Phytochemistry and Pharmacological Studies of Indian *Cinnamomum* Schaeff

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1 Introduction

Plants have been used for therapeutic purposes since the ancient times and about 400,000 plant species were reported around the world [1]. But only a small fraction of these plant species, i.e., about 35,000–70,000, has been screened for their medicinal use [2]. India has a vast geographical area with high potential medicinal plants used in Ayurveda, Sidha, Unani, and traditional medicines. The WHO reported that of the 21,000 medicinal plants used all around the world, 2500 are found in India [3]. The primary sources of medicine for early drug discovery are plants that are reported to have ethno-pharmacological uses. Plant-derived compounds have better patient tolerance and acceptance. Plant-derived compounds also have a long history of clinical use [4] Many currently prescribed drugs were originally isolated from plants and/or are semisynthetic analogues of phytochemicals [5].

The genus *Cinnamomum* belongs to the Lauraceae family consisting of 250 species of trees and shrubs distributed in Southeast Asia, Australia, China, and Africa. Most of *Cinnamomum* species are aromatic with a lot of medicinal and economic importance as sources of essential oils, spices, and therapeutic drugs. *Cinnamomum* species are widely used in herbal therapy in treating bronchitis, colds, sinusitis, and fungal infections [6]. Their barks and leaves were used in foods as flavoring agent and seasoning [7]. Several species of this genus such as *C. malabatrum, C. walaiwarense*, and *C. trivancoricum* were used to treat stomach pain. *Cinnamomum riparium*, *C. sulphuratum*, *C. filipedicellatum* and *C. wightii* were used for treating headaches, wounds, fever, and menstrual problems [8].

In traditional medicine, the cinnamon bark infusion was used as a remedy for arthritis, rheumatism, nasopharyngeal infections, and stomach pain, whereas its

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leaves, barks, and roots are used to treat diarrhea and dysentery [9], rheumatism and inflammation [10], and neuralgic headaches. *Mustaffa* et al. [11] reported that the leaves of *C. iners* are used to relieve fever and digestive problems and are used as carminative [12]. *Cinnamomum sulphuratum* is reported to have anti-inflammatory [13], hepatoprotective, and antimicrobial properties and is used for treating wounds, fever/pyrexia, headache, backache [14], cholera, dyspepsia [15], menstrual problems, and worm infestation [16].

Cinnamomum zeylanicum leaf oil is used to treat toothache and its dried leaves are used to induce menstruation [17] and also it has been used as a sweating agent and an analgesic [18]. A wide range of pharmacological effects has been reported in *C. cassia* including antitumor, anti-inflammatory, analgesic, neuroprotective, antibacterial, antiviral, cardiovascular protective, immunoregulatory, antidiabetic, antiobesity, cytoprotective, and anti-tyrosinase effects. Barks of *Cinnamomum camphora* are used as antispasmodic, anodyne, sedative, anthelmintic, diaphoretic, stimulative, and carminative agents [19]. Moreover, barks of *Cinnamomum malabatrum* are used as carminative agents and are reported to have antispasmodic, astringent, antiseptic, hemostatic, stomachic, and germicidal properties. It is reported that oil from the barks of *Cinnamomum malabatrum* has the ability to cure diarrhea, cough, and dysentery, and its roots and leaves are used to treat rheumatism. The plant has been known to have several pharmacological effects such as analgesic and anti-inflammatory [20], antioxidant [21], and anticancer effects [22]. Kurokawa et al. [23] reported that *C. verum* possesses significant antiulcerogenic, antiallergic, anesthetic, and antipyretic activities. Barks and leaves of *C. tamala* are used as stimulant and carminative agents to treat gonorrhea, rheumatism, and diabetes [24].

Phytochemicals are biologically active, naturally occurring chemical compounds found in plants, which provide health benefits for humans [25]. They are found in different parts of plants such as roots, stems, flowers, fruits, leaves, or seeds [26]. Bioactive compounds include an extremely heterogeneous class of compounds such as tocopherols, polyphenolic compounds, phytosterols, carotenoids, and organosulfur compounds [27]. The present review aims to compile the detailed information on phytocompounds and pharmacological properties reported in different species of *Cinnamomum* in India.

2 Phytochemicals Reported in *Cinnamomum* spp.

The species of *Cinnamomum* are potential sources of several medicinal phytocompounds. Leela et al. [28] isolated the essential oils obtained from aerial parts of *C. malabatrum* such as petiole, terminal shoot, leaf, and shoot and subjected to GC-MS analysis. Thirty-nine compounds are found in the leaves with (E)-caryophyllene, (E)-cinnamyl acetate, bicyclogermacrene, and benzyl benzoate as the major constituents. Moreover, 28 and 34 compounds are found in the petioles and shoots and terminal shoots, respectively. Linalool is commonly found in the essential oils of shoots, terminal shoots, and petioles. The leaf oil is found to be rich in sesquiterpene

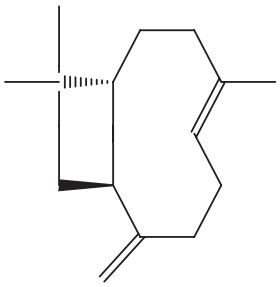
hydrocarbons, whereas other parts of the plant contained monoterpene alcohols. The oil is also reported to have oxides: humulene epoxide II and caryophyllene oxide. Humulene epoxide II is found only in the leaf oil, whereas petioles, terminal shoots, and shoots contain caryophyllene oxide (Fig. 1).

Agrawal et al. [22] reported that *C. malabatrum* leaves contain cinnamic aldehyde, benzaldehyde, eugenol, camphor, cadinene, α-terpineol, limonene, geraniol, eugenol acetate, ocimene, β-caryophyllene, γ-terpinene, β-phellandrene, benzyl cinnamate, and benzyl acetate. The major constituents of bark oil such as cinnamaldehydes, kaempferol-3-O-sophoroside, 3,4′,5,7-tetra hydroxyl flavones, quercetin 3-O- rutin, and 3,3′,4′,5,7-pentahydroxy flavones are also present in *C. malabatrum*.

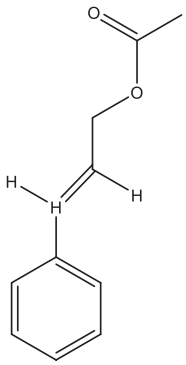
Aravind et al. [29] carried out the study on GCMS analysis of the *C. malabathrum* bark oil and identified 61 individual components, with linalool (68.21%) as the dominant one. Other constituents, such as limonene, myristyl aldehyde, geraniol, camphene, and eugenol, were also reported. Anil et al. [30] carried out the GC-MS analysis of *C. malabathrum* and revealed the presence of 5-benzyloxy-4-butyl-2-methyl-2-nonene (17.26%), hexadecanoic acid methyl ester (16.48%), and 1-deoxy-D-ribitol as the major constituents. Natarajan et al. [31] reported chemical compounds such as alkaloids, tannins, glycosides, triterpenoids, saponins, and flavonoids in the ethanolic extract of *C. malabatrum*. Nath et al. [32] reported eight components from the essential oil of *C. sulphuratum* leaf, of which linalool alone constitutes about 92.66% and other components such as geraniol (2.2%) and citronellol (l.47%) constitute over 1% of the oil. Baruah et al. [33] carried out the GC-MS analysis of stem and leaf bark oils of *C. sulphuratum*. Forty-six compounds were isolated from the leaf and 29 from the bark. Geranial, neral, and geraniol were the major constituents of the leaf oil. The bark oil was rich in (E)-cinnamaldehyde. Phytochemical screening of *C. sulphuratum* barks and leaves reported four chemotypes of *C. sulphuratum* such as linalool type [32], citral and cinnamaldehyde type [33], cinnamaldehyde type [34], and methyl cinnamate type [35].

Apart from this, a new natural chemotype, benzyl benzoate type, of *C. sulphuratum* was reported by analyzing leaf and stem bark oils collected from the Agasthyamalai forest area of the southern Western Ghats. Benzyl benzoate was the major constituent, followed by phenylethyl benzoate (4.9%). Benzyl benzoate content in stem bark oil was about 98.2%, and leaf oil was about 89.5%. The obtained results varied considerably from the earlier reports of *C. sulphuratum*, suggesting that it was a new natural chemotype [15]. Maridass [13] reported that the crude methanol extract of *C. sulphuratum* showed the presence of phenolic groups and triterpenoids. Kumar et al. [36] detected several constituents such as α-phellandrene, Z-β-ocimene, 1,1-dicyclopropyl-2-methyl-l-pentene, linalool, eugenol, β-phellandrene β-caryophyllene, and benzyl benzoate by GC-MS analysis of leaf essential oil from *C. sulphuratum* collected from Kodagu, Karnataka.

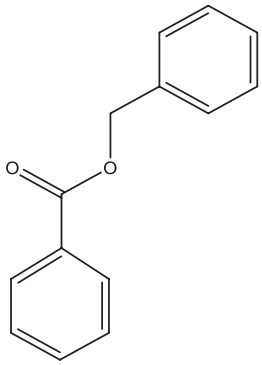
Singh et al. [37] isolated essential oils from the leaves of *C. sulphuratum* from Champawat, Uttarakhand, and detected the presence of 1,8-cineole and α-terpineol (major compounds) and terpinen-4-ol, sabinene, α-terpinene, α-phellandrene, linalool, and limonene (minor compounds). Rameshkumar and George [15] reported that the stem bark oils of *C. verum* contain cinnamaldehyde as the major



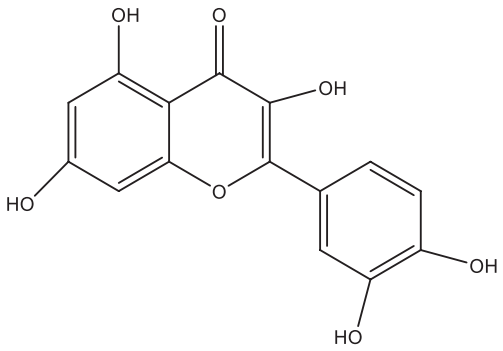
(E)-caryophyllene,



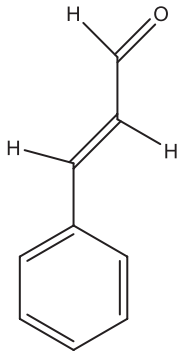
cinnamyl acetate



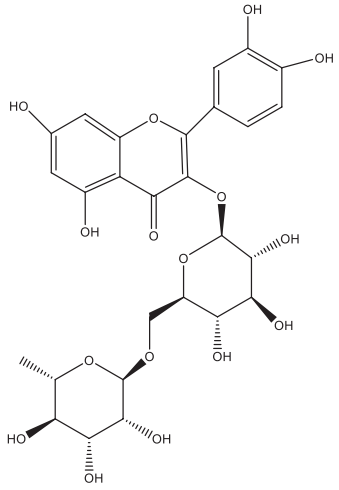
Benzyl benzoate



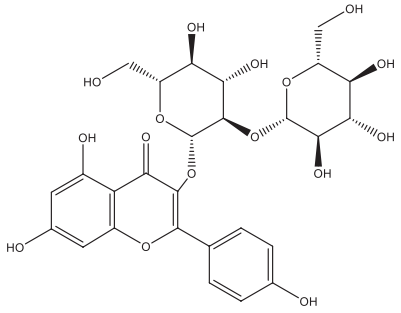
3,3',4',5,7-pentahydroxy flavones



Cinnamaldehyde

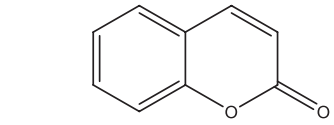


Quercetin 3-O- rutin

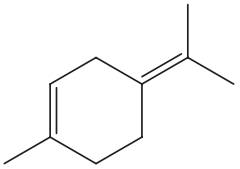


kaempferol-3-O-sophoroside

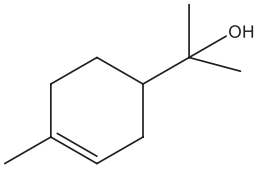
Fig. 1 Phytochemicals of *Cinnamomum* spp



Coumarin

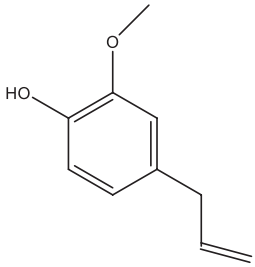


Terpinolene

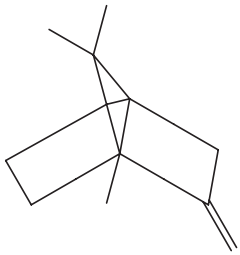


alpha terpineol

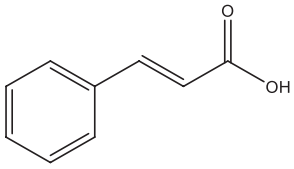
Linalool



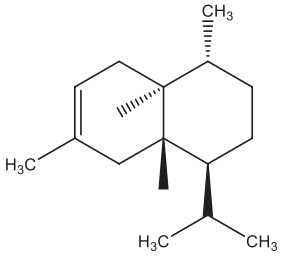
Eugenol



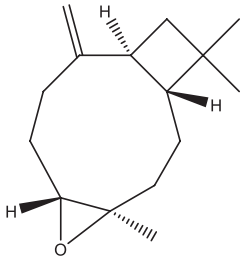
Camphor



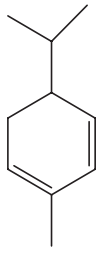
Cinnamic acid



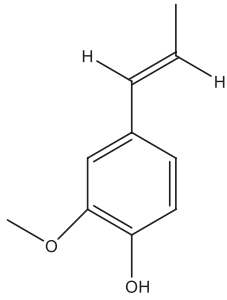
Alpha cubebene



Caryophyllene oxide



alpha-phellandrene



Isoeugenol

Fig. 26.1 (continued)

component, and also moderate levels stem bark oils were detected in *C. citriodorum* and *C. sinharajanse*. An unidentified *Cinnamomum* accession of Gammaduwa also reported the presence of cinnamaldehyde. Rao et al. [38] isolated 25 compounds from essential oils from the petiole of *C. verum* and carried out a GC-MS analysis. The major components were (E)-cinnamaldehyde, eugenol, (E)-cinnamyl acetate, and linalool.

Simic et al. [39] reported that the GC-MS analysis of *C. verum* detected eugenol, cinnamaldehyde, cinnamaldehyde propylene, and limonene and a variety of terpenoid compounds (α-pinene, camphene). Mollenbeck et al. [40] reported a study on *C. verum* essential oil. Trans-cinnamyl acetate was much higher in the flowers and fruit volatile oils than in buds. The minor compounds included α-humulene and α-muurolene. Leaf and bark oils of *C. verum* were rich in cinnamaldehyde [41] and eugenol [42, 43]. Nath et al. [44] reported a chemotype of *C. verum* yielding benzyl benzoate-rich leaf and bark essential oils from northeast India. The root-bark essential oil was reported to contain camphor as its main component in contrast to the stem bark essential oil [45]. Linalool and (E)-cinnamyl acetate were the main constituents of tender twigs' essential oil [47].

Linalool, β-caryophyllene, and (E)-cinnamyl acetate were reported in essential oils obtained from pedicels of buds, flowers, and fruits of *C. verum* [46, 47]. Mariappan et al. [48] analyzed chemical constituents of *C. verum* methanolic bark extracted by GC-MS analysis. Trans-cinnamaldehyde, (E)-3-(2-methoxyphenyl)-2-propenoic acid, 4-vinyl benzoic acid, and coumarin were the major chemical constituents identified. *Cinnamomum verum* dried leaves collected from Delhi were reported to contain 1,2-trans-sabinene hydrate, (Z)-β-ocimene, and germacrene A as the major compounds and α-gurjunene, myrcene, α-pinene, and β-sabinene as the minor compounds. Trans-sabinene hydrate, (Z)-β-ocimene, and germacrene A were the chemotypes reported [49].

Kapoor et al. [50] reported eugenol as a significant constituent of *C. verum* dried leaves collected from Gorakhpur, Uttar Pradesh. The minor constituents were spathulenol, aromadendrene, viridiflorene, and methyl eugenol. Joshi et al. [51] reported GC-MS analysis of fresh leaf oil collected from Jeolikote, Uttarakhand. The oil contains (E)-cinnamaldehyde and linalool as major compounds and (E)-cinnamyl acetate, β-pinene, and α-copaene as minor compounds. Chanotiya et al. [52] reported the chemical constituents of *C. verum* from Nainital district, Uttarakhand. (E)-Cinnamyl acetate, linalool, and (Z)-cinnamaldehyde were the significant compounds isolated, whereas camphene, α-Pinene, 3-phenylpropanal, benzaldehyde, bornyl acetate, (Z)-cinnamyl acetate, coumarin, salicylaldehyde, and β-copaen-4α-ol were reported with meager amount.

Agrawal et al. [53] collected fresh aerial parts of *C. verum* samples from three areas of Uttarakhand and analyzed their chemical compositions. Linalool and (E)-cinnamaldehyde were the major constituents, and 1,8-cineole was the minor constituent of samples collected from Munsiyari. Linalool, (E)-cinnamaldehyde, and camphor were the major compounds of Lohaghat and Champawat samples. Pithoragarh and Tanakpur samples were reported to contain significant compounds such as linalool, (E)-cinnamaldehyde, and cinnamyl acetate. Eugenol,

(E)-cinnamaldehyde, (E)-cinnamyl acetate, and epicubenol were the compounds reported from Pantnagar samples. *Cinnamomum verum* leaf samples collected from Chandigarh Botanical Garden were reported to contain methyl eugenol, eugenol, (E)-cinnamyl acetate, and β-caryophyllene (major components) and cinnamaldehyde and ascabin (minor components) [54]. Rana et al. [55] reported chemical constituents such as eugenol and eugenyl acetate (major components), and α-phellandrene (minor component) from fresh leaves of *C. verum*.

Lohani et al. (2015) [56] collected leaves of many populations of *C. verum* from Nainital, Pithoragarh, Pauri, Champawat, Tehri, Rudraprayag, Almora, and Chamoli. The shade-dried leaves of *C. verum* detected cinnamaldehyde (major compound) and caryophyllene oxide, cinnamyl acetate, benzaldehyde, β-pinene, and 1,8-cineole as minor compounds in 13 populations. Three populations contain cinnamyl acetate, cinnamaldehyde, benzaldehyde, β-pinene, 1, 8-cineole, and caryophyllene oxide (minor compounds). Linalool, cinnamaldehyde (major), β-pinene, 1,8-cineole, caryophyllene oxide, and benzaldehyde were reported in 6 populations. Thirteen populations were reported with cinnamaldehyde and linalool. The minor constituents were caryophyllene oxide, benzaldehyde, 1,8-cineole, and β-pinene. Shade-dried leaves of *C. verum* from Arunachal Pradesh contained α-phellandrene, eugenol, β-phellandrene, α-pinene, elixene, cis-caryophyllene, myrcene, and limonene [57].

Williams et al. [58] reported high concentrations of proanthocyanidins and trans-cinnamaldehyde in *C. verum* extract. *Cinnamomum verum* dried leaves collected from Delhi were reported to contain 1,2-trans-sabinene hydrate, (Z)-β-ocimene, and germacrene A as major compounds and α-gurjunene, myrcene, α-pinene, and β-sabinene as minor compounds. Trans-sabinene hydrate, (Z)-β-ocimene, and germacrene A were the chemotypes reported [49]. Bark and twig of *Cinnamomum verum* were reported to contain cinnamaldehyde and 2-methoxycinnamaldehyde [59–61]. Alva et al. [62] isolated and identified potential anti-quorum sensing (QS) compounds such as benzenamine, cyclohexyl-15-crown-5, N; N-diethyl-4-methyl-, 2-methyl-, and 2-propenoic acid; and oxybis(2,1-ethanediyloxy-2,1-ethanediyl) from leaf ethanolic extract of *C. verum* against *Pseudomonas aeruginosa* based on the in silico analysis.

Singh et al. [63] reported GC-MS analysis of *C. zeylanicum* leaf volatile oil and oleoresin identified 19 and 25 components. About 13 components were identified from the *C. zeylanicum* bark volatile oil, whereas its bark oleoresin showed the presence of 17 components. The major component was (E)-cinnamaldehyde followed by d-cadinene. Jayaprakash et al. [47] reported that the volatile oil from *C. zeylanicum* fruit grown at Karnataka and Kerala consists of hydrocarbons and oxygenated compounds, b-caryophyllene, and trans-cinnamyl acetate as major constituents. Raina et al. [64] reported eugenol, linalool, and piperitone as major components of leaf oil of Andaman. *Cinnamomum zeylanicum* leaf oil is used as a source of eugenol [65]. *Cinnamomum zeylanicum* was reported with high levels of eugenol and cinnamaldehyde [66]. Duke [67] reported that *C. zeylanicum* bark contains volatile oils of eugenol, trans-cinnamic acid, cinnamaldehyde, condensed tannins, phenolic compounds, catechins, proanthocyanidins, monoterpenes and sesquiterpenes, pinene, calcium-monoterpene oxalate, mucilage, gum, resin, and traces of coumarin.

The GC-MS studies of *C. zeylanicum* essential oil clearly showed the presence of 38 components which include monoterpenes, sesquiterpenes, aromatic aldehydes, and ketones. Cinnamaldehyde was the major compound, followed by benzaldehyde [68]. *Cinnamomum zeylanicum* bark essential oil possesses compounds such as cinnamic acid, cinnamaldehyde, eugenol, benzoic acid, benzaldehyde, triterpenes, monoterpenes, and sesquiterpenes [69]. Vangalapati et al. [70] reported presence of chemical constituents in different parts of *C. zeylanicum*. The barks and leaves contain cinnamaldehyde and eugenol, respectively. Roots and barks showed the presence of camphor and trans-cinnamyl acetate and the fruits β-caryophyllene. Buds showed the presence of terpene hydrocarbons, alpha-bergamotene, alpha-copaene, and oxygenated terpenoids. Flowers showed the presence of (E)-cinnamyl acetate, trans-alphabergamotene, and caryophyllene oxide.

Jakhetia et al. [71] reported that *C. zeylanicum* contains cinnamic acid, cinnamaldehyde, cinnamate, trans-cinnamaldehyde, caryophyllene oxide, l-borneol, l-bornyl acetate, eugenol, b-caryophyllene, E-nerolidol, cinnamyl acetate, terpinolene, a-terpineol, a-cubebene, and alpha-thujene. *Cinnamomum zeylanicum* oil has been reported to contain chemical constituents such as cinnamic acid, benzoic acid, and benzaldehyde whose lipophilic part is responsible for its antimicrobial properties [72]. *Cinnamomum zeylanicum* bark essential oil contains cinnamyl acetate [73]. Brari and Thakur [74] reported cinnamaldehyde and linalool from the essential oil isolated from *C. zeylanicum*. The essential oil of *C. zeylanicum* bark was rich in trans-cinnamaldehyde [75].

Cinnamomum zeylanicum bud volatile oil has been reported to contain δ-cadinene, tetradecanol, α-humulene, α-copaene, α-bergamotene, and viridiflorene. Leaf oil contains (E)-cinnamaldehyde, eugenol, β-caryophyllene, linalool, (E)-cinnamyl acetate, and α-terpineol. Moreover, fruit stalks oil contain α-humulene, caryophyllene, (E)-cinnamyl acetate, δ-cadinene, α-copaene, and (E)-τ-cadinol. Flower oil of *C. zeylanicum* contain trans-α-bergamotene, caryophyllene oxide, tetradecanal, α-cadinol, and globulol. Similar enantiomeric distributions have been reported for *C. camphora* essential oil [76]. Mallavarapu et al. [77] isolated essential oil of *C. zeylanicum* collected from Bangalore and Hyderabad and analyzed it by using GC and GC-MS. Eugenol was reported as the main constituent along with 47 other constituents. Both oil samples were different with respect to the quantities of linalool, (3-caryophyllene, (E)-cinnamaldehyde, (E)-cinnamyl acetate, and benzyl benzoate. The main phytocompounds of oil collected from Bangalore were a-phellandrene, eugenol, linalool, (E)-cinnamyl acetate (E)-cinnamaldehyde, and P-caryophyllene, while those of oil collected from Hyderabad contained eugenyl acetate, eugenol, benzyl benzoate, and linalool.

Mallavarapu and Ramesh [77] reported 49 constituents from fruit oil of *C. zeylanicum* from Bangalore. The main constituents were a-pinene, P-caryophyllene, G-cadinene, and a-muurolol. The phytocompounds of the oil under study were different from those of the earlier reports wherein (E)cinnamyl acetate and P-caryophyllene were the main constituents. The oil has been reported to contain phenyl propanoids, oxygenated monoterpenes, monoterpenes, and sesquiterpenes. The main constituents of the oil were a-pinene, P-pinene, P-caryophyllene,

a-muurolene, y-cadinene, 3-cadinene, and a-muurolol. The oil was devoid of eugenol, E-cinnamaldehyde, benzyl benzoate, and camphor which are major constituents of the leaf, stem bark, and root oils of *C. zeylanicum.*

Senanayake et al. [78] reported that *C. zeylanicum* essential oil contained several resinous compounds, such as cinnamic acid, cinnamaldehyde, and cinnamate. A spicy flavor and a strong aroma of *Cinnamomum* were reported due to the presence of cinnamaldehyde. Trans-cinnamaldehyde, terpinolene, cinnamyl acetate, eugenol, caryophyllene oxide, L-borneol, b-caryophyllene, E-nerolidol, alpha-cubebene, L-borneol acetate, alpha-terpineol, and alpha thujene were some of the essential oils found in *C. zeylanicum* [63, 79, 80]. Aldehydes, esters, phenols, acids, diterpenes, sesquiterpenes, monoterpenes, benzopyrones, hydrocarbon alcohols, and flavonoids were the chemical substances found in *C. zeylanicum*. Aldehydes present in *C. zeylanicum* bark essential oil were methoxycinnamaldehyde, benzenepropanal, cinnamaldehyde, vanillin, cuminaldehyde, benzaldehyde, hydrocinnamic, 2-methyl-3-phenyl-propanal, and citronellal. Alcohol groups present in *C. zeylanicum* were cinnamyl alcohol, α-terpineol, linalool, α-bisabolol, cinnamyl acetate esters, cinnamaldehyde, methyl cinnamate, hydrocinnamyl acetate, benzyl benzoate, and bornyl acetate [47, 81]. Brari and Thakur [74] reported cinnamaldehyde and linalool from essential oil isolated from *C. zeylanicum*.

Kamalakannan et al. [82] isolated hymecromone and umbelliferone from ethanolic extract of *C. cassia*. *Cinnamomum cassia* contains volatile oils with cinnamic acid, eugenol, cinnamyl alcohol, cinnamaldehyde, melilotic acid, δ-cadinene, phenolic compounds, epicatechins, cinnamic aldehydes, monoterpenes, tannins, procyanidins, diterpenes, glycosides (cinnacassides A–Z), oxalate, sesquiterpenes (pinene), and traces of coumarin [83]. Packiaraj et al. [84] reported major compounds such as NDidehydrohexacarboxyl-2,4,5-trimethylpiperazine, 1,2,4-triazoliumylide phenol, 3,5-dimethoxy acetate, and 4′-isopropylidene-bis-(2-cyclohexyl) phenol. Coumarin (1,2-benzopyrone) content was reported with a major difference between *C. cassia* and *C. zeylanicum* in their vegetative parts [85].

Tanaka et al. [86] isolated 3-(2-hydroxyphenyl)-propanoic acid and its O-glucoside from the stem bark of *C. cassia*. Chemical compounds of *C. cassia* were coumarin, (Z)-cinnamaldehyde, α-ylangene, and β-caryophyllene [87–89]. Barks and leaves of *C. cassia* contain cinnzeylanol, 19-dehydroxy-13-hydroxycinncassiol, (18R)-1-hydroxycinncassiol, (18S)-3-dehydroxycinncassiol glucoside, (18S)-3-dehydroxy-8-hydroxycinncassiol, (18S)-cinncassiol, (18S)-3,5-didehydroxy-1,8-dihydroxycinncassiol, and 2,3-dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone [90, 91]. Leaves contain (1R,2R)-4-[(3S)-3-hydroxybutyl]-3,3,5- trimethylcyclohex-4-ene-1,2-diol, (3S,5R,6R,7E,9S)-3,5,6,9-tetrahydroxy-7-enemegastigmane, and (1R,2R,4S,6S)-4-(2-hydroxypropan-2-yl)-1-methyl-7-oxabicyclo[4.1.0]heptan-2-ol dimethanol [90].

The twig of *C. cassia* was reported to contain certain chemical compounds such as cinnamyl alcohol and 2-hydroxy-cinnamyl alcohol [61, 92], (+)-syringaresinol, cinnamomulactone, 2-hydroxycinnamaldehyde [61, 91–93], cinnamic acid [92], and phenethyl (E)-3-[4-methoxyphenyl]-2-propenoate [61]. Chemical constituents reported in *C. cassia* leaves were 1-(3,4-dimethoxyphenyl)-1,2,3-propanetriol [90],

(7S,8S)-syringoylglycerol [91], (+)-(1S,2S)-1-(3-methoxy-4-hydroxyphenyl)-1,2,3-propanetril-2-O-β-D-glucopyranoside, n-butyl-β-D-fructofuranoside, tachioside [89], (−)-4-epi-lyoniresinol [94].

Twigs of *Cinnamomum cassia* were reported to contain cinncassin A1, cinncassin H, cinncassin I, cinncassin J, cinncassin K, cinncassin L, cinncassin M, cinnamomoside A.9 [95], 5R-methyl-3-heptatriacontyl-2(5H)-furanone [96], cinncassin A2, cinncassin A3, cinncassin A4, cinncassin A5, cinncassin A6, cinncassin A7, cinncassin N, cinncassin O, cinncassin F [61, 91–93], icariside D, isotachioside [97], 2-O-β-D-glucosyl-(1S)-phenylethylene glycol, and cinnamaldehyde [61]. Namomulactone was isolated from the *C. cassia* twigs together with nine known compounds: cinnamaldehyde, trans-cinnamic acid, coumarin, 2-hydroxycinnamaldehyde, 2-methoxycinnamaldehyde, benzoic acid, syringaresinol, 2-hydroxy-cinnamyl alcohol, and phenethyl (E)-3-[4-methoxyphenyl]-2-propenoate [62].

Several compounds were reported in *C. camphora* by various studies carried out on different plant parts. Barks and leaves contain (7α, 7′α, 8α, 8′α)-3,7-hydroxy-4-methoxy-3′,4′- methylenedioxy lignane and (−)-medioresinol and trans-4,5-dimethoxy-3-hydroxycinnamaldehyde [98]. Paulownin was also found in the bark [99]. Twigs of *C. camphora* were reported to contain cinnacassin F [95]. (+)-Epipinoresinol was identified in leaves and barks [98]. Dimethylmatairesinol and (7α,7′β,8α,8′α)-3-methoxy-4-hydroxy-3′,4′-methylenedioxy-7,9:7,9-diepoxylignane [98, 99] and trans-4,5-dimethoxy-3-hydroxycinnamaldehyde were reported from *C. camphora* barks and leaves [98].

Singh et al. [37] reported 18 compounds from the *C. glanduliferum* essential oil collected from Champawat (Uttarakhand). A high proportion of oil contain oxygenated monoterpenes among which the predominant compounds were 1,8-cineole and α-terpineol. Monoterpene hydrocarbons were present in *C. glanduliferum*. 1,8-cineole, α-terpineol, germacrene D-4-ol, α-pinene, and α-thujene were the major constituents. Chowdhury [100] reported the presence of 1,8- cineole, followed by caryophyllene oxide, camphor, α-terpineol, and linalool. Leaf essential oil composition of *C. glanduliferum* collected from Arunachal Pradesh was reported to contain (E)-nerolidol, caryophyllene oxide, β-pinene, and linalool [101]. Prakash et al. [102] reported chemical constituents such as germacrene D-4-ol, α-pinene, α-terpineol, α-thujene, and 1,8-cineole from *C. glanduliferum* oil.

Kumar et al. [103] reported cinnamaldehyde, trans-cinnamyl acetate, ascabin, hydrocinnamyl acetate, and beta-caryophyllene as the major constituents of *C. tamala* leaves. Agrawal et al. [53] isolated essential oils from fresh aerial parts of *C. tamala* collected from CIMAP, Pantnagar, Uttarakhand. Several chemical constituents such as (E)-cinnamyl acetate, linalool, and (E)-cinnamaldehyde were identified. The stem barks and leaves of *C. tamala* collected from Mizoram showed the presence of several chemical constituents. Methyl cinnamate was the major constituent of stem bark oil. Trans-cinnamaldehyde, styrene, benzyl benzoate, and linalool were the minor constituents being detected. Linalool and methyl cinnamate were detected as the phytocompounds of leaf oil. Benzyl benzoate, α-pinene, hexanol, β-pinene, and phellandrene were reported as the constituents of leaf oil [79].

Nath et al. [32] carried out GC-MS analysis in *C. tamala* essential oil from Assam, India. α-Linalool, α-pinene, and pinene were the major constituents, whereas cinnamaldehyde and eugenol were the minor constituents.

Cinnamomum tamala leaves collected from Dehradun, Uttarakhand, contain cinnamaldehyde, cis-linalool oxide, linalool, and cinnamyl acetate as the major constituents. Benzaldehyde, 1,8-cineole, bornyl acetate, 3-phenyl propanal, and p-cymene were the minor constituents [104]. Gulati et al. [105] reported linalool and cinnamaldehyde from the two samples of *C. tamala* from the Kumaun region. Cinnamaldehyde was reported as the main compound of *C. tamala* (Kubeczka and Formacek 2002) [106–108]. *Cinnamomum tamala* oil samples were also reported to contain cinnamic acid [109]. Showkat et al. [110] identified chemical constituents such as β-caryophyllene, germacrene A, β-sabinene, α-pinene, myrcene, (Z)-β-ocimene, linalool, α-gurjunene, and trans-sabinene hydrate in *C. tamala* leaf essential oil. Leaf samples were detected with three flavonoid compounds: quercetin, quercetin, and kaempferol [112]. Eugenol was the principal constituent in *C. tamala* essential oil followed by eugenyl acetate and α-phellandrene [55]. *Cinnamomum tamala* leaf volatile oil was reported to contain eugenol which is the major constituent [50, 112].

2,6,10-Trimethyl-12-oxatricyclo[7.3.0.0{1,6}]tridec-2-ene and hexahydropyridine,4- [4,5-dimethoxyphenyl]-in were isolated from hexane extract, and three compounds from dichloromethane extract, namely, 2,5-chloro-3β-hydroxy-6βnitro-5α-androstan-17-one, acetic acid,10,13-dimethyl-2-oxo-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H cyclopenta [a]phenanthren17-ylester, and 6á,19-CycloAndrost-4-ene-3,17-dione were reported from extracts of *C. tamala* [113]. Heer et al. [114] reported 21 compounds from fresh leaves of *C. tamala* essential oil collected from northwestern Himalaya by GC-MS analysis. They consist of complex mixtures of monoterpenes, phenylpropanoids, and sesquiterpenes. Kumar et al. [103] reported that *C. tamala* leaves contain several phytochemicals such as β-caryophyllene, trans-cinnamyl acetate, eugenol, and cinnamaldehyde. Srivastava et al. [115] reported the GC-MS analysis of *C. camphora* oil, and the major constituents were fenchone, camphene, a-thujene, L-limonene, and cisp-menthane. Camphor was found in *C. camphora* from Pantnagar, Uttarakhand [53]

Ghalib et al. [116] reported *C. iners* from chloroform and alcoholic leaf extracts. Nine components were detected as major components. Eicosanoic acid ethyl ester and caryophyllene are the most prominent components of the chloroform extract. Caryophyllene was the major compound of the alcohol extract. Udayaprakash et al. [117] reported six compounds, i.e., pentadecanoic acid, 14-methyl-, methyl ester; 4-piperidineacetic acid, 10-octadecenoic acid, methyl ester; cyclopropanebutanoic acid, 2-[[2-[[2-[(pentylcyclopropyl) methyl] cyclopropyl] methyl] cyclopropyl] methyl]-, methyl ester; cyclopentaneundecanoic acid, methyl ester; 1-acetyl-5-ethyl2-[3-(2-hydroxyethyl)-1H-indol-2-yl]-a-methyl-methylester; and 3-pentyl-, methyl ester, oxiraneundecanoic acid, found in the essential oil of leaves of *C. iners* by GC-MS analysis.

Baskaran and Ebbie [118] reported nine constituents including caryophyllene oxide, terpinen-4-ol linalool, and benzyl benzoate which were the major constituents in the essential oil of *C. chemungianum*. Rameshkumar et al. [119] reported β-selinene, caryophyllene oxide, longiborneol, tetradecanal, intermedeol, and α-cyperone as major constituents of *C. chemungianum* essential oil. Sriramavaratharajan and Murugan [120] reported a study on the essential oil of *C. chemungianum* in which chemical constituents such as veratrole, ρ-cymen-7-ol, germacrene B, longiborneol, and α-cyperone were not identified but had been recorded from earlier studies. Several minor constituents present in the present study were also not reported in the previous reports.

Five compounds, i.e., eugenol, isoobtusilactone, obtusilactone, 3,4-methylenedioxy-5-methoxy cinnamyl alcohol, and myristicin, were detected in *C. subavenium* roots [121]. Lai et al. [122] reported that *C. subavenium* barks contain (±)-subaveniumin A and (±)-subaveniumin B. Huang et al. [123] reported methyl cinnamate, methyl-trans-3-(3,4-dimethoxyphenyl)-3- propenoate, 3,4-methylenedioxycinnamyl alcohol, 3,4-dimethoxycinnamyl alcohol, methyleugenol, safrole, carvacrol, thymol, 3,4-methylenedioxy, cinnamaldehyde, and 3,4-dimethoxy cinnamaldehyde in the *C. subavenium* bark. Both leaves and barks of *C. subavenium* contain caryophyllene oxide and eugenol. Hao et al. [124] reported 1α,6β-dihydroxy-5, 10-bis-epi-eudesm15-carboxaldehyde-6-O-β-D-glucopyranoside, and D-threo-guaiacylglycerol 7-O-β-D-glucopyranoside in the barks of *C. subavenium.* Hao et al. [124] reported compounds such as wilsonol, (3S,5R,6S,7E)-megasfigma-7-ene-3,5,6,9-tetrol, (4R)-p-menthama-1,2α,8-triol, (3R,4R)-p-Menth-1-ene-3,4-diol 3-O-β-D-glucopyranosid, (3R,4S,6R)-p-menth-1-ene-3,6-diol 3-O-β-D-glucopyranoside, and asicariside B1 in the leaves of *C. subavenium*.

Bakar et al. [125] reported that the barks of *C. osmophloeum* contain cinnamaldehyde and eugenol. Rao and Gan [126] have also reported that the leaves of *C. osmophloeum* contain eugenol and cinnamaldehyde. Utchariyakiat et al. [127] reported that its fruits contain trans-cinnamyl acetate, and caryophyllene. Barceloux [129] has reported that its flowers contain trans-α-bergamotene, trans-cinnamyl acetate, and caryophyllene oxide.

Leaf oil of *C. cordatum* contains chemical constituents such as methyl (E)-cinnamate, terpinen-4-ol, linalool, α-terpineol, and methyl eugenol [66]. Camphor was the main constituent of the root bark oil, but unlike leaf and stem bark oils, it does not have any commercial value. The main constituents found from bark of root and stem were cinnamaldehyde and camphor [81]. Jantan et al. [128] identified 43 compounds from *C. cordatum* leaf essential oils with major constituents such as phellandrene, benzyl benzoate, linalool, terpinen-4-ol, benzyl salicylate, (E)-methyl cinnamate, and methyl eugenol. The essential oils obtained from the bark of *C. cordatum* contain cinnamaldehyde, leaves contain eugenol, roots have camphor, and buds show the presence of α-bergamotene and α-copaene. Flowers, fruits, and fruit stalks contain trans-cinnamyl acetate [87].

Baruah and Nath [101] have reported phytocompounds of *C. glaucescens* essential oils isolated from leaf, panicle, and stem bark in Assam. Leaf oils showed the

presence of α-phellandrene, α-farnesene, 1, 8-cineole, α-pinene, linalool, and α-phellandrene (major compounds) and β-pinene, β-caryophyllene, and terpineol (minor compounds). Essential oil composition of *C. impressinervium* was studied with both wild and fresh cultivated leaves. Presence of eugenol and δ-3-carene was detected in fresh wild leaves. Eugenol was detected in cultivated leaf samples and the minor constituents of fresh wild leaves were limonene, α-pinene, and eugenol acetate. Limonene, δ-3-carene (1.6%), and eugenol acetate were the minor constituents [129].

Baruah and Nath [130] reported that the essential oil compositions of *C. champokianum* leaves from Arunachal Pradesh were elemicin and methyl eugenol (4.9%). Nath et al. [44] carried out chemical analysis of shade-dried leaves, root bark, and stem bark of *C. pauciflorum* and detected the presence of cinnamaldehyde in all the samples. Nath et al. [129] reported (E)-cinnamaldehyde from *C. pauciflorum* leaves from Meghalaya. Shade-dried leaves of (E)-cinnamaldehyde and linalool were the major and minor compounds, respectively, of *C. pauciflorum* leaves.

Hrideek et al. [131] reported chemical constituents of bark and leaf oil of *C. macrocarpum* and *C. riparium*. The major constituents of *C. riparium* bark oil were shikimole, eugenyl methyl ether, and delta cadinene, whereas leaf contains shikimole and eugenyl methyl ether. The major compounds of *C. macrocarpum* bark oil were cinnamyl acetate, 4-teroinol, benzyl benzoate, and linalool. *Cinnamomum macrocarpum* leaf oil contains cinnamyl acetate, gamma terpinene, and azulene as the major compounds. Sriramavaratharajan et al. [133] reported phytocompounds of essential oil of *C. camphora*, and 1,8-cineole has been detected in the essential oils of *C. agasthyamalayanum*. However, camphor was the dominant compound of *C. agasthyamalayanum*. Pinene and terpineol were the two major constituents of *C. camphora*, but these were identified as minor constituents of essential oils of *C. agasthyamalayanum.*

Sriramavaratharajan et al. [133] reported leaf essential oils from *C. perrottetii* collected from three distinct populations in the southern Western Ghats, which were analyzed by GC-FID and GC-MS. A total of 56 volatile constituents representing 92.2–96.3% of the oils were identified. Variations in the chemical constituents of the oils were found. α-Pinene, tau-cadinol, and α-cadinol were the three major compounds present in all three samples. Tau-cadinol and α-cadinol were the characteristic constituents of *C. perrottetii* leaf. Twig and leaf essential oils of *C. osmophloeum* have been reported with tau-cadinol and α-cadinol as the major constituents (Cheng et al.) [134].

Coumarin content was reported to be higher in *C. cassia* than in *C. verum*, *C. tamala*, and *C. camphora*. *Cinnamomum cassia bark* was reported to have several cinnamaldehyde derivatives synthesized from cinnamic acid, such as 2′-hydroxycinnamaldehyde [89]. Baruah and Nath [135] reported that panicle essential oil of *C. bejolghota* from the Jorhat area of Assam contains (Z)-methyl α-farnesene, isoeugenol, β-caryophyllene, linalool, α-phellandrene, 1–8-cineole, α-pinene, β-pinene, and β-phellandrene. Stem bark oil was reported to have β-caryophyllene, β-pinene, α-terpineol, linalool, (E)-cinnamaldehyde, p-cymene,

α-pinene, l,8-cineole, (E)-methyl cinnamate, α-phellandrene, terpinen-4-ol, eugenol, and (Z)-methyl isoeugenol.

Eugenol, linalool, cinnamyl acetate, cinnamaldehyde, α-caryophyllene, and eugenol acetate were reported from cinnamon. *C. camphora* contains predominately (E)-cinnamaldehyde, 1,8-cineole and camphor. *C. fragrans* contains α-pinene, β-caryophyllene, β-pinenes, and 1,8-cineole. *C. angustifolium* contains α-phellandrene, 1,8-cineole, p-cymene, β-caryophyllene, and α-pinene. *C. altissimum* bark essential oil contains phenolic compounds such as linalool, limonene, methyl eugenol, terpinen-4-ol, c-terpinene, a-terpineol, 1,8-cineole, and a-terpinene [136, 137]. Active constituents of *C. keralaense* bark were flavonoids, cardiac glycosides, anthraquinone, and saponins [138]. Sriramavaratharajana et al. [132] reported main constituent of the EOs of *C. camphora*, 1,8-cineole, was not identified in the EOs of *C. agasthyamalayanum*. Camphor was the principal constituent of *C. agasthyamalayanum*; however, in *C. camphora* the concentration was much lower (Table 1).

3 Pharmacological Activity of *Cinnamomum* spp.

3.1 Antimicrobial Activity of Phytocompounds of Cinnamomum *spp.*

Bullerman et al. [139] reported that the bark oil of *C. zeylanicum* inhibited fungal growth and aflatoxin production due to the presence of eugenol and cinnamaldehyde. Montes-Belmont and Carvajal [140] reported fungitoxic properties against fungi involved in respiratory tract mycoses such as *Aspergillus niger*, *A. fumigatus*, *A. nidulans*, and *A. flavus.* Simic et al. [39] reported that *C. zeylanicum* oil has the strongest antifungal activity due to the presence of trans-cinnamaldehyde as the major component. A study has been reported that 80% of bacteria and fungi were killed by cinnamaldehyde [141]. Choudhary et al. [142] reported the antimicrobial activity of *Cinnamomum cassia* essential oil against several bacterial cultures. About 99.4% of the organisms including *Streptococcus oralis*, *Micrococcus roseus*, *S. anginosus*, *S. sanguinis*, *S. intermedius*, and *Enterobacter aerogenes* were inhibited, but it was not effective against *Salmonella* Paratyphi B.

Biavati et al. [143] studied the antimicrobial effects of *C. cassia* aqueous infusion and observed inhibition in the microbial strains such as *Micrococcus roseus*, *S. intermedius*, *S. anginosus*, *S. mutans*, *S. sanguis*, *S. oralis*, *S. morbillorum*, *S. salivarius*, *S. uberis*, *Klebsiella pneumonia*, and *Flavobacterium*. Rameshkumar et al. [144] reported that *C. filipedicellatum* essential oil showed moderate activity against gram-positive and gram-negative bacteria such as *Salmonella* Typhi and *Staphylococcus aureus*, and no inhibition was observed in *Pseudomonas aeruginosa*. Dongmo et al. [145] studied the antifungal activity of *C. zeylanicum* essential oil from Cameroon against some common fungi causing spoilage of stored food

Table 1 Chemical compounds reported in *Cinnamomum* spp

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
1.	*Cinnamomum malabatrum (Burm.f.) J.Presl*	India [Karnataka, Kerala, Tamil Nadu]; endemic	Linalool, (E)-caryophyllene (E)-cinnamyl acetate bicyclogermacrene, benzyl benzoate, caryophyllene oxide, and humulene epoxide II	Petiole, terminal shoot, leaf, and shoot	Essential oils	Leela et al. [28]
			3,4′,5,7-Tetrahydroxyl flavones, 3,3′,4′,5,7-pentahydroxy flavones, kaempferol-3-O-sophoroside, and quercetin 3-O-rutin	Leaves	Extract	Agrawal et al. [22]
			Eugenol, β-caryophyllene, cinnamic aldehyde, benzaldehyde, camphor, cadinene, limonene, geraniol, ocimene, γ-terpinene, eugenol acetate, benzyl cinnamate, β-phellandrene, α-terpineol, and benzyl acetate, cinnamaldehydes	Bark	Essential oils	Agrawal et al. [22]
			Alkaloids, tannins, glycosides, triterpenoids, flavonoids, and saponins	Leaf	Extract	Natarajan et al. [32]
			Cinnamic aldehyde, benzaldehyde, eugenol, camphor, cadinene, α-terpineol, limonene, geraniol, eugenol acetate, ocimene, β-caryophyllene, γ-terpinene, β-phellandrene, benzyl cinnamate, and benzyl acetate	Leaves	Essential oil	Agrawal et al. [22]
			Cinnamaldehydes. kaempferol-3-O-sophoroside, 3,4′,5,7-tetrahydroxyl flavones, 3,3′,4′,5,7-pentahydroxy flavones, and quercetin 3-O-rutin	Bark	Essential oil	Agrawal et al. [22]
			N-Didehydrohexacarboxyl-2,4,5-trimethylpiperazine, 1,2,4-triazoliumylide phenol 3,5-dimethoxy acetate, 4′-isopropylidene-bis-(2-cyclohexyl) phenol	Leaf		Packiaraj et al. [85]
			Cinnamaldehydes, kaempferol-3-O-sophoroside, 3,4′,5,7-tetrahydroxyl flavones, 3,3′,4′,5,7-pentahydroxy flavones, and quercetin 3-O-rutin	Bark	Essential oil	Agrawal et al. [22]
			Cinnamic aldehyde, benzaldehyde, eugenol, camphor, cadinene, α-terpineol, limonene, geraniol, eugenol acetate, ocimene, β-caryophyllene, γ-terpinene, β-phellandrene, benzyl cinnamate, and benzyl acetate	Leaves	Essential oil	Agrawal et al. [28]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
2.	*Cinnamomum sulphuratum Nees*	India [Assam, Karnataka, Kerala, Meghalaya, Tamil Nadu], Myanmar; 700–2000 m	Linalool, geraniol, citronellol	Leaf	Essential oil	Nath et al. [32]
			Geranial, neral, and geraniol	Stem, leaf, and bark leaf	Essential oil	Baruah et al. [33]
			Linalool-type	Bark and leaves	Essential oil	Nath et al. [32]
			Methyl cinnamate-type	–	–	Baruah et al. [35]
			Cinnamaldehyde-type	–	–	Baruah et al. [34]
			Benzyl benzoate Phenylethyl benzoate	Leaf and stem bark oils	Essential oil	Rameshkumar and George [15]
			Phenolic groups and triterpenoids	–	Crude methanol extract	Maridass [13]
			α-Phellandrene, Z-β-ocimene, 1,1-dicyclopropyl-2-methyl-l-pentene, linalool, eugenol, β-phellandrene β-caryophyllene, and benzyl benzoate	Leaf	Essential oil	Kumar et al. [36]

3.	*Cinnamomum verum* J.Presl	India [widely cultivated], Brazil, Cambodia, China, Fiji, Myanmar, Philippines, Seychelles, Taiwan, Tanzania, Vietnam; also cultivated in many other countries in Asia, native to Sri Lanka	Cinnamaldehyde	Stem bark	Essential oil	Rameshkumar and George [15]
			(E)-Cinnamaldehyde, eugenol, (E)-cinnamyl acetate, and linalool	Petiole	Essential oil	Rao et al. [38]
			Trans-cinnamyl acetate, α-humulene, α-muurolene	Flowers, buds, and fruit	Essential oil	Mollenbeck et al. [40]
			Cinnamaldehyde	Leaves and bark	Essential oil	Variyar and Bandyopadhyay [41]
			Eugenol	–	Essential oil	Mallavarapu et al. [42]; Rao et al. [43]
			Benzyl benzoate	Leaf and bark	Essential oil	Nath et al. [44]
			Camphor	Root and bark	Essential oil	Wijesekera et al. [45]
			Linalool and (E)-cinnamyl acetate	Tender twigs	Essential oil	Kaul et al. [46]
			Linalool, β-caryophyllene, and (E)- cinnamyl acetate	Pedicels of buds, flowers, and fruits	Essential oil	Kaul et al. [46] Jayaprakasha et al. [47]
			Trans-cinnamaldehyde, 4-vinyl benzoic acid, coumarin, (E)-3-(2-methoxyphenyl)-2-propenoic acid	Bark	Methanolic extract	Mariappan et al. [48]
			α-Linalool, α-pinene, and α-pinene cinnamaldehyde and eugenol	–	Essential oil	Nath et al. [32]
			1,2-Trans-sabinene hydrate, (Z)-β-ocimene, germacrene A, α-gurjunene, myrcene, α-pinene, β-sabinene, trans-sabinene hydrate, (Z)-β-ocimene, germacrene A	Dried leaves	Essential oil	Mir et al. [49]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
			Eugenol and α-phellandrene, p-cymene, α-pinene, 1,8-cineole, eugenol acetate, benzaldehyde, linalool	Fresh leaf	Essential oils	Baruah et al. [130]
			α-Terpineol, p-cymene, 1,8-cineole, α-phellandrene, terpin-4-ol, α-pinene, β-pinene, linalool, myrcene, α-terpinene, caryophyllene	Stem bark	Essential oils	Baruah et al. [130]
			Eugenol, spathulenol, aromadendrene, viridiflorene, and methyl eugenol	Dried leaves	Essential oils	Kapoor et al. [50]
			(E)-Cinnamaldehyde, linalool, (E)-cinnamyl acetate, β-pinene, and α-copaene	Leaf	Essential oils	Joshi et al. [209]
			Linalool and (E)-cinnamaldehyde, 1,8-cineole, camphor, eugenol, (E)- cinnamaldehyde, (E)-cinnamyl acetate, epicubenol	Fresh aerial parts	Essential oil	Agrawal et al. [53]
			Methyl eugenol, eugenol, (E)-cinnamyl acetate, and β-caryophyllene, ascabin, cinnamaldehyde	–	–	Kumar et al. [54]
			Cinnamaldehyde, cinnamyl acetate, and linalool	Leaves	Essential oil	Lohani et al. [56]
			Cinnamaldehyde, cis-linalool oxide, linalool, and cinnamyl acetate, benzaldehyde, 1,8-cineole, bornyl acetate, 3-phenyl propanal, and p-cymene	Leaves	Essential oil	Mohan et al. [104]
			α-Linalool, α-pinene, pinene, cinnamaldehyde, and eugenol	Leaf	Essential oil	Nath et al. [32]
			Cinnamaldehyde, cinnamyl acetate, and linalool	Leaves	Essential oil	Lohani et al. [56]
			α-Phellandrene, eugenol, β-phellandrene, α-pinene, elixene, cis-caryophyllene, myrcene, limonene	Leaves	Essential oil	Sankaran et al. [57]
			Proanthocyanidins and trans-cinnamaldehyde	Bark	Extract	Williams et al. [58]
			1,2-Trans-sabinene hydrate, (Z)-β-ocimene, germacrene A, α-gurjunene, myrcene, α-pinene, β-sabinene, trans-sabinene hydrate, (Z)-β-ocimene, and germacrene	–	Essential oil	Mir et al. [49]
			p-Cymene, α-pinene, 1,8-cineole, eugenol acetate, benzaldehyde, linalool, eugenol, and α-phellandrene	Leaf	Essential oil	Baruah et al. [130]

			α-Terpineol, p-cymene, 1,8-cineole, α-phellandrene, terpin-4-ol, α-pinene, β-pinene, linalool, myrcene, α-terpinene, caryophyllene	Stem bark	Essential oil	Baruah et al. [130]
			Eugenol, spathulenol, aromadendrene, viridiflorene, and methyl eugenol	Leaves	Essential oil	Kapoor et al. [50]
			(E)-Cinnamaldehyde, linalool, (E)-cinnamyl acetate, β-pinene, α-copaene, α-copaene	–	Essential oil	Joshi et al. [51]
			Cinnamyl acetate, linalool, and (Z)- cinnamaldehyde, camphene, α-pinene, 3- phenyl propanal, benzaldehyde, bornyl acetate, (Z)-cinnamyl acetate, coumarin, salicylaldehyde, and β-copaen-4α-ol	Leaves	Essential oil	Chanotiya et al. [52]
			Linalool, (E)-cinnamaldehyde and camphor linalool, (E)-eugenol, (E)- cinnamaldehyde, (E)-cinnamyl acetate, epicubenol	Aerial part	Essential oil	Agrawal et al. [53]
			Methyl eugenol, eugenol, (E)-cinnamyl acetate, and β-caryophyllene (major constituents) and cinnamaldehyde and ascabin (minor components)	Leaf	Essential oil	Kumar et al. [103]
			Cinnamaldehyde, cinnamyl acetate, and linalool	Leaves	Essential oil	Lohani et al. [56]
			Cinnamaldehyde, cis-linalool oxide, linalool, and cinnamyl acetate benzaldehyde, 1,8-cineole, bornyl acetate, 3-phenyl propanal, and p-cymene	Leaves	Essential oil	Mohan et al. [104]
			Eugenol, eugenyl acetate, α-phellandrene β-elemene, acetyl eugenol, and isoeugenol	Leaves	Essential oil	Rana et al. [55]
			Cinnamyl acetate, benzaldehyde β-pinene, 1,8-cineole, and caryophyllene oxide cinnamaldehyde and linalool	Leaves	Essential oil	Lohani et al. [56]
			α-Phellandrene, eugenol, β-phellandrene, α-pinene, elixene, cis-caryophyllene, myrcene, limonene	Leaves	Essential oil	Sankaran et al. [57]
			Proanthocyanidins and trans-cinnamaldehyde	–	Extract	Williams et al. [58]
			α-Linalool, α-pinene, cinnamaldehyde, and eugenol	Leaf	Essential oil	Nath et al. [32]
			α-Pinene, β-pinene, α-linalool, 1,2-trans-sabinene hydrate, germacrene A, myrcene, α-gurjunene, β-sabinene (Z)-β-ocimene	Leaves	Essential oil	Mir et al. [49]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
			Eugenol, p-cymene, α-pinene, 1,8-cineole, acetate, benzaldehyde, α-terpineol, terpin-4-ol, α-pinene, b-pinene, linalool, myrcene, α-terpinene, caryophyllene, terpineol, α-phellandrene	Leaf and stem bark	Essential oil	Baruah et al. [130]
			Cinnamaldehyde, 2-methoxycinnamaldehyde	Bark and twig	–	Yan et al. [59]; Liu et al. [60]; Kim et al. [61]
			Benzenamine, cyclohexyl-15-crown-5, N, N-diethyl-4-methyl-, oxybis (2,1-ethanediyloxy-2,1-ethanediyl) and 2-methyl-, 2-propenoic acid	Leaf	Ethanolic extract	Alva et al. [62]
			Eugenol	Leaf	Essential oil	Singh et al. [63]
4.	*Cinnamomum zeylanicum* Linn.	India [widely cultivated], Brazil, Cambodia, China, Fiji, Myanmar, Philippines, Seychelles, Taiwan, Tanzania, Vietnam; also cultivated in many other countries in Asia, native to Sri Lanka	Oxygenated trans-cinnamyl acetate and b-caryophyllene	Fruit	Essential oil	Jayaprakash et al. [47]
			Eugenol, linalool, and piperitone	Leaf	Essential oil	Raina et al. [64]
			Eugenol	Leaf	Essential oil	Reynolds [65]
			Eugenol, trans-cinnamic acid, cinnamaldehyde, condensed tannins, catechins, proanthocyanidins, phenolic compounds, gum, pinene, calcium-monoterpenes oxalate, resin, mucilage and traces of coumarin	Bark	Essential oil	Duke [67]
			Eugenol and cinnamaldehyde	–	–	Jantan et al. [66]
			Monoterpenes, ketones, sesquiterpenes, and aromatic aldehydes, cinnamaldehyde benzaldehyde	–	Essential oil	Uma et al. [68]
			Cinnamic acid, cinnamaldehyde, eugenol, benzoic acid, benzaldehyde, triterpenes, sesquiterpenes, and monoterpenes	Bark	Essential oil	Gupta et al. [69]
			Cinnamaldehyde and eugenol	Bark and leaves	Essential oil	Vangalapati et al. [70]
			(E)-Cinnamyl acetate, trans-alpha-bergamotene, and caryophyllene oxide	Flowers	Essential oil	Vangalapati et al. [70]
			Camphor	Bark and root	Essential oil	Vangalapati et al. [70]
			Trans-cinnamyl acetate and β-caryophyllene	Fruit	Essential oil	Vangalapati et al. [70]
			Terpene hydrocarbons, alpha-copaene, alpha-bergamotene, and oxygenated terpenoids	Buds	Essential oil	Vangalapati et al. [70]

			Cinnamic acid, benzoic acid, and benzaldehyde that is lipophilic	–	Essential oil	Ramos-Nino et al. [72]
			Cinnamyl acetate	Bark	Essential oil	Gupta et al. [73]
			Cinnamaldehyde, linalool	–	Essential oil	Brari and Thakur [74]
			Trans-cinnamaldehyde	Bark	Essential oil	Baratta et al. [75]
			Tetradecanol, α-humulene, δ-cadinene, α-copaene, viridiflorene, and α-bergamotene	Bud	Essential oil	Pragadheesh et al. [76]
			Contain (E)-cinnamaldehyde, eugenol, β-caryophyllene, linalool, (E)-cinnamyl acetate, and α-terpineol	Leaf	Essential oil	Pragadheesh et al. [76]
			Caryophyllene oxide, tetradecanal, trans-α-bergamotene, α-cadinol, and globulol	Flower	Essential oil	Pragadheesh et al. [76]
			α-Humulene, caryophyllene, (E)-τ-cadinol, (E)-cinnamyl acetate, δ-cadinene, α-copaene	Fruit stalks	Essential oil	Pragadheesh et al. [76]
			Linalool, 3-caryophyllene, (E)-benzyl benzoate, cinnamaldehyde, and (E)- cinnamyl acetate	–	Essential oil	Mallavarapu et al. [42]
			Cinnamic acid, cinnamaldehyde, cinnamate	–	Essential oil	Senanayake et al. [78]
			Terpinolene, cinnamyl acetate, trans-cinnamaldehyde, eugenol, caryophyllene oxide, L-borneol, b-caryophyllene, E-nerolidol, alpha-cubebene, L-borneol acetate, alpha-terpineol, and alpha thujene	–	Essential oil	Singh et al. [63]; Malsawmtluangi et al. [79]; Jayaprakasha et al. [80]
			Methoxycinnamaldehyde, benzenepropanal, cinnamaldehyde, vanillin, cuminaldehyde, benzaldehyde, hydrocinnamic, 2-methyl-3-phenyl-propanal, and citronellal; cinnamyl alcohol, α-terpineol, linalool, and α-bisabolol; cinnamyl acetate esters, diethyl acetal, cinnamaldehyde, methyl cinnamate, hydrocinnamyl acetate, benzyl benzoate, bornyl acetate	–	Essential oil	Jayaprakasha et al. [47, 81]
			Cinnamaldehyde and linalool	–	Essential oil	Brari and Thakur [74]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
5.	*Cinnamomum cassia* (L.) J.Presl	Southern China, Southeast Asia (India, Indonesia, Laos, Malaysia, Thailand, and Vietnam)	Hymecromone and umbelliferone	–	Ethanolic extract	Kamalakannan et al. [82]
			Cinnamic acid, eugenol, cinnamyl alcohol, cinnamaldehyde, melilotic acid, δ-cadinene, phenolic compounds, epicatechins, cinnamic aldehydes, monoterpenes, tannins, procyanidins, diterpenes, glycosides (cinnacassides A–Z), oxalate, sesquiterpenes (pinene), and traces of coumarin	–	Essential oil	Liao et al. [83]
			4′-Isopropylidene-bis-(2-cyclohexyl) phenol, NDidehydrohexacarboxyl-2,4,5-trimethylpiperazine, 1,2,4-triazoliumylide phenol 3, 5-dimethoxy acetate			Packiaraj et al. [84]
			Coumarin (1, 2-benzopyrone)	–	–	Archer [85]
			O-Glucoside and 3-(2-hydroxyphenyl)- propanoic acid	Root bark	Essential oil	Tanaka et al. [86]
			Coumarin, (Z)-cinnamaldehyde, α-ylangene, and β-caryophyllene	–	–	Mbaveng and Kuete [88]; Chericoni et al. [87]; Bansode [89]
			Cinnzeylanol, 19-dehydroxy-13-hydroxycinncassiol, (18R)-1-hydroxycinncassiol, (18S)-3-dehydroxycinncassiol glucoside, (18S)-3-dehydroxy-8-hydroxycinncassiol (18S)-cinncassiol, (18S)-3,5-didehydroxy-1,8-dihydroxycinncassiol, 2,3-dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone	Bark and leaves	–	Zhou [90] Yang [91]
			(1R,2R,4S,6S)-4-(2-Hydroxypropan-2-yl)-1-methyl-7-oxabicyclo[4.1.0]heptan-2-ol dimethanol (1R,2R)-4-[(3S)-3-Hydroxybutyl]-3,3,5-trimethylcyclohex-4-ene-1,2-diol and (3S,5R,6R,7E,9S)-3,5,6,9-tetrahydroxy-7-enemegastigmane	Leaves	–	Zhou [90]

			Cinnamyl alcohol 2-hydroxy-cinnamyl alcohol	Twig	–	Kim et al. [61]; Chen [92]
			(+)-Syringaresinol, cinnamomulactone, 2-hydroxycinnamaldehyde	–	–	Chen [92]; Yang [91]; He et al. [93] Kim et al. [61]
			Cinnamic acid	–	–	Chen [92]; Yan et al. [59]
			Phenethyl (E)-3-[4-methoxyphenyl]-2- propenoate	–	–	Kim et al. [61]
			1-(3,4-Dimethoxyphenyl)-1,2,3-propanetriol	Leaves	–	Zhou [90]
			(7S,8S)-Syringoylglycerol	–	–	Yang [91]
			(−)-4-epi-Lyoniresinol	Leaves	–	Zeng et al. [94]
			n-Butyl-β-D-fructofuranoside, (+)-(1S,2S)-1-(3-Methoxy-4-hydroxyphenyl)- 1,2,3-propanetril-2-O-β-D-glucopyroside, tachioside	–	–	Zhou [90]
			Cinncassin A1, cinncassin J, cinncassin I, cinncassin L, cinncassin M, cinncassin K, cinnamomoside, and cinncassin H	Twig	–	Liu et al. [95]
			5R-Methyl-3-heptatriacontyl-2(5H)-furanone	–	–	Li et al. [96]
			Cinncassin A2, cinncassin A3, cinncassin A4, cinncassin A5, cinncassin A6, cinncassin A7, cinncassin N, cinncassin O, cinncassin F	–	–	Chen [92]; Yang [91] Kim et al. [61] He et al. [93]
			Icariside D, isotachioside	–	–	Guo et al. [97]
			Namomulactone, a new butyrolactone, syringaresinol, cinnamaldehyde, coumarin, 2-hydroxycinnamaldehyde, trans-cinnamic acid, 2-methoxycinnamaldehyde, benzoic acid, phenethyl (E)-3-[4-methoxyphenyl]-2-propenoate, 2-hydroxy-cinnamyl alcohol	Twigs	–	Kim et al. [61]
			Cinnamaldehyde derivatives synthesized from cinnamic acid, such as 2′-hydroxycinnamaldehyde and coumarin	Bark	–	Bansode [89]
			2-O-β-D glucosyl-(1S)-phenylethylene glycol, cinnamaldehyde	–	–	Kim et al. [61]; Yan et al. [59]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
6.	*Cinnamomum camphora* (L.) J. Presl	India [Andhra Pradesh, Andaman Islands, Assam, Karnataka, Kerala, Nicobar Islands, Maharashtra, Tamil Nadu, Tripura, West Bengal – widely cultivated], China, Japan (native), Korea, and Vietnam and widely cultivated all over the world	(7α, 7′α, 8α, 8′α)-3, 7-Hydroxy-4-methoxy-3′,4′-methylenedioxy lignane and (−)-medioresinol and trans-4,5-dimethoxy-3-hydroxycinnamaldehyde	Bark and leaves	–	Feng [98]
			Trans-4,5-Dimethoxy-3-hydroxycinnamaldehyde, (+)-epipinoresinol	Bark and leaves	–	Feng [98]
			Dimethylmatairesinol and (7α, 7′β, 8α, 8′α)-3-Methoxy-4-hydroxy-3′,4′-methylenedioxy-7,9:7,9-diepoxylignane	–	–	Xu [99]; Feng [98]
			Fenchone, camphene, a-thujene, L-limonene, and cisp-menthane	–	Essential oil	Srivastava et al. [115]
			p-Cymene, camphor, a-pinene, alpha- humulene, 1,8-cineole, and camphene	–	Essential oils	Joshi et al. [51]
			Camphor	–	–	Agrawal et al. [53]
			Pinene and terpineol, 1,8-cineole	–	Essential oil	Sriramavaratharajana et al. [132]
			1,8-cineole, (E)-cinnamaldehyde, and camphor	–	–	Abdelwahab et al. [154]; Chalchat and Valade [137]

7.	*Cinnamomum glanduliferum* (Wall.) Meisn.	India [Assam, Meghalaya, Tripura], Bangladesh, Bhutan, China, Malaysia, Myanmar, Nepal, Tibet; 1500–2500 (−3000) m	1,8-Cineole and α-terpineol. Monoterpene hydrocarbons germacrene D-4-ol, α-pinene, and α-thujene	–	Essential oil	Singh et al. [37]
			1,8-cineole, caryophyllene oxide, camphor, α-terpineol, linalool.	–	–	Chowdhury [100]
			(E)-Nerolidol, caryophyllene oxide, β-pinene, and linalool	Leaf	Essential oil	Baruah and nath et al. [101]
			1,8-Cineole, α-terpineol, germacrene D-4-ol, α-pinene, and α-thujene	–	Essential oil	Singh et al. [37]
			β-Caryophyllene, β-pinene, α-terpineol, (E)-cinnamaldehyde, p-cymene, linalool, α-pinene, l,8-cineole, (E)-methyl cinnamate, α-phellandrene, terpinen-4-ol, eugenol, and (Z)-methyl isoeugenol	Stem bark	Oil	Baruah and Nath [101]
			Germacrene D-4-ol, α-pinene, α-terpineol, α-thujene, and 1,8-cineole	–	Essential oil	Prakash et al. [102]
8.	*Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm.		Ascabin, cinnamaldehyde, hydrocinnamyl acetate, beta-caryophyllene, and trans-cinnamyl acetate	Leaves	Essential oil	Kumar et al. [103]
			(E)-Cinnamyl acetate, linalool, and (E)-cinnamaldehyde	Fresh aerial parts	Essential oils	Agrawal et al. [53]
			Methyl cinnamate	Stem and bark	Essential oils	Malsawmtluangi et al. [79]
			Trans-cinnamaldehyde, styrene, benzyl benzoate, and linalool and methyl cinnamate, α-pinene, β-pinene, hexanol, and phellandrene	Leaf	Essential oils	Malsawmtluangi et al. [79]
			Linalool and cinnamaldehyde	–	–	Gulati et al. [105]
			Cinnamaldehyde	–	–	Gulati et al. [105]; Kubeczka and Formacek [106]; Dighe et al. [107]; Seth et al. [108]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
			Cinnamic acid	–	Essential oil	Husain et al. [109]
			Germacrene A, β-sabinene, β-caryophyllene, α-pinene, myrcene, (Z)-β-ocimene, linalool, α-gurjunene, and trans-sabinene hydrate	Leaf	Essential oil	Showkat et al. [110]
			Flavonoid compounds: quercetin, quercetin, and kaempferol	Leaf	–	Prasad et al. [111]
			Eugenol eugenyl acetate and α-phellandrene	–	Essential oil	Rana et al. [55]
			Eugenol	Leaf	Volatile oil	Dighe et al. [107]; Kapoor et al. [50]
			Two compounds: hexahydropyridine,4-[4,5-dimethoxyphenyl]-in and 2,6,10-trimethyl-12-oxatricyclo[7.3.0.0{1,6}] tridec-2-ene	–	Hexane extract	Khajapeer et al. [113]
			2,5-Chloro-3β-hydroxy-6βnitro-5α-androstan-17-one, acetic acid,10,13-dimethyl-2-oxo-2,3,4,7,8,9,10,11,12,13,14,15,16,17-tetradecahydro-1H cyclopenta [a]phenanthren17-ylester and 6á,19-CycloAndrost-4-ene-3,17-dione	–	Dichloromethane extract	Khajapeer et al. [113]
			Mixtures of monoterpenes, phenylpropanoids, and sesquiterpenes.	Leaves	Essential oil	Heer et al. [114]
			β-Caryophyllene, trans-cinnamyl acetate, eugenol, and cinnamaldehyde.	Leaves	–	Kumar et al. [54]
9.	*Cinnamomum iners* Reinw. ex Blume	India [Assam, Tripura], Bangladesh, Cambodia, China, Jawa, Indonesia, Laos, Malaysia, Myanmar, Philippines, Sri Lanka, Sumatra, Thailand, Tibet, Vietnam; 100–1000 m	Eicosanoic acid ethyl ester and caryophyllene	–	Chloroform extract	Ghalib et al. [116]
			caryophyllene	–	Alcohol extract	Ghalib et al. [116]
			Pentadecanoic acid, 14-methyl-, methyl ester; 4-piperidineacetic acid, 10-octadecenoic acid, cyclopentaneundecanoic acid, methyl ester; methyl ester; cyclopropanebutanoic acid, 2-[[2-[[2-[(pentylcyclopropyl) methyl] cyclopropyl] methyl] cyclopropyl] methyl]-, methyl ester; 1-acetyl-5-ethyl2-[3-(2-hydroxyethyl)-1H-indol-2-yl]-a-methyl-methylester; 3-pentyl-, methyl ester, oxiraneundecanoic acid	Leaves	–	Udayaprakash et al. [117]

10.	*Cinnamomum chemungianum* M.Mohanan & A.N.Henry	India [Kerala, Tamil Nadu]; 800–1100 m; endemic to the Western Ghats	Caryophyllene oxide, terpinen-4-ol linalool, and benzyl benzoate	–	Essential oil	Baskaran and Ebbie [118]
			Found to have β-selinene, caryophyllene oxide, longiborneol, tetradecanal, intermedeol, and α-cyperone	–	Essential oil	Rameshkumar et al. [119]
			Veratrole, ρ-cymen-7-ol, germacrene B, longiborneol, and α-cyperone, viridiflorene	–	–	Sriramavaratharajan and Murugan [120]
11.	*Cinnamomum glaucescens (Nees) Hand.-Mazz.*	India [Assam, Manipur, Sikkim, West Bengal], Bangladesh, Bhutan, Laos, Myanmar, Nepal, Vietnam	α-Phellandrene, α-farnesene, 1,8-cineole, α-pinene, linalool α-phellandrene b-pinene b-caryophyllene and terpineol	Leaf	Essential oils	Baruah and Nath [130]
12	*Cinnamomum impressinervium Meisn.*	Distribution: India [Assam, West Bengal, Sikkim], Bangladesh, Bhutan, Myanmar, Nepal	Eugenol and δ-3-careen, limonene α- pinene, and eugenol acetate	Leaf	Essential oil	Nath and Baruah [129]
13.	*Cinnamomum champokianum Baruah & S.C.Nath*	Distribution: India [Assam]; c. 83 m; endemic	Elemicin and methyl eugenol	Leaf	Essential oil	Baruah and Nath [101]
14.	*Cinnamomum pauciflorum* Nees.	Distribution: India [Assam, Meghalaya, Mizoram], Bangladesh, China, Myanmar, Nepal; 1000–1700 m	Cinnamaldehyde	Shade-dried leaves, root bark, and stem bark	–	Nath et al. [44]
			(E)-Cinnamaldehyde and linalool	Leaves	–	Baruah and Nath [101]
15.	*Cinnamomum macrocarpum Hook.f.*	India [Goa, Karnataka, Kerala, Maharashtra, Tamil Nadu], Myanmar; 600–1000 m	Cinnamyl acetate, 4-teroinol, benzyl benzoate, and linalool	Bark	Oil	Hrideek et al. [131]

(continued)

Table 1 (continued)

Sl. no	Plant name	Distribution	Phytocompounds isolated	Source of compound		Reference
16.	*Cinnamomum bejolghota (Buch.-Ham.) Sweet*	Distribution: India [Andaman Islands, Arunachal Pradesh, Assam, Himachal Pradesh, Madhya Pradesh, Meghalaya, Nicobar Islands, Orissa, Punjab, Sikkim, West Bengal, Tamil Nadu (cultivated), Tripura], Bangladesh, Bhutan, Cambodia, China, Laos, Myanmar, Nepal, Thailand, Vietnam; 600–1800 m	(Z)-Methyl α-farnesene, isoeugenol, β-caryophyllene, linalool, α-phellandrene, 1,8-cineole, α-pinene, β-phellandrene, and β-pinene	Panicle	Essential oil	Baruah and Nath [101]
17.	*Cinnamomum perrottetii Meisn.*	India [Kerala, Tamil Nadu]; 1600–2100 m; endemic	α-Pinene, α-cadinol, and tau-cadinol	Leaf	Essential oil	Sriramavaratharajan et al. [133]
18.	*Cinnamomum agasthyamalayanum* Robi, Sujanapal & Udayan	Distribution: India [Kerala]; 800–1000 m; endemic to the Western Ghats	1,8-cineole	–	Essential oils	Sriramavaratharajan et al. [132]
19.	*Cinnamomum riparium Gamble*	Distribution: India [Karnataka, Kerala, Tamil Nadu]; 250–1400 m; endemic to the Western Ghats	Shikimole, eugenyl methyl ether, delta cadinene	Bark	Oil	Hrideek et al. [131]

product. The inhibitory action of *C. zeylanicum* essential oil on *Aspergillus flavus* and *Fusarium moniliforme* was determined on potato dextrose agar, and 500 ppm of *C. zeylanicum* oil has inhibited the growth of *A. flavus* and *Fusarium*.

Ranasinghe et al. [146] reported that *C. zeylanicum* essential oil demonstrated high fungicidal activity against *Lasiodiplodia theobromae*, *Colletotrichum musae*, and *Fusarium proliferatum*. Shan et al. [147] studied the antibacterial activity, minimum inhibitory concentration (MIC), and minimum bactericidal concentration (MBC) of *C. burmannii* extract. Inhibitory effects of five common foodborne pathogenic bacteria such as *Listeria monocytogenes*, *Bacillus cereus*, *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella anatum* were evaluated in *C. burmannii.*

Gende et al. [148] studied the inhibitory activity of *C. zeylanicum* essential oil against three strains of *Paenibacillus larvae* of different geographical origins. Gupta et al. [149] reported that cinnamon oil exhibits a wide zone of inhibition against *B. cereus* (29.0 mm), followed by *S. aureus* with 20 mm. The inhibition was also observed against *P. aeruginosa*, *E. coli*, and *Klebsiella* sp. Jantan et al. [66] reported antimicrobial activity of eight *Cinnamomum* species such as *C. mollissimum*, *C. zeylanicum*, *C. impressicostatum*, *C. microphyllum*, *C. rhyncophyllum*, *C. scortechinii*, *C. pubescens*, and *C. cordatum.* Six dermatophytes such as *Trichophyton rubrum*, *Microsporum canis*, *T. mentagrophytes*, *M. gypseum*, *M. audouinii*, and *T. tonsurans*, *Aspergillus fumigates* (filamentous fungi), and five strains of yeasts such as *C. glabrata*, *C. tropicalis*, *C. parapsilosis*, *Candida albicans*, and *Cryptococcus neoformans* were examined. The strong inhibition was observed on fungal growth in the leaf oil of *C. cordatum* and bark and twig oils of *C. impressicostatum* and *C. pubescens*.

Aneja et al. [150] assessed the antimicrobial potentiality of ethanol, acetone, and methanol extracts of *C. zeylanicum* bark. The ethanolic, methanolic, and acetonic bark extracts exhibited greater antimicrobial activities than the water extracts against *Streptococcus mutans*, *Staphylococcus aureus*, *Saccharomyces cerevisiae*, and *Candida albicans*. *Lactobacillus acidophilus* was found as resistant to all the five extracts. The acetonic extract showed greater antimicrobial activity than the alcoholic and water extracts. The strongest inhibition was observed in the acetonic extract against *C. albicans* with inhibition zone of 29.30 mm and 12.5 mg/ml MIC as compared to the standard antifungal drug amphotericin B that has showed zone of inhibition of about 13 mm.

Goyal et al. [151] evaluated in vitro antibacterial activity of *C. tamala* stem bark extract by agar well diffusion assay. Ethanol, ethyl acetate, and methanol showed significant activity (11.26 mm to 20.77 mm) against all tested bacteria except *Escherichia coli*. Ethyl acetate extract showed minimum activity (12 mm–15 mm) against *Staphylococcus aureus*. Mishra et al. [152] carried out antifungal bioassay of *C. zeylanicum* bark and leaf extracts by hanging drop technique against *A. solani* and *C. lunata*. All the extracts showed 50 to 100% inhibition at 100 µg/ml concentration. However, the treatment of the spores of the two fungal species with the highest concentration (500 µg/ml) of bark and leaf extracts in all the solvents showed 100% fungicidal activity as it completely arrested the germination of spores.

Abdelwahab et al. [153] reported antimicrobial activity of *C. pubescens* essential oils and against methicillin-resistant *Staphylococcus aureus*. Methicillin-resistant

Staphylococcus aureus (MRSA), *Pseudomonas aeruginosa*, *Bacillus subtilis*, and *Salmonella choleraesuis* were tested against *C. pubescens*. Jantan et al. [66] reported the antifungal activity of *C. pubescens* essential oil. Friedman et al. [154] reported that cinnamaldehyde as the major constituent of *C. pubescens* (56.15%) was known to exhibit antibacterial activity against *Salmonella typhimurium* and *Escherichia coli*. Bouhdid et al. [155] studied the cellular damage induced by *C. verum* essential oil in *Staphylococcus aureus* and *Pseudomonas aeruginosa*.

Rattanachaikunsopon and Phumkhachorn [156] examined antimicrobial activities against *Streptococcus iniae*. Cinnamon oil exhibited minimal inhibitory concentration (MIC) of 40 mg/ml and cinnamaldehyde exhibited MIC of 20 mg/ml against *S. iniae*. There was no apparent mortality in fish fed on fish diets supplemented with 0.4% (w/w) of cinnamon oil and with 0.1% (w/w) of oxytetracycline 5 days prior to infection with *S. iniae*. Unlu et al. [157] reported that C. *zeylanicum* bark essential oil was highly effective against gram-positive bacteria *Staphylococcus*, *Streptococcus*, *Enterococcus*, and *Pseudomonas aeruginosa*.

Ababutain [158] reported that *C. verum* exhibited in vitro antimicrobial activity against *Staphylococcus aureus* and *Bacillus subtilis* and *Pseudomonas aeruginosa*, *Escherichia coli*, and *Candida albicans* (yeast) using hole-plate diffusion method. *Cinnamomum verum* strongly inhibited the growth of *B. subtilis* and *C. albicans* only. *Staphylococcus aureus* and *Escherichia coli* were found to be resistant. *Cinnamon* extracts showed remarkable effect on *B. subtilis* and *C. albicans* at MIC of 3.125–6.25 and 12.5–25 μg/ml, respectively. Jain et al. [159] reported the antimicrobial activity of methanolic extract of *C. tamala* against *S. aureus*, *E. coli*, *P. aeruginosa*, *Citrobacter braakii*, *Klebsiella pneumonia*, *Rhizopus stolonifer*, and *Microsporum gypseum* by disc diffusion method.

Shareef et al. [160] investigated essential oils of *Cinnamomum* sp. for their antibacterial activity against six bacterial species including *Escherichia coli*, *Staphylococcus aureus*, *Klebsiella pneumonia*, *Pseudomonas aeruginosa*, *Brucella* sp. and *Proteus* sp. Prabuseenivasan et al. [161] recorded that *Pseudomonas aeruginosa* was more sensitive to cinnamon essential oil, whereas *Klebsiella pneumoniae* and *Staphylococcus aureus* were less sensitive to cinnamon essential oil. Babu et al. [162] reported that *Escherichia coli* was found to be more sensitive to cinnamon essential oil and *Listeria monocytogenes* was less sensitive to cinnamon essential oil.

Boniface et al. [163] evaluated antibacterial and antifungal activities of *C. zeylanicum* essential oils. Minimum inhibitory concentration (MIC) and mycelial growth inhibition were investigated on *Candida albicans*, *Aspergillus ochraceus*, *Aspergillus parasiticus*, *Penicillium digitatum*, and *Fusarium oxysporum*. The oil has showed significant properties against *E. coli* and *S. aureus* and fungicidal activities against *C. albicans*, *Aspergillus ochraceus*, *Aspergillus parasiticus*, *Fusarium oxysporum*, and *Penicillium digitatum*. Mahmoud [164] carried out the antifungal activity of *C. zeylanicum* bark extracts against *Aspergillus niger* and *Penicillium digitatum*. Mohan et al. [104] examined antimicrobial activities of *C. tamala* essential oils against nine microbial strains by using broth micro-dilution method. *Cinnamomum tamala* oil exhibited significant antifungal activity and satisfactory antibacterial activity.

Dhara and Tripathi [165] investigated the antimicrobial activity of cinnamon essential oils and their bioactive compounds against pathogenic ESBL-producing bacteria by disc diffusion assay. MIC of bioactive compound and their interaction with ESBL proteins were determined by macro-broth dilution and molecular docking method. ESBL property was exhibited by *Enterobacteriaceae*, *Escherichia coli*, and *Klebsiella pneumoniae*. Cinnamon oil exhibited antibacterial properties against ESBL due to the presence of main bioactive compounds such as eugenol and cinnamaldehyde. Herman et al. [166] studied the antimicrobial activity of essential oils of *C. zeylanicum* against *Pseudomonas aeruginosa*, *Escherichia coli*, *Staphylococcus aureus*, and *Candida albicans*. Essentials oils showed higher inhibitory activity against tested microorganism strain.

Yadav and Dubey [167] reported that *C. tamala* had fungicidal/fungistatic activity and inhibited the growth of two ringworm fungi, *Microsporum audouinii* and *Trichophyton mentagrophytes*. The minimum concentration at which *C. tamala* essential oils inhibited fungal growth in poisoned food was 500 ppm. Kapoor et al. [50] reported that the volatile oil and oleoresins from *C. tamala* leaf were found to be effective against a number of fungi, but oleoresins were less effective. Complete fungal growth inhibition by volatile oil has been reported from this study at a dose of 6 μL against *Aspergillus niger*, *A. solani*, *A. flavus*, and *Fusarium moniliforme* by using the inverted petri plate assay. Mishra et al. [168] reported the antibacterial effect of *C. tamala* leaf against *Staphylococcus aureus*, *Pseudomonas vulgaris*, *Streptococcus pneumoniae*, and *E. coli*. The minimum inhibitory concentration (MIC) of oil and solvent extracts from *C. tamala* has varied between 2.40 and 0.60 mg/mL.

Elhag et al. [169] reported the antimicrobial activity of ethanolic, chloroform, petroleum ether, and methanolic extracts of *C. zeylanicum* bark against *Escherichia coli* and *Pseudomonas aeruginosa* (gram-negative bacteria, gram-positive bacteria (*Staphylococcus aureus* and *Bacillus subtilis*)), *Candida albicans*, and *Aspergillus niger* (fungal species). All extracts exhibited significant antimicrobial activity against the tested organisms and the petroleum ether (PE). Antimicrobial activity was most probably due to the presence of (E)-cinnamaldehyde, a known antimicrobial natural product and major compound of petroleum ether extract. Valizadeh et al. [170] conducted an antimicrobial study on *C. zeylanicum* barks and leaves against *S. typhimurium*, *E. coli*, and *B. cereus* by disk and agar well diffusion methods. The essential oil was effective on *B. cereus* in both methods with the highest inhibition zone of 30 mm in the highest concentration. MIC of all *Candida* species was 0.012%. The minimum fungicidal concentration of leaf extracts of *C. dublinienses*, *C. parapesilosis*, *C. albicans* was recorded as 0.048% and 0.012% against *C. parapesilosis*, *C. albicans* respectively. Hameed et al. [171] reported that *C. zeylanicum* was highly active against *Aspergillus flavus* with inhibition zone of 6.16 ± 0.42. The zone of inhibition of *C. zeylanicum* methanolic extract against *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Staphylococcus aureus*, *Escherichia coli*, and *Klebsiella pneumonia* ranged from 6.12 ± 0.52 to 0.39 ± 0.17 mm for all treatments.

Hassan et al. [172] reported the antimicrobial activity of *C. tamala* leaf methanolic extract against six gram-negative strains, three gram-positive bacterial strains,

and one fungal strain by agar well diffusion method. The extract showed variable degree of inhibition zones except for dichloromethane, aqueous fraction, and crude extract which were found to be completely inactive against *Salmonella* Typhi (a gram-negative strain). Adarsh et al. [173] reported significant antimicrobial activity of *C. zeylanicum* against *Escherichia coli* (gram-negative), *Enterococcus faecalis* (gram-positive), and *Salmonella* Typhi (gram-positive) by agar diffusion method. Naik et al. [174] assessed the antimicrobial activity of two cinnamon leaf oils and extracts by disc diffusion assay and the minimum inhibitory concentration by two-fold serial dilution method against *E. coli*, *S.* Typhi, *S. aureus*, *B. cereus*, and *C. perfringens*. Essential oils and extracts exhibited the highest zone of inhibition (ZOI) against *S. aureus* and *E. coli*. Both oils and extracts showed minimum inhibitory concentration in the range of 0.156 mg/ml to 5 mg/ml.

Cong et al. [175] demonstrated the antimicrobial activity of leaf essential oil from *C. longipaniculatum* against *Staphylococcus aureus*, *Bacillus subtilis*, *Sarcina lutea*, and *Salmonella typhimurium*. Chairunnisa et al. [176] reported that volatile compounds such as α-pinene, α-terpineol, 1,8-cineole, and trans-cinnamaldehyde from *C. burmannii* essential oil exhibit antibacterial activity against *Escherichia coli* and *Staphylococcus aureus*. Aqueous extracts from *C. camphora* leaves exhibit positive effect on *Penicillium purpurogenum*, *Trichoderma harzianum*, *Aspergillus fumigatus*, *Phanerochaete chrysosporium*, and *Gloeophyllum trabeum* with concentrations of 5% and 10% found to be effective against *Botryodiplodia theobromae* (Hu et al. 2017) [177].

Rangel et al. [178] reported the antifungal activity of *C. zeylanicum* leaf essential oil against *Candida* spp. with MIC and MFC values ranging from 62.5 to 1000 μg/mL. *Cinnamomum cassia* essential oil was reported to contain cinnamaldehyde, cinnamic acid, and benzaldehyde as the major constituents and with remarkable antibacterial activity against *Escherichia coli*, *Staphylococcus hyicus*, *Staphylococcus aureus*, *Propionibacterium acnes*, and *Pseudomonas aeruginosa* [179–181]. Lu et al. [182] reported that *C. cassia* acetone extract exhibited antifungal activity against *Alternaria alternata*, *Botrytis cinerea*, *Colletotrichum glycines*, *Fusarium decemcellulare*, and *Alternaria solani* with the half-maximal effective concentration ranging from 45.68 mg/L to 105.09 mg/L.

3.2 Antioxidant Activity of Phytocompounds of Cinnamomum *spp.*

Lin et al. [183] evaluated antioxidant activities of aqueous and ethanol extracts from *Cinnamomum cassia* dry bark. At a concentration of 1.0 mg/mL, *C. cassia* ethanol extracts exhibit greater inhibition than α-tocopherol. The same extract also showed an excellent antioxidant activity in enzymatic and nonenzymatic liver tissue oxidative systems. Ethanolic extract of *C. cassia* revealed the strongest antioxidant activity followed by α-tocopherol. The IC50 values of ethanolic extract of *C. cassia* compared to α-tocopherol were found to be lower in thiobarbituric acid test

(IC50 = 0.24 mg/mL vs 0.37 mg/mL), in xanthine oxidase inhibition test (IC50 = 0.09 mg/mL vs 0.19 mg/mL), and in cytochrome c test (IC50 = 0.16 mg/mL vs 0.27 mg/mL).

Mathew and Abraham [184] had reported the antioxidant activity of the methanolic bark extract of *C. verum*. The scavenging activity was found to be increased with increasing concentration of BHA and CBE up to 12.5 lg ml and then found as stable with increasing concentration. The EC50 value of CBE was found to be 4.21 lg ml and that of BHA 5.79 lg ml, which was inversely related to the antioxidant capacity. The hydroxyl radical scavenging activity was observed in a dose-dependent manner in 15–250 lg ml range. The percentage inhibition of peroxidation in linoleic acid system by various concentrations ranging from 25 to 200 lg ml was found to be 81.8% to 93.3%. Mathew and Abraham [184] had reported the antioxidant activity of the methanolic bark extract of *C. verum* (CLE) were studied and compared to antioxidant compounds like Trolox, butylated hydroxyl anisole, gallic acid, and ascorbic acid. The free radical scavenging activities were observed especially against DPPH radical and ABTS radical cation. They also exhibited hydroxyl radical scavenging activity, reducing power, and metal ion chelating activity. The peroxidation inhibiting activity of extract recorded using the linoleic acid emulsion system showed good antioxidant activity.

Jayaprakasha et al. [185] evaluated the antioxidant activity of various extracts from *C. zeylanicum* through in vitro model systems, such as β-carotene-linoleate and 1,1-diphenyl-2-picryl-hydrazyl (DPPH). The order of activity of extract in different solvents were water > methanol > acetone > ethyl acetate using β-carotene/linoleic acid system. Mancini-Filho et al. [186] reported that ether, aqueous extracts, and methanol of *C. zeylanicum* inhibited the oxidative process in 68%, 87.5%, and 95.5%, respectively. Okawa et al. [187] reported that flavonoids isolated from cinnamon have free radical scavenging activities and antioxidant properties.

Yang et al. [188] investigated the antioxidant activities of barks, buds, and leaves of *C. cassia* extracted with ethanol and supercritical fluid extraction. For the antioxidant activity comparison, IC50 values of the SFE and ethanol extracts in the DPPH scavenging assay were 0.562–10.090 mg/mL and 0.072–0.208 mg/mL, and the Trolox equivalent antioxidant capacity values were 6.789–58.335 mmole Trolox/g and 133.039–335.779 mmole Trolox/g, respectively. Mustaffa et al. [11] reported that methanolic extract of *C. iners* bark showed high effective scavenging activity with IC50 value of 0.02 mg/mL. The antioxidant activity at maximum concentration (2.0 mgmL) was found to be 84.33%. *Cinnamomum tamala* was reported with potential antioxidant activities in diabetic rats [55], while C. *osmophloeum* showed significant in vitro and in vivo antioxidant activities under oxidative stress [189].

Pandey and Chandra [190] evaluated the antioxidant activity of aqueous and ethanol extracts of *C. verum* leaf galls. The ethanol extracts of leaf galls showed high antioxidant and analgesic activity. The aqueous and ethanol extract possessed equal capacity of antioxidants to inhibit free radicals (IC50 = 13.3 and 13.53 μg/ml) but was less for ascorbic acid with IC50 = 9.96 μg/ml. Ethanol extract was more effective in scavenging superoxide radicals compared to ascorbic acid. For

analgesic activity, maximum time required for response against thermal stimuli was observed in ethanol extract and maximum % of writhing inhibition (44.57%) when compared to aqueous extract. Chua et al. [191] reported the antioxidant activity of *C. osmophloeum* ethanolic extracts from the twigs of *C. osmophloeum*. BuOH fraction exhibited the best performance and consequently, kaempferol-7-O-rhamnoside was also isolated and its activity was confirmed.

Chakraborty and Das [192] evaluated the antihyperglycemic activity of *C. tamala* leaf aqueous extracts. Quantification of antioxidants of the leaves – phenols, ascorbate, and carotenoids – revealed that *C. tamala* leaves had high antioxidants. Anis et al. [193] investigated the antioxidant activity of extracts from *C. iners* wood. The ethanol extract showed EC50 value of 14.96 μg/mL with the highest antioxidant activity followed by chloroform extract with EC50 > 30 μg/mL. No activity was observed in water extract. Park et al. [194] evaluated the antioxidant activity of *C. verum* extract by supercritical fluid extracts and Marc methanol extracts. Higher antioxidant activities were observed in DPPH and ABTS radical scavenging assay. Srinivasa et al. [195] reported that *C. aromaticum* showed significant antioxidant activity and was used as a natural antioxidant agent. Abeysekera et al. [196] reported that *C. zeylanicum* ethanolic extracts of both leaf and bark had significantly high antioxidant activity. Abdelwahab et al. [138] reported that *C. altissimum* bark extract displayed antioxidant activities with IC50 value of 38.5 ± 4.72 μg/ml using DPPH assay and 345.2 ± 14.8 (μM Fe (II)/g dry mass) using FRAP assay.

Salleh et al. [197] reported the antioxidant and anticholinesterase activity of *C. griffithii* and *C. macrocarpum* essential oil. The bark oil of *C. griffithii* exhibits IC50 value of 73.4 μg/mL on DPPH assay, while the leaf oil showed inhibition value of 65.5 μg/mL. *Cinnamomum macrocarpum* bark oil exhibits inhibition values of 55.8% and 66.1% at 1 mg/mL concentration. Udayaprakash et al. [117] conducted antioxidant studies on *C. iners* methanolic leaf extract. DPPH free radical scavenging activity of methanolic leaf extract recorded an IC50 value at the concentration of 15 g/ml. ABTS assay (99.36%) showed maximum inhibition followed by TBA (95.39%) and FTC (81.37%). Brodowska et al. [198] carried out the antioxidant activity of *C. cassia* essential oils. Lower IC50 value was observed in DPPH and ABTS assay (IC50 = 42.03 μg/L and IC50 = 5.13 μg/L) for cinnamon extracts and indicates higher radical scavenging activity. Extracts were found to be better radical scavenger than essential oils with IC50 values of 64.51 μg/L (ABTS) and147.23 μg/L (DPPH).

Valizadeh et al. [170] conducted an antioxidant study on *C. zeylanicum* barks and leaves by DPPH assay. Free radical scavenging activity was found to be increased by increasing *C. zeylanicum* essential oil concentration. The concentration of CEO resulting in 50% inhibition of the free radical (IC50) was 79.54 μg/mL. Ervina et al. [199] reported that the *C. zeylanicum* bark infusion showed the highest antioxidant activity with an IC50 value of 3.03 followed by ethanolic extract and its water and ethyl acetate fractions with IC50 values of 8.36, 8.89, and 13.51 μg/mL, respectively. Fu et al. [200] reported antioxidative effect in diet-induced obese rats by seed kernel oil of *C. camphora*. Liu et al. [201] reported that ferric scavenging activity test on *C. longipaniculatum* leaves displayed a higher reducing activity of

proanthocyanidins compared to vitamin C and BHT but lower than BHA by ferric scavenging activity test. Potassium ferricyanide reduction method confirmed a higher antioxidant activity than BHA (0.094 mg/mL), vitamin C (0.125 mg/mL), and BHT (0.125 mg/mL) when the proanthocyanidin concentration was 0.156 mg/mL.

Liu et al. [202] evaluated the antioxidative activity of the flavonoids isolated from *C. camphora* leaves. The flavonoids exhibited DPPH free radical scavenging activity similar to the positive control of vitamin C with increasing concentration. The reducing ability also increased significantly with the increase of concentration and was very close to vitamin C, BHA, and BHT. Kallel et al. [203] reported high cytotoxicity cell line effect in *C. zeylanicum* essential oil. In vitro cytotoxicity was examined using an MTT assay against HeLa and Raji cell lines. The essential oil inhibited the proliferation of HeLa and Raji cell lines and showed IC50 values of 0.57 μg/mL and 0.13 μg/mL. Priani et al. [204] reported that strong antioxidant activity with IC50 value of 10.04 ± 0.08 ppm was observed in the bark of *C. burmannii*. A peel-off mask which significantly exhibits potent antioxidant effects (IC50 = 47.31 ± 1.47 ppm) was formulated. Ribeiro et al. [205] reported the antioxidant activity of leaf and stem of *C. zeylanicum* by using DPPH method. The inhibition percentage for the leaves was 59.17 ± 0.11% and for the stem was 61.34 ± 0.11%.

Raksha et al. [206] conducted an antioxidant activity on *C. tamala* leaf extracts by DPPH free radical assay and observed significant antioxidant activity. The hydroalcoholic leaf extract at a 100 μm/ml concentration exhibited inhibition activity of about 96.99 ± 0.99%. Singh et al. [207] reported the antioxidant and antidiabetic effect of *C. cassia* bark methanolic extracts. In acute toxicity testing, up to 2000 mg/kg methanolic extracts did not show any significant toxic signs; hence, the antidiabetic activity was carried out at 125, 250, and 500 mg/kg dose levels. The diabetic animals showed significant increases in the levels of total cholesterol (TC), very-low-density lipoprotein, and TC/high-density lipoprotein radio compared with that of normal control and also the extracts prevent STZ-induced hyperlipidemia. In the histopathological analysis, sections from the liver, pancreas, and kidney of the diabetic animals and the animals treated with MECC 500 mg/kg showed mid-to-moderate toxic effects.

3.3 Anti-inflammatory and Anticancer Activity of Phytocompounds of Cinnamomum *spp.*

Chao et al. [208] evaluated the anti-inflammatory activity of *C. osmophloeum* leaf essential oil and reported that the essential oil has higher potential to inhibit proIL-1â protein expression induced by LPS-treated J774A.1 murine macrophage. Essential oil clearly inhibited proIL-1â protein expression at a dosage of 60 μg/mL. A dose of 60 μg/mL effectively inhibits IL-1â and IL-6 production but not for TNF-R. Maridass and Ghanthikumar [138] carried out the anti-inflammatory activity of ethanol extracts of *C. keralaense* bark extract in albino rats using

carrageenan-induced experimental model of inflammation. The volume of inflammation was significantly reduced by a maximum dose of 400 mg/kg. Joshi et al. [51] investigated the anti-inflammatory activity of *C. zeylanicum* bark extract. Ethanol extract of *C. zeylanicum* suppressed intracellular release of TNF in murine neutrophils as well as leukocytes in pleural fluid. The extract at 20 μg/ml concentration inhibits TNF gene expression in LPS-stimulated human PBMCs.

Liao et al. [210] investigated the anti-inflammatory effects of different constituents of *C. cassia* such as cinnamic acid, cinnamic alcohol, cinnamic aldehyde, and coumarin using lipopolysaccharide (LPS)-stimulated mouse macrophage and carrageenan (Carr)-induced mouse paw edema model. A significant concentration-dependent inhibition of nitric oxide (NO) and prostaglandin E2 (PGE2) tumor necrosis factor (TNF-α) levels were detected when macrophages were treated with cinnamic aldehyde together with LPS. After Carr injection, cinnamic aldehyde attenuated myeloperoxidase (MPO) activity and the malondialdehyde (MDA) level in the edema paw also decreases the NO, TNF-α, and PGE2 levels on the serum level. Cinnamic aldehyde showed excellent anti-inflammatory activities.

Hossain et al. [211] evaluated the anti-inflammatory activity of *C. tamala* leaf ethanolic extract using carrageenan- and histamine-induced rat paw edema test at 200 and 400 mg/kg body weight. At the dose of 400 mg/kg body weight, the extract showed a significant anti-inflammatory activity both in the carrageenan- and histamine-induced edema test models in rats showing 60.84% and 59.48% reduction in the paw volume comparable ($P < 0.01$) to that produced by indomethacin (63.63% and 66.01%) at 4 h. At 400 mg/kg body weight, the inhibition percentage of edema paw volume was statistically significant ($P < 0.05$; $P < 0.01$). Ho et al. (2013) [215] reported that cinnamon has potential therapeutic effect against neurodegenerative diseases and its potent anti-neuroinflammatory capacity. Cinnamaldehyde had the greatest anti-neuroinflammatory capacity.

Han and Parker [212] reported that essential oil from *C. zeylanicum* bark showed strong antiproliferative effects on skin cells and significantly inhibited the production of several inflammatory biomarkers, including intercellular cell adhesion molecule-1, monocyte chemoattractant protein-1, interferon-inducible T-cell alpha chemoattractant, vascular cell adhesion molecule-1, interferon gamma-induced protein 10, and monokine induced by gamma interferon. Prajapati et al. [213] carried out the anti-inflammatory activity of *C. zeylanicum* oil by using carrageenan-induced paw edema model. The highest anti-inflammatory activity (30.58%) was observed at 3-hour of post-oral administration at the dose of 200 mg/kg. Budiastuti et al. [214] conducted an anti-inflammatory activity on *C. burmannii* bark essential oil using paw test in Wistar rats. A significant increase was observed in the inhibition of edema in the administration of CBOK compared to the negative control. A number of inflammatory cells and TNF-α expression were also observed to be decreased.

Du et al. [215] evaluated the anti-inflammatory activity of *C. longepaniculatum* essential oil using three experimental models such as carrageenan-induced paw edema in rat and acetic acid-induced vascular permeability and dimethyl benzene-induced ear edema in mice. The inflammation was significantly inhibited in the

dose-dependent manner. A dose-dependent reduction of the connective tissue injury and infiltration of inflammatory cell and paw thickness were observed. Bhagavathy and Latha [216] studied the cytotoxic effect of *C. verum* ethanol extract tested with HL60 leukemia cell lines. Cell lines were free from any kind of bacterial and fungal contaminations. Plate 1 indicates dead cells and their cellular uptake of the dye which appear as blue in color. In MTT assay cell death and cell viability of leukemia cell line of anticancer activity was estimated. The results showed 84.1% cell viability in the concentration of 1 mg/ml. The IC50 of cell viability was observed at the concentration of 127 μg/ml of the ethanol extract. Al-Zereini et al. [217] reported the cytotoxic activity of *C. verum* barks. The cytotoxic activity was evaluated against the MDA-MB-231 breast cancer cell line. Both EOs showed cytotoxic activity against the breast cancer cell line with IC50 value of 0.14–0.46 μL/mL.

3.4 Wound Healing Activity of Phytocompounds of Cinnamomum *spp.*

Kamath et al. [218] evaluated the wound healing activity of *C. zeylanicum* bark ethanolic extract in Wistar rats. The extract at doses of 250 mg/kg and 500 mg/kg body weight significantly enhance the wound breaking strength, of wound contraction and epithelialization period. In the dead space wound, the granulation tissue weight, hydroxyproline content, and breaking strength were also increased by the extract. Soni et al. [219] reported that active extract from ethanolic extract of *C. tamala* leaves was responsible for the wound healing activity in diabetic Wistar albino rats. Both the wound area and day of epithelialization were significantly decreased in the excision wound model. Significantly higher tensile strength was observed in the rats treated orally with ethanolic extract treated in incision wound model. Weights of wet and dry granulation tissue also increase with increased amounts of hydroxyproline, elastin, and collagen.

Narkhede et al. [220] reported the wound healing activity of *C. zeylanicum* and *C. tamala* in Sprague Dawley rats. The time taken for complete epithelialization and wound contraction was significantly less than the control. The mean tensile strength was significantly greater after 16 days. Methanolic extract showed better granulation tissues, better tensile strength, and early and complete epithelialization. Deepa et al. [221] reported that the hydroalcoholic extract of *C. nitidum* stem bark showed dose-dependent percentage wound healing. Significant wound contraction and high degree of tensile strength were observed in treated animals as compared with the control. Hydroxyproline level was found to be significantly increased in a dose-dependent manner.

Ahmadi et al. [222] evaluated the effects of an ointment prepared from *C. verum* essential oil in infected wound model. Topical administration of *C. verum* remarkably shortened the inflammatory phase, increased fibroblast distribution and collagen deposition, and accelerated the cellular proliferation, reepithelialization, and keratin synthesis. The mRNA levels of IGF-1, FGF-2, and VEGF were remarkably

higher in *C. verum*-treated groups (especially 2%) than in the control group. Topical administration of *C. verum* increased the antioxidant power and reduced the MDA content in comparison to control animals. *C. verum* accelerates wound healing by upregulating the IGF-1, FGF-2, and VEGF expression and increasing cell proliferation, collagen synthesis, and reepithelialization ratio.

Kefayat et al. [223] reported cinnamon extracts were incorporated into the bacterial cellulose membranes to prepare an all-natural wound dressing. The cinnamon extract membrane maintains appropriate moisture content for an acceptable period of time. Although the tensile strength and elongation at break values of the cinnamon extract were slightly lower than the BC membrane, they are still in ideal ranges. The cinnamon extract membrane exhibits significantly more antibacterial effects against *Staphylococcus aureus* and *Escherichia coli*, and they are also found to be more biocompatible with L929 normal skin fibroblast cells than with the bacterial cellulose and chitosan membranes.

4 Conclusion

Research on *Cinnamomum* genus promotes further development and utilization of new drugs by revealing the presence of several bioactive compounds and their biological potentialities. The present review reported several chemical and clinical studies carried out in 25 Indian species and also their major biological potentialities such as antimicrobial, antioxidant, anti-inflammatory, wound healing, and anticancer potentialities. The *Cinnamomum* genus contains approximately 250 species, but chemical studies are focused only on few species such as *C. verum*, *C. tamala*, *C. cassia*, *C. subavenium*, *C. camphora*, *C. kotoense*, *C. glanduliferum*, etc. The main studies on *Cinnamomum* are focused on essential oils. Major chemical compounds reported in *Cinnamomum* are cinnamaldehydes, linalool, eugenol, (E)-cinnamyl acetate, β-caryophyllene, benzyl benzoate, 1,8-cineole, and α-terpineol. Only a few attempts were made to isolate the bioactive constituents; hence, the research should be focused on widened isolation and evaluation of their pharmacological potentialities both in vitro and in vivo. Deep and systematic studies are still required to explore this medicinally promising genus.

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