J. Plant Biol. 40 (4) : 267~274 (1997)

Variation of Monoterpenoids in *Artemisia feddei* and *Artemisia scoparia*

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The composition and concentration of monoterpenoids in the leaves and stems of *Artemisia feddei* and *Artemisia scoparia* were determined, and seasonal variation in the monoterpenoids of *Artemisia* species were investigated. The two species possessed different compositions and concentrations of monoterpenoids. The total amount of monoterpenoid in *A. scoparia* was always higher than that of *A. feddei*, and the monoterpenoid yields of leaves were higher than stem yields in both species as compounds formed. The major constituents of *A. scoparia* were 25 while *A. feddei* consisted of 26 compounds. Sixteen common monoterpenoid compounds were found in both plants. Large differences in the relative amounts of the monoterpenoids were found between species and seasons. Extremely large differences in the relative amounts of naphtalene, sabinene, β-pinene, cyclohexene, and octatrine were found in the leaf monoterpenoids of the two species. The largest differences in relative amounts of stem monoterpenoids were in s abinene and β-pinene levels.

Keywords: monoterpenoid, *Artemisia scoparia, Artemisia feddei*, Sabinene, β-pinene

Among all of the terpenoids, mixtures of volatile monoterpenoids and sesquiterpenoids (called essential oils, which are found in high levels in plants) are being increasingly implicated in plant-pest interactions (Edwards *et al.*, 1993). Essential oils have well-known insect repellent properties apart from their commercial value. Many monoterpenoids and their derivatives are especially important as agents of insect toxicity (Mattson *et al.*, 1988; Croteau, 1981) and allelochemicals (Kil *et al.*, 1991).

Terpenoids play an important role in the complex interactions within the ecosystem. Mixtures of volatile monoterpenoids lend a characteristic odor to plant foliage. Plant terpenoids have been widely used in taxonomic (Williams *et al.*, 1995), phylogenic (Harbone and Turner, 1984), microbial (White, 1986) and ecological (Langenheim, 1994; Kim and Langenheim, 1994) studies.

Beginning in the late 1960s, many secondary products were shown to have important ecological functions in plants (Harbone, 1982). Among these chief functions is protection against herbivore and infection by microbes. More important terpenoids have been shown to serve as attractants for pollinators and fruit-dispersing animals and as agents of plant-plant competition.

The genus *Artemisia* has been the object of numerous chemical studies (Marco *et al.*, 1994a, 1994b; Yasphe *et al.*, 1987; Kim, 1996; Kil *et al.*, 1991). There are large amounts of monoterpenoids and their derivates in *Artemisia* species (Ahmad and Misra, 1994). Large variations in the amounts of the constituents were found to due to plant age (Langenheim *et al.*, 1986), season (Nerg *et al.*, 1994), and in comparision of tissues of individuals (Kristina *et al.*, 1996). A previous study of *A. princeps* var. *orientalis* (Kim, 1996) indicated that there were marked qualitative and quantitative differences between plant parts and seasons, the monoterpenoid yields were more variable than monoterpenoid compositions in terms of seasonal variation.

Artemisia plants are widespread. 26 species occur in Korea. Most *Artemisia* plants have been used in traditional biomedicine for intestinal bacteria, as food, and for many other purposes in Korea. In spite of this, little is known about the amount or constituents of seasonal variation within and between the *Artemisia* species in Korea. Li *et al.* (1995) reported the phenotypic and ontogenetic variations in volatile leaf oils between and within the 12 species from the informal subgenus *Monocalytrus* in Tasmania. Many

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studies (Espinosa *et al.*, 1991; Rafii *et al.*, 1996; Barton *et al.*, 1991) have suggested that volatile terpenoids have been used as chemical indicators to classify terpenoid containing plants. The objective of this study is to identify and quantify monoterpenoids, to evaluate seasonal varitaion, and to find the interspecific differences of monoterpenoids between *A. scoparia* and *A. feddei.*

MATERIALS AND METHODS

A. scoparia and *A. feddei* were collected from five different sites at Mt. Muhak during their maturing periods at approximately one week intervals. Samples were sealed in plastic bags and trasported to the laboratory. Plants were separated into leaf and stem, and three grams of subsamples were immediately ground with pure sand and extracted with n-pentane and one ml, 1% tetradecane as an internal standard. The pentanes were steam distilled three times, using a glass distillation unit for 6 hours, which was used for all chemical analyses to increase the purification. Plant extracts were filtered with sodium sulfate and concentrated by evaporation with a gentle stream of nitrogen gas.

Samples were analysed by gas chromatography-mass spectrometry (Hewlett Packard 5890) using a 30 m long HP5 (i.d. 0.25 mm, a flame ionization detector) capillary column. Helium gas was used as the carrier gas. The temperature program for terpenoids was initially 37°C for five minutes, increased to 180°C at a rate of 5°C min^{-1}, then by 20°C min^{-1} until 320°C was reached.

Individual terpenoids were identified by their mass spectra and retention times. Peak areas were used to quantify the individual substances. For quantification, calibrations were made, using known amounts of available pure terpenoids, and response factors were determined for each substance relative to known amounts of the internal standard. The concentrations of some monoterpenoids were not identified because there was no available standard and the chromatograms were too complex. In this study, although some monoterpenoids were not present in quantities large enough to identify, the yield of absolute concentrations, the relative differences, and the assessment of sesonal variation in the two species are valid.

The ANOVA for variation in monoterpenoid components and t-testing for the differences of terpenoid amounts between two species were computed using the Excel program (ver. 7.0).

RESULTS

Approximately 35 monoterpenoids and other compounds were dectected in *A. scoparia* and *A. feddei.* However many compounds were present only in small or trace amounts. Fig. 1 and Fig. 2 show a gas chro-

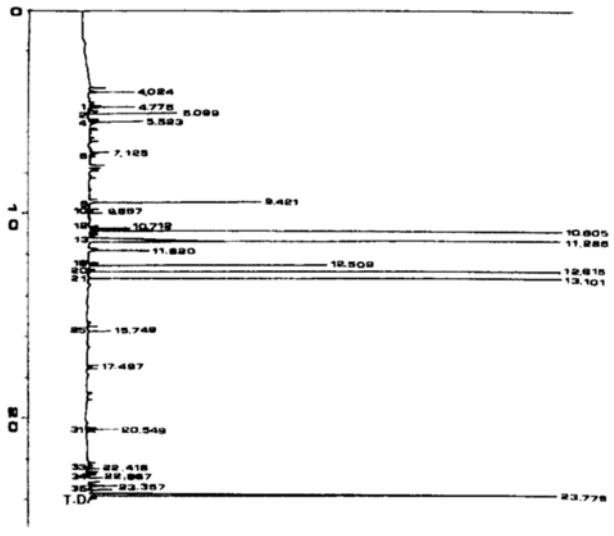

Fig. 1. Gas chromatographic assesment of the extraction from *Artemisia scoparia* leaf in June. Many monoterpenoids are presented only in small or trace amounts. Number means monoterpenoid compound with the same No. in Table 1. T.D. means tetra decane as internal standard.

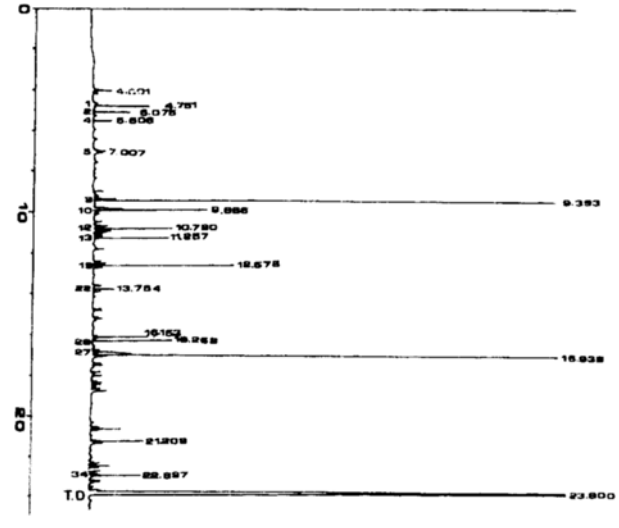

Fig. 2. Gas chromatographic assesment of the extraction from *Artemisia feddei* leaf in June. Many monoterpenoids are presented only in small or trace amounts. Number means monoterpenoid compound with the same No. in Table 1. T.D. means tetra decane as internal standard.

Table 1. The major monoterpenoids (%) in the leaf and stem of *A. scoparia* and *A. feddei*

Compound	Name	R.T.	*A. scoparia*		*A. feddei*		t-testing	
			Leaf	Stem	Leaf	Stem	Leaf	Stem
1	octene	4.73~4.64	3.96	6.63	13.2	25.58		
2		5.07~5.09	0.48	0.76	3.5	13.07		
3		5.34~5.37	3.59	0	0	0		
4		5.52~5.58	2.06	5.25	10.98	0.63		
5		7.12~7.18	0.34	0.13	0.91	5.43		
6	α-thujene	7.40~7.43	0.19	0.47	0	0		
7		8.01~8.04	0.06	0.16	0	0		
8		9.25~9.27	0	0	0.13	0		
9	α-pinene	9.41~9.45	3.67	5.03	8.72	2.16	*	
10	camphene	9.86~9.97	0.21	0.63	2.58	0.83		
11		10.52~10.56	0.65	0.32	0	0		
12	sabinene	10.76~10.79	21.59	23.69	3.41	1.75	**	**
13	β-pinene	11.24~11.27	20.5	21.48	3.92	2.49	**	***
14	β-myrcene	11.39~11.42	0	0.13	3.78	1.41		
15		11.89~11.93	0	0	0.91	3.3		
16		11.94~11.98	1.13	5.32	0	0		
17		12.19~12.22	0	0	0.38	0.08		
18		12.61~12.62	5.01	13.29	3.76	3.87		*
19	dl-limonene	12.58~12.59	0	0	6	1.56		
20	cyclohexene	12.92~12.93	19.78	13.35	1.82	0.54	***	
21	octatrine	13.26~13.27	9.42	0.14	1.16	0.46		*
22		13.62~13.64	0.25	0.23	0.23	0		
23		14.93~14.94	0	0	3.47	3.44		
24		15.32~15.34	0	0	1.25	1.19		
25	alloccimene	15.86~15.87	0.83	0.47	0	0		
26		16.26~16.28	0	0	2.38	2.35		
27	naphtalene	16.96~16.97	0	0	14.59	6.17	*	*
28	isomenthol	17.62~17.63	0.85	0.03	3.37	4.81		
29		18.77~18.78	0.22	0	0	0		
30		19.05~19.06	0.08	0.58	0	0		
31		19.18~19.19	1.25	0	0	0		
32	bornyl acetate	20.66~20.68	0	0	4.22	7.12		
33		22.41~22.58	0.31	0.73	0.25	2.52		
34	geranyl acetate	22.86~22.88	3.22	0.98	1.38	7.84		
35		23.35~23.40	3.34	0.42	3.7	1.41		
total			25	22	26	24		

R.T.: Retention Time
*: $p<0.01$, **: $p<0.001$, ***: $p<0.001$

matographic assessment of the extraction from the levels of *A. scoparia* and *A. feddei*. There are differences in the monoterpenoid fractions of the two species. Twenty five monoterpenoids in *A. scoparia* and 26 monoterpenoids in *A. feddei* were analysed, and 16 common monoterpenoids were found (Table 1). The leaf monoterpenoid fraction of *A. scoparia* was dominated by sabinene, β-pinene, No. 18 compound, cyclohexene, and octatrine, which were dectected in average amounts of more than 5% of the total monoterpenoids. The major relative amounts of *A. scoparia* leaf monoterpenoids ranged from 5.01 (No. 18) to 21.59% (sabinene), which were remarkable differences compared to the concentrations of other compounds. The major constituents of *A. feddei* monoterpenoids were octene, No. 4 (R.T.=5.52), α-pinene, and naphtalene. They ranged from 8.72 (α-pinene) to 14.59% (naphtalene).

Fig. 3 shows the total concentrations of leaf monoterpenoids between *A. scoparia* and *A. feddei*. The total amounts of *A. scoparia* leaf monoterpenoids were always higher than those of *A. feddei*. The total amount of monoterpenoids ranged from 3.243 mg/g to 0.721 mg/g in *A. scoparia*, and from 1.31 mg/g to 0.298 mg/g in *A. feddei*. The total amount of both leaf and stem monoterpenoids in both species

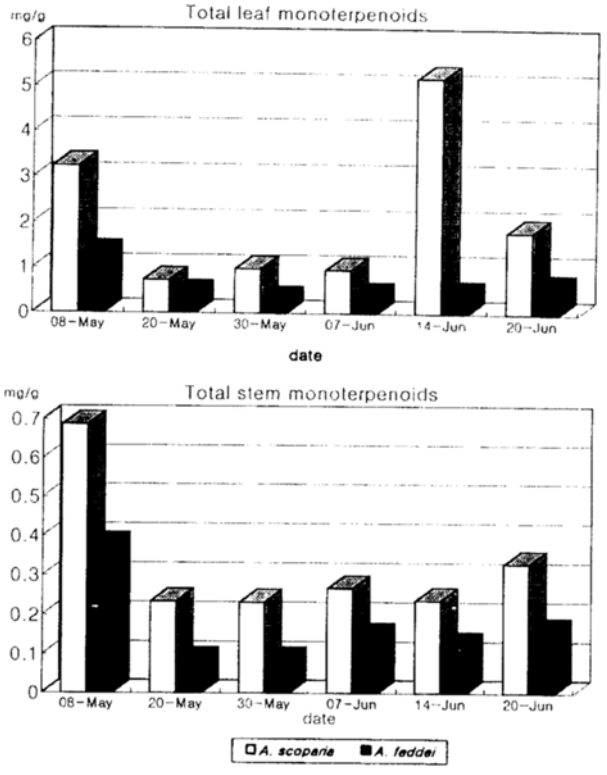

Fig. 3. Seasonal variation of total menoterpenoid concentration in *A. scoparia* and *A. feddei*.

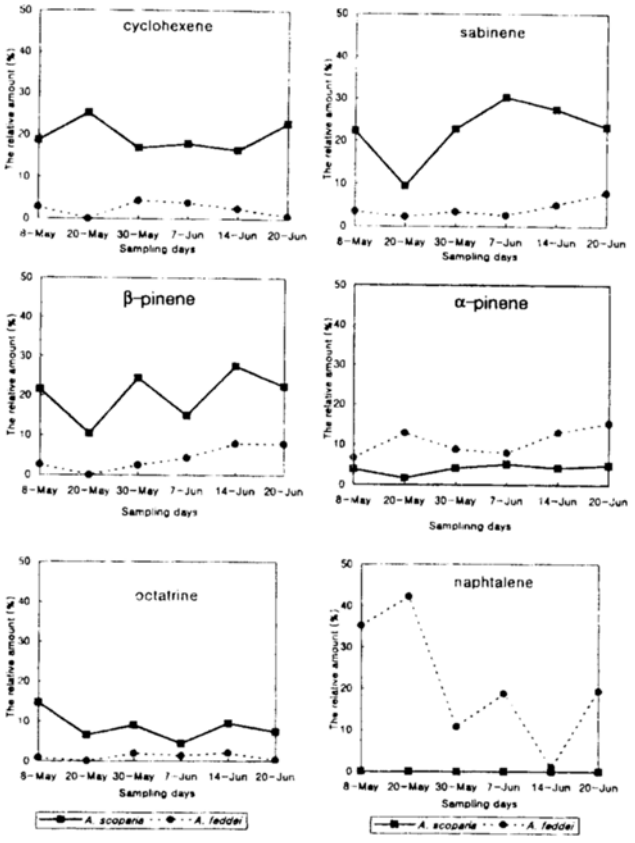

Fig. 4. The relative amounts of cyclohexene ($p<0.0001$), sabinene ($p<0.001$), β-pinene ($p<0.001$), α-pinene ($p<0.01$), octatrine ($p<0.05$) and naphtalene ($p<0.05$) in the leaf of *A. scoparia* and *A. feddei*.

rapidly decreased over time except for the *A. scoparia* leaf monoterpenoids of 14 June. After 29 May, the total amounts of monoterpenoids was almost constant in both species.

The total leaf monoterpenoid levels in *A. scoparia* ranged from 1.46 to 21.98 times the stem monoterpenoid levels in *A. scoparia*. The total amount of leaf monoterpenoids in *A. feddei* ranged from 2.71 to 3.69 times stem amounts.

The largest differences in relative amounts of leaf monoterpenoids between the two species were found in sabinene ($p<0.001$), α-pinene ($p<0.01$), β-pinene ($p<0.001$), cyclohexene ($p<0.0001$), octatrine ($p<0.05$), and naphtalene ($p<0.05$) (Fig. 4). The ratios of α-pinene and naphtalene in *A. feddei* were significantly higher than in *A. scoparia*. These compounds are the major monoterpenoids in *A. feddei*. Also, large differences in the relative amounts of stem monoterpenoids in the two species were found in levels of β-pinene ($p<0.0001$), sabinene ($p<0.001$), compound No. 18 (R.T.=12.61) ($p<0.01$), cyclohexene ($p<0.05$) and octatrine ($p<0.01$) (Fig. 5). There are significant differences in the leaf and stem monoterpenoids of each species (Fig. 4 and Fig. 5), and the seasonal variation of the relative amounts of leaf and stem monoterpenoid varied in both species with the exception of α-pinene and octatrine in the *A. scoparia* leaf.

Fig. 6 shows the seasonal variation of each monoterpenoid concentration in the leaf and stem of *A. scoparia*. The concentration of each monoterpenoid is represented over time. There were marked differences between each monoterpenoid, but the major components of leaf monoterpenoids were not varied ($p>0.05$) in response to time. On the other hand, although the concentrations of stem monoterpenoids were detected in small or trace, there was much variation within constituents and across time ($p<0.05$).

Fig. 7 shows the ratio of compositional monoterpenoid of the leaf and stem of *A. scoparia* over the time. There were no significant differences in the ratio of composition of monoterpenoids between leaf and stem of *A. scoparia*. Compared to these results from *A. scoparia*, there were highly significant differences in leaf ($p<0.0005$), and stem ($p<0.0001$) concentrations of monoterpenoids in *A. feddei* (Fig. 8). Contrary to *A.*

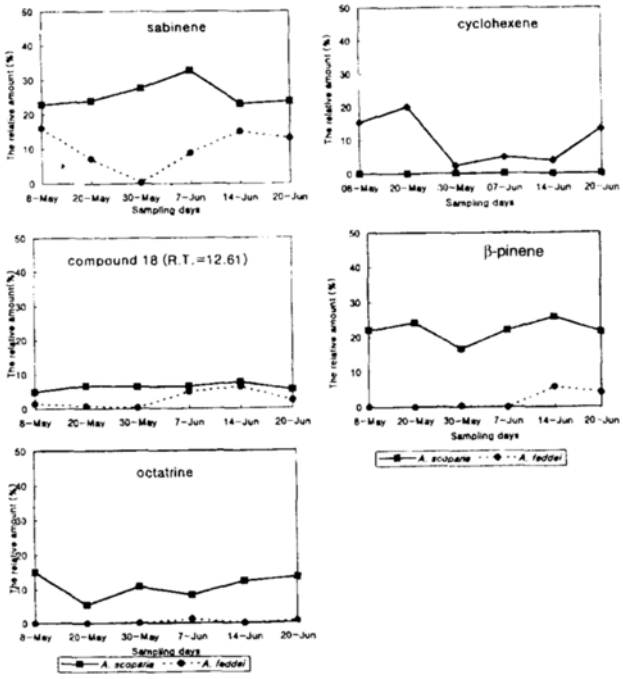

Fig. 5. The relative amounts of sabinene ($p<0.001$), cyclohexane ($p<0.05$), No. 18 compound ($p<0.01$), β-pinene ($p<0.0001$) and octatrine ($p<0.01$) in the stem of *A. scoparia* and *A. feddei*.

scoparia, there were significant differences in the ratio of compostion of monoterpenoids between leaf and stem of *A. feddei* ($p<0.00001$) (Fig. 9).

DISCUSSION

There were many differences in the gas chromatography of *A. scoparia* and *A. feddei* (Fig. 1 and 2). Generally, we can smell the difference in aroma from the leaves of *A. scoparia* and *A. feddei* easily, and we can readily see the differences in the shape of young leaves of the two species. Certain plants contain mixtures of volatile monoterpenoids and sesquiterpenoids which lend a characteristic odor to their foliage. Peppermint, lemon, basil and sage are examples of plants containing such essential oils. The chief monoterpenoid constituent of peppermint oil is menthol, of lemon oil limonene, and of pine oil pinene. Therefore, many volatile monoterpenoid compounds may be involved in the olfaction of *Artemisia* species, with the major monoterpenoids having the high peak area. The high concentration of the monoterpenoids sabinene, β-pinene, and cyclochexene might give a characteristic odor to *A. scoparia*, while naphtalene might give a characteristic odor to *A. feddei*. Although the specific aroma of plants is repre-

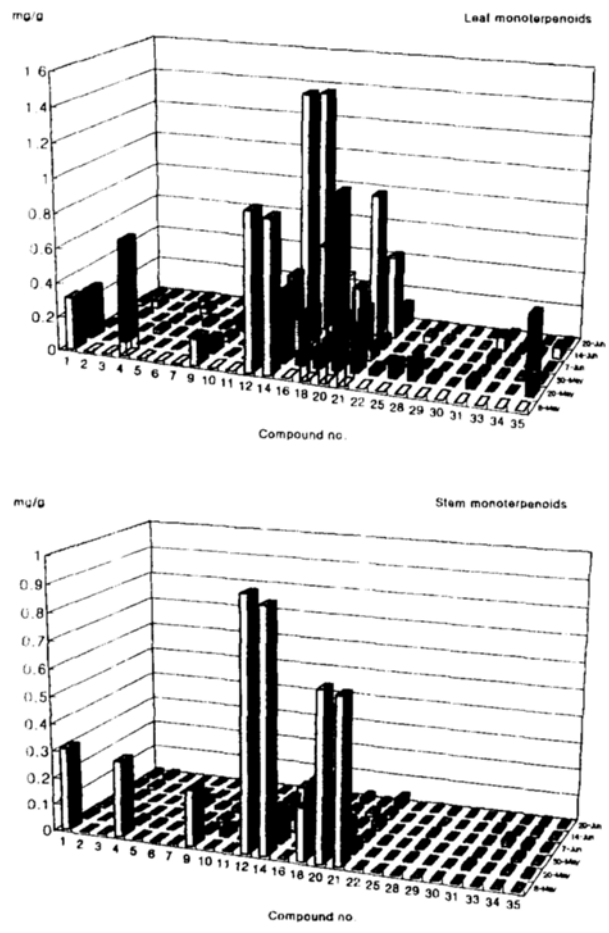

Fig. 6. Seasonal variation of each monoterpenoid concentration in the leaf and stem of *A. scoparia*. The concentration of each monoterpenoid varied in leaf ($p<0.05$) and stem over time ($p<0.05$).

sented by the highest concentration of constituents, we don't know which compound serves to give foliage its odor, because the compounds are composed of a mixture of several kinds of terpenoids.

Fig. 3 shows the total concentrations of leaf monoterpenoids in *A. scoparia* and *A. feddei*. The total amounts of *A. scoparia* leaf monoterpenoids were always higher than those of *A. feddei*. The total monoterpenoid levels were higher in early spring in both species. The reason for these results might be the differences in the shape of the young leaves of the two species. Because the shape of *A. scoparia*'s young leaf is a rosette and bunch type, the volatile monoterpenoid on the leaf might therefore be less volatile than on the expanded *A. feddei* leaf.

The total amounts of both leaf and stem monoterpenoids in the two species rapidly decreased across time with the exception of the *A. scoparia* leaf mo-

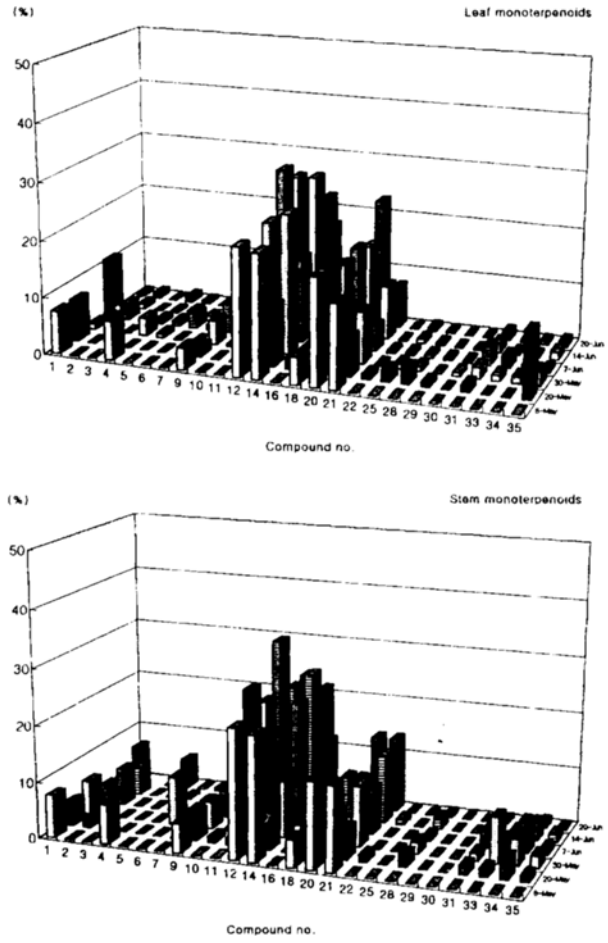

Fig. 7. Seasonal variation of compositional ratio of each monoterpenoid in the leaf and stem of *A. scoparia*. There are no significant difference in the ratio of monoterpenoids both in leaf and stem ($p>0.1$).

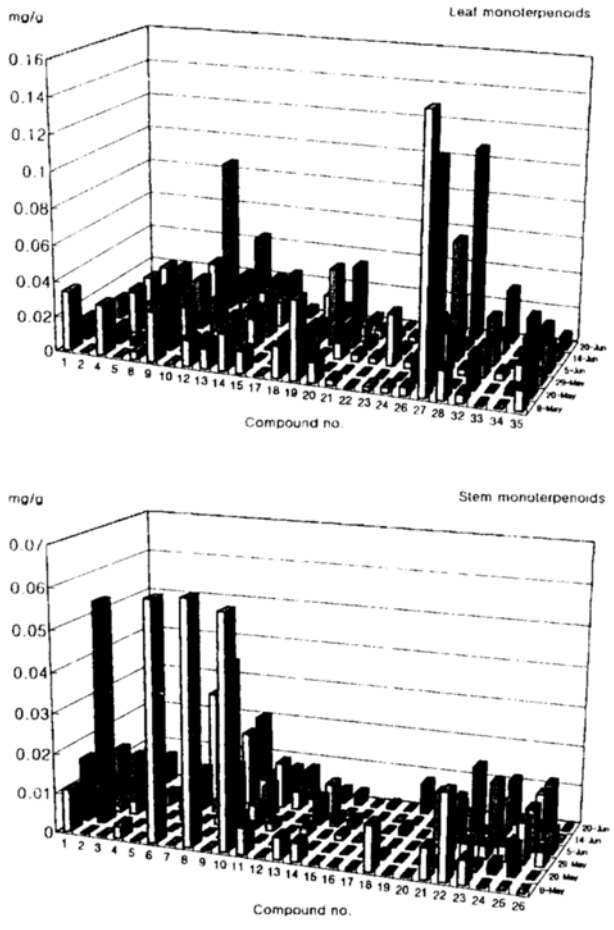

Fig. 8. Seasonal variation of each monoterpenoids concentration in the leaf and stem of *A. feddei*. The concentration of each monoterpenoid varied in leaf ($p<0.0001$) and stem ($p<0.0001$) with the time.

noterpenoids of 14 June. After 30 May, the total amounts of monoterpenoids were almost constant in both species. These results represent the same trends shown by the leaf and stem monoterpenoids of *A. princeps* var. *orientalis* (Kim, 1996). In general, volatile terpenoids are effective deterrents because they repel herbivores prior to defoliation (Levin, 1976). Since the early stages of most plants are the most vulnerable to browsing by herbivores, Levin (1976) and Goralka (1996) predicted that increased levels of defensive compounds occur in seedlings (Goralka, 1996). In particular, the high concentrations of monoterpenoids in the early stages of *Artemisia* plant development might be advantageous for developing mechanisms to deter herbivores. Therefore, the high concentration of leaf monoterpenoids in *A. scoparia,* sabinene, β-pinene, and cyclohexene, seem to affect the activites of herbivores. The most distinctive fluctuations in monoterpenoid concentrations are normally observed during the development of pine needles (Rudloff, 1975; Hanover, 1966; Michelozzi *et al.*, 1990), and this was also observed in this present study.

The leaf and stem monoterpenoid fraction of *A. scoparia* was dominated by sabinene, α-pinene, octene, No. 4, No. 18 compound, cyclohexene, and octatrine which were dectected in average amounts of more than 5%. The major leaf and stem monoterpenoids in *A. feddei* were octene, No. 4, α-pinene and naphtalene. This is markedly different from the levels of the other compounds, which were dectected in average amounts of more than 5% (Table 1). Monoterpenoid composition is quite stable in monoterpenoid-containing species, but the absolute amount of individual and total monoterpenoids fluctuates during the seasons (Schonwitz *et al.*, 1990; Kim, 1996).

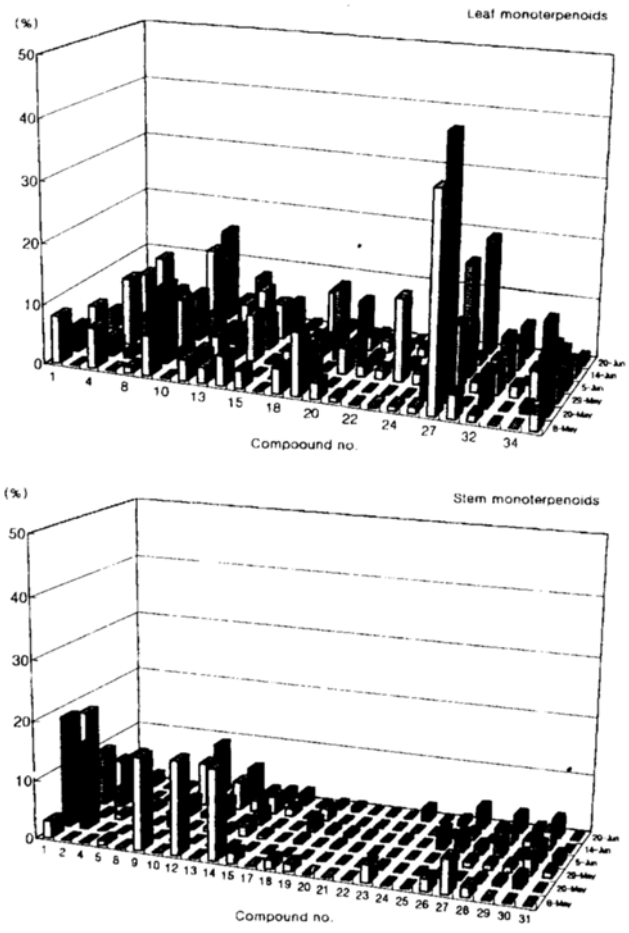

Fig. 9. Seasonal variation of compositional ratio of each monoterpenoids in the leaf and stem of *A. feddei*. The compositional ratio of each monoterpenoid were varied between leaf and stem ($p<0.00001$).

This phenomenon was also found in the present study, in which the greatest differences were found in the leaf concentrations of sabinene, cyclohexene, α-pinene, β-pinene, octatrine, naphtalene and in the total monoterpenoid levels between species. Of these, α-pinene and octatrine were not varied with time. Nerg *et al.* (1994) and Kristina *et al.* (1996) reported that the differences in monoterpenoid composition between seasons and tissues are large but mainly quantitative. In this study some monoterpenoid concentrations and compositions of *A. feddei* were similar to *A. princeps* var. *orientalis*, those of *A. scoparia* were different. In *Artemisia* foliage, the concentrations of sabinene and naphtalene might be the primarly monoterpenoids that determine chemotype. In the present study the absolute concentration of each monoterpenoid was varied across time, but the ratios of each monoterpenoid were not varied in *A. scoparia* (Fig. 6 and 7). This may indicate that the mechamisms of monoterpenoid production is to some extent connected with the genetics of monoterpenoids. The amounts of monoterpenoids are strongly dependent on the amounts of structurally similar monoterpenoids. Kristina *et al.* (1996) found that the amounts of γ-terpinene and terpinolene, among other constituents, were strongly dependent on the amount 3-carene. Several researchers (Tobolski and Hanover, 1971; Zavarin *et al.*, 1990) have suggested that concentrations of monoterpenoids are regulated in part by biological mechanisms common to developing foliage.

As has been pointed out by many studies (Baradat and Yazdani, 1988; Nerg *et al.*, 1994; Yazdani and Lebreton, 1991; Barton *et al.*, 1991; Marco *et al.*, 1994), because the total proportional quantities of monoterpenoids are dependent on the species, monoterpenoid analyses between species and within species give increased information for chemotaxonomical studies. Such analyses also provide a new tool for investigation of biosynthetic routes.

ACKNOWLEDGEMENTS

This work was supported by a grant from KOSEF (grant No. 961-0509-074-1).

LITERATURE CITED

Ahmad, A. and Laxmi N. Misra. 1994. Terpenoids from *Artemisia annua* and constituents of its essential oil. *Phytochemistry* **37**: 183-186.

Baradat and R. Yazdani. 1988. Genetic expression for monoterpenes in clones of *Pinus sylvestris* grown on different sites. *Scandinavian J. Forest Research* **3**: 25-36.

Barton, A. F. M., P. P. Cotterill and M. I. H. Brooker. 1991. Short note: Heritability of cineole yield in *Eucalyptus kodhii*. *Silvae Genetica* **40**: 37-38.

Croteau, R., M. Felton, F. Karp and R. Kjonaas. 1981. Relationship of camphor biosynthesis to leaf development in sage (*Salvia officinalis*) *Pl. Physiol.* **67**: 820-824.

Edwards, P. B., W. J. Wanjara and W. V. Brown. 1993. Selective herbivory by christmas beetles in response to intraspecific variation in *Eucalyptus terpenoids*. *Oecologia* **95**: 551-557.

Espinosa-Garcia, F. and J. H. Langenheim. 1991. Effect of some leaf essential oil phenotypes from coastal redwood on growth of its predominant endophytic fungus, *Pleuroplaconema. sp. J. Chem. Ecol.* **17**: 1837-1857.

Goralka, R. J. L. and J. H. Langenheim. 1996. Implications of foliar monoterpenoid variation among ontogenetic stages of the California Bay Tree (*Umbellu-*

laria californica) for deer herbivory. *Biochem. Syst. Ecol.* **24**: 13-23.

Hanover J. W. 1966. Environmental variation in the monoterpenes of *Pinus monticola Dougl. Phytochemistry* **5**: 713-717.

Harbone, J. B. 1982. Introduction to ecological biochemistry. 2nd. ed. Academic Press, London.

Harbone, J. B. and B. L. Turner. 1984. Plant chemosystematics. Academic Press, London.

Kil, Bong-Seop, Y. S. Kim and K. W. Yun. 1991. Allelopathic effects of growth inhibitor from *Artemisia princeps* var. *orientalis. Korean J. Ecol.* **14**: 132-135.

Kim, Jong Hee and J. H. Langenheim. 1994. The effects of *Pseudotsuga menziesii* monoterpenoids on nitrification. *Korean J. Ecol.* **17**: 251-260.

Kim, Jong Hee. 1996. Seasonal variation in concentration and composition of monoterpenes from *Artemisia princeps* var. *orientalis. Korean J. Ecol.* **19**: 321-328.

Kristina Sjodin, Monika Persson, Anna-Karin Borg-Karlson and Torbjorn Norin. 1996. Enantiomeric compositions of monoterpene hydrocarbones in different tissue of four individuals of *Pinus sylvestris. Phytochemistry* **41**: 439-445.

Langenheim, J. H., C. A. Macedo, M. K. Ross and W. H. Stubblebine. 1986. Leaf development in the tropical leguminous tree *Copaifera* relation to microlepidoteran herbivory. *Biochem. Syst. Ecol.* **14**: 51-59.

Langenheim, J. H. 1994. Higher plant terpenoids: A phytocentric overview of their ecological roles. *J. Chem. Ecol.* **20**: 1223-1280.

Levin, D. A. 1976. The chemical defenses of plants to pathogens and herbivores. *Am. Rev. Ecol. Syst.* **7**: 121-159.

Li, H. and J. L. Madden and B. M. Potts. 1995. Variation in volatile leaf oils of the Tasmanian *Eucalyptus* species. 1. Subgenus *Monocalyptus. Biochem. Syst. Ecol.* **23**: 299-318.

Marco, J. A., J. F. Sang-Cervera, J. M. Pareja, F. Sancenon and J. Valles-Xirau. 1994a. Sesquiterpene lactones and from north African *Artemisia* species. *Phytochemistry* **37**: 47-485.

Marco, J. A., J. F. Sang-Cervera, F. Sancenon, M. Arno and J. Valles-Xirau. 1994b. Sesquiterpene lactones and acetylenes from *Artemisia reptans. Phytochemistry* **37**: 1095-1099.

Mattson, W. J., J. Levieus and C. Bernard-Vagan. 1988. Mechnisms of woody plant defense against insects: search for pattern. Springer-Verlag, Berlin.

Michelozzi, M., A. E. Squillace and T. L. White. 1990. Monoterpene composition and fusiform rust resistance in Slash pine. *Forest Science* **36**: 470-475.

Nerg A., P. Kainulainen, M. Vuorinen, M. Hanso, J. K. Holopainen and T. Kurkela. 1994. Seasonal and geographical variation of terpenes. resin acids and total phenolics in nursery grown seedlings of scots pine (*Pinus sylvestris* L.). *New Phytol.* **128**: 703-713.

Raffi, Z. A., R. S. Dodd and E. Zavarin. 1996. Genetic diversity in foliar terpenoids among natural populations of European Black Pine. *Biochem. Syst. Ecol.* **24**: 325-339.

Rudloff, E. Von. 1975. Seasonal variation in the terpenes of the foliage of black spruce. *Phytochemistry* **14**: 1695-1699.

Schonwitz R., Lohwasser K., Kloos M., Ziegler H. 1990. Seasonal variation in the monoterpenes in needles of *Picea abies* (L). Karst. *Trees* **4**: 34-40.

Tobolski J. J. and Hanover J. W. 1971. Genetic variation in the monoterpenes of Scot pine. *For. Sci.* **17**: 293-299.

White, C. S. 1986. Volatile and water-soluble inhibitors of nitrogen mineralization in a ponderosa pine forest. *Biol. Fert. Soils.* **2**: 97-104.

Williams, C. A., Joseph C. Onyilagha and J. B. Harbone. 1995. Flavonoid profiles in leaves, flowers and stems of forty-nine members of the Phasoelinae. *Biochem. Syst. Ecol.* **23**: 655-667.

Yasphe, J., I. Feuerstein, S. Barel and R. Segal. 1987. The antibacterial and antispasmodic activity of *Artemisia herba-alba* asso. II. Examinatypes. *Int. J. Crude Drug. Res.* **25**: 89-96.

Yazdani, R. and Lebreton, Ph. 1991. Inheritance pattern of the flavonic compounds in scot pine (*Pinus sylvestris* L.). *Silvae Genetica* **40**: 57-59.

Zavarin E., Snajberk, K. and Cool L. 1990. Monoterpene variability of *Pinus monticola* wood. *Biochem. Syst. Ecol.* **18**: 117-124.

Received May 27, 1997
Accepted October 29, 1997