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REVIEW ARTICLE

Chemistry of *Amomum* essential oils

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ABSTRACT
Genus *Amomum* with 108 currently accepted species is distributed in tropical and subtropical Asia. This article is a comprehensive review of the chemical profiles of *Amomum* essential oils (EOs) and their spice and flavor properties. In genus *Amomum*, chemical profiles of EOs of only 29 species and 1 variety are studied so far. EOs of *Amomum subulatum, A. tsao-ko, A. kravanh, A. aromaticum, A. compactum, A. korarima* and *A. verum* are rich in 1,8-cineole. These *Amomum* species are used as spices and flavors. Bornyl acetate, camphor, methyl chavicol, *trans*-p-(1-butenyl) anisole, santolina triene, α-pinene and β-pinene are other major constituents in EOs of various *Amomum* species. The quality of EOs is decided by factors such as plant genotype, plant part, collection season, ecological and edaphic factors, isolation and analytical techniques. Studies on the chemical profiles and spice and flavor assessments of EOs of hitherto uninvestigated *Amomum* species are the future priorities.

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Amomum; essential oils; chemical profiles; spice value; cardamom; 1,8-cineole

Amomum essential oils

Amomum Roxb., a genus of 108 species in the family Zingiberaceae, is natively distributed in tropical and subtropical Asia to North Queensland (1). The etymology of the term '*amomum*' is linked to Greek-Latin words ('*ἄμωμον*' or '*amomon*') translating to '*eastern spice plant*' (2). Plants in genus *Amomum* are notable for their aromatic and pungent properties, and these characteristics are attributed to their volatile (EOs) and spicy (non-volatile) constituents (3). Oleoresins contribute a major share of pungent constituents (3–5). Examples of pungent non-volatile principles reported from genus *Amomum* and family Zingiberaceae are, (±)-*trans*-2,3,3a,7a-tetrahydro-1H-indene-4-carbaldehyde (*A. tsao-ko* (3)), (6)-gingerol, (6)-paradol, (6)–shogaol (*Zingiber officinale* (ginger) (6–8)), 1-(4′-hydroxy-3′-methoxyphenyl)-7-phenyl-3-heptanone (*Alpinia oxyphylla* (9)), galangal acetate or 1′–acetoxychavicol acetate (*A. galanga* (10)). Several *Amomum* species are used for the treatment of various ailments in folk and traditional practices (11–13). *Amomum* species are widely used as additives in cooking (14–23). Their EOs demonstrated various biological activities (12,13,20,24). Studies on the chemistry of *Amomum* EOs are scattered in the literature, and this review is discussing the current status of their chemistry and spice and flavor properties.

Isolation, chemical profiling

Chemical profiling studies of EOs in genus *Amomum* are listed in Table 1. In these reports, EOs were mostly isolated by hydrodistillation (HD) and rarely by steam distillation (SD). In some studies, *Amomum* EOs were isolated by advanced techniques such as super critical CO2 extraction, Microwave-Assisted Extraction (MAE), Solvent-Free Microwave Extraction (SFME), Modified-Solvent Free Microwave Extraction (MSFME), Deep Eutectic Solvent-based MHD (DES-MHD), Pressurized Hot Water Extraction-Liquid Phase Microextraction (PHWE-LPME) (Table 1, references therein).

Chemical profiles of isolated *Amomum* EOs were analyzed by gas chromatographic (GC-FID, GC-MS) techniques. In some cases, GC-MS profiles only were generated (examples, Noumi et al. (22), Masoumi-Ardakani et al. (25)). Chemical profiles of EOs depend on factors such as genotype (or eco-, chemo–type) of the plant material, plant part, growth stage, season and other edaphic/ecological parameters (16,26–32). The variation in chemical profiles could also be due to natural selection of plants leading to new varieties (33). Besides, EO composition depends on factors such as extraction method, experimental and chromatography conditions (34). These variations at various levels warranty the standardization of the genotype (of the plant), ecological conditions, pesticide/heavy metal contents, postharvest handling conditions and chemical

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Table 1. Chemical profiles of essential oils of various *Amomum* species.

Sl. No.	*Amomum* species	Collection location, country	Plant part	Isolation, yield (%, v/w)	Compounds identified (%)	Major constituents (%)	Reference
1.	*A. aculeatum*	Thua Thien-Hue, Vietnam	leaves	HD, 0.22	30 (96.5)	limonene (20.8), valencene (18.0), α-phellandrene (8.7), α-pinene (6.9), β-sesquiphellandrene (6.1), (Z)-β-ocimene (5.3), p-cymene (5.0)	(35)
2.	*A. agastyamalayanum*	Agastyamala Hills, India	rhizomes	HD, 0.02	85 (97.1)	*allo*-aromadendrene (16.2), β-pinene (8.7), (E)-caryophyllene (8.5)	(36)
3.	*A. aromaticum*	Ha Giang, Vietnam	fruits	HD, 1.49	25 (91.5)	1,8-cineole (48.2), geranial (9.2), neral (6.7)	(37)
4.	*A. biflorum*	Petchaboon, Thailand	whole plant	HD, 0.21 (w/w)	55 (81.6)	camphor (17.6), α-bisabolol (16.0), camphene (8.2), α-humulene (5.1)	(38)
5.	*A. cardamomum*	Bangkok, Thailand	fruits	SD, -	15 (98.4)	1,8-cineole (66.8), β-pinene (15.5), α-terpineol (5.4)	(39)
6.	*A. cannicarpum*	Ponmudi Hills, India	rhizomes	HD, 0.10	34 (84.6)	β-terpineol (13.4), β-pinene (9.4), α-pinene (6.9)	(40)
7.	*A. cannicarpum*	Ponmudi Hills, India	leaves	HD, 0.03	29 (88.7)	β-pinene (9.0), caryophyllene oxide (6.6), β-bisabolene (6.4), δ-cadinene (6.2), *cis*-calamenene (6.0), α-pinene (5.4)	(41)
8.	*A. cannicarpum*	Idukki, Kerala	fruits	HD, 0.08	33 (91.5)	β-pinene (14.0), elemol (10.5), α-cadinol (8.5), β–eudesmol (5.9)	(42)
9.	*A. compactum*	Tianjin, China	fruits	HD & MHD, 4.30–4.90	21–25 (95.5–97.1)	1,8–cineole (47.6–48.6), β–pinene (13.7–15.8), dipentene (7.8–8.3), α–terpineol (6.8–8.3)	(43)
10.	*A. gagnepainii*	Nghệ An, Vietnam	leaves	HD, 0.20	47 (99.2)	farnesyl acetate (18.5), zerumbone (16.4), β-caryophyllene (10.5), benzyl benzoate (6.5)	(26)
11.	*A. globosum*	Bangkok, Thailand	fruits	SD, 2.50	27 (92.3)	camphor (38.9), bornyl acetate (25.2)	(39)
12.	*A. hypoleucum*	Adimali, India	rhizomes, leaves	HD, rhizomes: 0.03 leaves: 0.04	rhizomes: 19 (93.0) leaves: 52 (97.6)	rhizomes: cryptone (15.4), β-pinene (11.9), caryophyllene oxide (7.6), caryophyllene acetate (6.9) leaves: (E)-nerolidol (26.5), α-fenchyl acetate (15.0), β-caryophyllene (8.4), caryophyllene oxide (8.0)	(44)
13.	*A. korarima*	Addis Ababa, Ethiopia	fruits	SD, 3.50	15 (87.6)	1,8-cineole (35.1), limonene (13.5), β-pinene (6.8), sabinene (6.7)	(45)
14.	*A. kravanh*	Anhui, China	fruits	HD & MHD, 4.10–4.80	27–29 (95.2–96.7)	1,8–cineole (43.0–50.1), α–terpinyl acetate (9.2–11.2), dipentene (6.6–8.1), β–pinene (5.4–6.2)	(43)
15.	*A. kravanh*	Hainan, China	fruits	HD, -	34 (95.8)	1,8-cineole (68.4), α–pinene (5.7)	(46)
16.	*A. kravanh*	Hangzhou, China	fruits	HD, MHD & DES-based MHD, 1.90–3.64 (w/w)	19–20 (96.6–99.7)	1,8–cineole (72.6–78.0), α–pinene (0.7–10.2), santolina triene (0.0–8.3), 4,7,7-trimethyl bicyclo[4.1.0]heptan-3–ol (3.4–5.3)	(23)
17.	*A. kravanh*	Yunnan, China	fruits	HD, 2.45	40 (96.5)	1,8-cineole (58.5), α–pinene (8.3)	(13)
18.	*A. linguiforme*	Assam, India	rhizomes	HD, 0.40	13 (99.5)	methyl chavicol (93.2)	(47)
19.	*A. longiligulare*	Nghệ An, Vietnam	leaves, stem, roots	HD, 0.20–0.25	leaves: 44 (99.6) stem: 45 (99.6) roots: 40 (99.4)	leaves: β–caryophyllene (26.6), α-pinene (15.6), humulene epoxide II (14.8), α-humulene (12.5) stem: β–caryophyllene (37.4), α–humulene (16.5), hexahydrofarnesyl acetone (10.0), α–pinene (5.4), eicosane (5.0) roots: camphene (15.7), hexadecanoic acid (10.0), octadecanoic acid (8.6), bornyl acetate (7.8)	(48)
20.	*A. maximum*	Yunnan, China	fruits	HD, 0.12	36 (89.7)	β-pinene (23.4), β–caryophyllene (16.4), α-pinene (7.6), sylvestrene (6.6)	(12)
21.	*A. maximum*	Nghệ An, Vietnam	leaves, stem, roots	HD, leaves: 0.31 stem: 0.25 roots: 0.34	leaves: 47 (96.8) stem: 52 (92.3) roots: 43 (93.5)	leaves: β-pinene (40.8), β-elemene (10.9), α-pinene (9.7), β-caryophyllene (8.3) stem: β-pinene (20.4), β-elemene (12.8), β-caryophyllene (10.3), α-pinene (6.8) roots: β–pinene (28.0), α-pinene (15.0), β–phellandrene (11.6), camphene (5.4)	(49)
22.	*A. muricarpum*	Nghệ An, Vietnam	leaves, stem, roots, fruits, flowers	HD, leaves: 0.30 stem: 0.26 roots: 0.40 fruits: 0.35 flowers: 0.32	leaves: 30 (97.4) stem: 43 (98.4) roots: 38 (97.0) fruits: 43 (93.2) flowers: 51 (94.2)	leaves: α–pinene (48.4), β–pinene (25.9), limonene (7.4) stem: α-pinene (47.2), δ-3-carene (9.4), β–pinene (9.2) roots: α-pinene (54.7), β–pinene (14.3), β–phellandrene (8.3) fruits: α–pinene (29.3), β–pinene (17.9), zingiberene (6.3) flowers: α-pinene (24.1), β–pinene (14.1), τ-muurolol (13.0)	(49)

(*Continued*)

Table 1. (Continued).

Sl. No.	*Amomum* species	Collection location, country	Plant part	Isolation, yield (%, v/w)	Compounds identified (%)	Major constituents (%)	Reference
23.	*A. muricatum*	Ponmudi Hills, India	leaves	HD, 0.04	14 (94.8)	β-pinene (35.9), δ–cadinene (8.9), α–pinene (8.2), α–copaene (6.6), (E)–nerolidol (5.6)	(50)
24.	*A. newmanii*	Agastyamala Hills, India	rhizomes	HD, 0.02	105 (98.3)	santolina triene (42.2), α–pinene (17.1)	(36)
25.	*A. pavieanum*	Chanthaburi, Thailand	rhizomes	SD, 0.23	41 (99.2)	methyl chavicol (91.6)	(51)
26.	*A. pterocarpum*	Adimali, India	rhizomes, leaves	HD, rhizomes: 0.03 leaves: 0.04	rhizomes: 36 (95.7) leaves: 36 (92.6)	rhizomes: β–pinene (65.5) leaves: β–pinene (41.7), phytol (26.5), isocaryophyllene (5.1)	(52)
27.	*A. repoense*	Nghệ An, Vietnam	leaves	HD, 0.25	51 (97.6)	β-pinene (33.5), (E)–β–ocimene (9.6), γ–terpinene (9.1), α-pinene (8.4)	(26)
28.	*A. rubidum*	Lam Dong, Vietnam	rhizomes	HD, 0.13	36 (95.4)	β-phellandrene (16.1), limonene (14.4), δ–3–carene (13.9), α–pinene (7.7), β–pinene (6.9), α–phellandrene (6.9)	(53)
29.	A. *schmidtti*	Hanoi, Vietnam	leaves, stem, roots	SD, leaves: - stem: - roots: -	leaves: 18 (98.8) stem: 18 (98.8) roots: 18 (98.5)	leaves: *trans*-p-(1-butenyl)anisole (91.2) stem: *trans*-p-(1-butenyl)anisole (94.7) roots: *trans*-p-(1-butenyl)anisole (90.0)	(54)
30.	*A. subulatum*	Lucknow, India	fruits	SD, 2.50	13 (99.2)	1,8-cineole (74.0), limonene (10.3), α-terpineol (5.6)	(45)
31.	*A. subulatum*	Sikkim, India	seeds	HD, fresh seeds: 1.60 dry seeds: 2.40–2.70	fresh seeds: 33 (99.1) dry seeds: 33 (99.6–99.7)	fresh seeds: 1,8-cineole (84.5) dry seeds: 1,8–cineole (81.5–86.0)	(55)
32.	*A. subulatum*	Sikkim, India	pericarp (husk)	HD, 0.18	37 (99.3)	1,8-cineole (38.7), β-pinene (13.6), α-terpineol (12.6), spathulenol (8.7)	(15)
33.	*A. subulatum*	Sikkim, India	seeds	SD, 2.50	37 (97.7)	1,8-cineole (61.3), β-pinene (8.9), α-terpineol (7.9)	(14)
34.	*A. subulatum*	Delhi, India	fruits	HD, 1.80	9 (95.1)	1,8-cineole (77.4), β-myrcene (5.0)	(56)
35.	*A. subulatum*	Terahthum, Nepal	fruits	HD, seeds: 4.50 rind: 1.00	seeds: 64 (99.1) rind: 66 (99.0)	seeds: 1,8-cineole (60.8), α-terpineol (9.8), β-pinene (8.3), α-pinene (6.4) rind: 1,8-cineole (39.0), β-pinene (17.7), α-terpineol (12.3), α–pinene (4.8)	(18)
36.	*A. subulatum*	Himachal Pradesh, India	seeds	HD, 0.98–1.95 (w/w)	30–34 (91.9–99.7)	1,8–cineole (50.6–60.5), α–terpineol (14.9–16.5), dl–limonene (5.5–11.8), nerolidol (3.8–6.0), 4–terpineol (2.6–5.4)	(19)
37.	*A. subulatum*	4 cultivars (Sikkim, Nagaland, West Bengal), India & Myanmar	seeds	HD, 1.20–2.80	10–15 (91.8–98.2)	1,8–cineole (63.2–73.4), β–pinene (4.0–11.1), α–terpineol (5.6–7.6), α–pinene (1.7–6.5)	(5)
38.	*A. subulatum*	Munnar, India	leaves	HD, 0.73	33 (94.4)	1,8-cineole (39.8), α-terpineol (11.5)	(27)
39.	*A. subulatum*	Jeddah City, Saudi Arabia	seeds	HD, -	27 (92.3)	1,8-cineole (41.7), geraniol (12.5), geranyl acetate (6.0), α–terpineol (5.4)	(22)
40.	*A. subulatum*	Sikkim, India	whole pods	HD, 0.90–1.50	33 (92.1)$^{\pm}$	1,8-cineole (52.8), α-terpineol (8.2), limonene (6.9), β-pinene (6.3)	(33)
41.	*A. testaceum*	Perak, Malaysia	fruits	HD, 0.83 (w/w)	18 (91.0)	myrtenol (16.1), β-pinene (15.9), 1,8-cineole (12.7), myrtenal (12.7), *trans*-pinocarveol (10.9), fenchone (10.5)	(57)
42.	*A. testaceum* (*Fructus Amomi Rotundus*)	Hangzhou, China	seeds	MAE-DLLME, -	47 (98.3)	1,8-cineole (64.3), α-terpineol (15.5)	(71)
43.	*A. tsao-ko*	Hoang Lien Son, Vietnam	seeds	SD, 1.40	21 (89.8)	1,8-cineole (30.6), 2-decenal (17.3), geranial (10.6), neral (7.0)	(59)
44.	*A. tsao-ko*	Guangxi, China	fruits	HD, 1.69	73 (97.6)	1,8-cineole (45.2), geraniol (5.1)	(16)
45.	*A. tsao–ko*	Yunnan, China	fruits	HD, MHD, 1.62–2.30	32–33 (96.4–96.9)	1,8–cineole (33.8–38.4), 2-*iso*-propylbenzaldehyde (10.0–10.2), nerol (6.8–8.5), α–methyl cinnamaldehyde (6.4–6.9), 3–heptylacrolein (4.3–5.1)	(60)
46.	*A. tsao-ko*	Yunnan, China	fruits	HD, 1.83 (w/w)	32 (98.4)	1,8–cineole (40.9), α–phellandrene (9.8), 2–isopropylbenzaldehyde (7.0)	(17)

(*Continued*)

Table 1. (Continued).

Sl. No.	*Amomum* species	Collection location, country	Plant part	Isolation, yield (%, v/w)	Compounds identified (%)	Major constituents (%)	Reference
47.	*A. tsao–ko* (4 cultivars)	Yunnan, China	fruits	HD, 1.47–1.90	21–30 (77.1–86.5)	1,8–cineole (35.3–37.0), citral (6.0-16.0), α–phellandrene (1.9–10.3), α–terpineol (5.4–8.7)	(28)
48.	*A. tsao-ko*	Guangxi, China	fruits	HD, 1.60	43 (90.4)	1,8–cineole (23.9), limonene (22.8), 2–isopropyltoluene (6.7), undecane (5.7)	(20)
49.	*A. tsao-ko*	Harbin, China	-	HD, SFME, M–SFME, 0.84–1.13 (w/w)	34 (91.1–95.3)	1,8–cineole (34.6–37.8), α–phellandrene (5.4–5.8), p–propylbenzaldehyde (5.3–5.8), geraniol (4.8–5.4)	(29)
50.	*A. tsao–ko*	Hangzhou, China	fruits	MHD, DES-based MHD, 0.43–2.16 (w/w)	41–47 (92.3-93.1)	1,8–cineole (44.6–44.7)	(23)
51.	*A. tsao–ko*	Yunnan, China	whole pods	HD, 0.70–1.80	60–61 (85.5-89.5)$^{\pm}$	1,8–cineole (22.6–28.1), geranial (1.6–7.8), geraniol (7.0–7.1), *trans*-2,3,3a,7a-tetrahydro-1H-indene-4-carbaldehyde (3.7–6.8), (2E)–decenal (3.0–6.1)	(33)
52.	*A. uliginosum*	Pahang, Malaysia	rhizomes	HD, 0.03	47 (81.9)	β–pinene (29.9), α–pinene (10.4), α–terpineol (7.6), isopinocamphone (5.1)	(61)
53.	*A. velutinum*	Ha Tinh, Vietnam	leaves, pseudo-stem, rhizomes	HD, leaves: 0.18 pseudo-stem: 0.11 rhizomes: 0.21	leaves: 33 (95.7) pseudo-stem: 35 (99.7) rhizomes: 46 (94.2)	leaves: β-pinene (46.3), myrtenyl acetate (10.5), α-pinene (8.1), thymol (6.8) pseudo-stem: β-pinene (43.5), β-caryophyllene (14.0), *cis*-β-elemene (9.8), α-pinene (5.2) rhizomes: β-pinene (45.9), α-pinene (7.0)	(62)
54.	*A. verum*	Chantaburi, Thailand	shoots	HD, 0.37	5 (97.8)	1,8–cineole (84.4), limonene (6.2)	(63)
55.	*A. villosum*	Yunnan, China	leaves	SD, 0.10–0.15	29 (99.9)	β–pinene (58.5), α–pinene (31.3), sabinene (5.8)	(64)
56.	*A. villosum* (dried fruit, *Fructus amomi*)	(Guangdong, Yunnan, Hainan, Jiangxi, Fujian), China	fruits	PHWE-LPME, SD, –	27 (97.1–99.7)	camphor (34.4–37.0), borneol (31.1–31.6), borneol acetate (11.4–11.5)	(65)
57.	*A. villosum* (dried fruit, *Fructus amomi*)	(Hainan, Guangdong), China	fruits	PHWE–HS-SPME, -	35 (97.4)	camphor (37.9), borneol acetate (15.5), camphene (7.6), d–limonene (5.9), borneol (5.6), caryophyllene (5.5)	(66)
58.	*A. villosum* (cultivar)	Guangdong, China	seeds	HD, -	44 (94.9)	bornyl acetate (30.5), camphor (22.3), limonene (8.3), camphene (6.7), β–caryophyllene (5.1)	(67)
59.	*A. villosum*	(Hà Tĩnh, Nghệ An), Vietnam	leaves, roots	HD, leaves: 0.28–0.30 roots: 0.21–0.25	leaves: 30–31 (96.4–98.6) roots: 42–43 (94.8-97.9)	leaves: β–pinene (53.6–56.6), α–pinene (22.0–22.1) roots: β–pinene (34.7–41.6), α–pinene (11.6–14.0)	(68)
60.	*A. villosum*	Yunnan, China	fruits	HD, 1.90	17 (98.8)	bornyl acetate (51.6), camphor (19.8), camphene (8.9), limonene (6.2)	(30)
61.	*A. villosum*	Nghệ An, Vietnam	stem	HD, 0.21	36 (98.5)	β–pinene (48.1), α–pinene (16.9)	(69)
62.	*A. villosum*	Yunnan, China	fruits (powder)	SD, 3.90	58 (94.2)	bornyl acetate (54.5). camphor (17.9), camphene (6.8), limonene (5.2)	(70)
63.	*A. villosum*	Hangzhou, China	fruits	MHD & DES-based MHD, 1.03–1.62 (w/w)	36–38 (92.5-93.4)	dl–camphor (39.4–41.8), isobornyl formate (26.0–26.0), camphene (6.3–7.7)	(23)
64.	*A. villosum* (*Fructus amomi*)	various locations, China	fruits	SD, 2.40–3.40	13 (94.7–97.2)	bornyl acetate (41.3–60.2), camphor (16.8–28.9), d-limonene (6.7–8.3), camphene (4.8–8.0)	(71)
65.	*A. villosum* var. *xanthioides*	Yunnan, China & locations in Vietnam, Thailand, Myanmar	fruits	SD, 0.90–1.70	13 (91.4–96.0)	camphor (29.1–44.8), bornyl acetate (15.9-31.6), d–limonene (8.1–11.4), camphene (3.2–8.3), borneol (3.8–8.1), β–myrcene (4.1–6.1)	(71)
66.	*Elettaria cardamomum*	4 varieties, Ceylon (Sri Lanka), Guatemala	seeds	CP, approx. 5.00 (w/w)	31 (96.6–97.9)	α–terpinyl acetate (0.1-52.5), 1,8–cineole (3.3–44.0), γ–terpinene (0.04–11.2), *trans*–sabinene hydrate (0.1–22.2), 4–terpineol (0.1–15.3), linalyl acetate (0.3–6.3)	(72)
67.	*E. cardamomum*	San Jose, Costa Rica	capsules	SD-E, 3.68	122 (99.2)	α-terpinyl acetate (39.3), 1,8-cineole (31.8), linalool (5.9)	(73)

(*Continued*)

Table 1. (Continued).

Sl. No.	*Amomum* species	Collection location, country	Plant part	Isolation, yield (%, v/w)	Compounds identified (%)	Major constituents (%)	Reference
68.	*E. cardamomum*	Mysore, India	seeds, fruit coats	HD, seeds: 6.00 fruit coats: 1.40	seeds: 24 (95.3) fruit coats: 20 (96.6)	seeds: α-terpinyl acetate (56.9), 1,8–cineole (15.1) fruit coats: α-terpinyl acetate (51.3), 1,8–cineole (23.7), α–terpineol (5.3)	(74)
69.	*E. cardamomum*	4 varieties (Malabar, Mysore, Vazhukka, Guatemala), Kerala, India	seeds	HD, 7.90–8.79	28–29 (91.7–98.1)	terpenyl acetate (61.7–68.2), 1,8–cineole (7.2–11.8), linalool (0.9–6.0), α–terpineol (2.9–5.5)	(75)
70.	*E. cardamomum*	-	-	HD, 3.10	73 (87.8)	α-terpineol acetate (11.8), linalool (10.2), nerolidol (8.8), α–pinene (8.1)	(76)
71.	*E. cardamomum*	Kerman, Iran	aerial parts	HD, 5.70	11 (93.5)	1,8-cineole (45.6), α–terpinyl acetate (33.7)	(25)
72.	*E. cardamomum*	Faisalabad, Pakistan	fruits	-, -	26 (99.0)	α-terpinyl acetate (38.4), 1,8-cineole (28.7), linalool acetate (8.4), sabinene (5.2)	(34)
73.	*E. cardamomum*	Jeddah City, Saudi Arabia	seeds	HD, -	19 (99.9)	1,8-cineole (55.4), α–terpinyl acetate (28.6)	(22)
74.	*E. cardamomum*	Kerala, India	whole pods	HD, up to 5.20	43 (97.6)$^{\pm}$	α-terpinyl acetate (44.8), 1,8–cineole (27.9)	(33)
75.	*Aframomum corrorima*	Jeddah City, Saudi Arabia	seeds	HD, -	33 (98.2)	1,8–cineole (51.8), 4–terpineol (10.4), limonene (5.4)	(22)
76.	*A. daniellii*	Balengou, Cameroon	seeds	HD, 2.30	25 (98.0)	1,8–cineole (48.9), limonene (12.8), β–pinene (12.7), α-terpineol (7.4)	(77)
77.	*A. daniellii*	Ibadan, Nigeria	seeds	HD, 3.20	40 (98.2)	1,8–cineole (59.8), β–pinene (13.2), α–terpineol (9.3)	(78)

HD – Hydrodistillation, SD – Steam Distillation, MHD – Microwave-assisted Hydrodistillation, DES-based MHD – Deep Eutectic Solvent-based Microwave-assisted Hydrodistillation, MAE-DLLME – Microwave-Assisted Extraction/Dispersive Liquid-Liquid MicroExtraction, SFME – Solvent Free Microwave Extraction, M-SFME – Modified-Solvent Free Microwave Extraction, PHWE-LPME – Pressurized Hot Water Extraction-Liquid Phase Microextraction, PHWE-HS-SPME – Pressurized Hot Water Extraction-Head Space-Solid Phase Microextraction, CP – Cold-Pressing, SD-E– Simultaneous Distillation-Extraction; Most studies, irrespective of species, plant parts and oil isolation techniques, reported the colour of *Amomum* EOs as 'yellow', 'light yellow', 'pale yellow' or 'faint yellow'; Pura Naik et al. (15) and Feng et al. (60) reported the colour of EOs as 'yellowish brown' (*A. subulatum)* and 'primrose yellow' (*A. tsao-ko*), respectively; Very few studies reported *Amomum* EOs as 'colorless' ((*A. subulatum* (14), *A. cannicarpum* (42), *A. linguiforme* (47), *A. pavieanum* (51)), 'pale' (*A. subulatum* (19)), 'orange' (*A. tsao-ko* (17)) and 'light blue' (*A. villosum* (30)); EO yields are listed in (v/w), in a few cases where oil yields are in (w/w) are indicated in Table 1; EO constituents with relative content ≥5% are listed as major constituents; GC-FID, GC-MS and associated techniques were used for chemical profiling of EOs; but in few cases GC-MS only was used; $^{\pm}$Major constituents (>0.1%); *Eletteria cardamomum, Aframomum daniellii* and *A. corrorima* are included in Table 1 (and in the article) primarily to compare their chemistry and spice characteristics with *Amomum* species.

fingerprinting to obtain high quality EOs and spice products from these aromatic plants.

Chemistry, spices

Spices are food ingredients which improve flavor and their trade played a major role in civilization of mankind and history of nations (4,34,79). Several plants in the genera *Elettaria, Amomum*, and *Aframomum*, all belonging to the Zingiberaceae family, are used as spices and are referred as 'cardamom' (33). More specifically, dried fruits of *Amomum subulatum* (black or large cardamom), *A. tsao-ko* (Chinese black cardamom), *Eletteria cardamomum* (true or green or small cardamom) and *Aframomum daniellii* (African cardamom) are the most widely used and economically important spices (33,78,80). The classification of cardamoms is based on colour (black, green) and size (small, large) of their dried fruits or their region of origin (China, Africa) (33). Owing to their commercial importance, the chemistry and trade prospects of *A. subulatum* and *E. cardamomum* are widely studied.

A. subulatum is a tall perennial rhizomatous herb cultivated in India (Sikkim, West Bengal, Arunachal Pradesh, Nagaland, Mizoram, Manipur, Uttarakhand etc.) between 600 and 2000 m asl. It is also cultivated in neighboring countries (Nepal, Bhutan). *A. subulatum* seed has a pleasant aromatic odor due to which it is extensively used for flavoring food preparations (24). Chemical profiles of EOs of *A. subulatum* (wild and cultivars) from diverse geographical locations were studied by various groups (Table 1). *A. subulatum* seeds contain approx. 2.5% EO (Table 1, references therein).

1,8-Cineole (commonly known as eucalyptol) is invariably the major constituent in EOs from various parts of *A. subulatum* (leaves 39.8% (27); fruits 74.0% (45), 77.4% (56); whole pods: 52.8% (33); pericarp (rind or husk): 38.7% (15), 39.0% (18); seeds: 81.5–86.0% (55), 61.3% (14), 60.8% (18), 50.6–60.5% (19), 63.2–73.4% (5), 41.7% (22)) collected from various geographical locations. Other major constituents in essential oils of *A. subulatum* varied between plant parts and their collection locations (Table 1). Large cardamom has a woody, smoky, camphorous flavor (24), and its EO is responsible for its typical flavor (odor). Joshi and co-workers (2013) reported the monoterpenes *viz*., 1,8-cineole, dl-limonene, α-pinene, β-myrcene, *trans*-sabinene hydrate, and sesquiterpenes *viz*., α-bisabolol, α-caryophyllene, as the odor-active constituents among the various aroma compounds in *A. subulatum* EO (19).

In India, Western Asia and in other parts of the world, large cardamom is used as a flavor/spice ingredient in various dishes and preparations such as pulavu, biriyani, curries, soups, sweets, sausages, meat dishes and pickles (24). It is also used as an ingredient in curry powders and masala mixtures and as a flavoring component in colas, biscuits, liquors and teas (15,24,27). EO isolated from *A. subulatum* seeds is used as spice and for medicinal purposes (24). *A. subulatum* EO is also used as a preventive as well as curative agent for throat troubles, congestion of lungs, inflammation of eye lids, digestive disorders and in the treatment of pulmonary tuberculosis.

India is the largest producer of large cardamom (*A. subulatum*), with the highest production (50% of world production) in Sikkim (22,81). In 2008, Parthasarathy and co-workers listed the annual production of large cardamom in India, Nepal and Bhutan as 4000, 2500 and 1000 MT (metric tons), respectively (4). Purohit and co-workers estimated the production of large cardamom in India as 4465 MT in 2013–14, with an export of approx. 25% (1110 MT) (21).

E. cardamomum (true cardamom) is known as the 'Queen of Spices' with characteristic taste and aroma for its seed pods (22,33,76,80). Its EO is one of the oldest raw materials in perfumery and one of the most expensive spices. *E. cardamomum* is native to southern India and Sri Lanka, naturalized in Tanzania and Guatemala and cultivated in several other regions of the world including Nepal, Iran, Thailand, Myanmar, Vietnam, Combodia, Morocco, Costa Rica, Papua New Guinea, Malaysia, El Salvador and Central America (31,33,76).

Most studies reported α–terpinyl acetate (seeds: 0.-1–52.5% (72), 56.9% (74), 61.7–68.2% (75), 11.8% (76); capsules: 39.3% (73), fruit coat: 51.3% (74), fruits: 38.4% (34), whole pods: 44.8% (33)) as the major constituent and 1,8-cineole (seeds: 3.3–44.0% (72), 15.1% (74), 7.-2–11.8% (75), 4.3% (76); capsules: 31.8% (73); fruit coat: 23.7% (74); fruits: 28.7% (34); whole pods: 27.9% (33)) as the second major constituent in EOs of various parts of *E. cardamomum*. A few studies reported *vice versa*, 1,8-cineole (aerial parts: 45.6% (25); seeds: 55.4% (22)) and α-terpinyl acetate (aerial parts: 33.7% (25); seeds: 28.6% (22)) as the first and second major constituents in *E. cardamomum* EOs (Table 1). Govindarajan and co-workers (1982) compiled the chemical profiles of cardamom EOs from 6 varieties (or sources), and their major constituents were 1,8-cineole (26.5–41.0%), α-terpinyl acetate (28.1–39.7%) and d-limonene (1.7–14.3%). The same study reported the major volatile constituents in true cardamom oleoresin as α-terpinyl acetate (53.2%), 1,8-cineole (22.2%) and linalyl acetate (5.3%) (80). Lawrence (1978) listed 1,8-cineole (36.3%), α-terpinyl acetate (31.3%) and limonene (11.6%) as the major constituents in wild cardamom EOs (80,82). The flavor characteristics of cardamom EO are reported as penetrating, irritating, cineolic, camphoraceous, warm, sweet, spicy, aromatic, pleasing and citrus-like odor (83). The impact constituents in cardamom EO are the major terpenoids, α-terpinyl acetate and 1,8-cineole. α-Terpinyl acetate (along with geranyl acetate, nerol, α-terpineol) contributes to the pleasant aroma and 1,8-cineole to the pungency in true cardamom (31,83).

E. cardamomum, as a traditional herbal medicine, has been prescribed in the treatment of gastrointestinal, stomachic, resolvent, retentive, digestive, antiemetic and carminative disorders. *E. cardamomum* seeds are also used for controlling cold and associated symptoms (84). It is used as flavor in masala chai in India, coffee and tea in Iran and the black Turkish tea or Kakakule in Turkey (74,76). In some countries, such as Saudi Arabia, chewing the cardamom seed is a habit among people (85). Cardamom capsule powder is used for bronchial asthma patients with excess saliva and mucus in the respiratory tract, and as an excellent cough suppressant (84). *E. cardamomum* EO is known for its traditional health care, flavoring agent, fine perfumery and cosmetic applications. Its EO is mainly used as a flavoring agent in the preparation of curries, coffee, cakes, breads, pickles, rice and drinks (76). In addition, *E. cardamomum* EO is used in perfumery, liquor and pharmaceutical industries as a flavor and carminative (76). *E. cardamomum* EO also has antimicrobial, anti-inflammatory, analgesic and antispasmodic activities. *E. cardamomum* EO, due to its high 1,8-cineole and terpinyl acetate contents, has profound effects on the respiratory system, and promotes clear breathing and respiratory health (5,31). *E. cardamomum* seed EO is listed as GRAS (Generally Recognized as Safe) by the Food and Drug Administration (FDA) (86).

A. danielli (African cardamom) is native to south east Africa especially Tanzania, Cameroon, Guinea and Madagascar (78,80,84). Similarly, *A. corrorima* (Ethiopian cardamom) is native to east Africa (Burundi, Ethiopia, Kenya, Tanzania, Uganda) (1). 1,8-cineole is the major constituent in *A. daniellii* and *A. corrorima* EOs, *viz.*, 51.8% (*A. corrorima*, Jeddah City, Saudi Arabia (22)); 48.9% (*A. daniellii*, Balengou region, Cameroon (77)); 59.8% (*A. daniellii*, Ibadan, Nigeria (78)). 4-Terpineol (10.4%, *A. corrorima* (22)); limonene (12.8%) and β-pinene (12.7%) (*A. daniellii* (77)) and β-pinene (13.2%) (*A. daniellii* (78)) are the second major constituents in *A. corrorima* and *A. daniellii* EOs (Table 1).

A. tsao-ko is widely distributed in the south-west of China (66). Its dried fruit is a commercially important spice and flavoring in south-east Asia. *A. tsao–ko* is used in Traditional Chinese Medicine (TCM), and its EO displays various biological activities (3,16,20,28,29,60,65,71). Pungent principles (with trigeminal effect) were also isolated from *A. tsao-ko* (3). In China, it is popularly used for the treatment of stomach disorders, dyspepsia, nausea, vomiting, diarrhea, malaria, throat infections and abdominal pain (87). *A. tsao-ko* EO has sedative, analgesic and hypnotic effects, and could increase the percutaneous permeation rate of rutondine *in vitro* (88). 1,8-Cineole is the major constituent in EOs of *A. tsao-ko* collected from various geographical locations (seeds: 30.6% (59); fruits: 45.2% (16), 33.8–38.4% (60), 40.9% (17), 35.3–37.0% (28), 23.9% (20), 34.6–37.8% (29), 44.6–44.7% (23); whole pods: 22.6–28.1% (33)) (Table 1). 2-Decenal, undecane, geranial, geraniol, neral, nerol, cinnamaldehyde, propylbenzaldehyde, isopropylbenzaldehyde, α-terpineol, α-phellandrene and limonene are the other major constituents in *A. tsao-ko* EOs. Sim and coworkers (2019) described the odor characteristics of *A. subulatum, A. tsao-ko* and *E. cardamomum* EOs, and this study differentiated the odor of *A. subulatum* and *A. tsao-ko* EOs (from *E. cardamomum* EO) based on the smoky notes derived from the phenolics (thymol, carvacrol, eugenol) and their derivatives (33).

A. kravanh is widely distributed in Cambodia, Thailand, Vietnam and cultivated in South China. It is also used in Traditional Chinese Medicine (TCM) (90). Its fruits are used as spices throughout the world and are commonly used to treat stomach diseases and digestive disorders (46). *A. kravanh* fruit EOs from various locations in China also showed 1,8-cineole (fruits: 43.0–50.1% (43), 68.4% (46), 72.6–78.0% (23), 58.5% (13)) as its major constituent (Table 1). Several studies on EOs of various *Amomum* species distributed in China are published in the Chinese language (33,48).

In Table 1, irrespective of variations in factors such as origin of the plant samples, plant parts, collection season/ecological parameters, isolation and analytical parameters, EOs of several *Amomum* species have 1,8–cineole as their major constituent, *viz., A. aromaticum* (48.2%), *A. caradamomum* (66.8%), *A. compactum* (47.6–48.6%), *A. testaceum* (64.3%), *A. korarima* (35.1%), *A. kravanh* (43.0–50.1%, 68.4%, 72.6–78.0%, 58.5%), *A. subulatum* (74.0%, 81.5–86.0%, 38.7%, 62.1%, 61.3%, 43.7%, 77.4%, 61.3%, 60.8%, 39.0%, 50.6–60.5%, 63.2–73.4%, 39.8%, 41.7%, 52.8%), *A. tsao-ko* (30.6%, 45.2%, 33.8–38.4%, 40.9%, 35.3–37.0%, 23.9%, 34.6–37.8%, 44.6–44.7%, 22.6–28.1%), *A. verum* (84.4%) (Table 1). The literature on these eight *Amomum* species *viz., A. aromaticum, A. compactum, A. testaceum, A. korarima, A. kravanh, A. subulatum, A. tsao–ko, A. verum*, corroborates their use as flavors and spices either locally, regionally or globally (5,14–20,22,23,27–29,33,37,43,45,46,55,56,58–60,63,91).

1,8-Cineole, its combination with α-terpinyl acetate and the overall chemical profiles of EOs with several minor entities elucidate the spice/flavor characteristics of various *Amomum, Elettaria* and *Aframomum* EOs (*viz., A. aromaticum, A. compactum, A. testaceum, A. korarima, A. kravanh, A. subulatum, A. tsao-ko, A. verum, E. cardamomum, A. daniellii, A. corrorima*). 1,8-Cineole and several of its derivatives reported from other Zingiberaceae species (example, *Alpinia galanga* (92,93), *A. mutica* (39)) are proven aroma constituents, justifying the use of *Amomum* species enriched with them as flavors and spices. It has a pungent, cooling, spicy taste and it induces a strong camphoraceous odor to EOs (23,29,80,93,67). It is also minty, fresh and diffusive and has a poor tenacity (80). This monoterpene (C10)-cyclic ether has been employed in diverse applications, including in flavors, fragrances and cosmetics, medicinal purposes, as a therapeutic ingredient and as an additive in cigarettes (70). Therapeutic applications of 1,8-cineole for treatment of respiratory diseases, muscle pain, neurosis, rheumatism and kidney stones have also been investigated (29). It is also used in a wide variety of products such as nasal inhalers and sprays, external analgesics and mouth washes (95). In genus *Amomum, A. subulatum, A. tsao-ko* and *A. kravanh* EOs are good sources of 1,8-cineole. It is also a major constituent in *Eucalyptus* sp., sage (*Salvia officinalis*) and tea tree (*Melaleuca alternifolia*) EOs (95).

Recently, more emphasis is given to the therapeutic effects of 1,8-cineole in respiratory conditions such as anti-inflammatory and bronchodilatory effects (38). It has demonstrated therapeutic benefits in inflammatory airway diseases such as asthma, chronic obstructive pulmonary disease (COPD) and against viral infections (98,42). It is known to induce interferon regulatory factor 3 (IRF3), control nuclear factor kappa-light-chain-enhancer of activated B cells (NF-κB) and release of proinflammatory cytokines and decrease mucin genes (MUC2, MUC19) (11,42). 1,8-Cineole is also a licensed medicinal product used against respiratory infections, acute and chronic bronchitis and sinusitis (97,49). Volatile molecules (such as 1,8-cineole) are characterized by high vapor pressure, and consequently are easily exhaled by the lungs after ingestion. The physiochemical properties of 1,8-cineole (melting point 1.5 °C with flash point of 49 ^{o}C) allow significant concentrations to be achieved in the lungs through pulmonary exhalation. Currently, the possibility of 1,8-cineole as a treatment against the acute respiratory syndrome induced by SARS-CoV-2 is also being appraised (49). Since they are widely used as spices and food additives, 1,8-cineole-rich *Amomum* species (fruits, seeds) *viz., A. aromaticum, A. compactum, A. testaceum, A. korarima, A. kravanh, A. subulatum, A. tsao-ko, A. verum*, could strengthen immunity, prevent infection, and function against SARS-CoV−2 and other viral infections (51). However, more experimental data are to be obtained to substantiate these claims.

A. villosum is grown in south east Asia, especially in southern China. *A. villosum* has diverse medicinal functions such as dissipating dampness, warming the spleen, regulating Qi flow and preventing miscarriage. Dried ripe fruits (with aromatic seeds) of *A. villosum* (also known as *Fructus Amomi*) have been used to treat digestive diseases such as abdominal pain, vomiting and dysentery. *Fructus Amomi* is a common TCM (52,57). In addition, *Fructus Amomi* has been approved by China Food and Drug Administration, and due to its aroma and flavor characteristics, it has been widely used in Chinese cuisine for preparation of food, liquors and tea (102,61). The desired characteristics of *Fructus Amomi* in medicine and cuisine are mainly attributed to its EO (66,102,104). Owing to the nature of the effective components in its oil, *Fructus Amomi* is usually added to tea and wine. *Fructus Amomi* EOs mainly consist of camphor (34.4–37.0% (65), 37.9% (66), 16.8–28.9% (71)) and bornyl acetate (11.4–11.5% (65), 15.5% (66), 41.3–60.2% (71) as its major terpenoids. EOs of the dried fruits of *A. villosum* (*Fructus amomi*) obtained from Guangdong, Yunnan, Hainan, Jiangxi and Fujian provinces in China isolated by PHWE–LPME and SD showed borneol (31.1–31.6%) as one of the major terpenoid entities (65) (Table 1). Camphor is an oxygenated monoterpene with strong aroma. Bornyl acetate (ester of borneol, a bicyclic monoterpene alcohol) is the quality standard of *Fructus Amomi* according to the Chinese Pharmacopeia (102). Moreover, bornyl acetate extracted from *A. villosum* showed analgesic and anti-inflammatory effects (60). Again, with a strong piney aroma, bornyl acetate is used as a food additive and a flavoring agent and reported to have antioxidant, anti-inflammatory, anticancer and antiabortion activities (102).

The chemical profiles of EOs of several *Amomum* species were reported from south India (Table 1). We recently studied the chemical profiles of rhizome EOs of *A. sahyadrica* and *A. fulviceps* collected from the evergreen forests of Agastyamala Hills in Kerala in south India. Major constituents in *A. sahyadrica* rhizome oil were bulnesol (36.2%), longiborneol acetate (6.1%), butylated hydroxytoluene (5.5%) and 7-*epi*-α-selinene (5.4%) (unpublished data). Similarly, camphene (23.4%), *trans*-isolimonene (11.6%) and γ-terpinene (5.5%) were the major terpenoids in *A. fulviceps* rhizome oil (unpublished data). These two *Amomum* species, *A. sahyadrica* and *A. fulviceps*, were recently transferred to the genus *Meistera* as *Meistera sahyadrica*

(V.P.Thomas & M.Sabu) Škorničk. & M.F. Newman and *Meistera fulviceps* (Thwaites) Škorničk. & M.F. Newman (64). Similarly, EO chemical profiling studies of *Amomum* species were reported from Vietnam (Table 1). Ao and co-workers (2019) used GC-MS profiles of EOs and chemometric techniques to differentiate between *A. villosum* and *A. villosum* var. *xanthioides* collected from various locations in China, Vietnam, Thailand and Myanmar (71) (Table 1).

These studies also display the species-specific chemical patterns of EOs in genus *Amomum* (26). A combination of the EO profile and major marker compounds in each *Amomum* species is distinct (species-specific) within the genus and across members of other genera in the family Zingiberaceae (Tables 1; 8, 68, 69). These distinct chemical profiles of *Amomum* species could be used for (chemo-)–taxonomic assessments.

Essential oil constituents, flavor characteristics

Most *Amomum* species have monoterpenes and their oxygenated derivatives as major constituents in their EOs (Table 1, references therein). Camphor is the major constituent in EOs of *A. globosum* (38.9% (39)), *A. villosum* (*Fructus amomi*) (34.4–37.0% (65), 37.9% (66), 22.3% (67), 19.8% (30), 17.9% (70), 39.4–41.8% (23), 16.8–28.9% (71)), *A. villosum* var. *xanthioides* (29.1–44.8% (71)) and *A. biflorum* (17.6% (38)). It is a commercially important aroma chemical. Camphor is widely used as a flavoring food additive, fragrance in cosmetics and preservative in confectionary goods. Several biological activities are also attributed to camphor and EOs enriched with it (109).

Methyl chavicol (phenyl propene) is the major constituent in *A. linguiforme* (93.2%) and *A. pavieanum* (91.6%) (Table 1). It is used in food flavoring and perfumery and as the main raw material for the manufacture of its isomer, anethole. *A. schmidtti* showed *trans*-p-(1-butenyl) anisole as the major constituent in EOs of its leaves (91.2%), stem (94.7%) and roots (90.0%) (Table 1). Similarly, santolina triene (42.2%) is the major constituent in EO of *A. newmanii* from the southern Western Ghats in India (Table 1).

β–Pinene is the major component in EOs of *A. cannicarpum* (fruits 14.0% (42)), *A. maximum* (fruits 23.4% (12), leaves 40.8%, stem 20.4%, roots 28.0% (49)), *A. muricarpum* (leaves 25.9%, roots 14.3%, fruits 17.9%, flower 14.1% (49)), *A. muricatum* (35.9% (50)), *A. pterocarpum* (rhizomes 65.5%, leaves 41.7% (52)), *A. repoense* (leaves 33.5% (26)), *A. subulatum* (pericarp 13.6% (15), rind 17.7% (18), seeds 4.0–11.1% (5)), *A. testaceum* (fruits 15.9% (57)), *A. uliginosum* (rhizomes 29.9% (61)), *A. velutinum* (leaves 46.3%, pseudo-stem 43.5%, rhizomes 45.9% (62)) and *A. villosum* (leaves 58.5% (64), leaves 53.6–56.6%, roots 34.7–41.6% (43), stem 48.1% (69)) (Table 1). The aroma characteristics of β-pinene (at a concentration of 10%) are cooling, woody, piney and turpentine, with traces of fresh mint, eucalyptus and camphor. It can be detected at a threshold of 140 ppb. At 15 to 100 ppm, it has a characteristically fresh, pine, woody and resinous taste and a slight nuance of spicy, mint and camphor (36).

Similarly, α–pinene is a major component of EOs of *A. kravanh* (0.7–10.2% (23)), *A. longiligulare* (15.6% (48)), *A. maximum* (root 15.0% (49)), *A. muricarpum* (leaf 48.4%, stem 47.2%, root 54.7%, fruit 29.3%, flower 24.1% (49)), *A. newmanii* (rhizomes 17.1% (36)), *A. uliginosum* (rhizomes 10.4% (61)) and *A. villosum* (leaves 31.3% (64), leaves 22.0–22.1%, roots 11.6–14.0% (68), stem 16.9% (69)) (Table 1). α-Pinene has an intense and characteristic odor similar to pine and turpentine. α-Pinene (at 1 ppm) has citrus and spicy, woody-pine and turpentine like aroma. Its gustative threshold is 10 ppm, and it presents an intense, woody, piney taste with a notable camphor-like and turpentine taste (36).

1,8-Cineole, the major constituent in several *Amomum* EOs, displays a characteristic fragrance, camphoraceous features and a spicy flavor (see previous sections for details). Similar characteristics of various other major and minor terpenoids in *Amomum* EOs were reported in previous studies *viz*., α-terpinyl acetate (mildly herbaceous, sweet spicy; piney variations in odor, warm, mild spicy taste), α-terpineol (delicately floral, sweet, lilac like), 4-terpinenol (warm peppery woody with earthy, musty notes pleasantly green), linalyl acetate (sweet, floral, fruity odor and taste; poor tenacity, but stronger than terpinyl acetate), linalool (floral, woody, with citrusy note; creamy floral taste at low levels), geranyl acetate (sweet, floral, fruity with green note; stronger than geraniol), geraniol (floral, rosy with warm dry tones), geranial (citrus-like aroma), neryl acetate (very sweet, fruity, floral), nerol (isomeric to geraniol, citrus-like floral odor), farnesol (sweet oily, changing to floral green note), citronellol (fresh rosy odor and floral rosy bitter taste), nerolidol (woody, floral, slightly green), borneol (dry camphoraceous, woody peppery), camphor (warm minty odor, bitter, warm and cool mouth feel), citral (mixture of neral and geranial, powerful lemon fruity odor), citronellal (powerful fresh green, citrusy, slightly woody), methyl eugenol (musty tea like, mildly spicy, warm, slightly earthy), dl-limonene (citrus-like), α-pinene (woody), β-myrcene (metallic), α-bisabolol (floral), *trans*-sabinene hydrate (sweet) and α-caryophyllene (woody) (5,19,29,80,93,96,111,112).

These constituents, their relative composition and flavor characteristics, decide the flavor or spice value of EOs and their parent *Amomum* species. Pungent non-volatile entities (3,6–10) also play a role in the flavor/spice value of aromatic plants.

Conclusions, future perspectives

Of the 108 *Amomum* species, the chemical profiles of EOs of only 29 (and one variety) were studied so far. EOs in rest of the *Amomum* species are to be investigated for their chemistry and spice and flavor potentials. Similarly, to date, only few non-volatile pungent principles are isolated from genus *Amomum*. Flavor characteristics of 1,8-cineole and several other terpenoids are already described. But, more similar data of *Amomum* EOs and their minor constituents are necessary. Moreover, there is scope for more biological activity studies of *Amomum* EOs and their constituents. The complete chloroplast genome sequence of *A. villosum* has been elucidated recently (103). Biosynthesis of most EO constituents remains unknown (102). Biosynthetic, transcriptomic and metabolomic studies on *Amomum* species could help enhance the yield of desired terpenoids through genetic/metabolic engineering. Quality of plant materials and EOs are determined by numerous factors from genetic material to chromatographic analysis, and these parameters are to be standardized.

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