl acetate (77.58%)], and 12 sesquiterpenes [β-caryophyllene, germacrene-D, α-curcumene, caryophyllene oxide, α-muurolene, γ-cadinene, δ-cadinene, calacornene, spathulenol, γ-muurolene, T-muurolol, and farnesyl acetate (1.95%)]. Among them, β-phellandrene was the most abundant volatile flavor compound in the *Z. schinifolium* oil, comprising 22.54%, and is responsible for its peppery mint flavor (20). β-Myrcene (7.73% in *Z. schinifolium* and 2.87% in *Z. piperitum* A.P. DC, respectively) is reported to have antioxidant activity by the DPPH method, as well as hypoglycemic activity (21). There were 2 alcohol compounds (1.19%) in the *Z. schinifolium* oil, consisting of 2,6-dimethyl-1-hepten-4-ol and 1-undecanol. Geraniol, a monoterpenic alcohol compound, is generated from geranyl acetate by geranyl acetate esterase and is reported to possess *in vitro* and *in vivo* anti-tumor activities (22). Isopulegol, also a monoterpenic alcohol, is widely used in the flavor industry to produce fragrances with blossom notes, and is an important ingredient in various pharmaceuticals. It was reported that isopulegol can be obtained from citronellal through cyclization (23). There were 5 aldehydes compounds (0.88%, more than in *Z. piperitum* A.P. DC.) in the *Z. schinifolium* oil, including hexanal, heptanal, phenylacetaldehyde, 2,6-dimethyl-5-haptanal, and decanal, as well as 5 ketone compounds (3.78%), consisting of 2-heptanone, cryptone, piperitone, 2,4-ditert-butylquinone, and cyclododecanone. Also detected by GC and GC/MS were 2 carboxylic acids (1.81%, more than in *Z. piperitum* A.P. DC.), with octanoic acid and nonanoic acid, and 1 ester (methyl palmitate, 0.54%). The 3 major constituents (>10%) identified were β-phellandrene (22.54%), citronellal (16.48%), and geranyl acetate (11.39%), followed by β-myrcene (7.73%), citronellyl acetate (3.07%), and citronellol (2.55%). β-Phellandrene, the major volatile flavor compound in the *Z. schinifolium* essential oil, has also been found in the essential oil of aerial parts from *Stachys lavandulifolia* Vahl. produced in Iran (21.96%) (24). Furthermore, it was evaluated as having antimicrobial, antioxidant, and hypoglycemic activities (25). The second most abundant compound, citronellal, was described in one report as having citrus, cucumber, and fatty flavors (20). This volatile flavor compound was also present in the red bud borer, *Resseliella oculiperda,* from grafted apple trees (26), and was reported to have an antimicrobial effect on airborne microbes in a study using an airwasher (27). It is noteworthy that the major abundant compounds in *Z. schinifolium* essential oil (β-phellandrene, 22.54% and citronellal, 16.48%) would be useful and beneficial materials for industrial and medicinal purposes due to their physicochemical and biofunctional properties.

Volatile compounds in *Z. piperitum* A.P. DC. The yield of the essential oil from *Z. piperitum* A.P. DC. was 2.0%(w/w) (20 g of the oil/1 kg of the materials, d.w.), and its color was pale yellow. As shown in Table 1 and 2, 60

Table 1. Volatile flavor compounds in *Zanthoxylum*

Compounds	RT[1]	RI[2]	PA%[3]	PA%[4]	QA%[5]	QA%[6]	Method of ID[7]
Hexanal	06.70	0800	0.25	0.06	86	83	A,B,C
3-Methylcyclopentanol	06.79	0836	-	0.01	-	91	A,B
2-Heptanone	08.27	0870	0.01	0.01	83	87	A,B,C[b)]
Heptanal	08.57	0899	0.07	0.04	87	87	A,B,C
α-Thujene	09.65	0927	-	0.09	-	94	A,B
α-Pinene	09.91	0935	0.20	0.15	96	96	A,B,C
Benzaldehyde	11.30	0959	-	0.04	-	94	A,B
Sabinene	11.96	0973	0.55	-	97	-	A,B,C
β-Pinene	11.99	0978	-	0.26	-	95	A,B,C[a)]
β-Myrcene	13.28	0988	7.73	2.87	96	96	A,B,C
α-Phellandrene	13.76	1,001	0.55	0.47	93	91	A,B,C
Octanal	14.02	1,005	-	0.06	-	90	A,B,C
α-Terpinene	14.21	1,017	-	0.08	-	98	A,B,C[b)]
Limonene	15.39	1,030	-	18.04	-	99	A,B,C*
β-Phellandrene	15.52	1,032	22.54	-	94	-	A,B,C
Phenylacetaldehyde	16.04	1,034	0.04	-	80	-	A,B,C
(*E*)-β-Ocimene	16.35	1,049	0.11	0.08	96	96	A,B,C
2,6-Dimethyl-5-heptenal	16.50	1,054	0.27	0.20	95	97	A,B
γ-Terpinene	16.61	1,058	0.13	0.16	97	97	A,B,C*
3,8-Menthadiene	16.98	1,062	-	0.02	-	97	A,B
cis Linalool oxide	17.25	1,070	0.09	0.39	90	91	A,B,C
α-Terpinolene	18.02	1,087	1.27	-	98	-	A,B,C
2,6-Dimethyl-1-hepten-4-ol	18.26	1,090	0.09	-	62	-	A,B
Perillene	18.63	1,097	-	0.32	-	59	A,B
Linalool	18.79	1,101	2.52	1.44	97	94	A,B,C
Rose oxide	19.14	1,110	-	1.50	-	93	A,B
cis-Sabinen hydrate	19.61	1,116	0.18	-	90	-	A,B,C[a)]
cis-Rose oxide	19.87	1,118	-	0.37	-	76	A,B,C[a)]
Terpinen-1-ol	19.92	1,121	0.73	-	78	-	A,B
(E)-Limonene oxide	20.32	1,124	-	0.25	-	69	A,B,C
Dehydro *p*-cymene	20.56	1,128	-	0.53	-	64	A,B
Isopuegol	21.08	1,140	0.90	1.58	72	97	A,B,C[b)]
Citronellal	22.15	1,150	16.48	7.08	98	98	A,B,C[c)]
β-Thujone	22.53	1,167	0.12	-	68	-	A,B,C
Terpinen-4-ol	22.62	1,180	0.37	0.52	93	83	A,B,C*
Cryptone	23.23	1,190	2.20	8.51	69	69	A,B,C
β-Fenchyl alcohol	23.35	1,194	0.74	-	76	-	A,B
Estragole	23.56	1,196	0.11	-	91	-	A,B,C*
Terpinen-3-ol	23.75	1,198	0.63	-	78	-	A,B
(E)-Dehydrocarvone	23.78	1,207	-	0.83	-	99	A,B,C[b)]
Decanal	23.93	1,210	0.25	-	87	-	A,B,C
Neral	24.31	1,215	-	0.08	-	59	A,B
cis-Piperitol	24.42	1,218	0.41	-	75	-	A,B
Octanoic acid	25.15	1,225	0.40	-	78	-	A,B
Cuminal	25.34	1,230	-	6.21	-	95	A,B
Citronellol	25.51	1,235	2.55	1.17	86	83	A,B,C[c)]
Piperitone	26.09	1,250	1.17	4.43	96	96	A,B
Linalyl acetate	26.26	1,253	0.44	-	80	-	A,B,C[c)]
1-Undecanol	26.54	1,255	0.36	-	89	-	A,B,C
Geraniol	26.65	1,258	0.43	2.36	94	94	A,B,C
Phellandral	27.24	1,270	-	5.21	-	94	A,B
Chrysanthenone	27.52	1,274	-	1.81	-	78	A,B
2-Hydroxy piperitone	28.10	1,280	-	0.46	-	86	A,B

Table 1. Continued

Compounds	RT[1)]	RI[2)]	PA%[3)]	PA%[4)]	QA%[5)]	QA%[6)]	Method of ID[7)]
Geranial	28.38	1,285	1.23	0.83	89	86	A,B,C[b)]
Cuminol	28.75	1,292	1.62	3.18	97	95	A,B,C
Nonanoic acid	29.19	1,298	1.41	0.42	80	93	A,B,C
α-Terpinyl acetate	30.22	1,336	0.47	0.81	91	91	A,B
Citronellyl acetate	30.74	1,354	3.07	3.18	91	95	A,B,C[b)]
Geranic acid	31.66	1,360	0.02	-	60	-	A,B
Geranyl acetate	32.52	1,386	11.39	15.33	91	91	A,B,C[a)]
cis-Geranyl acetate	32.93	1,426	-	0.08	-	59	A,B
β-Caryophyllene	33.10	1,430	0.45	0.03	99	90	A,B,C
Cinnamyl acetate	33.43	1,439	0.11	0.05	95	95	A,B
α-Humulene	34.52	1,450	-	0.04	-	69	A,B,C
2,4-Ditert-butylquinone	35.11	1,471	0.37	-	93	-	A,B,C
3-Dodecyne	35.20	1,473	0.04	-	78	-	A,B
Cyclododecanone	35.33	1,477	0.03	-	58	-	A,B
Germacrene D	35.59	1,486	0.11	-	97	-	A,B,C
α-Curcumene	35.76	1492	0.06	0.04	69	81	A,B
α-Campholene aldehyde	35.87	1,498	-	0.08	-	64	A,B
α-Muurolene	36.40	1,501	0.06	-	95	-	A,B,C[a)]
γ-Cadinene	36.90	1,525	0.22	-	95	-	A,B,C[b)]
δ-Cadinene	37.31	1,530	0.17	0.08	97	98	A,B,C
Calacorene	38.03	1,547	0.04	0.04	59	69	A,B,C
Neroloidol	39.25	1,560	-	0.02	-	69	A,B
Spathulenol	39.42	1,578	0.06	0.03	78	91	A,B,C
Caryophyllene oxide	39.51	1,590	0.09	0.09	99	95	A,B,C
γ-Muurolene	41.00	1,600	0.03	-	91	-	A,B
Calarene	41.38	1,635	-	0.04	-	83	A,B
T-muurolol	41.70	1,650	0.16	0.03	90	90	A,B,C[b)]
8-Heptadecene	43.29	1,677	0.02	-	96	-	A,B,C
Heptadecane	44.41	1,700	0.08	-	83	-	A,B,C
Farnesyl acetate	50.43	1,767	0.50	-	98	-	A,B
Methyl palmitate	53.56	1,881	0.54	0.50	98	98	A,B
Hexadecanoic acid	54.16	1,898	-	0.54	-	85	A,B,C
2-Nonadecene	54.52	1,900	-	1.10	-	69	A,B,C
Oleic acid methyl ester	55.76	1,995	-	0.34	-	94	A,B

[1)]Retention time.
[2)]Retention indices were determined using *n*-alkanes (C_8-C_{22}) as external references.
[3)]PA is peak area %; average of the relative percentage of the peak area in the MS total ion chromatogram (n=3) from *Z. schinifolium* oil.
[4)]Average of the relative percentage of the peak area in the MS total ion chromatogram (n=3) from *Z. piperitum* A.P. DC. oil.
[5)]QA means quality % of the MS data (n=3) from *Z. schinifolium* oil.
[6)]Quality % of the MS data (n=3) from *Z. piperitum* A.P. DC. oil.
[7)]Method of identification based on reference no.15, 16. A, retention time; B, tentative identification index was performed as follows: mass spectrum was identical to that of Wiley mass spectral database (2001, Hewlett Packard Co., Palo Alto, CA, USA): MS, mass spectrum was consistent to that of Wiley mass spectrum database; C, retention index was consistent with that in the literature. [a)]Identification based on reference no.17; [b)] Identification based on reference no.18; [c)] Identification based on reference no.19; *Identification based on co-injection with authentic compounds (Acros, Sigma-Aldrich, St. Louis, MO, USA).

volatile flavor compounds were tentatively characterized from the essential oil of *Z. piperitum* A.P. DC., consisting of 43 terpenes, 1 hydrocarbon, 1 alcohol, 6 aldehydes, 2 esters, 5 ketones, and 2 carboxylic acids (28). There were 43 terpene compounds (77.15%), with 33 monotperpenes [α-thujene, α-pinene, β-pinene, β-myrcene, α-phellandrene, α-terpinene, limonene, *(E)*-β-ocimene, γ-terpinene, 3,8-menthadiene, *cis*-linlool oxide, perillene, linalool, rose oxide, *cis*-rose oxide, *(E)*-limonene oxide, dehydro-*p*-cymene, isopulegol, citronellal, terpinen-4-ol, neral, cuminal, citronellol, geraniol, phellandral, chrysanthenone, geranial, cuminol, α-terpinyl acetate, citronellyl acetate, geranyl acetate, cinnamyl acetate, and *cis*-geranyl acetate (76.71%)], and 10 sesquiterpenes [β-caryophyllene, humulene, α-curcumene, δ-cadinene, calacornene, nerolidol, spathulenol, caryophyllene oxide, calarene, and T-muurolol (0.44%)]. Among them, limonene (18.04%) was the most abundant compound, this compound also detected against *Aedes aegypt* (37.99%), and repellent activity has been reported (29). And this volatile compound also studied antimicrobial

Table 2. Relative constitution of *Zanthoxylum* by functional group

Functional group	No. of peak		% peak area[1)]	
	I[2)]	II[3)]	I[2)]	II[3)]
Terpene	41	43	79.53	77.15
Hydrocarbon	4	1	0.25	1.10
Aldehyde	5	6	0.88	0.48
Ester	1	2	0.54	0.84
Alcohol	2	1	0.45	0.01
Ketone	5	5	3.78	14.24
Acid	2	2	1.81	0.96
Total	60	60	87.24	94.78

[1)]Average (n=3) of the relative percentage of the peak area in the MS total ion chromatogram.
[2)]Essential oil of *Z. schinifolium* by steam distillation-GC and GC/MS.
[3)]Essential oil of *Z. piperitum* A.P. DC. by steam distillation-GC and GC/MS.

activities and physicochemical properties of the essential oil from *Amomum subulatum*. In addition, limonene has reported to have hypoglycemic, antimicrobial, and antioxidant activities (30). As the most abundant component in *Z. piperitum* A.P. DC., limonene's several bioactivities and physicofunctional properties would make the essential oil a beneficial, highly valuable, and worthy compound for industrial and medicinal purposes. There was 1 alcohol compound in the *Z. piperitum* A.P. DC. oil, 3-methylcyclopentanol (0.01%). And there were 2 esters compounds (0.84%, more than in *Z. schinifolium*), consisting of methyl palmitate and oleic acid methyl ester, and 6 aldehydes (0.48%), including hexanal, heptanal, benzealdehyde, octanal, 2,6-dimethyl-5-haptanal, and α-campholene aldehyde. In addition, there were 5 ketone compounds (14.24%, approximately 4 times more than in the *Z. schinifolium* oil), with 2-heptanone, cryptone, piperitone, *(E)*-dihydrocarvone, and 2-hydroxy piperitone. Among them, piperitone was described as powerful fresh-minty-camphoraceous odor and used in spice with caraway and estragon (20). Also detected by GC and GC/MS were 2 carboxylic acids (0.96%) (nonanoic acid and hexadecanoic acid). The 2 major identified constituents (>10%) were limonene (18.04%) and geranyl acetate (15.33%), followed by cryptone (8.51%), citronellal (7.08%), cuminal (6.21%), and phellandral (5.21%) (>5%).

The common constituents (>5%) in the essential oils of *Z. schinifolium* and *Z. piperitum* A.P. DC. were citronellal (16.48, 7.08%), geranyl acetate (11.39, 15.33%), respectively. *Z. schinifolium* also presented substantial amounts of β-phellandrene (22.54%) and citronellal (16.48%); whereas *Z. piperitum* A.P. DC. was dominated by high concentrations of limonene (18.04%) and geranyl acetate (15.30%). Limonene, the predominant volatile compound in *Z. piperitum* A.P. DC., was not found in *Z. schinifolium*; and β-phellandrene, the predominant volatile compound in *Z. schinifolium*, was not detected in *Z. piperitum* A.P. DC. However, geranyl acetate was found as the common abundant and predominant volatile flavor compound in both species. The essential oils of *Zanthoxylum* species can decrease cell viability, and one major component, geranyl acetate, possessed antitumor activity against Hep G2 human hepatoma cells by inducing apoptosis (22). This compound was found to be abundant in both of the *Zanthoxylum* species, and is described as having a sweet rose aroma (20). The essential oils of Korean *Zanthoxylum* species have been studied by several researchers, and the most predominant compounds in *Z. schinifolium* and *Z. piperitum* A.P. DC were 1,8-cineol, limonene, and geranyl acetate, respectively (10-13). However, some differences occurred in the present study, where the 3 dominant compounds in *Z. schinifolium* and *Z. piperitum* A.P. DC were β-phellandrene (22.54%), citronellal (16.48%), and geranyl acetate (11.39%); and limonene (18.04%), geranyl acetate (15.33%), and crypton (8.52%), respectively. The variation in the volatile flavor compounds found in these Korean *Zanthoxylum* species may be attributed to their region or area of production, season, extraction method, or the storage conditions of samples. In conclusion, these plants have many common volatile flavor compounds. In particular, the common constituents (>1%) of both essential oils were β-myrcene, linalool, citronellal, cryptone, citronellol, piperitone, cuminol, geranyl acetate, and citronellyl acetate. However, their predominant volatile aroma compounds were different. β-Phellandrene was the major abundant compound in *Z. schinifolium*, whereas limonene was the major volatile component in *Z. piperitum* A.P. DC.

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