桉属挥发油化学成分及其生物活性研究进展

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摘　要:桉树为桃金娘科 Myrtaceae 桉属 *Eucalyptus* L. Herit 常绿性乔木,全球桉属有 600 多种,主要种植于世界各地热带亚热带地区。我国引入近 80 种,主要分布于华南地区,其中广东和广西为桉树的主要种植基地。药理研究表明,桉属植物挥发油具有良好的杀虫驱虫、抗菌、消炎镇痛、抗氧化等生物活性。本文结合国内外已经发表的相关文献,对 120 种桉树的 948 个挥发油化学成分和生物活性进行分类阐述,其中萜类化合物共 685 个、脂肪族化合物共 29 个、芳香族化合物共 39 个、其他化合物共 195 个,旨在为桉属植物挥发油成分、药理活性的深入研究及综合开发利用提供借鉴。

关键词:桉属;挥发油;化学成分;生物活性

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Research progress on volatile oil of *Eucalyptus* and its biological activities

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Abstract:*Eucalyptus* is an evergreen tree belonging to the *Eucalyptus* L. Herit of Myrtaceae family. There are more than 600 types of *Eucalyptus* in the world,mainly planted in tropical and subtropical regions around the world. Nearly 80 species of *Eucalyptus* were introduced into China,which mainly cultivated in south China. Guangdong and Guangxi are important production base for *Eucalyptus* planting. According to pharmacological research,the volatile oil of *Eucalyptus* showed insecticidal and repellent,anti-bacterial,anti-inflammatory,analgesic,and anti-oxidant activities. Research progress on chemical constituents and biological activities of 948 volatile oils from 120 *Eucalyptus* species were reviewed in this paper,including 685 terpenoids,29 aliphatic compounds,39 aromatic compounds and 195 other compounds,and in order to make references for further research on the constituents and pharmacological activities of the volatile oil of *Eucalyptus*.

Key words:*Eucalyptus*;volatile oil;chemical constituents;biological activity

桉树为桃金娘科(Myrtaceae)桉属(*Eucalyptus* L. Herit)的常绿性乔木,原产于澳大利亚、印度尼西亚岛屿和马布亚新几里亚,共有 945 个种和变种,具有挥发性物质排放量大特性,尤其是枝叶富含挥发油,但不同种类不同地区的挥发油含量差异较大[1-4]。现全球桉属约有 600 多种,我国引进桉树已有百年历史,目前我国的桉树主要分布于华南地区,广东和广西为桉树主要种植区域,主要用于造纸、生产人造板和抽取桉油,目前我国也是最大的桉树油出口国之一。迄今为止,从桉属植物中发现了大量挥发性化学成分,主要为萜类(包括单萜、倍半萜等)、脂肪族化合物、芳香族化合物及其他化合物。现代药理研究已证实桉属挥发油化学成分具有抗菌消炎、改善呼吸道功能、杀虫、抗氧化、抗炎镇痛等功效,国内外学者已对其挥发油化学成分和生物活性进行了广泛研究[1-4]。据笔者统计,国内外学者已从桉属植物中分离鉴定了 948 个挥发性化学成分,其中萜类化合物共 685 个、脂肪族化合物共 29 个、芳香族化合物共 39 个、其他化合物共 195 个。本文对近三十年来桉属植物挥发油化学成分和生物活性的研究进展进行了系统综述,为更好地利用桉叶资源

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的药用价值及进一步深入研究开发提供依据。

1 化学成分

1.1 萜类

萜类广泛存在于植物中,是分子式为异戊二烯的整数倍的烯烃类化合物,具有较强的挥发性香气及生物活性。桉属挥发油中已知最主要的化学成分是萜类化合物,主要分为单萜、含氧单萜、倍半萜和含氧倍半萜。

1.1.1 单萜

单萜化合物是桉属挥发油中重要的活性成分,桉属挥发油中的单萜化合物主要有萜品油烯(terpinolene)、对伞花烃(*p*-cymene)、松油烯(terpinene)、柠檬烯(limonene)、蒎烯(pinene)和罗勒烯(ocimene)等,本文综述了桉属挥发油中单萜化合物共85种,化合物名称详见表1,代表性化合物结构详见图1。

表1 桉属单萜化合物

Table 1 Monoterpenes of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
1	α-萜品油烯 α-Terpinolene	*E. globulus* *E. citriodora*	2,4
2	萜品油烯 Terpinolene	*E. radiata* *E. globulus*	2,4
3	Isoterpinolene	*E. globulus*	2,4
4	Sylvestrene	*E. saligna*	3,5,13
5	对伞花烃 p-Cymene	*E. globulus* *E. falcata*	2,4
6	Neoalloacymene	*E. globulus*	2,4
7	*L*-水芹烯 *L*-Phellandrene	*E. citriodora* *E. brockwayii*	5,6
8	α-Terpinene acetate	*E. largiflorens* *E. oleosa*	8
9	萜品烯 Terpinene	*E. maidenii*	11
10	Iso-terpinene	*E. globulus*	2,4
11	τ-萜品烯 τ-Terpinene	*E. globulus*	2,4
12	δ-萜品烯 δ-Terpinene	*E. staigeriana*	9
13	α-萜品烯 α-Terpinene	*E. torquata* *E. melanophloia* *E. tereticornis*	5,8
14	Earane	*E. robusta*	13,22
15	柠檬烯 Limonene	*E. polybractea* *E. smithii* *E. approximans* *E. sideroxylm*	16,18,19
16	水芹烯 Phellandrene	*E. microtheca* *E. brockwayi*	21
17	γ-萜品烯 γ-Terpinene	*E. decaisneana* *E. houseana*	14
18	α-水芹烯 α-Phellandrene	*E. elata* *E. largiflorens*	19
19	β-水芹烯 β-Phellandrene	*E. dundasii* *E. diversicolor*	3,15,18,24
20	Epi-bicyclosesquiphellandrene	*E. camaldulensis*	5,12
21	Phellandrene epoxide	*E. camaldulensis* *E. viminali*	5,12
22	α-Phellandrene epoxide	*E. camaldulensis* *E. viminalis*	5,20
23	*cis*-Piperitol	*E. gigantea* *E. camaldulensis*	11
24	*trans*-Piperitol	*E. dundasii* *E. melanophloia*	3,24
25	Piperitol	*E. urophylla* *E. staigeriana*	2,13
26	β-Myrecene	*E. cinerea*	5
27	β-月桂烯 β-Myrcene	*E. globulus* *E. cinerea*	2,4
28	月桂烯 Myrcene	*E. nesophila* *E. cladocalyx*	6,17,25
29	Sabinine	*E. oleosa*	7
30	桧萜 Sabinene	*E. botryoides* *E. tereticornis*	6

续表 1(Continued Tab. 1)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
31	α-蒎烯 α-Pinene	*E. maidenis* *E. bridgesiana*	32
32	β-蒎烯 β-Pinene	*E. sargentii* *E. microthec*	8,28
33	2-β-蒎烯 2-β-Pinene	*E. gunnii* *E. globulus*	5,11
34	莰烯 Camphene	*E. macrorrhyncha* *E. procera*	11
35	崖柏烯 Thujene	*E. camaldulensis*	5,12
36	2-崖柏烯 2-Thujene	*E. camaldulensis*	5,12
37	α-崖柏烯 α-Thujene	*E. globulus* *E. radiata*	2,4
38	*D*-萜二烯 *D*-Limonene	*E. leucoxylon* *E. staigeriana*	19,24
39	顺式-罗勒烯 *cis*-Ocimene	*E. dunnii* *E. radiata*	3,5,13
40	α-罗勒烯 α-Ocimene	*E. exserta*	13,35
41	β-罗勒烯 β-Ocimene	*E. globulus* *E. citriodora*	2,4
42	(*E*)-β-罗勒烯 (*E*)-β-Ocimene	*E. dunnii* *E. saligna*	3,5,13
43	反式-罗勒烯 *trans*-Ocimene	*E. exserta* *E. urophylla*	13,35
44	罗勒烯 Ocimene	*E. urophylla* *E. saligna*	2,13
45	β-顺式-罗勒烯 β-*cis*-Ocimene	*E. citriodora* *E. cinerea*	5,6
46	β-反式-罗勒烯 β-*trans*-Ocimene	*E. globulus* *E. grandis*	2,4
47	Neo-allo-ocimene	*E. oleosa* *E. spathulata*	7
48	别罗勒烯 Allo-ocimene	*E. alba* *E. tereticornis*	2,5,13,14,33
49	Orto-cimeno	*E. urograndis*	38,39
50	Thuja-2,4(10)-diene	*E. gillii* *E. fasciculosa*	6,8
51	Verbenene	*E. ovata* *E. macarthurii*	6
52	o-异丙基甲苯 o-Cymene	*E. globulus* *E. staigeriana*	2,4
53	Cymenene	*E. lehmannii* *E. sideroxylon*	23,24
54	*m*-Cymenene	*E. citriodora* *E. dunnii*	5,6
55	*m*-Cymene	*E. globulus*	2,4
56	*p*-Cymenene	*E. globulus* *E. occidentalis*	2,4
57	3-蒈烯 3-Carene	*E. globulus* *E. sideroxylon*	2,4
58	Bornylene	*E. cinerea*	5
59	β-葑醇 β-Fenchol	*E. teretecornis*	40
60	葑醇 Exo-fenchol	*E. camaldulensis*	5,12
61	δ-3-蒈烯 δ-3-Carene	*E. kitsoniana* *E. kitsoniana*	21,24,29
62	4-蒈烯 4-Carene	*E. globulus* *E. procera*	2,4
63	δ-蒈烯 δ-Carene	*E. camaldulensis*	5,12
64	蒈烯 Carene	*E. urophylla*	2,13
65	2-蒈烯 2-Carene	*E. grandisx*	2,33,35

续表 1(Continued Tab. 1)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
66	4-Allyloxyimino-2-carene	*E. oleosa*	7
67	δ-2-蒈烯 δ-2-Carene	*E. citriodora*	5,6
68	薄荷呋喃 *p*-Mentha-3,8-diene	*E. grandis* *E. citriodora*	8
69	1-甲基-4-(1-甲基乙基)-1,4-环己二烯 *p*-Mentha-1,4-diene	*E. globulus*	2,4
70	1,3,8-*p*-Menthatriene	*E. grandisx*	2,33,35
71	1-Methyl-3-(1-methyl ethyl) benzene	*E. robusta*	13,22
72	Benzene,1-methyl-4-(1-methylethenyl)	*E. tereticornis*	2,5,13,14
73	(1*R*)-2,2-Dimethyl-3-methylene-dicyclo[2.2.1] heptane	*E. robusta*	13,22
74	α-葑醇 α-Fenchol	*E. grandis* *E. urophylla*	8
75	2,4-Dimethyl styrene	*E. grandisx*	2,33,35
76	*D*-Sylvestrene	*E. camaldulensis*	5,12
77	2.4(10)-Thujadiene	*E. dunnii*	3,5,13
78	γ-松油烯 γ-Terpinen	*E. globulus* *E. camaldulensis*	2,4
79	α-Fenchene	*E. globulus* *E. gracilis*	2,4
80	*cis*-2,6-Dimethyl-2,6-octadiene	*E. citriodora*	5,6
81	杜烯 Durene	*E. globulus*	2,4
82	Neoalloocimene	*E. torquata* *E. urophylla*	8
83	*p*-Mentha-1(7),8-diene	*E. dives* *E. citriodora*	5,18,19
84	*p*-Mentha-1(7),5-dien-2-ol	*E. houseana* *E. robusta*	22 13,22
85	Fenchene	*E. procera* *E. globulus*	43

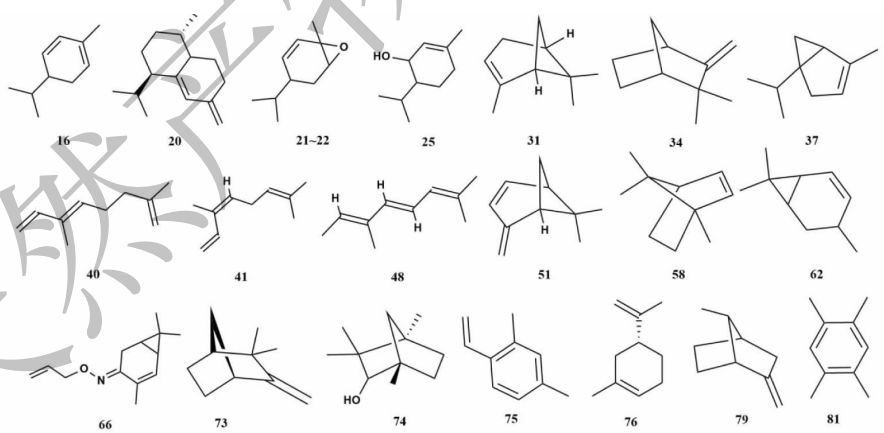

图 1 桉属中单萜代表性化合物的结构

Fig. 1 Structures of representative monoterpenes from *Eucalyptus*

1.1.2 含氧单萜

含氧单萜化合物是桉树挥发油中最主要的活性成分,是医药、食品和日用化妆品工业的重要原料。桉属挥发油中含氧单萜化合物主要有桉叶油素(cineole)、芳樟醇(linalool)、香茅醛(citronellal)、异胡薄荷醇(isopulegol)、松油醇(terpinol)、香茅醇(citronellol)等,本文综述了桉属挥发油中含氧单萜化合物共 309 种,化合物名称详见表 2,代表性化合物结构详见图 2。

表 2 桉属含氧单萜化合物

Table 2 Oxygen-contain monoterpenes of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
86	1,4-桉叶油醇 1,4-Cineole	*E. globulus* *E. citriodo*	2,4
87	Methyl geraniate	*E. staigeriana*	9
88	Methyl geranate	*E. staigeriana*	9
89	Amyl isovalerate	*E. oleosa* *E. saligna*	7
90	Isoamyl isovalerate	*E. bicostata* *E. spathula*	11,20
91	Limoneneoxide, cis	*E. staigeriana*	9
92	3-Cyclohexene-1-citral	*E. radiata*	2,3
93	1-Acetyl-4-isopropylcyclopentene	*E. globulus*	2,4
94	1-Terpinene-4-yl acetate	*E. citriodora*	5,6
95	Isopulegyl acetate	*E. torelliana* *E. citriodora*	13,25
96	柠檬醛 Citral	*E. globulus* *E. radiata*	2,4
97	α-Citral	*E. cinerea*	5
98	β-Citral	*E. cinerea* *E. radiata*	5
99	*E*-Citral	*E. staigeriana* *E. citriodo*	9
100	*Z*-Citral	*E. staigeriana* *E. citriodo*	9
101	*Z*-Isocitral	*E. staigeriana*	9
102	*E*-Isocitral	*E. staigeriana*	9
103	乙酸松油酯 Terpineol acetate	*E. globulus* *E. dunnii*	2,4
104	乙酸香茅酯 Citronellyl acetate	*E. polycarpa* *E. citriodo*	25
105	Dehydro-1,8-cineole	*E. globulus*	2,4
106	2-羟基桉叶油素 2-Hydroxycineole	*E. globulus*	2,4
107	1-Methyl-4-(1-methyl-acetal)cyclohexene	*E. globulus*	2,4
108	氧化芳樟醇 Linalool oxide	*E. viminalis*	5,20
109	顺式-氧化芳樟醇 *cis*-Linalool oxide	*E. globulus* *E. botryoide*	2,4
110	反式-氧化芳樟醇 *trans*-Linalool oxide	*E. grandis* *E. oleosa*	2,33,35
111	*cis*-Thujone	*E. globulus* *E. grandis*	2,4
112	α-Thujone	*E. tereticornis*	2,5,13,14
113	β-thujone	*E. tereticornis*	2,5,13,14
114	Thujone	*E. globulus*	2,4
115	Sabinyl acetate	*E. torelliana*	13,25
116	Artemisia ketone	*E. camaldulensis*	5,12
117	Thuj-3-en-10-al	*E. staigeriana*	9
118	3-Thujen-2-ol	*E. camaldulensis*	5,12
119	*trans*-Thujenol	*E. globulus*	2,4
120	氧化柠檬烯 Limonene oxide	*E. globulus*	2,4
121	1,8-Cineole	*E. umbellate* *E. falcata*	35
122	Rose oxide	*E. globulus* *E. saligna*	2,4
123	*trans*-Rose oxide	*E. citriodora*	2,5,13,14

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
124	*cis*-Rose oxide	*E. tereticornis*	2,5,13,14
125	Dehydro-sabina ketone	*E. sphaerocarpa*	27
126	Sabina ketone	*E. camaldulensis*	5,12
127	Dihydromyrcenol	*E. torelliana*	13,25
128	香茅醛 Citronellal	*E. globulus*	2,4
129	Citronellal oxime	*E. tereticornis* *E. crebra*	2,5,13,14
130	(*L*)-香茅醛 (*L*)-citronellal	*E. grandis*	2,33,35
131	(*R*)-香茅醛 (*R*)-Citronellal	*E. urophylla*	2,13
132	*β*-Citronellal	*E. citriodora*	5,6
133	*α*-Pinene oxide	*E. dunnii* *E. saligna*	3,5,13
134	Pinocamphone	*E. sideroxylon* *E. rudis*	5
135	*trans*-Pinocamphone	*E. globulus*	2,4
136	Iso-pinocamphone	*E. astringens* *E. gillii*	23,24
137	*α*-芳樟醇 *α*-Linalool	*E. globulus*	2,4
138	*β*-芳樟醇 *β*-Linalool	*E. globulus* *E. cinerea*	2,4
139	芳樟醇 Linalool	*E. globulus* *E. oleosa*	2,4
140	Linalool acetate	*E. olida* *E. camaldulensis*	5,15
141	*trans*-2-Menthenol	*E. meliodora*	42
142	Neoiso-isopulegol	*E. citriodora*	5,6
143	Iso-isopulegol	*E. oldfieldii* *E. woodwardii*	8
144	Neo-isopulegol	*E. globulus*	2,4
145	胡薄荷醇 Isopulegol	*E. houseana* *E. rudis*	22
146	Isoisopulegol	*E. citriodora* *E. exerta*	5,6
147	Methyl cinammate	*E. andrewsii*	27
148	1-*S*-*β*-Fenchol	*E. camaldulensis*	5,12
149	Endo-fenchol	*E. resinifera* *E. dunnii*	27
150	*α*-Terpinol	*E. globulus*	2,4
151	Terpinen-4-ol	*E. globulus* *E. dives*	2,4
152	Terpinene-4-ol	*E. maculate* *E. rudis*	24
153	*p*-Menth-3-en-8-ol	*E. tereticornis*	2,5,13,14
154	*p*-Menth-1-en-8-ol	*Eucalyptus*	10
155	Isopulegol isomers	*E. tereticornis*	2,5,13,14
156	反式-松香芹醇 *trans*-Pinocarveol	*E. falcate* *E. radiata*	24
157	顺式-松香芹醇 *cis*-Pinocarveol	*E. erythrocorys*	36
158	松香芹醇 Pinocarveol	*E. globulus* *E. procera*	2,4
159	松香芹醇 1-Pinocarveol	*E. grandisx*	2,33,35
160	*L*-松香芹醇 *L*-Pinocarveol	*E. globulus*	2,4
161	Isopinocarveol	*E. globulus* *Eucalyptus*	2,4
162	香茅醇 Citronellol	*E. globulus* *E. olida*	2,4

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
163	*D*-香茅醇 *D*-Citronellol	*E. pellita*	13,35
164	β-香茅醇 β-Citronellol	*E. globulus* *E. oleosa*	2,4
165	β-香茅醇(-)-β-Citronellol	*E. tereticornis*	2,5,13,14
166	β-香茅醇(+)-β-Citronellol	*E. tereticornis*	2,5,13,14
167	Carvotanacetone	*E. globulus* *E. dunnii*	2,4
168	(+)-Carvotanacetone	*E. tereticornis*	2,5,13,14
169	Limonen-4-ol	*E. tereticornis*	2,5,13,14
170	α-Terpinyl acetate	*E. bridgesiana*	37
171	Terpinyl acetate	*E. occidentalis*	8
172	β-松油醇(*Z*)-β-Terpineol	*E. oleosa* *E. cinerea*	7
173	α-乙酸松油酯 α-Terpineol acetate	*E. globulus* *E. cinerea*	2,4
174	α-松油醇 α-Terpineol	*E. radiata* *E. dives*	27
175	β-松油醇 β-Terpineol	*E. citriodora*	5,6
176	γ-松油醇 γ-Terpineol	*E. siderophloia*	27
177	δ-松油醇 δ-Terpineol	*E. globulus* *E. dunnii*	2,4
178	σ-松油醇 σ-Terpineol	*E. gracilis* *E. ovata*	11
179	Carvenone	*E. globulus* *E. saligna*	2,4
180	Sabinol	*E. globulus* *E. oleosa*	2,4
181	*trans*-Sabinol	*E. occidentalis* *E. urophylla*	8
182	1-萜品醇 1-Terpineol	*E. pauciflora* *E. oleosa*	11
183	4-萜品醇(-)-4-Terpineol	*E. globulusssp* *E. maidenii*	5
184	Isoborneol	*E. globulus* *E. olida*	2,4
185	Endo-borneol	*E. oleosa* *E. spathulata*	3,7
186	龙脑 Borneol	*E. globulus*	2,4
187	*L*-龙脑 *L*-Borneol	*E. camaldulensis* *E. procera*	5,12
188	2,3-蒎烷二醇 2,3-Pinanediol	*E. tereticornis*	2,5,13,14
189	Myrtanal	*E. camaldulensis* *E. cinerea*	5,12
190	Myrtenol	*E. globulus* *E. dunnii*	2,4
191	*p*-Mentha-1,4-dien-7-ol	*E. camaldulensis*	5,12
192	*p*-Mentha-1,5-dienol-8	*E. staigeriana* *E. dunnii*	9
193	(*E*)-*p*-Mentha-1(7),8-dien-2-ol	*E. globulus* *E. cinerea*	2,4
194	(*Z*)-*p*-Mentha-1(7),8-dien-2-ol	*E. globulus* *E. cinerea*	2,4
195	*p*-Ment-1(7)-en-2-one	*E. globulus*	2,4
196	*cis*-*p*-Mentha-1,8-dien-6-ol	*E. globulus* *E. exerta*	2,4
197	*trans*-*p*-Mentha-1,8-dien-6-ol	*E. diversifolia*	23,24
198	*p*-Cymene-8-ol	*E. grandisx* *E. urophylla*	2,33,35
199	Cuminol	*E. viminalis*	5,20
200	Dihydroconiferyl alcohol	*E. viminalis*	5,20
201	Coniferyl alcohol	*E. viminalis*	5,20

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
202	3-Nopinenone	*E. grandisx* *E. urophylla*	2,33,35
203	茉莉酮 Jasmone	*E. globulus*	2,4
204	顺式-茉莉酮 *cis*-Jasmone	*E. citriodora* *E. cinerea*	5,6
205	(*E*)-Jasmone	*E. grandis* *E. urophylla*	2,33,35
206	2,2-Dimethyl-5-(1-methyl-1-1-propenyl) tetrahydrofuran	*Eucalyptus*	10
207	*p*-Menthane 3,8-diol	*E. citriodora*	5,6
208	Tetrahydroger-anylacetone	*E. tereticornis*	2,5,13,14
209	香茅酸 Citronellic acid	*E. citriodora*	5,6
210	Thymol	*E. globulus* *E. rudis*	2,4
211	Geranyl acetate	*E. globulus* *E. gunnii*	2,4
212	Geranylisobutyrate	*E. saligna*	3,5,13
213	*cis-p*-Menth-2-en-1-ol	*E. tereticornis* *E. dives*	2,5,13,14
214	*trans-p*-Menth-2-en-1-ol	*E. citriodora* *E. dives*	5,6
215	*trans-p*-Menth-1,8-dien-6-ol	*E. citriodora* *E. exerta*	5,6
216	*cis-p*-Mentha-2,8,dien-1-ol	*E. camaldulensis*	5,12
217	*p*-Menth-2-en-1-ol	*E. globulus* *E. tereticornis*	2,4
218	*trans-p*-Mentha-2,8-diénol	*E. globulus*	2,4
219	Campholenal	*E. citriodora* *E. saligna*	5,6
220	α-龙脑烯醛 α-campholenal	*E. globulus* *E. crebra*	2,4
221	氧化橙花醇 Nerol oxide	*E. oleosa* *E. dunnii*	7
222	Diphenyl oxide	*E. grandis* *E. ovata*	8
223	Pinacarvone	*E. salubris* *E. cinérea*	3
224	反式-松香芹酮 *trans*-Pinocarvone	*E. grandisx* *E. urophylla*	2,33,35
225	松香芹酮 Pinocarvone	*E. globulus*	2,4
226	松香芹酮 Pinocarvone	*E. dealbata*	30
227	Crypton	*E. gomphocephala*	23,24
228	隐酮 Cryptone	*E. globulus* *E. rudis*	2,4
229	-(-)-Myrtenal	*E. salmonophloia*	8
230	Myrtenal	*E. citriodora* *E. exerta*	5,6
231	Verbenone	*E. globulus* *E. oleosa*	2,4
232	*m*-Cumeno	*E. camaldulensis*	5,12
233	Cumin aldehyde	*E. gracilis* *E. salubris*	3,11
234	*p*-Cumin aldehyde	*E. meliodora*	42
235	Cumic alcohol	*E. camaldulensis*	5,12
236	香芹酮 Carvone	*E. globulus* *E. ovata*	2,4
237	*D*-香芹酮 *D*-Carvone	*E. globulus*	2,4
238	*E*-Dihydrocarvone	*E. camaldulensis* *E. cinerea*	5,12
239	Myrtenyl-acetate	*E. camaldulensis*	5,12

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
240	Terpenyl acetate	*E. viminalis*	5,20
241	α-Terpenyl acetate	*E. camaldulensis*	5,12
242	薄荷烯酮 Piperitone	*E. globulus* *E. oleosa*	2,4
243	*p*-Menth-1-en-7-al	*E. camaldulensis*	5,12
244	α-Terpinen-7-al	*E. camaldulensis*	5,12
245	顺式-香芹酚 *cis*-Carvacrol	*E. nitens* *E. dunnii*	47
246	香芹酚 Carvacrol	*E. globulus* *E. oleosa*	2,4
247	3-Oxo-p-menth-1-en-7-al	*E. camaldulensis*	5,12
248	Isodihydro carveol	*E. camaldulensis*	5,12
249	Neo-iso-dihydro carveol	*E. globulus* *E. salubris*	2,4
250	*cis*-Myrtanol	*E. camaldulensis* *E. citriodora*	5,12
251	Neric acid	*E. staigeriana*	9
252	Geranic acid	*E. staigeriana*	9
253	反式-香芹醇 *trans*-Carveol	*E. globulus* *E. ovata*	2,4
254	顺式-香芹醇 *cis*-Carveol	*E. macarthurii* *E. oleosa*	11
255	香芹醇 Carveol	*E. globulus* *E. viminalis*	2,4
256	Iso-carveol	*E. robusta*	13,22
257	Phellandral	*E. citriodora* *E. rudis*	5,6
258	Linalyl acetate	*E. citriodora*	5,6
259	乙酸龙脑酯 Bornyl acetate	*E. citriodora* *E. oleosa*	5,6
260	Isobornyl acetate	*E. torelliana* *E. globulus*	13,25
261	2-羟基桉树脑 Exo-2-hydroxycineole acetate	*E. globulus* *E. cinerea*	2,4
262	樟脑 Camphor	*E. robusta* *E. oleosa*	13,22
263	Neral	*E. globulus* *E. olida*	2,4
264	Neral oxime	*E. tereticornis*	2,5,13,14
265	Geranial	*E. globulus* *E. olida*	2,4
266	橙花醇 Nerol	*E. globulus* *E. radiata*	2,4
267	反式-香叶醇 *trans*-Geraniol	*E. staigeriana*	9
268	香叶醇 Geraniol	*E. globulus* *E. ovata*	2,4
269	Acetic acid geraniol ester	*E. globulus*	2,4
270	Geraniol acetate	*E. globulus* *E. radiata*	2,4
271	α-β-γ-桉树脑 α-β-γ-Eucalyptol	*E. globulus*	2,4
272	α-β-桉树脑 α-β-Eucalyptol	*E. globulus*	2,4
273	β-桉树脑 β-Eucalyptol	*E. globulus*	2,4
274	1,3,7-Dimethyl-1,3,7octatriene	*E. saligna*	3,5,13
275	水合樟烯 Camphene hydrate	*E. oleosa* *E. crebra*	7
276	糠醇 2-Furanmethanol	*E. globulus*	2,4
277	Lavandulol	*E. staigeriana* *E. cinerea*	9
278	Eugenol	*E. caryophyllus* *E. dives*	41

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
279	Methyl eugenol eugenol methyl ether	*E. pruinosa* *E. rudis*	21
280	1,4-Dimethyl-3-cyclohexenyl methyl ketone	*E. oleosa*	7
281	Cuminic aldehyde	*E. globulus*	2,4
282	Biosol	*E. globulus* *E. radiata*	2,4
283	*D*-Fenchyl alcohol	*E. globulus* *E. radiata*	2,4
284	葑醇 Fenchol	*E. globulus* *E. rudis*	2,4
285	Pentanal,3-(acetyloxy)-2,2,4-trimethyl	*E. grandisx* *E. urophylla*	2,33,35
286	1,5,7-Octatrien-3-ol,2,6-dimethyl-	*E. oleosa*	7
287	4-Ethyl-1-dimethoxybenzene	*E. viminalis*	5,20
288	4-Hydroxy-3-methyl-6-(1-methylethyl)-*trans*-2-cyclohexene-1-one	*E. viminalis*	5,20
289	(*S*)-(-)-Isopropenyl-1-cyclohexene-1-carboxylic acid	*E. viminalis*	5,20
290	Perilla aldehyde	*E. cinerea* *E. camaldulensis*	5
291	Noreugenine	*E. viminalis*	5,20
292	*p*-Mentha-1-ene-8-ol	*E. tereticornis*	2,5,13,14
293	Bicyclo[2.2.1]heptan-3-one,6,6-dimethyl-2-methylene	*E. tereticornis*	2,5,13,14
294	Bicyclo[3,1,1]heptan-3-ol	*E. globulus*	2,4
295	[1*S*-(1,3,5)]-6,6-Dimethyl-2-methylenebicyclo[3.1.1]heptan-3-ol	*E. saligna*	3,5,13
296	2-Cyclohexen-1-one,2-methyl-5-(1-methylethenyl)	*E. tereticornis*	2,5,13,14
297	3-Cyclohexen-1-one 2-isopropyl-5-methyl-	*E. oleosa*	7
298	3-Cyclopentene-1-acetaldehyde,2,2,3-trimethyl	*E. tereticornis*	2,5,13,14
299	2-Caren-10-al	*E. tereticornis*	2,5,13,14
300	*trans*-Caren-2-ol	*E. globulus*	2,4
301	Endo-borneol	*E. oleosa* *E. torquata*	7
302	Cirtronellol	*E. tereticornis*	2,5,13,14
303	4-Isopropilbenzaldehyde	*E. globulus* *E. tereticornis*	2,4
304	(2*R*,5*R*)-2-Methyl-5-(prop-1en-2-yl) Cyclohexanone	*E. globulus*	2,4
305	6-Camphenol	*E. dunnii*	3,5,13
306	6-Camphenone	*E. brockwayii* *E. spathulata*	3,46
307	Limonene dioxide-4	*E. globulus*	2,4
308	*cis*-Menth-2-en-1-ol	*Eucalyptus*	10
309	*trans*-Menth-2-en-1-ol	*E. melanophloia*	10
310	*trans*-Piperitol	*Eucalyptus* *E. dives*	10
311	*trans-p*-Mentha-2,8-dien-1ol	*E. torelliana* *E. oleosa*	13,25
312	*E*-4,5-Epoxy-*E*-2-decenal	*E. cinerea*	5
313	(*E*,*E*,*Z*)-2,4,7-Decatrienal	*E. cinerea*	5
314	Dihydrocarveol	*E. citriodora*	5,6
315	Perillyl alocohol	*E. globulus* *E. gillii*	2,4
316	Isopentyl-2-methyl butanoate	*E. globulus* *E. dunnii*	2,4

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
317	3-Methyl-2-butenyl 2-methylbutanoate	*E. camaldulensis*	5,12
318	3-Methyl-3-butenyl 3-methylbutanoate	*E. camaldulensis*	5,12
319	Cuminaldehyde	*E. saligna* *E. oleosa*	5,12
320	Cumyl alcohol	*E. gunnii*	5,11
321	Cuminal	*E. cinerea* *E. cinerea*	5
322	Eucarvone	*E. cinerea*	5
323	Ipsdienol	*E. dunnii*	3,5,13
324	氧化橙花醇 Nerol oxide	*E. dunnii*	3,5,13
325	2-Methyl-1-phenylpropan-2-ol	*E. cinerea* *E. camaldulensis*	5
326	2,7-Dimethyle octan-3,5-dione	*E. globulus*	2,4
327	Thujyl alcohol	*E. citriodora*	5,6
328	(*E*)-Dehydroxylinalool oxide	*E. saligna*	3,5,13
329	Iso-menthone	*E. globulus*	2,4
330	薄荷酮 Menthone	*E. globulus*	2,4
331	*cis*-Verbenol	*E. globulus* *E. salmonophloia*	2,4
332	*trans*-Verbenol	*E. torelliana* *E. globulus*	13,25
333	异香芹醇 Cyclohexanol,2-methylene5-isopropenyl	*E. globulus* *E. radiata*	2,4
334	2(10)-Pinen-3-one	*E. crebra* *E. rudis*	21
335	Neo-isodihydrocarveol	*E. globulus*	2,4
336	*trans*-Anethole	*E. oleosa* *E. torquata*	7
337	2,3,3-Trimethyl-2-norbornanol	*E. globulus*	2,4
338	*p*-Menthen-8-ol	*E. globulus*	2,4
339	*p*-Menthen-4-ol	*E. globulus*	2,4
340	2-Isopropenyl-5-methylhex-4-enal	*E. kitsoniana*	21,24,29
341	Fenchone	*E. occidentalis*	8
342	α-Fenchone	*E. oleosa*	7
343	α-Camphenaldehyde	*E. oleosa*	7
344	5-Caranol	*E. robusta*	13,22
345	2-Methyl-4-(1-methylethyl)-2-cyclohexenone	*E. oleosa*	7
346	*Z*-4-Octene-2,7-diol,2,7-dimethyl	*E. oleosa*	7
347	4-(1-Methylethyl)-benzenemethanol	*E. oleosa*	7
348	Propanal,2-methyl-3-phenyl-	*E. oleosa*	7
349	Citronelal	*E. staigeriana*	9
350	α-Phellandrene epoxide	*E. viminalis*	5,20
351	α-Campholene aldehyde	*E. oleaosa* *E. saligna*	7,26
352	Menthofuran	*Eucalyptus*	10
353	Umbellulon	*E. globulus*	2,4
354	Durohydroquinone	*E. saligna*	3,5,13
355	对伞花-8-醇 *p*-Cymen-8-ol	*E. globulus* *E. crebra*	2,4

续表 2(Continued Tab. 2)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
356	对伞花-3-醇 *p*-Cymen-3-ol	*E. crebra* *E. rudis*	21
357	间伞花-8-醇 *m*-Cymen-8-ol	*E. globulus*	2,4
358	对伞花-7-醇 *p*-Cymen-7-ol	*E. oleosa* *E. gunnii*	7
359	*trans*-Ascaridol glycol	*E. saligna*	3,5,13
360	*p*-Menth-1(7)-en-2-one	*E. robusta*	13,22
361	4-松油烯醇 *p*-Menth-1-en-4-ol	*E. robusta* *E. dives*	13,22
362	*p*-Menth-1-en-8-ol	*E. robusta*	13,22
363	(*Z*)-Ocimenone	*E. occidentalis*	8
364	Dihydrocarvone	*E. oleosa*	7
365	(*E*)-Dihydrocarvone	*E. occidentalis* *E. dunnii*	8
366	反式-松香芹 *trans*-Pinocarvone	*E. dunnii* *E. salubris*	3,5,13
367	*trans*-Linalyl oxide	*E. grandisx* *E. urophylla*	2,33,35
368	*cis*-Linalyloxide	*E. globulus* *E. dunnii*	2,4
369	*Z*-Linalol oxide	*E. staigeriana*	9
370	Linalol	*E. globulus* *E. dunnii*	2,4
371	薄荷烯酮 Piperitone	*E. globulus* *E. oleosa*	2,4
372	*D*-薄荷烯酮 *D*-Piperitone	*E. grandis* *E. ovata*	8
373	δ-薄荷烯酮 δ-Piperitone	*E. falcata* *E. rudis*	23
374	Piperitenone	*E. torelliana*	13,25
375	Isomenthol	*E. salubris* *E. brockwayii*	3
376	Menthol	*E. globulus*	2,4
377	龙脑烯醛 Campholenic aldehyde	*E. globulus*	2,4
378	Umbellulol	*E. globulus*	2,4
379	Phellandral	*E. grandis* *E. oleosa*	8
380	松香芹酮 Pinocarvone	*E. globulus* *E. radiata*	2,4
381	萜品醇 Terpineol	*E. globulus*	2,4
382	Rhodinic acid	*E. citriodora*	5,6
383	Carvol	*Eucalyptus* *E. dunnii*	10
384	Isopulegone	*E. citriodora*	5,6
385	Pulegone	*E. oleosa* *E. gracilis*	7
386	Neoiso(iso)pulegol	*E. citriodora*	5,6
387	Eucamalol	*E. camaldulensis*	5,12
388	Turpentine propionate	*E. grandisx* *E. urophylla*	2,33,35
389	Geranyl propionate	*E. grandisx* *E. urophylla*	2,33,35
390	α-Terpinyl propionate	*E. grandisx* *E. urophylla*	2,33,35
391	α-乙酸松油酯 α-Terpineol acetate	*E. grandis*	8
392	Dihydro-linalool acetate	*E. salubris*	3
393	Turpentine propionate	*E. grandisx* *E. urophylla*	2,33,35
394	Geranyl propionate	*E. grandisx* *E. urophylla*	2,33,35

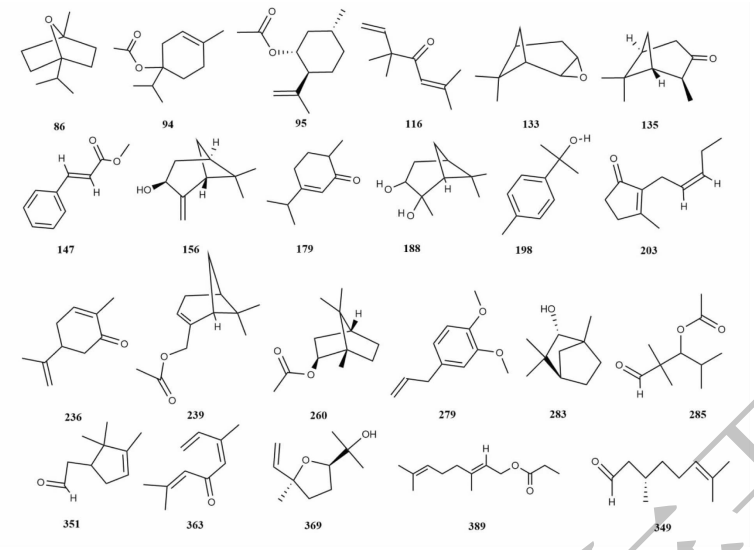

图 2　桉属中含氧单萜代表性化合物的结构

Fig. 2　Structures of representative oxygen-containing monoterpenes from *Eucalyptus*

1.1.3　倍半萜

倍半萜是萜类化合物中最大的一个分支,大多具有较高沸点。桉属挥发油中倍半萜化合物主要有荜澄茄烯(cubebene)、石竹烯(caryophyllene)、香橙烯(aromadendrene)、葎草烯(humulene)、蛇床烯(selinene)、古芸烯(gurjunene)、杜松烯(cadinene)、愈创木烯(guaiene)等。本文综述了桉属挥发油中倍半萜化合物共 146 种,化合物名称详见表 3,代表性化合物结构详见图 3。

表 3　桉属倍半萜化合物

Table 3　Sesquiterpenes of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
395	α-荜澄茄油萜 α-Cubebene	*E. globulus*　*E. gillii*	2,4
396	β-Cubebene	*E. citriodora*　*E. gracilis*	5,6
397	荜澄茄油萜 Cubebene	*E. globulus*	2,4
398	可巴烯 Copaene	*E. camaldulensis*	5,12
399	α-可巴烯 α-Copaene	*E. globulus*　*E. saligna*	2,4
400	Guaia-3,9-diene	*E. viminalis*	5,20
401	Eudesma-3,7(11)-diene	*E. viminalis*	5,20
402	*trans*-Cadina-1,4-diene	*E. camaldulensis*　*E. urophylla*	5,12
403	τ-石竹烯 τ-Caryophyllene	*E. tereticornis*	2,5,13,14
404	Isocaryophyllene	*E. cinerea*	5
405	石竹烯 Caryophyllene	*E. globulus*　*E. crebra*	2,4
406	(*Z*)-石竹烯 (*Z*)-Caryophyllene	*E. globulus*　*E. dunnii*	2,4
407	(*E*)-石竹烯 (*E*)-Caryophyllene	*E. citriodora*　*E. olida*	5,6
408	异喇叭烯 Isoledene	*E. globulus*　*E. oleosa*	2,4
409	喇叭烯 Ledene	*E. globulus*　*E. procera*	2,4
410	喇叭烯 Ledene	*E. globulus*　*E. grandis*	2,4
411	Ledene oxide-(II)	*E. meliodora*　*E. meliodora*	42

续表 3(Continued Tab. 3)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
412	Cadina-1,4-diene	*E. diversifolia* *E. odorata*	23,24
413	*trans*-Cadina-1,4-diene	*E. citriodora* *E. maculata*	5,6
414	α-Caryophyll-adienol	*E. meliodora*	42
415	α-石竹烯 α-Caryophyllene	*E. citriodora* *E. camaldulensis*	5,6
416	(*Z*)-β-石竹烯 (*Z*)-β-Caryophyllene	*E. globulus* *E. dunnii*	2,4
417	顺-β-石竹烯 *trans*-β-Caryophyllene	*E. staigeriana*	9
418	Bycyclo germacrene	*E. urophylla*	2,13
419	Bicycle germacrene	*E. grandisx* *E. urophylla*	2,33,35
420	Byciclogermacrene	*E. gunnii*	5,11
421	β-石竹烯 β-Caryophyllene	*E. globulus* *E. oleosa*	2,4
422	α-香木兰烯 α-Aromadendrene	*E. lehmannii* *E. leucoxylon*	23,24
423	香木兰烯 Aromadendrene	*E. globulus* *E. falcate*	2,4
424	香木兰烯 Aromadendrene	*E. falcate* *E. rudis*	2
425	香树烯 Alloaromadendrene	*E. globulus* *E. cinerea*	2,4
426	Allo-4-aromadendrene	*E. torelliana*	13,25
427	α-Humulene	*E. globulus* *E. gunnii*	2,4
428	β-Humulene	*E. globulus*	2,4
429	Humulen-(Ⅳ)	*E. microtheca*	21
430	α-Santalene	*E. camaldulensis*	5,12
431	α-Selinene	*E. globulus* *E. oleosa*	2,4
432	β-Selinene	*E. globulus* *E. gracilis*	2,4
433	δ-芹子烯 δ-Selinene	*E. globulus* *E. torquata*	2,4
434	γ-Selinene	*E. globulus* *E. oleosa*	2,4
435	β-Germacrene	*E. lehmannii* *E. astringens*	23,24
436	Germacrene A	*E. citriodora*	5,6
437	Germacrene B	*E. globulus* *E. rudis*	2,4
438	Germacrene D	*E. citriodora* *E. crebra*	5,6
439	α-Amorphene	*E. camaldulensis* *E. polycarpa*	5,12
440	2-龙脑 2-Borneol	*E. urophylla*	2,13
441	β-古芸烯 β-Gurjunene	*E. globulus* *E. saligna*	2,4
442	δ-古芸烯 δ-Gurgunene	*E. erythrocorys*	36
443	α-古芸烯 α-Gurjunene	*E. globulus* *E. maculata*	2,4
444	γ-古芸烯 γ-Gurjunene	*E. globulus* *E. saligna*	2,4
445	γ-杜松烯 γ-Cadinene	*E. globulus* *E. nesophila*	2,4
446	δ-杜松烯 δ-Cadinene	*E. odorata* *E. olida*	5,20
447	Cadinene	*E. camaldulensis* *E. lehmannii*	5,12
448	α-Cadinene	*E. citriodora* *E. urophylla*	5,6
449	β-Cadinene	*E. globulus*	2,4
450	σ-Cadinene	*E. globulus* *E. gillii*	2,4

续表 3(Continued Tab. 3)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
451	τ-Cadinene	*E. robusta*	13,22
452	t-Nerolidol	*E. citriodora*	5,6
453	*E*-Nerolidol	*E. globulus* *E. cinerea*	2,4
454	β-Bourbonene	*E. oleosa* *E. salubris*	7
455	榄香烯 Elemene	*E. globulus*	2,4
456	α-榄香烯 α-Elemene	*E. globulus*	2,4
457	β-榄香烯 β-Elemene	*E. globulus* *E. maculata*	2,4
458	γ-榄香烯 γ-Elemene	*E. camaldulensis* *E. tereticornis*	5,12
459	δ-Elemene	*E. camaldulensis* *E. maidenii*	5,12
460	α-Muurolene	*E. citriodora* *E. maculata*	5,6
461	γ-Muurolene	*E. globulus* *E. gracilis*	2,4
462	Bicyclogermacrene	*E. ficifolia* *E. polycarpa*	23
463	Pregeijerene	*E. camaldulensis*	5,12
464	Cyclo sativene	*E. camaldulensis*	5,12
465	Longifolene	*E. globulus*	2,4
466	Isolongifolene	*E. camaldulensis*	5,12
467	Isolongifolane	*E. globulus*	2,4
468	1,7-Di-epi-α-cedrene	*E. camaldulensis*	5,12
469	Thujopsene	*E. camaldulensis*	5,12
470	β-Gurejuene	*E. camaldulensis*	5,12
471	Patchoulene	*E. citriodora* *E. crebra*	5,6
472	γ-Patchoulene	*E. camaldulensis*	5,12
473	(*E*)-Farnesene	*E. camaldulensis*	5,12
474	(*E*,*E*)-α-Farnesene	*E. citriodora* *E. dunnii*	5,6
475	β-Farnesene	*E. meliodora* *E. camaldulensis*	42
476	(*Z*)-β-Farnesene	*E. meliodora*	42
477	9-Epi-(*E*)-caryophyllene	*E. torelliana* *E. dunnii*	13,25
478	14-Hydroxy-9-epi-*E*-caryophyllene	*E. camaldulensis* *E. cinerea*	5,12
479	*cis*-β-Guaiene	*E. camaldulensis* *E. maculata*	5,12
480	Bicylogermacrene	*E. camaldulensis*	5,12
481	*cis*-Muurola-4(14),5-diene	*E. camaldulensis* *E. maculata*	5,12
482	*trans*-Muurola-3,5-diene	*E. camaldulensis* *E. citriodora*	5,12
483	Guaiene	*E. astrengens*	34
484	*trans*-β-Guaiene	*E. nesophila* *E. polycarpa*	25
485	α-愈创木烯 α-Guaiene	*E. globulus* *E. gigantea*	2,4
486	β-Guaiene	*E. globulus* *E. cinerea*	2,4
487	δ-Guaiene	*E. blakelyi* *Eucalyptus*	13,19
488	Eromophilene	*E. globulus* *E. radiata*	2,4
489	Calarene	*E. globulus* *E. dunnii*	2,4

续表 3(Continued Tab. 3)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
490	*cis*-Calamenene	*E. camaldulensis* *E. citriodora*	5,12
491	去氢白菖烯 Calamenene	*E. globulus* *E. brockwayi*	2,4
492	*trans*-Calamenene	*E. torelliana* *E. maculata*	13,25
493	10,11-Epoxy-calamenene	*E. camaldulensis*	5,12
494	2-Isopropenyl-4a,8-dimethyl-1,2,3,4,4a,5,6,7-octahydronaphthalene	*E. viminalis*	5,20
495	1H-Cycloprop[e]azulene,decahydro-1,1,7-trimethyl-4-methylene-,(1aR,4aR,7R,7aR,7bS)-(+)	*E. tereticornis*	2,5,13,14
496	1H-Cycloprop[e]azulene,decahydro-1,1,7-trimethyl-4-methylene-,[1a*R*-(1aα,4aβ,7α,7aβ,7bα)]	*E. tereticornis*	2,5,13,14
497	1H-Cycloprop[e]azulene,1a,2,3,5,6,7,7a,7b-octahydro1,1,4,7-tetramethyl(1a*R*,7*R*,7a*S*,7b*R*)-	*E. globulus*	2,4
498	Bicyclogermacrene	*E. citriodora* *E. polycarpa*	5,6
499	Eremophyllene	*E. radiata*	2,3
500	Longicyclene	*E. cinerea* *E. decaisneana*	5
501	β-Acoradiene	*E. cinerea*	5
502	Eremophilene	*E. oleosa* *E. astringens*	7
503	Dehydro-aromadendrene	*E. dunnii*	3,5,13
504	(*Z*)-Eudesma-6,11-diene	*E. dunnii*	3,5,13
505	*cis*-Calamene	*E. grandisx*	2,33,35
506	凡伦橘烯 Valencene	*E. citriodora* *E. decaisneana*	5,6
507	*trans*-Cadina-1,4-diene	*E. camaldulensis* *E. maculata*	5,12
508	Bicycloelemene	*E. camaldulensis* *E. gunnii*	5,12
509	Cadalene	*E. torelliana* *E. globulus*	13,25
510	Di-epi-α-cedrene	*E. melanophloia*	21
511	Cyperene	*E. globulus*	2,4
512	Selina-3,7(11)-diene	*E. globulus*	2,4
513	*cis*-Muurola-3,5-diene	*E. maculata*	13
514	*trans*-Cadina-1(6),4-diene	*E. maculata*	13
515	*trans*-Muurola-4(14),5-diene	*E. maculata* *E. nesophila*	13
516	9-Epi-β-caryophyllene	*E. grandis*	8
517	1,4-Cadinadiene	*E. camaldulensis* *E. cinerea*	5,12
518	α-Calacorene	*E. citriodora* *E. torelliana*	5,6
519	*trans*-α-Bergamotene	*E. citriodora*	5,6
520	α-Muurolene	*E. maculata*	13
521	α-Ylangene	*E. citriodora*	5,6
522	α-Himachalene	*E. salmonophloia* *E. oleosa*	8
523	β-Panasinsene	*E. lehmannii* *E. astringens*	23,24
524	γ-Amorphene	*E. dunnii*	3,5,13
525	β-Vatirenene	*E. camaldulensis*	5,12
526	γ-Maaliene	*E. torelliana* *E. citriodorax*	13,25

续表 3(Continued Tab. 3)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
527	β-Bourbonene	*E. oleosa* *E. salubris*	7
528	γ-Muurolene	*E. oleosa* *E. radiata*	7
529	Isolongifolen-8-ol	*E. globulus*	2,4
530	Tricyclo[6.3.0.1(2,3)]undec-7-ene,6,10,11,11-tetramethyl	*E. procera*	43
531	甘香烯 Elixene	*E. urophylla*	2,13
532	Guaiazulene	*E. camaldulensis*	5,12
533	Calamanene	*E. lehmannii* *E. astringens*	23,24
534	喇叭烯 Ledene	*E. robusta*	13,22
535	绿花白千层烯 Viridiflorene	*E. globulus* *E. polycarpa*	2,4
536	异喇叭烯 Isoledene	*E. globulus* *E. torquata*	2,4
537	Longipinene	*E. citriodora*	5,6
538	Eucalteretial A	*E. tereticornis*	2,5,13,14
539	Eucalteretial B	*E. tereticornis*	2,5,13,14
540	Eucalteretial D	*E. tereticornis*	2,5,13,14

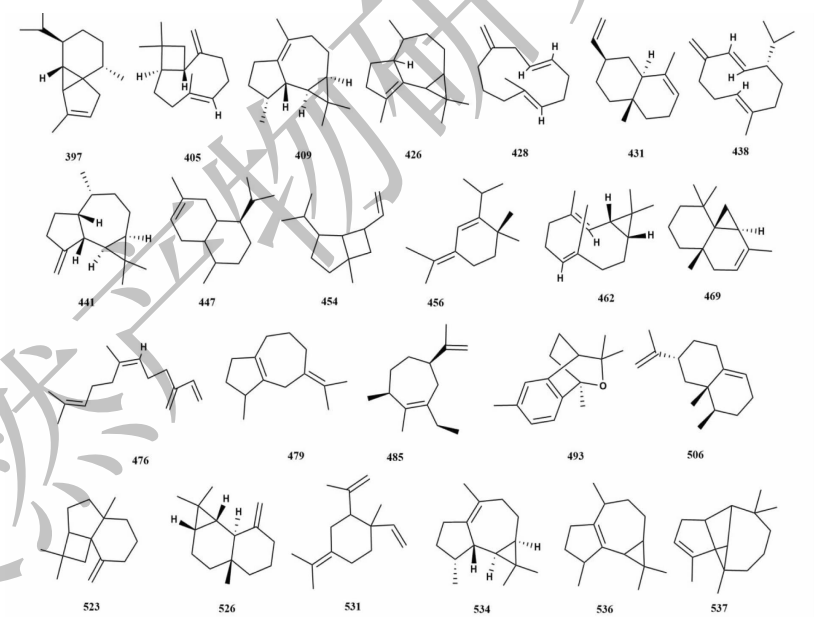

图 3 桉属中倍半萜代表性化合物的结构

Fig. 3 Structures of representative sesquiterpenes from *Eucalyptus*

1.1.4 含氧倍半萜

桉属挥发油中含氧倍半萜化合物主要有环氧石竹烯(caryophyllene oxide)、蓝桉醇(clobulol)、绿花白千层醇(viridiflorol)、斯巴醇(spathulenol)、桉油醇(eudesmol)、喇叭茶醇(ledol)、毕橙茄醇(cadinol)等。本文综述了桉属挥发油中含氧倍半萜化合物共145 种,化合物名称详见表 4,代表性化合物结构详见图 4。

表 4 桉属含氧倍半萜化合物

Table 4 Oxygen-containing sesquiterpenes of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
541	环氧石竹烯 Caryophyllene oxide	*E. globulus* *E. spathulata*	2,4
542	β-环氧石竹烯 β-Caryophyllene oxide	*E. oleosa* *E. salubris*	7
543	Viridiflorol	*E. globulus* *E. radiata*	2,4
544	Dihydrofarnesal	*E. citriodora*	5,6
545	Methyl ionone	*E. citriodora* *E. oleosa*	5,6
546	β-Ionone	*E. exerta* *E. gunnii*	11
547	Thujopsene-2α-ol	*E. siderophloia*	27
548	表蓝按醇 Epiglobulol	*E. platypus* *E. spathulata*	23,24
549	蓝桉醇 Globulol	*E. nitens* *E. falcata*	47
550	绿花白千层醇 Viridiflorol	*E. intertexta* *E. citriodora*	31
551	Viridiflorol	*E. citriodora* *E. oleosa*	5,6
552	玫瑰叶悬钩子醇 Rosifoliol	*E. camaldulensis* *E. procera*	5,12
553	喇叭茶醇 Palustrol	*E. globulus* *E. gillii*	2,4
554	Spahulenol	*E. cinerea* *E. maidenii*	5
555	Spathunelol	*E. erythrocorys*	36
556	斯巴醇 Spathulenol	*E. globulus* *E. astringens*	2,4
557	5-Epi-neointermedeol	*E. globulus* *E. radiata*	2,4
558	γ-松油醇 γ-Eudesmol	*E. globulus* *E. grandis*	2,4
559	愈创木醇 Guaiol	*R. sideroxylon* *E. amplifolia*	13,44
560	Aristolene	*E. globulus* *E. robusta*	2,4
561	(-)-Aristolene	*E. tereticornis*	2,5,13,14
562	Hinesol	*E. cinerea* *E. camaldulensis*	5
563	7-Epi-α-cadinol	*E. tereticornis* *E. pyrocarpa*	2,5,13,14
564	Epi-α-cadinol	*E. citriodora* *E. torelliana*	5,6
565	桉油醇 Eudesmol	*E. occidentalis* *E. globulus*	8
566	α-桉油醇 α-Eudesmol	*E. populifolia* *E. grandis*	24
567	τ-桉油醇 τ-Eudesmol	*E. globulus*	2,4
568	β-桉油醇 β-Eudesmol	*E. falcata* *E. torelliana*	23
569	N-Nonadecanoic acid	*E. camaldulensis*	5,12
570	Nonadecanoic acid	*Eucalyptus*	10
571	Caryophylla-4(12),8(13)-dien-5β-ol	*E. tereticornis*	2,5,13,14
572	Caryophylla-4(12),8(13)-dien-5-beta-ol	*E. robusta*	13,22
573	10-Epi-c-eudesmol	*E. camaldulensis* *E. olida*	5,12
574	榄香醇 Elemol	*E. globulus* *E. meliodora*	2,4
575	α-榄香醇 α-Elemol	*E. raveretiana* *E. urophylla*	22
576	喇叭茶醇 Ledol	*E. globulus* *E. saligna*	2,4
577	Spathulenol isomer	*E. camaldulensis*	5,12
578	Humulene epoxide II	*E. torelliana* *E. maculata*	13,25

续表 4(Continued Tab. 4)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
579	环氧化 α-蒎烯 α-Pinene epoxide	*E. stricklandii* *E. nesophila*	8
580	10-Epi-γ-eudesmol	*E. phaeotricha* *E. decaisneana*	27
581	1,10-Di-epi-cubenol	*E. camaldulensis* *E. urograndis*	5,12
582	Epi-cubenol	*E. camaldulensis* *E. urophylla*	5,12
583	Isospathulenol	*E. polyanthemos* *E. populifolia*	23,24
584	Allo-spathulenol	*E. camaldulensis*	5,12
585	Tau-muurolol	*E. camaldulensis*	5,12
586	T-muurolol	*E. camaldulensis* *E. occidentalis*	5,12
587	α-Muurolol	*E. torelliana* *E. dundasii*	13,25
588	α-杜松醇 α-Cadinol	*E. globulus* *E. salubris*	2,4
589	δ-杜松醇 δ-Cadinol	*E. globulus* *E. botryoides*	2,4
590	γ-杜松醇 γ-Cadinol	*E. camaldulensis*	5,12
591	τ-杜松醇 τ-Cadinol	*E. globulus* *E. occidentalis*	2,4
592	Isobicyclogermacrenal	*E. camaldulensis*	5,12
593	β-Copaen-4a-ol	*E. camaldulensis*	5,12
594	β-Piotol	*E. camaldulensis*	5,12
595	Cedranone(5)	*E. camaldulensis*	5,12
596	Cubenol	*E. globulus* *E. melanophloia*	2,4
597	Vulgarone B	*E. camaldulensis*	5,12
598	Khusinol	*E. camaldulensis*	5,12
599	Cedranol(5-Neo)	*E. camaldulensis*	5,12
600	(*Z*)-α-Sanatalol	*E. camaldulensis*	5,12
601	(*Z*)-*trans*-α-Bergamotol	*E. camaldulensis*	5,12
602	trans-α-Bergamotene	*E. torelliana* *E. citriodora*	13,25
603	α-14-Hydroxyhumulene	*E. camaldulensis*	5,12
604	Khusimol	*E. camaldulensis*	5,12
605	Bisabolone(6*R*,7*R*-)	*E. camaldulensis*	5,12
606	Aristolone	*E. camaldulensis*	5,12
607	α-14-Oxymuurolene	*E. camaldulensis*	5,12
608	β-Bisabolene	*E. camaldulensis*	5,12
609	(*E*)-α-Atlantone	*E. camaldulensis*	5,12
610	Nootkatone	*E. camaldulensis* *E. oleosa*	5,12
611	Isoacorone	*E. camaldulensis*	5,12
612	β-Vetivone	*E. camaldulensis*	5,12
613	α-Vetivone	*E. camaldulensis*	5,12
614	α-Acorenol	*E. melliodora* *E. siderophloia*	46
615	β-Acorenol	*E. torelliana* *E. brockwayii*	13,25
616	7-Epi-α-eudesmol	*E. pyrocarpa*	27
617	Selin-11-en-4α-ol	*E. crebra* *E. siderophloia*	21

续表 4(Continued Tab. 4)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
618	Butylhydroxytoluene	*E. viminalis*	5,20
619	10-Di-epi-(γ)-eudesmol	*E. viminalis*	5,20
620	Epi-crytomeridiol	*E. viminalis*	5,20
621	1H-Cycloprop[e]azulen-4ol,decahydro-1,1,4,7tetramethyl-,(1a*R*,4*R*,4a*R*,7*R*,7a*S*,7b*S*)-	*E. globulus*	2,4
622	1,10-Dioxotayloriane	*E. globulus*	2,4
623	Iso-leptospermone	*E. citriodorax* *E. camaldulensis*	48
624	Leptospermone	*E. dundasii* *E. nesophila*	3,24
625	Bulnesol	*E. decaisneana* *E. torelliana*	14
626	Epicubenol	*Eucalyptus* *E. melanophloia*	10
627	*cis*-Arteannuic alcohol	*E. melliodora*	46
628	Himachalol	*E. melliodora*	46
629	Opposita-4(15)-dien-12-al	*E. camaldulensis*	5,12
630	Eremoligenol	*E. dunnii*	3,5,13
631	Platambin	*E. oleosa*	7
632	5-Epi-7-epi-α-eudesmol	*E. torelliana* *E. polycarpa*	13,25
633	4,6,6-Trimethyl-2-(3-methylbuta-1,3-dienyl)-3-oxatricyclo[5.1.0.0(2,4)]octane	*E. camaldulensis*	5,12
634	1,10-Di-epi-cubenol	*E. maculata*	13
635	Humulene 1,2-epoxide	*E. torelliana* *E. nesophila*	13,25
636	*trans*-Calamenen-10-ol	*E. citriodora*	5,6
637	*cis*-Calamenen-10-ol	*E. citriodora* *E. citriodora*	5,6
638	Cedrenol	*E. camaldulensis* *E. cinerea*	5,12
639	Gleenol	*E. dunnii*	3,5,13
640	Valerenal	*E. oleosa*	7
641	Dihydro-eudesmol	*E. globulus* *E. dealbata*	2,4
642	α-Muurolol	*E. dunnii*	3,5,13
643	Epi-α-muurolol	*E. dunnii* *E. maculata*	3,5,13
644	β-Copaen-4-ol	*E. oleosa*	7
645	Carotol	*E. oleosa*	7
646	Carissone	*E. torelliana* *E. maculata*	13,25
647	Selin-11-en-4-*a*-ol	*E. siderophloia*	27
648	Epi-cubebol	*E. maculata*	13
649	Cubebol	*E. camaldulensis*	5,12
650	8,14-Cedranoxide	*E. camaldulensis* *E. cinerea*	5,12
651	Germacrene *D*-4-ol	*E. maculata*	13
652	Thujopsan-2-*a*-ol	*E. siderophloia*	27
653	Maaliol	*E. grandisx* *E. urophylla*	2,33,35
654	Cubeban-11-ol	*E. grandisx* *E. urophylla*	2,33,35
655	β-Atlantol	*E. citriodora*	5,6
656	Caryophyllene alcohol	*E. cinerea* *E. camaldulensis*	5

续表 4(Continued Tab. 4)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
657	α-Cadinol	*E. globulus* *E. salmonophloia*	2,4
658	β-Elemenol	*E. globulus*	2,4
659	β-桉叶烯 β-Eudesmene	*E. melanophloia* *E. benthamii*	21,35
660	β-Santalol	*E. globulus*	2,4
661	*trans*-β-Elemenone	*E. globulus*	2,4
662	*cis*-Isolongifolanone	*E. globulus* *E. camaldulensis*	2,4
663	*trans*-Isolongifolanone	*E. globulus*	2,4
664	Espatulenol	*E. globulus* *E. robusta*	2,4
665	Caryophylla-2(12),6(13)-dien-5-one	*E. torquata*	8
666	*trans*-*Z*-α-Bisabolene epoxide	*E. camaldulensis*	5,12
667	Pogostol	*E. saligna*	3,5,13
668	Iso-leptospermone	*E. grandisx* *E. urophylla*	2,33,35
669	杜松醇 Cadinol	*E. globulus* *E. citriodora*	2,4
670	法尼醇 Farnesyl alcohol	*E. citriodora*	5,6
671	Carotol	*E. globulus* *E. citriodora*	2,4
672	α-Cyperone	*E. camaldulensis*	5,12
673	*E*-γ-Curcumen-12-ol	*E. camaldulensis*	5,12
674	*E*,*Z*-Farnesol	*E. camaldulensis* *E. cinerea*	5,12
675	(2*Z*,6*Z*)-Farnesol	*E. camaldulensis*	5,12
676	(*Z*,*Z*)-Farnesol	*E. camaldulensis* *E. maculata*	5,12
677	金合欢醇 Farnesol	*E. punctata* *E. polycarpa*	13,27
678	Lepidozenol	*E. robusta*	13,22
679	Lepidozenal	*E. camaldulensis*	5,12
680	喇叭茶醇 Ledol	*E. robusta* *E. melanophloia*	13,22
681	Epi-globulol	*E. torelliana* *E. nesophila*	13,25
682	Santalol	*E. robusta*	13,22
683	*cis*-β-Santalol	*E. cinerea* *E. camaldulensis*	5
684	Eucalteretial C	*E. tereticornis*	2,5,13,14
685	Eucalteretial E	*E. tereticornis*	2,5,13,14

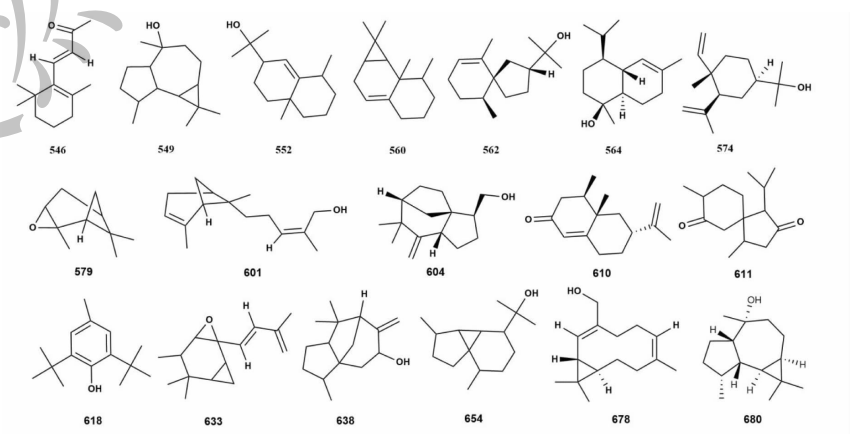

图 4 桉属中含氧倍半萜代表性化合物的结构

Fig. 4 Structures of representative oxygen-containing sesquiterpenes from *Eucalyptus*

1.2 脂肪族化合物

桉属挥发油中的脂肪族化合物主要为小分子脂肪酸和脂肪醇,本文综述了桉属挥发油中小分子脂肪酸化合物共7种,化合物名称详见表5;脂肪醇化合物共22种,详见表6,其化合物结构详见图5与图6。

表5 桉属小分子脂肪酸化合物

Table 5 Small molecule aliphatic acid of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
686	戊二酸 Glutaric acid	*E. citriodora*	5,6
687	苹果酸 Malic acid	*E. globulus* *E. citriodora*	2,4
688	琥珀酸 Succinic acid	*E. globulus*	2,4
689	富马酸 Fumaric acid	*E. globulus*	2,4
690	己酸 Hexanoic acid	*E. urograndis*	38,39
691	墟珍酸 Uronic acid	*E. citriodora*	5,6
692	柠檬酸 Citric acid	*R. sideroxylon* *E. globulus*	44

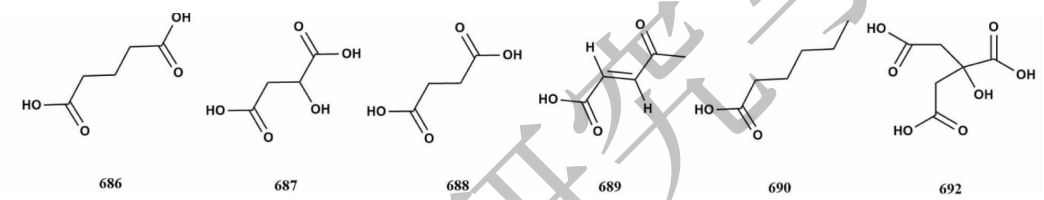

图5 桉属中小分子脂肪酸代表性化合物的结构

Fig. 5 Structures of representative small molecule aliphatic acid from *Eucalyptus*

表6 桉属脂肪醇化合物

Table 6 Aliphatic alcohol of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
693	1,6-Octadien-3-ol	*E. globulus* *E. citriodora*	2,4
694	2,6-Octadien-1-ol	*E. staigeriana*	9
695	2,6-Octadienal	*E. staigeriana*	9
696	Cholest-5-en-3-ol	*E. cinerea*	5
697	Geranylacetone	*E. occidentalis*	8
698	2-羟甲基戊烷 2-Methylolpentane	*E. grandisx* *E. urophylla*	2,33,35
699	Benzene methanol	*E. globulus*	2,4
700	Benzyl alcohol	*E. viminalis*	5,20
701	*D*-Phencol	*E. viminalis*	5,20
702	2-(*Z*)-戊醇 2-(*Z*)-Pentenol	*E. dunnii*	3,5,13
703	3-Cyclohexen-1-methanol	*E. radiata*	2,3
704	3-Cyclohexen-1-ol	*E. staigeriana*	9
705	*Z*-3-Hex-en1-ol	*E. radiata*	2,3
706	6-Octen-1-ol	*E. citriodora*	5,6
707	6-Octenal	*E. citriodora*	5,6

续表 6(Continued Tab. 6)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
708	Cyclohexanol	*E. citriodora*	5,6
709	Hex-3-en-1-ol	*E. occidentalis*	8
710	Phenylactealdehyde	*E. saligna*	3,5,13
711	顺胡椒醇 cis-Pipertol	*E. globulus*	2,4
712	茴香醇 Anisalcohol	*E. robusta*	13,22
713	正卅烷醇 Triacontanol	*E. robusta*	13,22
714	戊醇 Pentanol	*E. dunnii*	3,5,13

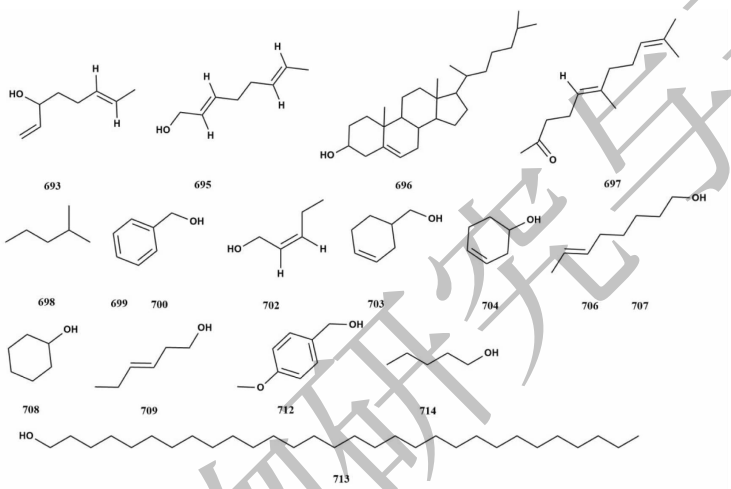

图 6 桉属中脂肪醇代表性化合物的结构

Fig. 6 Structures of representative aliphatic alcohol from *Eucalyptus*

1.3 芳香族化合物

芳香族化合物包括芳香烃及其衍生物,本文综述了桉属挥发油中 39 种芳香族化合物,包括 vanillin、*p*-coumaric acid 和 ferulicacid 等,化合物名称详见表 7,代表性化合物结构详见图 7。

表 7 桉属挥发油芳香族化合物

Table 7 Essential oil aromatic of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
715	香兰素 Vanillin	*E. urograndis*	38,39
716	*p*-Voumaric acid	*E. urograndis*	38,39
717	*cis*-Ferulic acid	*Eucalyptus*	10
718	*trans*-Ferulic acid	*E. urograndis*	38,39
719	1-Ethyl-4-methylbenzene	*E. camaldulensis*	5,12
720	1,2-Benzeneldiol	*E. viminalis*	5,20
721	1,4-Benzenediol	*E. viminalis*	5,20
722	1,2,3-Trimethylbenzene	*E. cinerea* *E. camaldulensis*	5
723	3-Methoxy-1,2-benzenediol	*E. viminalis*	5,20

续表 7(Continued Tab. 7)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
724	3-Hydroxy-4-methoxybenzaldehyde	*E. viminalis*	5,20
725	Acetophenone	*E. citriodora*	5,6
726	4-Ethenylphenol	*E. viminalis*	5,20
727	2-Methoxy-4-ethenyl-phenol	*E. viminalis*	5,20
728	2,6-Dimethoxyphenol	*E. viminalis* *E. camaldulensis*	5,20
729	2-Propylphenol	*E. viminalis*	5,20
730	2,4-Tretbutyl-phenol	*E. viminalis*	5,20
731	2,6-Dimethoxy-4-ethenylphenol	*E. viminalis*	5,20
732	Phenol	*E. viminalis* *E. globulus*	5,20
733	2,6-Dimethoxy-4-(2-propenyl)-phenol	*E. viminalis*	5,20
734	4-(1*E*)-3-Hydroxy-1-propenyl-2-methoxyphenol	*E. viminalis*	5,20
735	4-(1*E*)-3-Hydroxy-1-propenyl-2-methoxyphenol	*E. viminalis*	5,20
736	Phenol,2-(1,1-dimethylethyl)-4-methyl-	*E. torquata*	8
737	4-Ethenylphenol	*E. viminalis*	5,20
738	1,2-Benzenedicarboxylic acid	*E. globulus*	2,4
739	Benzeneacetaldehyde	*E. viminalis*	5,20
740	Benzophenone	*E. viminalis*	5,20
741	Styrene	*E. globulus*	2,4
742	Benzaldehyde	*E. olida* *E. saligna*	15
743	(*E*)-Ethyl cinnamate	*E. olida*	15
744	Anisic acid	*E. cinerea* *E. camaldulensis*	5
745	Veratrole	*E. camaldulensis*	5,12
746	Phenanthrene	*E. globulus*	2,4
747	Lilial	*E. camaldulensis*	5,12
748	Cyanobenzene	*E. grandisx*	2,35
749	Benzene	*E. globulus* *E. radiata*	2,4
750	Azulene	*E. globulus*	2,4
751	Cumene	*E. globulus* *E. robusta*	2,4
752	4-Hydroxybenzoate	*E. cinerea*	5
753	2-(Diphenylphosphoryl)-4-nitrophenol	*E. cinerea*	5

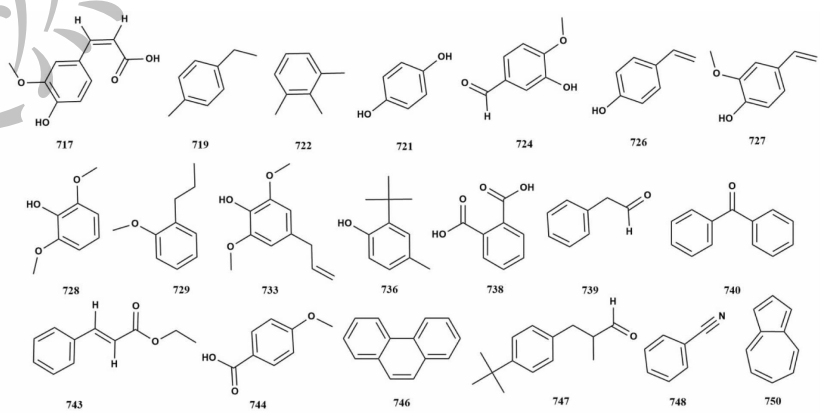

图 7 桉属中挥发油芳香族代表性化合物的结构

Fig. 7 Structures of representative essential oil aromatic from *Eucalyptus*

1.4 其他化合物

本文综述桉属挥发油中其他化合物共 195 种，包括酯类、醛类、酮类和醌类等，化合物名称详见表 8，代表性化合物结构详见图 8。

表 8 桉属其他化合物

Table 8 Other compounds of *Eucalyptus*

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
754	甜瓜醛 Melonal	*E. citriodora*	5,6
755	*p*-Cumenol	*E. meliodora* *E. oleosa*	42
756	Glycerol	*Eucalyptus*	10
757	3-Metoxi-acetofenona	*E. urograndis*	38,39
758	Acetato de *a*-terpinila	*E. urograndis*	38,39
759	4-Ethenylphenol	*E. viminalis*	5,20
760	2,6-Dimethyl-5-heptenal	*E. citriodora*	5,6
761	Neohexane	*E. tereticornis*	2,5,13,14
762	Tert-butanol	*E. tereticornis*	2,5,13,14
763	γ-Nonanoic lactone	*E. tereticornis*	2,5,13,14
764	Terpynil acetate	*E. staigeriana*	9
765	1-Octene	*E. camaldulensis*	5,12
766	Neryl acetate	*E. staigeriana* *E. torelliana*	9
767	5-Methyl-3-hexen-2-one	*E. camaldulensis*	5,12
768	2-Nonanone	*E. camaldulensis*	5,12
769	Phosphoglycerol	*E. cinerea*	5
770	Inositol	*E. cinerea*	5
771	1,2,4,8-Tetramethylbicyclo[6.3.0]undeca-2,4-diene	*E. cinerea*	5
772	1H-Cycloprop[e]azulene	*E. cinerea* *E. camaldulensis*	5
773	Cyclononanone	*E. globulus*	2,4
774	O-Dimethoxy-benzoyl ajugol	*E. sideroxylon*	5
775	(*E*)-1-Methyl-1-diallyl alcohol	*E. grandisx* *E. urophylla*	2,33,35
776	3-甲基丁基环己烷 (3-Methylbutyl)cyclohexane	*E. oleosa*	7
777	3-Methoxy aceptophenone	*E. globulus*	2,4
778	1-甲基-4-(1 甲基乙基)-1,4-环己二烯 1-Methyl-4-(1-methylethyl)-1,4-cyclohexadiene	*E. grandisx* *E. urophylla*	2,33,35
779	1,4-Cyclohexadiene	*E. globulus* *E. radiata*	2,4
780	1,4-Methanoazulene	*E. citriodora*	5,6
781	Propanoic acid,2-methyl-,ethyl ester	*E. oleosa*	7
782	Flavesone	*E. grandis* *E. nitens*	8
783	5-Hydroxymethyl-furancarboxaldehyde	*E. viminalis*	5,20
784	Endo-acetoxy-1,8-cyneole	*E. viminalis*	5,20
785	Terpenyl acetate	*E. viminalis*	5,20
786	1,2,3-Trioxybenzene	*E. viminalis*	5,20
787	Methyl nerolate	*E. camaldulensis*	5,12
788	Undecan-2-one	*E. cinerea* *E. camaldulens*	5
789	1-Tridecene	*E. cinerea*	5

续表 8(Continued Tab. 8)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
790	Dihydroactinidiolide	*E. viminalis*	5,20
791	3-Methylbutanal	*E. viminalis* *E. oleosa*	5,20
792	Ethanoic acid	*E. viminalis*	5,20
793	Propinoic acid	*E. viminalis*	5,20
794	Methyl-2-propeonate	*E. viminalis*	5,20
795	(2H)-Furanone	*E. viminalis*	5,20
796	3-Furaldehyde	*E. viminalis*	5,20
797	3-Methylbutanoic acid	*E. viminalis*	5,20
798	2-Methylbutanoic acid	*E. saligna*	3,5,13
799	(*Z*)-3-Hexenol	*E. saligna*	3,5,13
800	(*E*)-2-Hexen-1-ol	*E. saligna*	3,5,13
801	1,2-Dimethyl-1,4-cyclohexadiene	*E. saligna*	3,5,13
802	Butanoic acid	*E. globulus*	2,4
803	Furfuryl alcohol	*E. viminalis*	5,20
804	2(3H)-Dihydrofuranone	*E. viminalis*	5,20
805	Dihydromethylfuranone	*E. viminalis*	5,20
806	1,2-Cyclopentanedione	*E. viminalis*	5,20
807	1,1-二乙氧基-3-甲基丁烷 1,1-Diethoxy-3-methylbutane	*E. viminalis*	5,20
808	5-Methylfurfural	*E. viminalis*	5,20
809	2,4-Dihydropyranone	*E. viminalis*	5,20
810	3-Methyl-2,5-furandione	*E. viminalis*	5,20
811	Benzeneacetaldehyde	*E. viminalis*	5,20
812	4-Hydoxy-2,5-dimethyl-3(2P)-furanone	*E. viminalis*	5,20
813	Diethyl propanedioate	*E. viminalis*	5,20
814	Furaneol	*E. viminalis*	5,20
815	2,3-Dihydro-5-hydroxy-6-methyl-4H-pyran-4-one	*E. viminalis*	5,20
816	2,3-Dihydro-3,5-dihyroxy-5-methyl-4H-pyran-4-one	*E. viminalis*	5,20
817	Quinic acid	*E. viminalis*	5,20
818	Benzophenone	*E. viminalis*	5,20
819	Quinosol	*E. viminalis*	5,20
820	Loliolide	*E. viminalis*	5,20
821	Methyl palmitate	*E. viminalis*	5,20
822	Dibutyl phthalate	*E. viminalis*	5,20
823	3,5-Dimethoxy-4-hydroxycinnamicaldehyde	*E. viminalis*	5,20
824	Ethyl palmitate	*E. viminalis*	5,20
825	1(2-Naphthyl)hept-1-en-3-one	*E. viminalis*	5,20
826	Octadecenamide	*E. viminalis*	5,20
827	6,6-二甲基二环[3.1.1]-2-庚烯-2-甲醇 Bicyclo[3.1.1]hept-2-ene-2-methanol,6,6-dimethyl	*E. tereticornis*	2,5,13,14
828	Bicyclo[2.2.1]heptan-2-ol,1,7,7- trimethyl-,formate,endo	*E. tereticornis*	2,5,13,14

续表 8(Continued Tab. 8)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
829	2-金刚烷 2-Methyladamantane	*E. tereticornis* *E. oleosa*	2,5,13,14
830	2,2,5,5-Tetramethyl-3-cyclopenten-1-one	*E. saligna*	3,5,13
831	1,2,3,3-Tetramethyl cyclopenten-4-one	*E. globulus*	2,4
832	Methyl dihydrojasmonate	*E. globulus*	2,4
833	Methyl 15-oxoeicosanoate	*E. globulus*	2,4
834	1-(2,6-Dihydroxy-4-methoxy-3,5-dimethylphenyl)-2-Methylbutan-1-one	*E. globulus*	2,4
835	1,3,3-三甲基二环[2.2.1]庚烷-2-醇 Bicyclo[2.2.1]heptan-2-ol,1,3,3-trimethyl	*E. tereticornis*	2,5,13,14
836	1-Tridecyn-4-ol	*E. grandisx* *E. urophylla*	2,33,35
837	Hexahydropyridine,1-methyl-4-[4,5-dihydroxyphenyl]	*E. procera*	43
838	4-烯丙亚氨-2-蒈烯 4-Allyloxyimino-2-caren	*E. largiflorens*	8
839	2-(*Z*)-己醛 2-(*Z*)-Hexenal	*E. dunnii*	3,5,13
840	5-甲氧基糠醛 5-Methoxyfurfural	*Eucalyptus*	10
841	Bergamal	*E. citriodora*	5,6
842	十四烷 Tetradecane	*E. decaisneana*	14
843	十五烷 Pentadecane	*E. decaisneana*	14
844	Khusimone	*E. olida*	15
845	*E*-2-Dodecenal	*E. cinerea*	5
846	Linalyl anthranilate	*E. grandisx* *E. urophylla*	2,33,35
847	Nopinone	*E. dunnii*	3,5,13
848	Isobornyl formate	*E. dunnii*	3,5,13
849	Nopol	*E. olida*	15
850	Isobutyrate	*E. globulus*	2,4
851	2-Nonanol	*E. nitens*	47
852	4,6-Nonanedione	*E. globulus*	2,4
853	Cyclohexene	*E. staigeriana*	9
854	3-Methyl-4-cyclohexene	*E. globulus*	2,4
855	4-Acetyl-1-methyl-cyclohexene	*E. gracilis*	11
856	Bicyclohex-2-ene	*E. staigeriana*	9
857	2,4-二甲基-3-戊酮 2,4-Dimethyl-3-pentanone	*E. saligna*	3,5,13
858	Perhydrofarnesyl acetone	*E. globulus*	2,4
859	*β*-Ionone epoxyde	*E. globulus*	2,4
860	6-Methyl-5-hepten-2-one	*E. staigeriana*	9
861	*α*-Cardinol	*E. camaldulensis*	5,12
862	Blumenol A	*E. globulus*	2,4
863	蒿甲醚 Artemether	*E. grandisx*	2,33,35
864	Dehydrovomifoliol	*E. camaldulensis*	5,12
865	5,13-Dimethylheptadecane	*E. camaldulensis*	5,12
866	己醛 Hexanal	*E. dunnii*	3,5,13
867	甲基环戊烷 Methylcyclopentane	*E. pellita*	13,35

续表 8(Continued Tab. 8)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
868	Sabina ketone	*E. saligna*	3,5,13
869	Diydro-sabina ketone	*E. andrewsii* *E. siderophloia*	27
870	植酮 Phytone	*E. torelliana* *E. benthamii*	13,25
871	异戊酸 Isovaleric acid	*E. saligna*	3,5,13
872	6,7-Dimethyltetralin	*E. cinerea*	5
873	2-Pentanone-4-hydroxy-4-methyl	*E. globulus*	2,4
874	Isovaleraldehyde	*E. camaldulensis* *E. globulus*	5,12
875	*cis*-Sabinene hydrate acetate	*E. camaldulensis* *E. cladocalyx*	5,12
876	Sebacic acid dibutyl ester	*E. viminalis*	5,20
877	葑基乙酸酯 Fenchylacetate	*E. tereticornis*	2,5,13,14
878	3-Phenylpropyl acetate	*E. cinerea*	5
879	3-顺式-乙酸已烯酯 3-(Z)-Hexenyl acetate	*E. dunnii* *E. saligna*	3,5,13
880	Isoamy acetate	*E. loxophleba* *E. citriodora*	8
881	*trans*-Sabinene hydrate	*E. brockwayi* *E. oleosa*	83
882	*cis*-Sabinene hydrate	*E. maidenii* *E. slmonophloia*	11
883	Isodihydro carveol acetate	*E. camaldulensis*	5,12
884	(*Z*)-Sesqulavanduly acetate	*E. camaldulensis*	5,12
885	γ-Eudesmol acetate	*E. camaldulensis*	5,12
886	(*Z*)-α-Santalol acetate	*E. camaldulensis*	5,12
887	Dodecanoic acid butyl ester	*E. camaldulensis*	5,12
888	(*Z*)-Lanceol acetate	*E. camaldulensis*	5,12
889	*Z*-Nuciferol acetate	*E. globulus*	2,4
890	Santolinyl acetate	*E. dundasii* *E. spathulata*	3,24
891	*trans*-Methyl cinnamate	*E. staigeriana* *E. radiata*	9
892	*cis*-Methyl cinnamate	*E. olida*	15
893	Methyl cinnamate	*E. dives* *E. radiata*	5,18,19
894	Safrole	*E. citriodora*	5,6
895	Dihydrocarveol acetate	*E. gamphocephala*	19
896	Nerol acetate	*E. rudis* *E. tereticornis*	21,23,24
897	Endo-fenchyl acetate	*E. dunnii*	3,5,13
898	(*E*)-Linalyl oxide acetate	*E. dunnii*	3,5,13
899	(*Z*)-Pinocavyl acetate	*E. dunnii*	3,5,13
900	Caryophyllene acetate	*E. globulus*	2,4
901	Methyl citronellate	*E. staigeriana* *E. olida*	9
902	Phenylethyl-3-methylbutanoate	*E. dunnii*	3,5,13
903	Phenyl ethyl isobutyrate	*E. nitens*	47
904	Benzyl isobutyrate	*E. nitens*	47
905	Isobutyl isovalerate	*E. nitens*	47
906	Isoamyl valerate	*E. oleosa*	7

续表 8(Continued Tab. 8)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
907	Isoamyl valerianate	*E. oleosa*	7
908	Isoamyl propionate	*E. nitens*	47
909	Isobornyl propionate	*E. globulus*	2,4
910	Isobutyl methacrylate	*E. nitens*	47
911	Isobutyl propionate	*E. grandis* *E. nitens*	8
912	1-Butanol-3-methyl propanoate	*E. globulus*	2,4
913	3-Methylbutyl propanoate	*E. saligna*	3,5,13
914	Isobutyl isobutyrate	*E. grandis* *E. saligna*	8
915	Isoamyl isobutyrate	*E. grandis* *E. saligna*	8
916	*trans*-Pinocarvyl acetate	*E. torelliana* *E. maculata*	13,25
917	(3*Z*)-Hexenyl angelate	*E. radiata*	2,3
918	Citronellyl formate	*E. torelliana* *E. citriodora*	13,25
919	Neryl formate	*E. staigeriana*	9
920	Neryl acetato	*E. staigeriana*	9
921	Iso(iso)pulegyl acetate	*E. citriodorax* *E. torelliana*	48
922	Verbanol acetate	*E. globulus*	2,4
923	Neo-verbanol acetate	*E. globulus*	2,4
924	*trans*-Verbenylacetate	*E. citriodora*	5,6
925	*cis*-Carvyl propionate	*E. grandis*	8
926	Ethyl acetate	*E. polycarpa*	25
927	1,2-Diacetoxyethane	*E. oleosa*	7
928	*β*-Phenylethyl phenyl acetate	*E. aggregata*	19
929	Isoamyl phenylacetate	*E. oleosa*	7
930	Isobutyl phenylacetate	*E. citriodora*	5,6
931	Isoamyl benzoate	*E. oleosa*	7
932	Cyclohexyl benzoate	*E. oleosa*	7
933	Ethyl benzoate	*E. cinerea* *E. camaldulensis*	5
934	2,3-Butanediol diacetate	*E. grandisx* *E. urophylla*	2,33,35
935	Phenylethyl butyrate	*E. saligna*	3,5,13
936	Butyl butanoate	*E. grandisx* *E. citriodora*	2,33,35
937	Iso-n-hexyl butyrate	*E. grandisx* *E. urophylla*	2,33,35
938	*E*-Linalol oxide acetato	*E. staigeriana*	9
939	Methyl geranato	*E. staigeriana*	9
940	*cis*-3-Hexeayl acetate	*E. grandisx* *E. urophylla*	35,2,33
941	1-Hexylacetate	*E. saligna*	5,3,13
942	Acetic acid 1,3,3-trimethyl-2-oxabicyclo[2,2,2]octan-6-yl ester	*E. urophylla*	2,13
943	Eugenyl acetate	*E. oleosa*	7
944	Leaf acetate	*E. robusta*	13,22
945	Isopentyl isobutanoate	*E. nitens*	47

续表 8(Continued Tab. 8)

编号 No.	化合物名称 Compound name	来源 Source	参考文献 Ref.
946	苯二甲酸酯 Benzyl isobutanoate	*E. saligna*	5,3,13
947	Isopentylisopentanoate	*E. procera*	43
948	三环素 Tricyclene	*E. dives* *E. globulus*	15,19,18

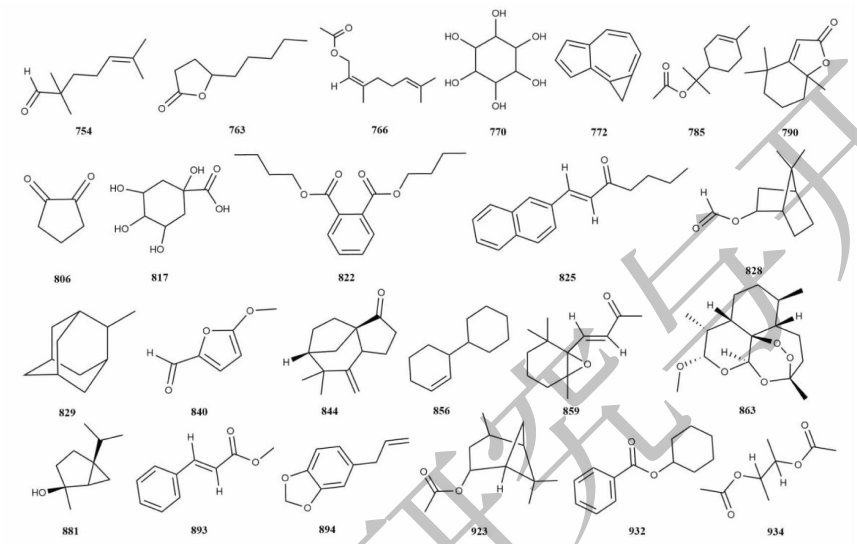

图 8 桉属中其他代表性化合物的结构

Fig. 8 Structures of other representative compounds in *Eucalyptus*

2 生物活性

2.1 杀虫驱虫作用

2.1.1 抗农作物害虫作用

为减少使用合成农药,并寻求替代或创新的害虫防治方法,国内外学者为此开展了很多研究。Byung-Ho 等[49]表明 *E. blakelyi* 挥发油(**5**、**121**)对水稻害虫米象(*Sitophilus oryzae*)、谷蠹(*Rhyzopertha dominica*)和赤拟谷盗(*Triborium castaneum*)具有强力的熏蒸毒性,半数致死量(LD_{50})分别为 31.2、9.7 和 15.5 μL/L。Sefidkon 等[39]报道了 *E. microtheca*、*E. sargentii*、*E. viminalis*、*E. grandis*、*E. camaldulensis* 和 *E. occidentalis* 等 6 种桉树挥发油均对米象具有很强的熏蒸活性,半数致死量浓度(LC_{50})分别为 11.11、11.94、14.73、15.65、17.49 和 28.9 μL/L,*E. microtheca* 挥发油对米象的熏蒸毒性最强。Sefidkon 等[39]还报道了 *E. microtheca* 和 *E. saligna* 挥发油对玉米象(*S. zeamais*)和杂拟谷盗(*T. confusum*)具有很强的熏蒸毒性,*E. microtheca* 挥发油对玉米象和杂拟谷盗的半数致死量分别为 0.82 和 0.99 μL/cm^2,*E. saligna* 挥发油对玉米象和杂拟谷盗的半数致死量分别为 0.36 和 0.48 μL/cm^2。从半数致死量结果可知,*E. saligna* 挥发油对玉米象和杂拟谷盗的毒性更强,可作为抗玉米象和杂拟谷盗虫农药的替代品。Toudert-Taleb 等[50]研究表明含有 α-pinene(**31**)、β-pinene(**32**)、limonene(**15**)、*p*-cymene(**5**)、camphene(**34**)和 terpinolene(**2**)的 *E. globulus* 挥发油(5、121)能够防治四纹豆象(*Callosobruchus maculatus*)。*E. globulus* 挥发油蒸气通过卵膜扩散,通过影响与胚胎发育相关的生理和生化过程,从而达到杀虫和驱虫的目的。

2.1.2 驱杀蚊虫作用

Lucia 等[51]报道了 *E. globulus*(**31**、**121**、**174**、**423**)、*E. dunnii*(**5**、**103**、**121**、**174**、**549**)、*E. gunnii*(**5**、**16**、**31**、**121**、**556**)、*E. tereticornis*(**5**、**16**、**19**、**121**、**174**)、*E. camaldulensis*(**5**、**19**、**121**、**174**、**556**)和 *E. saligna*(**5**、**17**、**31**、**121**、**174**)等 6 种桉树挥发油对埃及伊蚊幼虫杀虫作用,6 种桉树对埃及伊蚊幼虫的半数致死浓度分别为 32.4、25.2、21.1、22.1、26.8 和 22.2

p. p. m. ,*E. gunnii* 挥发油对埃及伊蚊幼虫毒性最强。Lucia 等[51]还报道了桉树挥发油单体化合物 α-pinene(**31**)、β-pinene(**32**)、1,8-cineole(99%)(**121**)和 *p*-cymene(**5**)具有抗埃及伊蚊幼虫作用,α-pinene、β-pinene 和 1,8-cineole(99%)半数致死浓度分别为 15.4、12.1 和 57.2 p. p. m.。1,8- cineole(99%)杀虫作用较低,幼虫死亡率为(36±8.5)%,*p*-cymene 的幼虫死亡率可高达 100%,在对照溶液或阳性对照中未观察到幼虫死亡率。Daizy 等[33]报道了含 *p*-menthane-3,8-diol 的 *E. citriodora* 挥发油可防蚊虫叮咬。Gao 等[52]通过药理研究实验发现 β-caryophyllene 具有驱赶蚊虫作用。Park 等[53]研究表明 α-terpinene(**13**)、*p*-cymene(**5**)、limonene(**15**)和 γ-terpinene(**17**)的幼虫杀虫率可高达 95%。Zhou 等[71]报道了巨尾桉叶油中 α-pinene(**31**)、α-terpineol(**174**)和 limonene(**15**)等对昆虫具有引诱活性,这些物质可以参与昆虫诱杀剂的合成或建立引诱区进而开发成生物杀虫剂。因此,桉树挥发油可开发为天然驱蚊虫剂。

2.1.3 抗人头虱作用

Daizy[33] 和 Lucia[54] 分别报道了 *E. cinerea*(**121**)、*E. viminalis*(**121**)、*E. saligna*(**31**)、*E. camaldulensis*(**5**、**31**、**121**、**387**)、*E. grandis*(**31**、**121**)和 *E. tereticornis*(**5**、**31**)等 6 种桉树挥发油对耐氯菊酯人头虱的熏蒸毒性或驱避活性,其半数击倒时间(KT_{50})分别为 12.0、14.9、17.4、35.01、25.57 和 31.3 min。*E. cinerea* 挥发油对耐氯菊酯人头虱半数击倒时间最短,具有最强的抗耐氯菊酯人头虱毒性。Daizy 等[33]研究表明含 1,8-cineole 的挥发油对人头虱具有毒性,1,8-cineole(半数致死温度 LT_{50} = 0.125 mg/cm^2)与阳性药 δ-吩噻菌灵或除虫菊(LT_{50} = 0.25 mg/cm^2)相比具有更高的杀虫活性。Tian 等[55]认为 1,8-cineole 对试虫较强的抑制作用是 1,8-cineole 抑制了乙酰胆碱酯酶的活性,从而阻碍细胞的发育和成熟。Lucia 等[54]报道了 carvacrol(**246**)、citronellol(**162**)、geraniol(**268**)、eugenol(**278**)、thymol(**210**)、α-terpineol(**174**)、1,8-cineole(**121**)和 linalool(**139**)等 8 种化合物对耐氯菊酯的人头虱具有毒性,其杀虫率分别为 28%、39%、51%、3%、51%、8%、53%、55%、56% 和 61%,linalool 具有较强的杀虫作用。桉树挥发油各种成分协同作用,可达到整体杀虫活性,故桉树挥发油可开发为控制人头虱的新产品。

2.1.4 杀螨作用

Han 等[56]报道了 menthol(**376**)、citronellyl acetate(**104**)、geranyl acetate(**211**)、citral(**96**)、eugenol(**278**)、β-citronellol(**164**)、geraniol(**268**)、isopulegol(**145**)、citronellal(**128**)、terpinen-4-ol(**151**)、α-terpineol(**174**)、β-caryophyllene(**416**)和 linalool(**139**)具有较强杀二斑叶螨毒性,半数致死浓度分别为 12.9、16.7、25.3、25.5、25.9、26.1、32.0、30.7、34.8、36.7、39.3、49.1 和 58.9 μg/cm^3。Menthol 为最有效的杀二斑叶螨化合物,可作为天然的杀螨剂。

2.1.5 抗细粒棘球蚴原头节作用

Zhao[57]报道了大叶桉叶和巨桉叶石油醚和二氯甲烷提取物对细粒棘球蚴原头节的杀虫作用。大叶桉叶和巨桉叶石油醚提取物对细粒棘球蚴原头节的半数致死浓度分别为 2.577 和 3.110 261 4 μg/mL。大叶桉叶和巨桉叶二氯甲烷提取物对细粒棘球蚴原头节的半数致死浓度分别为 21.84 和 2.678 μg/mL。大叶桉叶石油醚提取物和巨桉叶二氯甲烷提取物对细粒棘球蚴原头节具有很强的杀虫作用,可考虑将其作为抗细粒棘球蚴原头节新产品的来源。

2.2 抗炎作用

Bai 等[58]报道了大叶桉叶挥发油具有抗炎作用,能够显著抑制炎症部位 PGE_2 的渗出、明显减少肉芽组织增生,可用于奶牛急慢性乳房炎的治疗。Eucalyptol 是桉树挥发油中的主要活性成分,Caceres 等[59]表明 eucalyptol 能够对抗哮喘,eucalyptol 对哮喘的作用可能是通过干扰血液中单核细胞花生四烯酸的代谢,抑制由脂多糖(LPS)诱导的人类单核细胞中 IL-1β 的产生,从而抑制 LPS 诱导巨噬细胞系中一氧化氮(NO)的产生,并减少 LPS 诱导的表达,转运和转录人细胞系中早期生长反应因子 1、Egr1 和 NF-kappaB 的活性。Caceres 等[59]还报道了 eucalyptol 具有抗炎作用,能减轻鼻窦炎的症状和防止慢性阻塞性肺疾病(COPD)恶化、消除由角叉菜胶引起的水肿、缓解结肠炎、胃损伤、过敏原引起的支气管收缩和炎症、吸入烟气刺激物和内毒素引起的呼吸道刺激、肝衰竭和肺部炎症。Eucalyptol 是伤害感受器中表达的刺激性受体(TRPA1)抑制剂,可抑制 TRPA1 引起的炎性反应。

2.3 抗菌作用

Tan 等[60]报道了含 α-pinene(**31**)、1,8-cineole(**121**)和 caryophyllene(**405**)等化合物的桃金娘科挥

发油对革兰氏阴性、阳性细菌和真菌均有较强的抑制活性。Mervat 等[61]表明 *E. camaldulensis* 挥发油(**31**、**121**、**262**、**376**)对青枯菌(*Ralstonia solanacearum*)、果胶杆菌(*Pectobacterium carotovorum*)、根癌农杆菌(*Agrobacterium tumefaciens*)和马铃薯黑胫病菌(*Dickeya* spp.)具有较强的抗菌作用。Ma 等[62]认为 cineole、ocimene(**44**)、camphene(**34**)、α-terpineol(**174**)、caryophyllene(**405**)、α-pinene(**31**)和β-pinene(**32**)等化合物是抑菌、抗菌的活性成分,其中 cineole、ocimene、camphene、α-pinene 和 β-pinene 对葡萄球菌及绿脓杆菌均具有较强抑制活性。Nameghi 等[63]研究表明薄荷和 *E. globules* 挥发油(**5**、**31**、**121**)混合物可通过改变细菌细胞壁的通透性,使致病菌孔形成和渗透压休克、细胞质及其活性成分泄漏到细胞外,导致细菌死亡从而发挥抗菌作用。Bhuyan 等[64]认为 *E. camaldulensis*、*E. tereticornis*、*E. alba*、*E. citriodora*、*E. globulus*、*E. saligna*、*E. robusta* 和 *E. staigeriana* 等 8 种桉树粗提物具有对抗耐甲氧西林的金黄色葡萄球菌、铜绿假单胞菌、松鼠葡萄球菌(*Staphylococcus sciuri*)、产色葡萄球菌(*Staphylococcus chromogenes*)、木糖葡萄球菌(*Staphylococcus xylosus*)、华纳葡萄球菌(*Staphylococcus warneri*)、寄生曲霉和黄曲霉的作用。Casey 等[65]发现桉树挥发油(主要含 1,8-cineole)可以增强洗必泰(CHG)在皮肤中的传递,从而减少皮肤深层微生物的数量,达到降低手术部位感染风险的目的。

2.4 麻醉镇痛作用

2.4.1 麻醉作用

Bodur 等[66]研究表明桉树挥发油能够引起受试鱼类血浆皮质醇浓度升高、肝组织中糖皮质激素受体(gr)表达增加头、肾组织中与类固醇生成相关的基因 star 和 cyb11b1 表达增加,从而发挥麻醉作用。桉树挥发油可作为新型鱼类天然麻醉剂。

2.4.2 镇痛作用

Gouveia 等[67]报道了 α-terpineol 能显著降低机械性痛觉过敏和自发、触诊引起的痛觉,且不改变肿瘤的生长、无明显的生化和血液学毒性,可认为 α-terpineol 具有开发为有效控制癌症疼痛的新型安全止痛药的潜力。Caceres 等[59]报道了 eucalyptol 具有较强的镇痛作用,能减轻酸、福尔马林和热诱发的疼痛感。Eucalyptol 是 TRPM8(外周感觉神经元中的冷/Menthol 受体)的强效激动剂,半最大效应浓度(EC_{50})为 120.4 μM,比小鼠 TRPM8(EC_{50} = 924.5 μM)和大鼠 TRPM8(EC_{50} = 1.21 μM)强,eucalyptol 的镇痛作用可能是通过表达 TRPM8 周围神经元的输入,从而激活中央抑制电路。Eucalyptol 还可减轻因应用 TRPA1 激动剂而引起的人体皮肤疼痛。另外,eucalyptol 代谢产物 2-hydroxyl-1,8-cineol 也能激活 TRPM8 通道,可能会延长 eucalyptol 的镇痛作用。Eucalyptol 有望开发为新型天然长效镇痛剂。

2.5 抗氧化作用

Singh 等[15]研究 *E. tereticornis* 新鲜叶、腐叶挥发油和抗氧化剂 BHT(2,6-二叔丁基-4-甲基苯酚)对 DPPH、OH 和 O_2^- 自由基的清除活性比较。新鲜叶挥发油的主要成分为 α-pinene(28.53%)(**31**)和 1,8-cineole(19.48%)(**121**),腐叶挥发油的主要成分为 β-citronellal(14.15%)(**132**)、(-)-isopulegol(13.35%)和(+)-β-citronellol(10.73%)。*E. tereticornis* 两种挥发油均显示出很强的 DPPH 自由基清除活性,新鲜和腐叶挥发油的半数抑制浓度(IC_{50})分别为 110 和 139.8 μg/mL,对 DPPH 自由基清除活性高于现有的抗氧化剂 BHT(IC_{50} = 164.2 μg/mL)。*E. tereticornis* 两种桉叶挥发油对 O_2^- 自由基的半数清除浓度分别为 234.5 和 274.7 μg/mL,*E. tereticornis* 新鲜叶挥发油与抗氧化剂 BHT(IC_{50} = 207.5 μg/mL)具有相近的清除 O_2^- 自由基活性。两种挥发油对 OH 自由基的半数抑制浓度分别为 304.3 和 312.4 μg/mL,清除活性弱于抗氧化剂 BHT(IC_{50} = 85.78 μg/mL)。*E. tereticornis* 两种桉叶挥发油对 DPPH 和 O_2^- 自由基清除作用较强,可考虑开发为天然抗氧化剂。Park 等[68]报道了 *E. globules* 挥发油可通过上调干燥皮肤中的神经酰胺水平来预防皮肤干燥,延缓肌肤老化。

2.6 其他活性

Nameghi 等[63]分析 *E. globules*、百里香和薄荷的混合挥发油中主要成分为 α-pinene(3.10%)(**31**)、γ-terpinene(4.49%)(**17**)、menthone(4.84%)(**330**)、1,8-cineol(5.70%)(**121**)、*p*-cymene(9.25%)(**5**),thymol(9.40%)(**210**)、menthol(16.62%)(**376**)和 carvacrol(28.20%)(**246**),将混合挥发油添加到受试鸡的饮用水中,观察到可明显改善肉鸡的体液免疫力、生长性能、微生物区系和回肠形态,因此,三种植物挥发油可以替代抗生素生长促进剂。Zhou 等[69]研究表明经 *E. globules* 挥发油(最佳浓度 = 0.75%)处理砂糖橘后,可有效减少其腐烂损失、降低生理生化反应速率、延缓砂糖橘果实

品质的劣变进程,且在贮藏 35 天后,好果率高达 99%,因此 *E. globules* 挥发油可作为天然的食品保鲜剂。Qu 等[70] 报道了 α-pinene(**31**)、γ-terpineol(**176**)、caryophyllene(**405**)和 jasmone(**203**)可作为合成香料的原料。其中右旋 α-pinene 可作为合成 terpineol、camphor、dihydromyrcenol 等香料的原料,γ-terpineol 可作为香料及食用香精增香剂,caryophyllene 可以用于合成具有高香料价值的 acetylcaryophyllene、jasmone 可作为高级茉莉系列化妆品香精中的原料。

3 结语

桉属植物资源种类丰富,但其化学成分及生物活性的研究还有待更深入的研究。近年来,研究人员对桉属挥发油的化学成分和药理活性等进行了较为广泛的研究,主要含有萜类化合物、脂肪族化合物、芳香族化合物以及其他化合物等,且这些化合物表现出良好的杀虫驱虫、抗菌、消炎镇痛、局部麻醉、抗氧化等广泛的生物活性,另外其还可作为抗生素生长促进剂的替代品,用于砂糖橘的保鲜、以及作为重要的香料等。已发现有一些新颖的萜类活性显著,但更深入的活性机制研究尚未见报道,故展望未来有更多关于桉属发挥油生理作用机制的研究,使桉属能更好地应用于医药、食品、日用化学工业等领域。本课题组致力于桉属植物资源开发与利用,已经取得部分成果,后续将进行更系统的化学成分和生物活性的研究,为桉属的药用资源开发与药效物质基础研究提供更多参考。

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