Available online at www.sciencedirect.com

ScienceDirect

Biochemical Systematics and Ecology xx (2007) 1–10

biochemical systematics and ecology

www.elsevier.com/locate/biochemsyseco

Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica

Ramona A. Cole [a], William A. Haber [b,1], William N. Setzer [a,*]

[a] *Department of Chemistry, University of Alabama in Huntsville, Huntsville, AL 35899, USA*
[b] *Missouri Botanical Garden, St. Louis, MO 63166, USA*

Received 25 March 2007; accepted 29 June 2007

Abstract

The leaf essential oils of seven species of *Eugenia* from Monteverde, Costa Rica (*Eugenia austin-smithii*, *Eugenia cartagensis*, *Eugenia haberi*, *Eugenia monteverdensis*, *Eugenia zuchowskiae*, *Eugenia* sp. A aff. *haberi*, and *Eugenia* sp. B aff. *oerstediana*) have been obtained by hydrodistillation and analyzed by GC–MS. The seven species were compared to determine the similarities and differences among their volatile chemical compositions. The major component in each of the seven species was as follows: *E. austin-smithii* and *E. cartagensis* was *trans*-2-hexenal, *E. haberi* and *E. zuchowskiae* was α-pinene, *E. monteverdensis* was linalool, *Eugenia* sp. A was zingiberene, and *Eugenia* sp. B was 1,8-cineole. The following six components were present in all seven species: α-copaene, β-caryophyllene, α-humulene, δ-cadinene, *trans*-nerolidol, and torreyol. The complex array and differing abundances of these compounds among the *Eugenia* species studied suggest that they may provide useful characters in understanding the phylogenetic relationships among closely related species.

Keywords: *Eugenia austin-smithii*; *Eugenia cartagensis*; *Eugenia haberi*; *Eugenia monteverdensis*; *Eugenia zuchowskiae*; *Eugenia* sp. A aff. *haberi*; *Eugenia* sp. B aff. *oerstediana*; Myrtaceae; Essential oil composition

1. Introduction

The Myrtaceae consists of around 129 genera and 4620 species (Mabberley, 1997). One important member of this family is *Eugenia*, which is one of the larger genera with around 500 species (Mabberley, 1997). Several species of *Eugenia* have been reported for uses in folk medicine. The shrubby tree *Eugenia uniflora* has been investigated and determined to be effective in treatment against digestive disorders and commonly used as an anti-febrile, anti-rheumatic, anti-inflammatory, diuretic, and to lower blood glucose levels (Kanazawa et al., 2000; Ogunwande et al., 2005). Several of the *Eugenia* species have fruits that are edible; two examples are *E. uniflora* and *Eugenia involucrata* (Apel et al., 2002a,b,c). This present study targets seven species of *Eugenia* from Monteverde, Costa Rica. The examined species include *Eugenia austin-smithii* Standl., *Eugenia cartagensis* O. Berg, *Eugenia haberi*

* Corresponding author. Tel.: +1 256 824 6519; fax: +1 256 824 6349.
E-mail address: wsetzer@chemistry.uah.edu (W.N. Setzer).
[1] Present address: Apdo. 50-5655, Monteverde, Puntarenas, Costa Rica, Central America.

0305-1978/$ - see front matter © 2007 Elsevier Ltd. All rights reserved.
doi:10.1016/j.bse.2007.06.013

Barrie, *Eugenia monteverdensis* Barrie, *Eugenia zuchowskiae* Barrie, *Eugenia* new sp. A aff. *haberi* Barrie (subsequently referred to as *Eugenia* sp. A), and *Eugenia* new sp. B aff. *oerstediana* O. Berg (subsequently referred to as *Eugenia* sp. B). This work includes a description of the collection and hydrodistillation of the leaves and the gas chromatographic–mass spectrometric analysis of the essential oils. To our knowledge, no previous research has been conducted on these species.

2. Materials and methods

2.1. Plant material

Leaves of *E. austin-smithii*, *E. haberi*, *E. monteverdensis*, *E. cartagensis*, *E. zuchowskiae*, *Eugenia* sp. A, and *Eugenia* sp. B were collected from mature trees in the Monteverde region of Costa Rica. The plants were identified by W.A. Haber. Voucher specimens have been deposited in the herbarium, Missouri Botanical Garden and the National Herbarium of Costa Rica. The fresh leaves were chopped and hydrodistilled and the distillate extracted with $CHCl_3$ to give the essential oils (Table 1).

2.2. Gas chromatographic–mass spectrometric (GC–MS) analysis

The leaf oils of the *Eugenia* species were subjected to GC–MS analysis on an Agilent system consisting of a model 6890 gas chromatograph, a model 5973 mass selective detector (MSD), and an Agilent ChemStation data system. The GC column was an HP-5ms fused silica capillary with a (5% phenyl)-methylpolysiloxane stationary phase, film thickness of 0.25 μm, a length of 30 m, and an internal diameter of 0.25 mm. Helium was the carrier gas with a flow rate of 1.0 mL/min. The inlet temperature was 200 °C and the oven temperature program was as follows: 40 °C initial temperature, hold for 10 min; increased at 3 °C/min to 200 °C; increased 2 °C/min to 220 °C, with an interface temperature of 280 °C. Each sample was dissolved in $CHCl_3$ and a splitless injection technique was used. Identification of oil components was achieved based on their retention indices (determined with reference to a homologous series of normal alkanes), and by the comparison of their mass spectral fragmentation patterns with the literature (Adams, 1995) and the MS library [NIST database (G1036A, revision D.01.00)/ChemStation data system (G1701CA, version C.00.01.08)].

3. Results and discussion

A total of 130 compounds were identified, accounting for 97.2–100% of the total compositions of each of the seven *Eugenia* species, and are compiled in Table 2. The leaf essential oil of *E. austin-smithii* was made up largely of oxygenated monoterpenoids (52.1%) and fatty acid-derived compounds (33.8%) with lesser amounts of monoterpene hydrocarbons (9.5%) and oxygenated sesquiterpenoids (3.2%). The most abundant essential oil components were

Table 1
Collection and hydrodistillation of leaves of *Eugenia* species from Monteverde, Costa Rica

Plant	Voucher number	Collection site (date)	Mass of leaves (g)	Mass of leaf oil (mg)
E. austin-smithii	Haber 11651	Monteverde Preserve[a] (5-26-03)	152.8	25.2
E. cartagensis	Haber 10989	Los Llanos[c] (5-19-06)	33.1	4.26
E. haberi	Haber 10720	El Bosque[b] (6-2-03)	84.2	25.6
E. monteverdensis	Haber 765	El Bosque[b] (6-7-03)	140.4	92.0
E. zuchowskiae	Haber & Zuchowski 10036	Las Nubes[d] (5-23-05)	88.1	140.5
Eugenia sp. A	Haber 12730	Las Nubes[d] (5-23-05)	94.9	65.5
Eugenia sp. B	Haber 13275	San Luis[e] (5-23-02)	102.4	85.6

[a] Monteverde Cloud Forest Preserve (10.3483N, 84.7633W, 1530 m above sea level).
[b] Hotel El Bosque, Monteverde (10.3059N, 84.8144W, 1380 m above sea level).
[c] Los Llanos field station, Monteverde (10.3056N, 84.8370W, 1200 m above sea level).
[d] Along road between Santa Elena and Las Nubes (10.3445N, 84.8317W, 1420 m above sea level).
[e] Along road between Monteverde and San Luis (10.2557N, 84.8394W, 810 m above sea level).

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013

trans-2-hexenal (33.6%), α-terpineol (16.3%), linalool (13.9%), α-pinene (9.3%), *trans*-pinocarveol (6.5%), and terpinen-4-ol (5.7%). *E. austin-smithii* contains one major component, α-pinene, which is reported as being a common major contributor to other species of *Eugenia* (Apel et al., 2002a,b, 2004a; Medeiros, 2003). *E. austin-smithii* is different, though, from other *Eugenia* species because some of its other major components, *trans*-2-hexenal and linalool, have been rarely reported in the literature as abundant. In the present study, *E. austin-smithii* is similar to *E. haberi*, *E. monteverdensis*, and *Eugenia* sp. B because each is made up largely of oxygenated monoterpenes (see below).

The most abundant components of *E. haberi* were α-pinene (29.0%), α-terpineol (19.4%), *trans*-2-hexenal (11.2%), and terpinen-4-ol (4.7%). Monoterpene hydrocarbons (38.0%) and oxygenated monoterpenoids (37.8%) made up a large part of the leaf oil of *E. haberi* with smaller amounts of fatty acid derivatives (11.3%), oxygenated sesquiterpenoids (6.2%), and sesquiterpene hydrocarbons (3.5%). *E. haberi* is similar to other members of the genus in that the major component, α-pinene, is common to a number of other *Eugenia* species (Apel et al., 2002b, 2004a).

The leaf essential oil of *E. monteverdensis* was composed mostly of oxygenated monoterpenoids (54.6%), fatty acid derivatives (22.5%), and oxygenated sesquiterpenoids (18.0%) with a smaller quantity of sesquiterpene hydrocarbons (3.7%). The most abundant compounds in *E. monteverdensis* were linalool (30.4%), *trans*-2-hexenal (22.5%), α-terpineol (5.3%), and *trans*-pinocarveol (4.5%). *E. monteverdensis* varies from what is reported in other *Eugenia* species due to the abundant presence of linalool and *trans*-2-hexenal, which are rarely reported as abundant for the genus.

The most abundant components of *E. cartagensis* were *trans*-2-hexenal (31.2%), *trans*-β-ocimene (16.2%), germacrene D (12.3%), β-caryophyllene (6.3%), germacrene B (6.0%), and bicyclogermacrene (4.1%). The bulk of the leaf oil of *E. cartagensis* was made up of sesquiterpene hydrocarbons (40.9%), fatty acid derivatives (33.9%), and monoterpene hydrocarbons (17.9%) with oxygenated sesquiterpenoids (5.7%) and diterpene hydrocarbons (1.1%) making up the remainder. *E. cartagensis* also differs from other *Eugenia* species reported in the literature because of the presence of *trans*-2-hexenal. *E. cartagensis* is similar to *E. zuchowskiae* and *Eugenia* sp. A, two other species in this study, based on the abundance of sesquiterpene hydrocarbons, which make up the majority of each.

The leaf essential oil of *E. zuchowskiae* was mostly made up of sesquiterpene (53.1%) and monoterpene (33.0%) hydrocarbons and oxygenated sesquiterpenoids (12.0%). α-Pinene (28.3%), β-caryophyllene (13.2%), α-humulene (13.1%), α-copaene (8.1%), and δ-cadinene (6.2%) were the major components of *E. zuchowskiae*. *E. zuchowskiae* is very similar to other members of *Eugenia* with each of its major components reported as common for other *Eugenia* species (Apel et al., 2002a,b,c, 2004a,b,c, 2005).

The most abundant components of the essential oil of *Eugenia* sp. A were zingiberene (24.7%), germacrene D (11.1%), *trans*-2-hexenal (7.2%), δ-cadinene (6.5%), 1-*epi*-cubenol (6.2%), 7-*epi*-α-eudesmol (6.1%), and *epi*-α-cadinol (5.6%). The essential oil of *Eugenia* sp. A was dominated by sesquiterpene hydrocarbons (61.1%), oxygenated sesquiterpenoids (30.5%), and fatty acid derivatives (7.2%). A key characteristic of *Eugenia* sp. A is the presence of its major component zingiberene, which was not found in other *Eugenia* species in both this study and the literature.

The leaf essential oil of *Eugenia* sp. B was largely made up of oxygenated monoterpenoids (68.8%) and fatty acid derivatives (16.5%) with smaller amounts of monoterpene hydrocarbons (6.1%), sesquiterpene hydrocarbons (4.4%), and oxygenated sesquiterpenoids (2.7%). 1,8-Cineole (26.0%), *cis*-3-hexenol (16.5%), terpinen-4-ol (15.1%), α-terpineol (6.1%), and piperitone (4.3%) are the major compounds in the essential oil of *Eugenia* sp. B. *Eugenia* sp. B differs from the species in this study in that it contains a large amount of 1,8-cineole, only present in small amounts in two other species. 1,8-Cineole has been reported in the literature as a major contributor to many of the members of the Myrtaceae such as *Eucalyptus globulus*, *Eucalyptus nitens/denticulata* (Li and Madden, 1995), and *Myrcianthes cisplatensis* (Lorenzo et al., 2001; Zygadlo et al., 1997).

There are six compounds, four sesquiterpenes, and two oxygenated sesquiterpenes that were common to all seven *Eugenia* species in this study. The common sesquiterpenes are α-copaene, β-caryophyllene, α-humulene, and δ-cadinene. These sesquiterpenes seem to be common to many species of *Eugenia*, including *Eugenia dysenterica* (Costa et al., 2000), *Eugenia bacopari*, *Eugenia burkartiana*, *Eugenia dimorpha* (except α-copaene and δ-cadinene), *Eugenia catharinensis* (except β-caryophyllene and δ-cadinene), *Eugenia joenssonii* (Apel et al., 2002a), *Eugenia platysema* (except β-caryophyllene), *Eugenia pluriflora* (except δ-cadinene), *Eugenia ramboi*, *Eugenia umbelliflora*, *Eugenia uruguayensis* (except α-copaene) (Apel et al., 2002b), *Eugenia cuprea*, *Eugenia speciosa*, *Eugenia arenosa* (only β-caryophyllene), *Eugenia brasiliensis*, *Eugenia multicostata* (except δ-cadinene), *Eugenia pitanga*, *Eugenia sulcata* (except α-humulene and δ-cadinene), *Eugenia xiriricana* (Apel et al., 2004a), *Eugenia beaurepaireana*,

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013

Table 2
Chemical compositions of *Eugenia* leaf essential oils

RI	Compound	QI	Percent composition						
			E. austin-smithii	*E. haberi*	*E. monteverdensis*	*E. cartagensis*	*E. zuchowskiae*	*Eugenia* sp. A	*Eugenia* sp. B
855	*cis*-3-Hexenol	94							16.5
856	*trans*-2-Hexenal	97	33.6	11.2	22.5	31.2	0.8	7.2	
899	2-Heptanone	91				2.0			
924	*trans*,*trans*-2,4-Hexadienal	95	0.1	0.2	Trace				
936	α-Thujene	91		Trace					
940	α-Pinene	96	9.3	29.0	1.0	0.7	28.3		1.4
953	Camphene	96		Trace			0.1		
961	2-Heptenal	93	0.1			0.7			
981	β-Pinene	97	Trace	1.6		0.7	1.9		0.3
989	6-Methyl-5-heptene-2-one	81	0.3		Trace				
992	Myrcene	94		Trace			Trace		
1005	α-Phellandrene	95		0.2					2.5
1015	α-Terpinene	94		0.1					
1025	*p*-Cymene	95		0.9					1.6
1031	Limonene	97	0.2	3.0		Trace	2.8		
1033	1,8-Cineole	98	0.5		Trace				26.0
1038	*cis*-Ocimene	96		1.5		Trace		0.2	
1042	Phenyl acetaldehyde	94	0.2						0.4
1047	*trans*-β-Ocimene	94		0.2		16.2			
1060	γ-Terpinene	97		1.7		0.4			0.3
1073	*cis*-Linalool oxide	90			1.8				0.3
1087	Fenchone	76	0.2	0.2					
1088	*trans*-Linalool oxide	91		0.4	2.4				0.9
1100	Linolool	97	13.9	0.4	30.4				1.7
1107	2,2,6-Trimethyl-3-keto-6-vinyltetrahydropyran	95							1.5
1112	α-Fenchyl alcohol	94	1.0	2.0	1.8				0.4
1120	*trans*-Pinan-2-ol	94		0.2					
1121	*cis*-*p*-Menth-2-en-1-ol	98	0.3						2.0
1125	α-Campholene aldehyde	90	0.2	0.1	0.3				0.1
1138	*trans*-Isopinocarveol	80	6.5	3.3	4.5				
1138	1-Terpineol	95							2.9
1142	Camphor	96	0.3	0.2	0.3				Trace
1146	Camphene hydrate	96	0.8	0.7	0.5				
1161	Pinocarvone	90	1.1	0.4	0.9				
1165	*endo*-Borneol	91	2.1	4.0	3.1				0.7
1177	Terpinen-4-ol	97	5.7	4.7	2.5				15.1
1185	*p*-Cymen-8-ol	94	0.4		0.2				0.7
1190	α-Terpineol	91	16.3	19.4	5.3				6.1
1195	*cis*-Piperitol	95							0.6
1196	Myrtenol	96	0.7						Trace
1202	Unknown		0.6						

1202	α-Phellandrene epoxide	96							2.5
1206	*trans*-Piperitol	94							0.9
1207	Verbenone	91			Trace				
1217	*trans*-Carveol	97	0.6	0.4	0.2				0.2
1235	Unknown								1.1
1241	Carvone	93	Trace	Trace					Trace
1244	Carvotanacetone	97							0.5
1251	Piperitone	97	0.2	0.2	0.1				4.3
1253	Geraniol	80			0.1				
1281	Bornyl acetate	98	0.3	1.0					
1283	Safrole	96		0.4					
1283	*trans*-Linalool oxide acetate	50	0.7						
1290	Thymol	89							Trace
1294	*trans*-Verbenyl acetate	91	0.3						
1305	Carvacrol	91		0.2					0.3
1339	δ-Elemene	98				2.0		3.0	
1350	α-Terpinyl acetate	91							0.2
1366	Cyclosativene	99					Trace		
1372	α-Ylangene	95	Trace				0.1	Trace	
1376	α-Copaene	99	0.1	0.4	0.4	0.6	8.1	1.9	0.3
1384	β-Bourbonene	98				0.6	Trace	0.4	
1390	β-Cubebene	99						0.1	
1392	β-Elemene	99				1.1		0.4	
1399	*cis*-Jasmone	99							0.1
1402	Italicene	95							Trace
1407	Methyl eugenol	97			Trace				
1411	α-Gurjunene	99					0.4		
1418	β-Caryophyllene	99	0.2	1.3	1.0	6.3	13.2	2.5	2.2
1428	α-Ionone	94			Trace				
1432	Calarene (β-gurjunene)	97				0.5	0.6	0.4	
1434	γ-Elemene	98				1.0		0.2	
1435	α-Bergamotene	96							Trace
1437	Aromadendrene	98		Trace			4.7	Trace	0.2
1439	α-Guaiene	96				0.4	0.3		
1454	α-Humulene	98	Trace	1.1	0.1	1.6	13.1	2.0	0.2
1460	*cis*-Methyl isoeugenol	93			Trace				
1460	*trans*-β-Farnesene	96						0.5	Trace
1463	Epibicyclosesquiphellandrene	93				0.2		0.1	
1463	Alloaromadendrene	99					1.1		
1472	γ-Gurjunene	99					0.1		
1477	γ-Muurolene	99			0.5		0.3		
1480	γ-Curcumene	97							0.2
1483	Germacrene D	92				12.3		11.1	
1486	β-Selinene	99		0.3	0.3	0.3	0.2	0.2	0.5

(*continued on next page*)

Table 2 (*continued*)

RI	Compound	QI	Percent composition						
			E. austin-smithii	*E. haberi*	*E. monteverdensis*	*E. cartagensis*	*E. zuchowskiae*	*Eugenia* sp. A	*Eugenia* sp. B
1493	Valencene	50				0.4			
1491	*cis*-β-Guaiene	70						1.3	
1493	α-Selinene	99		0.1	0.6				0.4
1498	Ledene	96					1.8		
1497	Bicyclogermacrene	96				4.1	1.3	1.6	
1499	*trans*-Methyl isoeugenol	98			0.2				
1500	α-Muurolene	96		Trace		0.4	0.3		
1503	*trans*-α-Bisabolene	94							Trace
1509	Zingiberene	87						24.7	
1509	Unknown							1.1	
1509	β-Bisabolene	98							0.1
1513	γ-Cadinene	96		Trace	Trace	0.7	0.8		
1513	(*E*,*E*)-α-Farnesene	99						1.9	
1515	Cubebol	90					1.0		
1515	7-*epi*-α-Selinene	94			Trace				
1523	δ-Cadinene	99	Trace	0.4	0.7	2.3	6.2	6.5	0.2
1533	Cadina-1,4-diene	98		Trace	Trace	Trace	0.1	0.7	
1538	α-Cadinene	96					Trace	0.2	
1542	α-Calacorene	98		Trace			0.3	0.1	
1550	Elemol	91						0.9	
1556	Germacrene B	99				6.0	Trace	1.5	
1559	Elemicin	96			Trace				
1564	*trans*-Nerolidol	87	0.3	0.2	0.3	0.6	1.5	3.1	0.1
1577	Spathulenol	46				0.3	0.8		
1580	Caryophyllene oxide	97		Trace					Trace
1583	Globulol	95		1.8	0.4	0.6	3.9	0.6	
1586	Unknown			0.7					
1590	Viridiflorol	94			0.5	0.7	0.9	1.3	
1601	Unknown						1.1		
1602	Guaiol	89						0.4	
1607	Humulene epoxide II	72		1.0			0.2		Trace
1612	1,10-di-*epi*-Cubenol	95	0.5	Trace	Trace	Trace	Trace	0.2	
1616	10-*epi*-γ-Eudesmol	97			3.1		0.8	0.8	
1627	1-*epi*-Cubenol	97	0.9	2.0	3.7	0.6	0.8	6.2	
1630	Unknown					0.6			
1631	γ-Eudesmol	96			1.2			1.3	
1633	Unknown			1.3					
1634	Caryophylla-4(12),8(13)-dien-5-β-ol	99			1.5				0.5
1636	Unknown			0.8					
1639	*epi*-α-Cadinol	94	0.7			1.2	1.4	5.6	0.1
1641	Cubenol	96		0.6	1.7				
1645	α-Muurolol (torreyol)	97	0.8	0.1	0.4	0.3	0.2	1.3	Trace

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013

1648	β-Eudesmol	97			0.8				
1650	α-Eudesmol	96						0.7	
1652	Kongol	92							1.9
1654	α-Cadinol	95		0.5	3.4	1.4	0.5		
1656	Valerianol	95			0.5			1.4	
1657	7-*epi*-α-Eudesmol	90						6.1	
1667	Bulnesol	95						0.1	
1669	14-Hydroxy-9-*epi*-(*E*)-caryophyllene	86			0.5				
1672	Cadalene	97		Trace					
1685	α-Bisabolol	95						0.4	
1692	Juniper camphor	98			0.2				
2025	Kaurene	99				1.1			
	Total identified		99.4	97.2	100.0	99.4	98.9	99.0	98.9
	Fatty acid derived compounds		33.8	11.3	22.5	33.9	0.7	7.2	16.5
	Monoterpene hydrocarbons		9.5	38.0	1.0	17.9	33.0	0.2	6.1
	Oxygenated monoterpenoids		52.1	37.8	54.6	0.0	0.0	0.0	68.8
	Sesquiterpene hydrocarbons		0.3	3.5	3.7	40.9	53.1	61.1	4.4
	Oxygenated sesquiterpenoids		3.2	6.2	18.0	5.7	12.0	30.5	2.7
	Diterpene hydrocarbons		0.0	0.0	0.0	1.1	0.0	0.0	0.0
	Phenylpropanoids		0.0	0.4	0.2	0.0	0.0	0.0	0.0
	Aromatics		0.2	0.0	0.0	0.0	0.0	0.0	0.4
	Others		0.3	0.0	Trace	0.0	0.0	0.0	0.1

Eugenia pyriformis (except α-humulene) (Apel et al., 2004b), *Eugenia hyemalis* (Apel et al., 2004c), *Eugenia mattosii* (Apel et al., 2005), and the leaves and fruits of *E. uniflora* (except α-copaene) (Ogunwande et al., 2005). The common oxygenated sesquiterpenoids found in this study were *trans*-nerolidol and torreyol. These oxygenated sesquiterpenes were found to be present in some *Eugenia* species. For example, *trans*-nerolidol was found in *E. catharinensis*, *E. joenssonii* (Apel et al., 2002a), *E. cuprea*, *E. sulcata* (Apel et al., 2004a), and *E. pluriflora* (Apel et al., 2002b). Torreyol has been reported in *E. dysenterica* (Costa et al., 2000), *E. bacopari* (Apel et al., 2002a), and *E. multicostata* (Apel et al., 2004a). Both compounds were found in *E. ramboi* (Apel et al., 2002b). *trans*-Nerolidol and torreyol seem to be less common to the genus than the sesquiterpenes in this group of six; they were not reported in, for example, *E. burkartiana*, *E. dimorpha* (Apel et al., 2002a), *E. platysema*, *E. umbelliflora*, *E. uruguayensis* (Apel et al., 2002b), *Eugenia moraviana*, *Eugenia klappenbachiana*, *Eugenia repanda* (Apel et al., 2002c), *E. speciosa*, *E. arenosa*, *E. brasiliensis*, *E. pitanga*, *E. xiriricana* (Apel et al., 2004a), *E. beaurepaireana*, *E. pyriformis* (Apel et al., 2004b), *E. hyemalis* (Apel et al., 2004c), *E. mattosii* (Apel et al., 2005), and *E. uniflora*, leaves and fruits (Ogunwande et al., 2005). *Eugenia stigmatosa* was one *Eugenia* species from the literature that varied greatly from the species studied here; it did not have any of these six common compounds (Apel et al., 2004c).

There were five compounds that were common to six of the seven *Eugenia* species in this study. *trans*-2-Hexenal, a fatty acid derivative was found in large amounts in *E. austin-smithii*, *E. monteverdensis*, and *E. cartagensis*, and smaller amounts in *E. haberi*, *E. zuchowskiae*, and *Eugenia* sp. A. Large amounts of the monoterpene α-pinene were found in *E. haberi* and *E. zuchowskiae*, while lesser amounts were found in *E. austin-smithii*, *E. monteverdensis*, *E. cartagensis*, and *Eugenia* sp. B. Small amounts of β-selinene were found in all except for *E. austin-smithii.* The oxygenated sesquiterpenoids 1,10-di-*epi*-cubenol and 1-*epi*-cubenol were found in small amounts in all except *Eugenia* sp. B.

The five compounds *trans*-2-hexenal, α-pinene, β-selinene, 1,10-di-*epi*-cubenol, and 1-*epi*-cubenol have been reported in varying degrees in other *Eugenia* species. *trans*-2-Hexenal, 1,10-di-*epi*-cubenol, and 1-*epi*-cubenol seem to be relatively uncommon to other *Eugenia* species, having been reported in about six species or fewer. *trans*-2-Hexenal has been reported in *E. cuprea* (Apel et al., 2004a), *E. hyemalis* (Apel et al., 2004c), and the leaves of *E. uniflora* (Ogunwande et al., 2005). 1,10-di-*epi*-Cubenol has been reported in *E. uruguayensis* (Apel et al., 2002b) and *E. pyriformis* (Apel et al., 2004b). 1-*epi*-Cubenol has been reported in *E. bacopari*, *E. burkartiana* (Apel et al., 2002a), *E. umbelliflora* (Apel et al., 2002b), *E. repanda* (Apel et al., 2002c), *E. pyriformis* (Apel et al., 2004b), and *E. mattosii* (Apel et al., 2005). 1-*epi*-Cubenol is slightly more common than *trans*-2-hexenal and 1,10-di-*epi*-cubenol, but less common than α-pinene and β-selinene, which have been reported more frequently. α-Pinene has been found in *E. burkartiana*, *E. dimorpha* (Apel et al., 2002a), *E. pluriflora*, *E. umbelliflora*, *E. uruguayensis* (Apel et al., 2002b), *E. moraviana*, *E. repanda* (Apel et al., 2002c), *E. cuprea*, *E. brasiliensis*, *E. multicostata*, *E. sulcata*, *E. xiriricana* (Apel et al., 2004a), *E. beaurepaireana*, *E. pyriformis* (Apel et al., 2004b), *E. hyemalis* (Apel et al., 2004c), and the leaves and fruits of *E. uniflora* (Ogunwande et al., 2005). β-Selinene has been reported in *E. bacopari*, *E. dimorpha*, *E. catharinensis*, *E. joenssonii* (Apel et al., 2002a), *E. platysema*, *E. ramboi*, *E. uruguayensis* (Apel et al., 2002b), *E. moraviana*, *E. repanda* (Apel et al., 2002c), *E. brasiliensis*, *E. multicostata*, *E. xiriricana* (Apel et al., 2004a), *E. beaurepaireana* (Apel et al., 2004b), and the leaves and fruits of *E. uniflora* (Ogunwande et al., 2005).

Two common compounds, α-pinene and 1,8-cineole, have been reported in abundant quantities in members of the Myrtaceae family. α-Pinene has been shown to be abundant in *Melaleuca unicinata*, *Thryptomene kochii*, *Malleostemon tuberculatus*, *Eucalyptus stoatei* (Lassak and Brophy, 2004), and *Calyptranthes pallens* (Bansal et al., 2006). *Psidium sartorianum* (Pino, 2003) and *Myrceugenia cucullata* (Limberger et al., 2005) have also shown notable concentrations of α-pinene. The abundance of 1,8-cineole in the Myrtaceae family has been reported in *Eucalyptus erythrocorys*, *E. stoatei*, *Eremaea pauciflora*, *M. tuberculatus* (Lassak and Brophy, 2004), *E. globulus*, *E. nitens/denticulata* (Li and Madden, 1995), *Eucalyptus torreliana* (Silifat et al., 2005), *M. cisplatensis* (Lorenzo et al., 2001; Zygadlo et al., 1997), *Myrcianthes pungens* (Zygadlo et al., 1997), and *Myrcianthes* sp. A aff. *fragrans* (Setzer et al., 1999). One of these compounds, α-pinene, is common to six of the seven *Eugenia* species in the present study. The other compound, 1,8-cineole, was present in three of the species in this study, one of which was a major component.

Previous research of *Eugenia* has brought to light some similarities between members of this genus. There appears to be an abundance of α-pinene, β-caryophyllene, and bicyclogermacrene in the genus. As mentioned earlier, α-pinene has been reported in many of the *Eugenia* species. α-Pinene is seen in large amounts in *E. dimorpha* (Apel et al., 2002a), *E. pluriflora*, *E. umbelliflora*, *E. uruguayensis* (Apel et al., 2002b), *E. cuprea*, *E. brasiliensis*, *E. multicostata*,

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013

E. sulcata (Apel et al., 2004a) and *Eugenia axillaris* (Schmidt et al., 2006). β-Caryophyllene and bicyclogermacrene have also appeared in many of the *Eugenia* species. Although these are not reported as having the large amounts as often as α-pinene, they are still fairly abundant. For example, it has been shown that β-caryophyllene is present in abundance in *Eugenia stipitata* (Medeiros, 2003) and *E. umbelliflora* (Apel et al., 2002b). β-Caryophyllene and bicyclogermacrene are slightly abundant in *E. burkartiana* (Apel et al., 2002a), *E. ramboi* (Apel et al., 2002b), *E. moraviana*, *E. repanda* (Apel et al., 2002c), *E. cuprea*, *E. pitanga* (Apel et al., 2004a), *E. beaurepaireana*, *E. pyriformis* (Apel et al., 2004b), *E. hyemalis* (high in bicyclogermacrene) (Apel et al., 2004c), *E. mattosii* (Apel et al., 2005). Of the *Eugenia* species in the present study all except *Eugenia* sp. A contain α-pinene and of those six, α-pinene was the major component in two, *E. haberi* and *E. zuchowskiae*. β-Caryophyllene was found in all seven species and in *E. zuchowskiae* it was the second most abundant compound. Bicyclogermacrene was found in only three of the seven species and in small amounts, *E. cartagensis*, *E. zuchowskiae*, and *Eugenia* sp. A. Notably, *Eugenia caryophyllus* (=*Syzygium aromaticum*, clove tree) leaf oil is rich in eugenol (not observed in any of the *Eugenia* species in this present study) and β-caryophyllene (Jirovetz et al., 2006). Neither α-pinene nor bicyclogermacrene were observed in *E. caryophyllus*, however.

There are some compounds that are common to *Eugenia* in small amounts such as, α-copaene, aromadendrene, α-humulene, alloaromadendrene, and globulol (Apel et al., 2002a,b,c, 2004a,b,c, 2005). All seven of the species in this present study contain small amounts of α-copaene and α-humulene. Only four, *E. haberi*, *E. zuchowskiae*, *Eugenia* sp. A, and *Eugenia* sp. B, contained either small or trace amounts of aromadendrene and only one, *E. zuchowskiae*, contained alloaromadendrene. Globulol was found in small amounts in five of the species studied, all except for *E. austin-smithii* and *Eugenia* sp. B.

Each species of *Eugenia* studied contained a different array and concentration of leaf essential oils. The striking differences in the mix of these compounds among the *Eugenia* species suggest that they may provide useful characters in understanding phylogenetic relationships in this large genus whose species are notoriously difficult to classify and identify.

Acknowledgments

This research was made possible by a generous grant from a private donor. We would also like to thank the Monteverde Cloud Forest Preserve and the Hotel El Bosque, Monteverde, Costa Rica for the permission to collect plant material.

References

Adams, R.P., 1995. Identification of Essential Oil Components by Gas Chromatography/Mass Spectroscopy. Allured Publishing, Carol Stream, IL.

Apel, M.A., Limberger, R.P., Sobral, M., Henriques, A.T., Ntalani, H., Verin, P., Menut, C., Bessiere, J., 2002a. Chemical composition of the essential oils from southern Brazilian *Eugenia* species. Part II. J. Essent. Oil Res. 14, 163–166.

Apel, M.A., Limberger, R.P., Sobral, M., Henriques, A.T., Ntalani, H., Verin, P., Menut, C., Bessiere, J., 2002b. Chemical composition of the essential oils from southern Brazilian *Eugenia* species. Part III. J. Essent. Oil Res. 14, 259–262.

Apel, M.A., Sobral, M., Henriques, A.T., Menut, C., Bessiere, J., 2002c. Chemical composition of the essential oils from southern Brazilian *Eugenia* species. Part IV: section Racemulosae. J. Essent. Oil Res. 14, 290–292.

Apel, M.A., Sobral, M., Schapoval, E.E.S., Henriques, A.T., 2004a. Essential oils from *Eugenia* species – part VII: sections Phyllocalyx and Stenocalyx. J. Essent. Oil Res. 16, 135–138.

Apel, M.A., Sobral, M., Schapoval, E.E.S., Henriques, A.T., 2004b. Chemical composition of the essential oils of *Eugenia beaurepaireana* and *Eugenia pyriformis*: section Dichotomae. J. Essent. Oil Res. 16, 191–192.

Apel, M.A., Sobral, M., Schapoval, E.E.S., Henriques, A.T., Menut, C., Bessiere, J., 2004c. Chemical composition of the essential oils of *Eugenia hyemalis* and *Eugenia stigmatosa*. Part VI: section Biflorae. J. Essent. Oil Res. 16, 437–439.

Apel, M.A., Sobral, M., Schapoval, E.E.S., Henriques, A.T., Menut, C., Bessiere, J., 2005. Volatile constituents of *Eugenia mattosii* Legr. (Myrtaceae). J. Essent. Oil Res. 17, 284–285.

Bansal, A., Boehme, A.K., Eiter, L.C., Schmidt, J.M., Setzer, W.N., Vincent, M.A., 2006. Chemical composition and bioactivity of the leaf oil of *Calyptranthes pallens* (Poir.) Griseb. from Abaco Island, Bahamas. Nat. Prod. Commun. 1, 303–306.

Costa, T.R., Fernandes, O.F.L., Santos, S.C., Oliveira, C.M.A., Liao, L.M., Ferri, P.H., Paula, J.R., Ferreira, H.D., Sales, B.H.H., Silva, M.R.R., 2000. Antifungal activity of volatile constituents of *Eugenia dysenterica* leaf oil. J. Ethnopharmacol. 72, 111–117.

Jirovetz, L., Buchbauer, G., Stoilova, I., Stoyanova, A., Krastanov, A., Schmidt, E., 2006. Chemical composition and antioxidant properties of clove leaf essential oil. J. Agric. Food Chem. 54, 6303–6307.

Kanazawa, A., Patin, A., Greene, A.E., 2000. Efficient, highly enantioselective synthesis of selina-1,3,7(11)-trien-8-one, a major component of the essential oil of *Eugenia uniflora*. J. Nat. Prod. 63, 1292–1294.

Lassak, E.V., Brophy, J.J., 2004. Steam volatile leaf oils of some Western Australian species of the family Myrtaceae. Flavour Fragrance J. 19, 12–16.

Li, H., Madden, J.L., 1995. Analysis of leaf oils from *Eucalyptus* species trial. Biochem. Syst. Ecol. 23 (2), 167–177.

Limberger, R.P., Sobral, M., Henriques, A.T., 2005. Intraspecific volatile oil variation in *Myrceugenia cucullata* (Myrtaceae). Biochem. Syst. Ecol. 33, 287–293.

Lorenzo, D., Dellacassa, E., Bonaccorsi, I., Mondello, L., 2001. Uruguayan essential oils. Composition of leaf oil of *Myrcianthes cisplatensis* (Camb.) Berg. (Guayabo Colorado) (Myrtaceae). Flavour Fragrance J. 16, 97–99.

Mabberley, D.J., 1997. The Plant-book. Cambridge University Press, Cambridge, UK.

Medeiros, J.R., 2003. Composition of the bioactive essential oils from the leaves of *Eugenia stipitata* McVaugh ssp. *sororia* from the Azores. J. Essent. Oil Res. 15, 293–295.

Ogunwande, I.A., Olawore, N.O., Ekundayo, O., Walker, T.M., Schmidt, J.M., Setzer, W.N., 2005. Studies on the essential oils composition, antibacterial and cytotoxicity of *Eugenia uniflora* L. Int. J. Aromather. 15, 147–152.

Pino, J.A., 2003. Leaf oils of *Psidium cymosum* Urb. and *Psidium sartorianum* Niedz. from Cuba. J. Essent. Oil Res. 15, 187–188.

Schmidt, J.M., Noletto, J.A., Vogler, B., Setzer, W.N., 2006. Abaco bush medicine: chemical composition of the essential oils of four aromatic medicinal plants from Abaco Island, Bahamas. J. Herbs, Spices, Med. Plants 12 (3), 45–67.

Setzer, W.N., Setzer, M.C., Moriarity, D.M., Bates, R.B., Haber, W.A., 1999. Biological activity of the essential oil of *Myrcianthes* sp. nov. "black fruit" from Monteverde, Costa Rica. Planta Med. 65, 468–469.

Silifat, J.T., Ogunwande, I.A., Olawore, N.O., Walker, T.M., Schmidt, J.M., Setzer, W.N., Olaleye, O.N., Aboaba, S.A., 2005. In vitro cytotoxic activity of essential oils of *Eucalyptus torreliana* F.v. Muell (leaves and fruits). J. Essent. Oil-bearing Plants 8, 110–119.

Zygadlo, J.A., Rotman, A.D., Alonso, M.J.P., Negueruela, A.V., 1997. Leaf oils of two *Myrcianthes* species from Argentina: *M. pungens* (Berg.) Legrand and *M. cisplatensis* (Camb.) Berg. J. Essent. Oil Res. 9, 237–239.

Please cite this article in press as: Ramona A. Cole et al., Chemical composition of essential oils of seven species of *Eugenia* from Monteverde, Costa Rica, Biochem. Syst. Ecol. (2007), doi:10.1016/j.bse.2007.06.013