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Review

# Traditional uses, phytochemistry and pharmacological activities of the genus *Cinnamomum* (Lauraceae): A review

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ABSTRACT

Species of *Cinnamomum* exhibit excellent economic and medicinal value, and have found use in traditional medicine, are consumed as a spice, as well as being cultivated as landscape plants. Investigations into the pharmacological activities of the genus *Cinnamomum* revealed that it manifested a wide range of pharmacological properties including antimicrobial, antioxidant, anti-inflammatory and analgesic, antitumor, anti-diabetic and anti-obesity, immunoregulation, insecticidal and acaricidal, cardiovascular protective, cytoprotective, as well as neuroprotective properties both *in vivo* and *in vitro*. In the past five years, approximately 306 chemical constituents have been separated and identified from the genus *Cinnamomum*, covering 111 terpenes, 44 phenylpropanoids, 51 lignans, 17 flavonoids, 53 aromatic compounds, 17 aliphatic compounds, four coumarins, two steroids. This article highlights the traditional uses, phytochemistry and pharmacological properties of the few studied taxa of *Cinnamomum* through searching for the pieces of literature both at home and abroad, which would provide a reference for the pharmaceutical research and clinical application of this genus.

## 1. Introduction

The genus *Cinnamomum*, first described in 1760, is subordinate to the family Lauraceae [1]. Together with the genus *Laurus* and *Persea*, *Cinnamomum* is known as the three most economically valuable genus in family Lauraceae. Approximately 250 species of the genus *Cinnamomum* are mainly distributed in tropical and subtropical Asia, Australia, Pacific islands, and other regions [2]. In China, nearly 50 species and two variants are found in Yunnan, Guangxi, Guangdong, Hubei, Sichuan and other provinces [2]. Species of the genus *Cinnamomum* are not only one of the most commonly used Chinese medicines in clinical practice but also the important condiments and landscape plants. In the past few decades, an increasing number of studies have been carried out on the phytochemistry and pharmacology of *Cinnamomum* taxa. Abundant chemicals have been isolated and identified from this genus, such as terpenes, phenylpropanoids, lignans, flavonoids, aromatic and aliphatic compounds, coumarins, alkaloids, steroids, *etc.* Modern pharmacological studies manifested that *Cinnamomum* taxa possessed various biological activities, including antimicrobial [3,4], antitumor [5], antioxidant [6], anti-diabetic [7], anti-inflammatory and analgesic activities [8,9] and other effects. In 2016, Zhao and Ma [10] presented a review of 127 phytochemicals and four biological activities of eleven *Cinnamomum* species over the period from 1980 to 2014. The chemical constituents and their structures were mainly discussed, but the pharmacological activities are rarely summarized. Later in 2019, Sanjay et al. [11] provided detailed information about history, traditional uses, phytochemistry and clinical impacts of 33 *Cinnamomum* species, but the chemical structures of most compounds were not displayed. Based on the above two studies, we compile the progress on phytochemical studies of about twelve species of the genus *Cinnamomum* that are wildly distributed in Asian countries over the past five years, with the elucidated structures listed. The traditional uses and biological characterizations of the extracts or components isolated from *Cinnamomum* are summarized as well. This paper intends to provide accurate data for the research on the chemical identification of the genus *Cinnamomum* and to lay a foundation for its further study and development.

## 2. Material and methods

An extensive literature search related to the twelve plants of the genus *Cinnamomum* was conducted on to gather all relevant information about the traditional uses, phytochemicals and pharmacological activities. Publicly accessible databases and primary sources were searched, including PubMed, CNKI, SciFinder, Web of Science, Science

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Direct, Wanfang Data, VIP, PhD and MSc dissertations, and so on. A large number of literature articles published from 2015 to 2019 were reviewed. Searching for regarding information on the genus *Cinnamomum* was carried out using Latin names of the twelve species, covering "*Cinnamomum cassia*", "*Cinnamomum camphora*", "*Cinnamomum chartophyllum*", "*Cinnamomum porrectum*", "*Cinnamomum subavenium*", "*Cinnamomum burmannii*", "*Cinnamomum longipaniculatum*", "*Cinnamomum verum*" , "*Cinnamomum Japonicum*", "*Cinnamomum Septentrionale*", "*Cinnamomum osmophloeum*", "*Cinnamomum tamala*". The extracted data included plant names, traditional uses, purified compounds, and pharmacological activities. Species names were validated using The Plant List (www.theplantlist.org). All chemical structures were drawn using ChemDraw 17.0 software.

## 3. Traditional uses

Analysis of the scientific literature suggested that species of the genus *Cinnamomum* are extensively used in local and traditional medicine for the treatment of a multitude of disorders, like indigestion, cold, cough and microbial infections. Among them, *C. cassia*, *C. verum*, and *C. tamala* are famous medicinal materials. Furthermore, *C. camphora* and *C. longipaniculatum* are used to extract camphor and camphor oil, which are important source of raw materials for spices, food, medicine, and chemical industry [12]. Some *Cinnamomum* species, such as *C. cassia*, *C. verum* and *C. tamala*, are consumed as a spice in cooking to add flavor [13]. Additionally, some plants of *Cinnamomum* genus are cultivated as landscape plants and sidewalk trees. A summary regarding the scientific names, common names, geographical distribution, and traditional uses of the twelve *Cinnamomum* species are given in Table 1.

## 4. Phytochemistry

In the past five years, a large number of scholars at home and abroad have drawn great attention to the genus *Cinnamomum*. Researches on the chemical constituents of twelve species with relatively abundant resources and wide geographical distribution have yielded substantial achievements. Our results show that a total of 306 compounds, which include 111 terpenes (**1**−**111**), 44 phenylpropanoids (**112–155**), 51 lignans (**156–206**), 17 flavonoids (**207–223**), 53 aromatic compounds (**224–276**), four coumarins (**277–280**), 17 aliphatic compounds (**281–297**), two steroids (**298–299**), and seven other constituents (**300–306**), have been isolated and identified from the roots, stems, twigs, leaves, buds and fruits of *Cinnamomum* plants. Among them, a total of 67 are new compounds obtained from *Cinnamomum* species. All compounds are summarized and compiled in Table 2, and their corresponding structures are detailed in Figs. 1∼9. (See Figs. 2–8.)

## 5. Pharmacology

### 5.1. Antimicrobial activity

Ethanol extracts of *C. cassia* species were investigated for their strong antibacterial and antifungal activities against *Escherichia coli*, *Bacillus subtilis*, *Staphylococcus aureus*, *Aspergillus niger*, *Penicillium*, and *beer yeast* in meat food, with the highest activity against *Penicillium*, which demonstrated an inhibition zone of 54.5 mm, and minimum inhibitory concentration (MIC) value of 0.4 mL/L [58]. The authors concluded that *C. cassia* had a broad-spectrum bacteriostatic effect, however, the isolation and identification of antibacterial constituents from *C. cassia* ethanol extracts still need further study. Zhong et al. [59] found that the total polyphenols in the non-volatile parts of *C. cassia* branches and leaves exhibited antibacterial activity *in vitro* against Gram-positive (*Staphylococcus aureus* and *Streptococcus pneumoniae*) and Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) bacteria. Other studies [60–63] have shown that *C. cassia* essential oil, whose major components were cinnamaldehyde (**120**) (86.07%), cinnamic acid (**130**) (11.04%) and benzaldehyde (1.28%), manifested remarkable antibacterial activity against *Propionibacterium acnes*, *Staphylococcus hyicus*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*. Based on the findings of the antifungal activity, Liu et al. [64] found that *C. cassia* extracts exhibited notable antifungal potential towards *Penicillium italicum* and *Penicillium digitatum* under the optimal extracting conditions (ethanol concentration is 90%, extraction temperature is 30 °C, extraction time is 0.5 h, and the solid-liquid ratio is 1:26) *via* suppressing the germination of pathogenic spores, destroying the cell membrane structure of the bacteria as well as affecting the healthy growth and development of fungi mycelium. Additionally, Lu et al. [65] studied the antifungal effects of acetone extracts of *C. cassia* against five kinds of plant pathogenic germ including *Alternaria solani*, *Alternaria alternata*, *Fusarium decemcellulare*, *Botrytis cinerea*, and *Colletotrichum glycines* with the half-maximal effective concentration ($EC_{50}$) of 45.68 mg/L, 50.13 mg/L, 91.09 mg/L, 86.59 mg/L, 105.09 mg/L respectively. The result indicated that acetone extracts of *C. cassia* were the most sensitive to *Alternaria solani*. Also, the antifungal effects might attribute to the presence of cinnamaldehyde (**120**).

The bactericidal property of chlorophylls extracted from *C. camphora* leaves was studied against Gram-positive bacteria represented by *Staphylococcus aureus*[66]. The experimental data showed that the optimum inhibitory concentration was 10 mmol/L while the optimum treatment time was 25 min in the NaCl-water system (pH = 7.0). Furthermore, Hu et al. [67] reported that the water extract of *C. camphora* leaves has a positive effect on two kinds of wood fungi (*Phanerochaete chrysosporium*, *Gloeophyllum trabeum*) and three kinds of wood moulds (*Penicillium purpurogenum*, *Trichoderma harzianum*, *Aspergillus funigatus*) with the concentration of 5%, one kind of wood stain fungus (*Botrydiplodia theobromae*) could also be suppressed when the concentration came to 10%. The authors pointed out that the antimicrobial property of the water extract might be related to the chemical compositions including D-campher (76.23%), 3-methyl-2-butenoic acid (8.63%), eucalptol (4.69%) and 1,6-octadien-3-ol (4.54%). In addition, the essential oil of *C. camphora* leaves from three origins (Guangxi, Jiangxi, and Anhui province) was determined by Wang et al. [68]. The antimicrobial assay suggested noticeable inhibitory activities of *C. camphora* leaves produced in Guangxi province against plant pathogenic fungi such as *Colletotrichum gloeosporioides*, *Botrytis cinerea*, and *Fusarium graminearum* with the half-maximal inhibitory concentration ($IC_{50}$) values of 31.74, 35.79 and 38.02 mg/L (after 48 h of treatment) respectively. Therefore, using *C. camphora* leaf essential oil as preservatives of fruits and vegetables is expected to achieve good application prospects. The essential oil of *C. camphora* leaves also demonstrated different degrees of antibacterial effect towards the tested bacteria, and stronger inhibitory capacity on Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) than Gram-positive (*Staphylococcus aureus*, *Bacillus subtilis*) bacteria [69]. Subsequently, Wu et al. [70] investigated the mechanism of antibacterial activity of essential oil from *C. camphora* var. linaloofera Fujita (EOL) at vapor phase against *Escherichia coli*. The authors revealed that the main antibacterial component of the vapor-phase EOL was linalool, and vapor-phase EOL treatment affected the average growth and the physiological metabolism of the *E. coli via* making the bacterial cell membrane rupture, increasing permeability of the bacterial cell, leaking intracellular substance, and alternating the protein structure.

The suppression activity of *C. porrectum* essential oil was confirmed against aflatoxigenic strains covering *A. flavus* IMI 242684 and *A. parasiticus* IMI 283883 by contact and vapor treatments at a concentration greater than 200 ppm [71]. The authors revealed the complete fungistatic activity against both Aspergillus strains with the number of essential oils at 1000 ppm. Furthermore, at 600 and 1000 ppm essential oil completely suppressed the sporulation of both Aspergillus strains. Additionally, the authors concluded that the *C.*

**Table 1**
Traditional uses of the genus *Cinnamomum*.

| Scientific name | Common name | Distribution | Traditional uses |
|---|---|---|---|
| *Cinnamomum cassia* (L.) J.Presl | *Cinnamomum aromaticum* Nees<br>Chinese cinnamon<br>Chinese cassia | China, India, Vietnam, Indonesia, Laos | The leaves are used to treat headache, chills, abdominal pain, dysentery, vomiting, cold stomachache, chest tightness, diarrhea, frostbite, and cough [14]. The twigs are used to treat blood circulation disturbances, diabetes, dyspepsia, and gastritis [15]. The stem barks are used to treat tussis, gastrointestinal neurosis, diarrhea, amenorrhea, dysmenorrhea, impotency, arthralgia, edema, and cardiac palpitation [16]. The buds are used to treat cardiothoracic pains, cold pain in the stomach and abdomen, nausea, vomiting, belch, hiccup, cough, and dyspnea and deficiency [17]. |
| *Cinnamomum camphora* (L.) J.Presl | Camphor tree | Japan, Vietnam, Korea, China, India, Mongolia, Australia | Treating rheumatism, sprains, bronchitis, asthma, indigestion, muscle pains, diarrhea, menstrual disorders, colds and chills [18,19]. |
| *Cinnamomum chartophyllum*H.W.Li | – | China | – |
| *Cinnamomum porrectum* (Roxb.) Kosterm. | *Cinnamomum parthenoxylon* (Jack) Meisn.<br>*Cinnamomum inunctum* (Nees) Meisn. | China, Pakistan, India, Southern Thailand, through Malaysia to Indonesia | Treating colds, rheumatic arthritis, abdominal pain, diarrhea, asthma, fever, headache, malaria, and menstrual disorders [20,21]. |
| *Cinnamomum subavenium* Miq. | *Cinnamomum randaiense* Hayata | China, Malaysia, Indonesia, Cambodia, Burma, Vietnam, North Thailand, India, Laos, Myanmar | Treating stomachache, chest pain, abdominal pain, carcinomatous swelling, hernia, diarrhea, rheumatism, nausea, and vomiting (peel, fruits, and leaves) [22]. |
| *Cinnamomum burmanni* (Nees & T. Nees) Blume | Indonesian cinnamon<br>Indonesian cassia<br>Java cinnamon | Southeast Asia | Treating cold stomachache, abdominal pain, diarrhea, anorexia, lumbago and leg pain, bruise and injury, trauma and bleeding, sore boil, as well as swollen poison [23]. |
| *Cinnamomum longipaniculatum* (Gamble) N.Chao ex H.W.Li | – | China | The volatile oil of leaves is used as a source of raw materials for spices, food and medicine [12]. |
| *Cinnamomum verum* J.Presl | *Cinnamomum zeylanicum* Blume<br>Ceylon cinnamon<br>Sri Lankan cinnamon<br>True cinnamon | Sri Lanka, India | Consumed as spices [13]. Treating indigestion, diabetes, acne, indigestion, respiratory and urinary troubles [24]. The bark essential oil is used for soothe aching joints and numb pain [25]. |
| *Cinnamomum japonicum* Siebold | *Cinnamomum pedunculatum* Nees | Northern Korea, Japan, Southern China | Treating stomachache, abdominal pain, and rheumatic arthritis [26]. |
| *Cinnamomum septentrionale* Hand.-Mazz. | – | China | Used as analgesic in medicine [27]. |
| *Cinnamomum osmophloeum* Kaneh. | Indigenous Cinnamon | Taiwan | Treating inflammation, intestinal infections, astringent, diuretic and diabetic complications (leaves) [28]. |
| *Cinnamomum tamala* (Buch.-Ham.) T.Nees & Eberm. | Indian Cassia | India, Nepal, Bhutan, China | Used as spices, carminative, anthelmintic, and diuretic (leaves) [29]. Treating rheumatism, colic, diarrhea, nausea, vomiting, dyspepsia, fever, anemia, body odor (leaves and barks), dysentery, and cough (seeds) [7]. |

*porrectum* essential oil was an effective biocontrol agent against aflatoxigenic strains contaminated in human food, animal feed, and other agricultural products.

Chairunnisa et al. [72] demonstrated that the gas compounds of *C. burmannii* essential oil including *trans*-cinnamaldehyde (56.10%), 1,8-cineole (16.53%), *α*-pinene (3.44%) and *α*-terpineol (3.05%) played an essential role in suppressing the *Escherichia coli* and *Staphylococcus aureus*, produced MID values of 12.5 μL/L and 6.26 μL/L respectively, that showed it was more effective for Gram-positive bacteria than Gram-negative bacteria. However, the authors discussed the results of only presenting the MIC values instead of the disc diffusion method measured by the diameter of inhibition zones.

Two solvent extracts (*n*-butane and ethanol) of four *Cinnamomum* species covering *C. cassia*, *C. loureiroi*, *C. wilsonii*, and *C. burmannii* were investigated for their antibacterial (against *Listeria monocytogenes*, *Staphylococcus aureus*, *Escherichia coli*, and *Salmonella anatum*) [73]. Different extracts demonstrated noticeable antibacterial activity towards the tested bacteria that *n*-butane extracts were much more sensitive than ethanol extracts; the inhibition zone and the minimum bactericidal concentrations for *n*-butane extracts against tested strains ranged from 18.98 to 37.45 mm, and from 0.31 to 2.50 mg/ml respectively while for ethanol extracts from 7.11 to 10.11 mm, and 20.00 to 160.00 mg/ml respectively. Moreover, it was also found that the *n*-butane extracts of *C. cassia* and *C. loureiroi* had much higher antibacterial activity than *C. wilsonii* and *C. burmannii*.

Cong et al. [74] indicated the presence of a particular antimicrobial activity of *C. longipaniculatum* leaf essential oil against 15 kinds of tested strain such as *Bicillus subilis*, *Staphylococcus aureus*, *Salmonella typhimurium* and *Sarcina lutea* et al., that has a broad-spectrum antimicrobial property. However, the compounds responsible for the antimicrobial activity were not mentioned.

The antifungal property of *C. zeylanicum* leaves essential oil against *Candida* spp. was determined by Rangel et al. [75]. The result showed the MIC, and minimal fungicidal concentration (MFC) values ranged from 62.5 to 1000 μg/mL. Moreover, the authors suggested that the antifungal effect might attribute to the presence of eugenol (**112**) (68.96%). Subsequently, Wang et al. [76] studied the antibacterial effects of *C. zeylanicum* bark essential oil and its main component cinnamaldehyde (**120**) (57.97%) on *Porphyromonas gingivalis* with the MIC values of 6.25 μg/mL and 2.5 μM respectively, showing cinnamaldehyde was active component responsible for the inhibitory action against *P. gingivalis*. In addition, the antimicrobial mechanism of *C. zeylanicum* essential oil was to interfere with biofilm integrity.

From the above-mentioned results, we came to the conclusion that the genus *Cinnamomum* demonstrated significant antimicrobial potential, however, these published reports focused only on the killing effects, with little research on the mechanisms involved. Additionally, only a few compounds have been identified as active ingredients responsible for the antimicrobial effects.

**Table 2**
List of chemical compounds of *Cinnamomum* taxa studied in this article.

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **Diterpenes** | | | | |
| **1** | Anhydrocinnzeylanol | *C. cassia* | Bark | [30,31] |
| **2** | Anhydrocinnzeylanine | *C. cassia* | Bark | [30,31] |
| **3*** | Epianhydrocinnzeylanol | *C. cassia* | Bark | [31] |
| **4** | Cinncassiol A | *C. cassia* | Bark | [31] |
| **5** | Cinnzeylanol | *C. cassia* | Bark, Leaves | [14,30,31] |
| **6** | Cinnzeylanine | *C. cassia* | Bark | [30,31] |
| **7** | Cinnzeylanone | *C. cassia* | Bark | [30] |
| **8*** | (18*S*)-Cinncassiol $D_1$ | *C. cassia* | Leaves | [14] |
| **9*** | (18*S*)-1-Hydroxycinncassiol $D_1$ | *C. cassia* | Leaves | [14] |
| **10*** | (18*R*)-1-Hydroxycinncassiol $D_1$ | *C. cassia* | Leaves | [14] |
| **11*** | 19-Dehydroxy-13-hydroxycinncassiol $D_1$ | *C. cassia* | Leaves | [14] |
| **12*** | (18*S*)-Cinncassiol $D_3$ | *C. cassia* | Leaves | [14] |
| **13*** | (18*S*)-3-Dehydroxycinncassiol $D_3$ | *C. cassia* | Leaves | [14] |
| **14*** | (18*S*)-3-Dehydroxycinncassiol $D_3$ glucoside | *C. cassia* | Leaves | [14] |
| **15*** | (18*S*)-3,5-Didehydroxy-1,8-dihydroxycinncassiol $D_3$ | *C. cassia* | Leaves | [14] |
| **16*** | (18*S*)-3-Dehydroxy-8-hydroxycinncassiol $D_3$ | *C. cassia* | Leaves | [14] |
| **17** | Perseanol | *C. cassia* | Leaves | [32] |
| **18*** | 16-*O*-*β*-D-glucopyranosyl-perseanol | *C. cassia* | Leaves | [14] |
| **19** | 18-Hydroxyperseanol | *C. cassia* | Buds | [17] |
| **20*** | (*E*)-3-Dehydroxy-13(18)-ene-19-*O*-*β*-D-glucopyranyl-cinncassia $D_3$ | *C. cassia* | Leaves | [14] |
| **21*** | Cinncassiol C | *C. cassia* | Leaves | [14] |
| **22*** | Cinncassiol D | *C. cassia* | Leaves | [14] |
| **23*** | Cinnamomol E | *C. cassia* | Leaves | [14] |
| **24*** | Cinnamomol F | *C. cassia* | Leaves | [14] |
| **25*** | Cinnamomol F 13-*O*-*β*-D-glucopyranosyl | *C. cassia* | Leaves | [14] |
| **26*** | Cinnacasiol H | *C. cassia* | Bark | [31] |
| **27*** | Cinnamomol A | *C. cassia* | Leaves | [32] |
| **28*** | Cinnamomol B | *C. cassia* | Leaves | [32] |
| **29*** | Cassiabudanol A | *C. cassia* | Buds | [17] |
| **30*** | Cassiabudanol B | *C. cassia* | Buds | [17] |
| **Sesquiterpenes** | | | | |
| **31** | Caryolane-1,9*β*-diol | *C. cassia* | Bark, Buds | [30,33] |
| **32** | Clovane-2*β*,9*α*-diol | *C. cassia* | Bark | [30] |
| **33*** | Cinnamoid D | *C. cassia* | Bark | [30] |
| **34** | Cinnamoid E | *C. cassia* | Bark | [30] |
| **35** | Mustakone | *C. cassia* | Bark | [30] |
| **36** | 4(15)-Eudesmene-1*β*,7,11-triol | *C. cassia* | Buds | [33] |
| **37** | 1*β*,6*α*-Dihydroxyeudesm-4(15)-ene | *C. cassia* | Buds | [33] |
| **38*** | 1*α*,6*β*-Dihydroxy-5,10-bis-epi-eudesm-15-carboxaldehyde-6-*O*-*β*-D-Glucopyranoside | *C. subavenium* | Leaves | [34] |
| **39** | 1*β*,4*β*,11-Trihydroxyl-6*β*-gorgonane | *C. cassia* | Buds | [33] |
| **40** | *β*-Eudesmol | *C. longipaniculatum* | Leaves | [35] |
| **41*** | Cinnamosim B | *C. cassia* | Buds | [33] |
| **42** | (−)-15-Hydroxy-T-muurolol | *C. cassia* | Bark | [30] |
| **43** | 15-Hydroxy-*α*-cadinol | *C. cassia* | Bark | [30] |
| **44** | (4*α*,10*β*)-4,10-Dihydroxy cadin-1(6)-en-5-one | *C. cassia* | Bark | [30] |
| **45*** | Cinnamoid B | *C. cassia* | Bark | [30] |
| **46*** | Cinnamoid C | *C. cassia* | Bark | [30] |
| **47*** | Cinnamoid A | *C. cassia* | Bark | [30] |
| **48** | 1*β*,7-Dihydroxyl opposit-4(15)-ene | *C. cassia* | Buds | [33] |
| **49** | 1*β*,11-Dihydroxyl opposit-4(15)-ene | *C. cassia* | Buds | [33] |
| **50*** | Cinnamosim A | *C. cassia* | Buds | [33] |
| **51** | Aromadendrane-4*β*,10*α*-diol | *C. cassia* | Bark, Buds | [30,33] |
| **52** | Aromadendrane-4*α*,10*α*-diol | *C. cassia* | Buds | [33] |
| **53** | 1-Epimeraromadendrane-4*β*,10*α*-diol | *C. cassia* | Buds | [33] |
| **54** | 4*α*-10*α*-Dihydroxy-5*β*-H-guaja-6-ene | *C. cassia* | Buds | [33] |
| **55** | Guaiol | *C. japonicum* | Leaves | [36] |
| **56** | Caryophyllene oxide | *C. osmophloeum* | Leaves | [8] |
| | | *C. subavenium* | Bark | [37] |
| **57** | *cis*-Caryophyllene | *C. longipaniculatum* | Leaves | [35] |
| | | *C. japonicum* | | [36] |
| | | *C. tamala* | | [38] |
| **58** | Wilsonol G | *C. subavenium* | Leaves | [34] |
| **59** | (3*S*,5*R*,6*S*,7*E*,9*R*)-7-Megastigmene-3,6,9-triol | *C. cassia* | Leaves | [14] |
| **60** | (3*S*,5*R*,6*S*,9*S*)-3,6,9-Trihydroxy megastigman-7-ene 3-*O*-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **61** | Wilsonol H | *C. subavenium* | Leaves | [34] |
| **62** | (3*S*,5*R*,6*S*,7*E*)-Megasfigma-7-ene-3,5,6,9-tetrol | *C. subavenium* | Leaves | [34] |
| **63** | (3*S*,5*R*,6*R*,7*E*,9*S*)-3,5,6,9-Tetrahydroxy-7-ene-megastigmane | *C. cassia* | Leaves | [14] |
| **64*** | (1*R*,2*R*)-4-[(3*S*)-3-Hydroxybutyl]-3,3,5-trimethylcyclohex-4-ene-1,2-diol | *C. cassia* | Leaves | [14] |

(*continued on next page*)

**Table 2** (*continued*)

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **65** | (1*R*,2*R*)-4-[(3*R*)-3-Hydroxybutyl]-3,3,5-trimethylcyclohex-4-ene-1,2-diol | *C. cassia* | Leaves | [14] |
| **66** | Megastigmen-9-one | *C. cassia* | Bark | [30] |
| **67** | Asicariside B1 | *C. subavenium* | Leaves | [34] |
| **68** | 2-Methyl-6-(*p*-tolyl) heptane-2,3-diol | *C. chartophyllum* | Aerial part | [40] |
| **69** | Litseachromolaevanes A | *C. cassia* | Bark | [20] |
| **70** | 1,10-seco-4ζ-Hydroxy-muurol-5-ene-1,10-diketone | *C. cassia* | Bark | [20,41] |
| **71** | γ- Elemene | *C. japonicum* | Leaves | [36] |
| **72** | (2*E*,9*E*)-6,7-*cis*-Dihydroxyhumulan-2,9-diene | *C. cassia* | Bark | [30] |
| **73** | *β*-Humulene | *C. longipaniculatum* | Leaves | [35] |
| **74** | 3*S*-(+)-9-Oxonerolidol | *C. chartophyllum* | Aerial part | [40] |
| | | *C. camphora* | | [42–44] |
| **Monoterpenes** | | | | |
| **75** | 3,7-Dimethyl-1-octene-3,6,7-triol | *C. cassia* | Buds | [39] |
| **76** | 3,7-Dimethyl-oct-1-en-3,6,7-triol-6-*O*-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **77** | (6*R*)-Geraniol-6,7-diol | *C. cassia* | Buds | [39] |
| **78** | Myrcene | *C. tamala* | Leaves | [38] |
| **79** | Linalool | *C. osmophloeum* | Leaves | [8] |
| **80** | Geranial | *C. septentrionale* | Leaves | [45] |
| **81** | *cis*-Citral | *C. septentrionale* | Leaves | [45] |
| **82** | Lavandulyl acetate | *C. longipaniculatum* | Leaves | [35] |
| **83** | 5*α*-Hydroxy-2-oxo-*p*-menth-6(1)-ene | *C. chartophyllum* | Aerial part | [40] |
| **84** | l-8-Hydroxycarvotanacetone | *C. chartophyllum* | Aerial part | [40] |
| **85** | (4*R*,6*R*)-6-Hydroxypiperitone | *C. chartophyllum* | Aerial part | [40] |
| **86** | (4*S*,6*R*)-6-Hydroxypiperitone | *C. chartophyllum* | Aerial part | [40] |
| **87** | (4*R*)-*p*-Menthama-1,2*α*,8-triol | *C. subavenium* | Leaves | [34] |
| **88** | (3*R*,4*R*)-*p*-Menth-1-ene-3,4-diol 3-*O*-*β*-D-glucopyranoside | *C. subavenium* | Leaves | [34] |
| **89** | (3*R*,4*S*,6*R*)-*p*-Menth-1-ene-3,6-diol 3-*O*-*β*-D-glucopyranoside | *C. subavenium* | Leaves | [34] |
| **90*** | (1*R*,2*R*,4*S*,6*S*)-4-(2-Hydroxypropan-2-yl)-1-methyl-7-oxabicyclo[4.1.0]heptan-2-ol | *C. cassia* | Leaves | [14] |
| **91*** | Dimethanol | *C. cassia* | Leaves | [14] |
| **92** | Carvacrol | *C. subavenium* | Bark | [37] |
| **93** | Thymol | *C. subavenium* | Bark | [37] |
| **94** | *α*-Phellandrene | *C. tamala* | Leaves | [38] |
| **95** | *β*-Phellandrene | *C. longipaniculatum* | Leaves | [35] |
| | | *C. tamala* | | [38] |
| **96** | Limonene | *C. osmophloeum* | Leaves | [8] |
| | | *C. tamala* | | [38] |
| **97** | *α*-Terpineol | *C. longipaniculatum* | Leaves | [35] |
| | | *C. japonicum* | | [36] |
| **98** | Terpinen-4-ol | *C. longipaniculatum* | Leaves | [35] |
| | | *C. japonicum* | | [36] |
| **99** | Terpinolene | *C. longipaniculatum* | Leaves | [35] |
| **100** | 4- Terpinenyl acetate | *C. longipaniculatum* | Leaves | [35] |
| **101** | *trans*-Linalool-3,6-oxide-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **102** | *α*-Pinene | *C. osmophloeum* | Leaves | [8] |
| | | *C. japonicum* | | [36] |
| | | *C. tamala* | | [38] |
| | | *C. septentrionale* | | [45] |
| **103** | Camphor | *C. osmophloeum* | Leaves | [8] |
| | | *C. septentrionale* | | [45] |
| **104** | Bornyl acetate | *C. osmophloeum* | Leaves | [8] |
| | | *C. japonicum* | | [36] |
| **105** | Borneol | *C. japonicum* | Leaves | [36] |
| **106** | 1,8-Cineole | *C. japonicum* | Leaves | [36] |
| | | *C. septentrionale* | | [45] |
| **107** | 3-Carene | *C. longipaniculatum* | Leaves | [35] |
| **108*** | 5-(2,3-Dihydroxy-3-methylbutyl)-4-hydroxy-4-methyldihydrofuran2(3*H*)-one | *C. porrectum* | Fruit | [21] |
| **109*** | 5-(2,3-Dihydroxy-3-methylbutyl)-4-methylfuran-2(5*H*)-one | *C. porrectum* | Fruit | [21] |
| **110*** | 8-Hydroxy-4,7,7-trimethyl-1,6-dioxaspiro[4.4]non-3-en-2-one | *C. porrectum* | Fruit | [21] |
| **111*** | 8-Hydroxy-4,7,7-trimethyl-1,6-dioxaspiro[4.4]non-3-en-2-one | *C. porrectum* | Fruit | [21] |
| **Phenylpropanoids** | | | | |
| **112** | Eugenol | *C. subavenium* | Bark | [37] |
| | | *C. tamala* | Leaves | [38] |
| | | *C. camphora* | Bark, Leaves | [43,44] |
| **113** | Methyleugenol | *C. subavenium* | Bark | [37] |
| **114** | Safrole | *C. subavenium* | Bark | [37] |

(*continued on next page*)

**Table 2** (*continued*)

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **115** | Estragole | *C. osmophloeum* | Leaves | [8] |
| **116** | Cinnamyl alcohol | *C. cassia* | Bark, Twig | [20,30] |
| **117** | 2-Hydroxy-cinnamyl alcohol | *C. cassia* | Twig | [46] |
| **118** | 3,4-Methylenedioxycinnamyl alcohol | *C. subavenium* | Bark | [37] |
| **119** | 3,4-Dimethoxycinnamyl alcohol | *C. subavenium* | Bark | [37] |
| **120** | Cinnamaldehyde | *C. cassia* | Bark, Twig | [20,30,46] |
| | | *C. verum* | Bark | [47] |
| **121** | 2-Methoxycinnamaldehyde | *C. verum* | Bark | [5] |
| | | *C. cassia* | Bark, Twig | [46] |
| **122** | 2-Hydroxycinnamaldehyde | *C. cassia* | Twig | [46] |
| **123** | Coniferaldehyde | *C. cassia* | Bark | [41] |
| **124** | Cassiferaldehyde | *C. cassia* | Bark | [41] |
| **125** | 2-Hydroxy-4-methoxyl-cinnamaldehyde | *C. cassia* | Bark | [48] |
| **126** | Sinapaldehyde | *C. cassia* | Bark | [20] |
| **127** | *trans*-4,5-Dimethoxy-3-hydroxycinnamaldehyde | *C. camphora* | Bark, Leaves | [43] |
| **128** | 3,4-Methylenedioxy cinnamaldehyde | *C. subavenium* | Bark | [37] |
| **129** | 3,4-Dimethoxy cinnamaldehyde | *C. subavenium* | Bark | [37] |
| **130** | Cinnamic acid | *C. cassia* | Bark, Twig, Buds | [20,30,39,41,46] [48] |
| **131** | 2-Methoxy-cinnamic acid | *C. cassia* | Bark | [41] |
| **132** | Methyl cinnamate | *C. subavenium* | Bark | [37] |
| **133** | Methyl *trans*-3-(3,4-dimethoxyphenyl)-3-propenoate | *C. subavenium* | Bark | [37] |
| **134** | Phenethyl (*E*)-3-[4-methoxyphenyl]-2-propenoate | *C. cassia* | Twig | [46] |
| **135** | D-threo-guaiacylglycerol 7-*O*-*β*-D-glucopyranoside | *C. subavenium* | Leaves | [34] |
| **136** | 1-(3,4-Dimethoxyphenyl)-1,2,3-propanetriol | *C. cassia* | Leaves | [14] |
| **137** | 1-(3,5-Dimethoxyphenyl)-1,2,3-propanetriol | *C. cassia* | Leaves | [14] |
| **138** | (7*S*,8*S*)-Syringoylglycerol | *C. cassia* | Leaves | [41] |
| **139** | 1-Phenyl-1,2,3-propanetriol | *C. cassia* | Bark | [41] |
| **140** | 1-Phenylpropane-1,3-diol | *C. cassia* | Bark | [41] |
| **141** | (+)-(1*S*,2*S*)-1-(3-Methoxy-4-hydroxyphenyl)-1,2,3-propanetril-2-*O*-*β*-D-glucopyroside | *C. cassia* | Leaves | [14] |
| **142*** | Cinnacassoside D | *C. cassia* | Bark | [49] |
| **143*** | Cinnamomulactone | *C. cassia* | Twig | [46] |
| **144*** | Cinncassin A | *C. cassia* | Bark | [49] |
| **145*** | Cinncassin $A_1$ | *C. cassia* | Twig | [50] |
| **146*** | Cinncassins $A_2$ | *C. cassia* | Twig | [50] |
| **147*** | Cinncassins $A_3$ | *C. cassia* | Twig | [50] |
| **148*** | Cinncassins $A_4$ | *C. cassia* | Twig | [50] |
| **149*** | Cinncassins $A_5$ | *C. cassia* | Twig | [50] |
| **150*** | Cinncassins $A_6$ | *C. cassia* | Twig | [50] |
| **151*** | Cinncassins $A_7$ | *C. cassia* | Twig | [50] |
| **152** | (+)-*erythro*-(7*R*,8*S*)-Guaiacylglycerol-8-vanillin ether | *C. cassia* | Bark | [49] |
| **153** | 2,3-Dihydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl)-1-propanone | *C. cassia* | Leaves, Bark | [14,41] |
| **154*** | Cinnacassin N | *C. cassia* | Twig | [50] |
| **155*** | Cinnacassin O | *C. cassia* | Twig | [50] |
| **Lignans** | | | | |
| **156** | (−)-Sesamin | *C. chartophyllum* | Aerial part | [40] |
| | | *C. subavenium* | Bark | [37] |
| | | *C. camphora* | Aerial part | [43,44,51] |
| **157*** | 4,3′-Dihydroxy-4′-methoxysesamin | *C. camphora* | Leaves | [42] |
| **158** | (+)-Syringaresinol | *C. cassia* | Bark, Twig | [20,41,46,49] |
| **159** | Pinoresinol | *C. cassia* | Bark | [20] |
| | | *C. camphora* | Aerial part | [44] |
| **160** | Piperitol | *C. chartophyllum* | Aerial part | [40] |
| | | *C. camphora* | | [43,44] |
| **161** | (7α,7'α,8α,8'α)-3,7-Hydroxy-4-methoxy-3′,4′-methylenedioxy lignane | *C. camphora* | Bark, Leaves | [43] |
| **162** | (−)-Medioresinol | *C. camphora* | Bark, Leaves | [43] |
| **163** | Paulownin | *C. camphora* | Bark | [51] |
| **164** | Pinoresinol methyl ether | *C. camphora* | Aerial part | [44] |
| **165*** | Cinnacassin F | *C. cassia* | Twig | [50] |
| **166** | (7*α*,7'*β*,8*α*,8'*α*)-3-Methoxy-4-hydroxy-3′,4′-methylenedioxy-7,9:7,9-diepoxylignane | *C. camphora* | Bark, Leaves | [43] |
| **167** | (+)-Epipinoresinol | *C. camphora* | Bark, Leaves | [43] |
| **168** | (+)-Kusunokinin | *C. camphora* | Leaves | [42] |
| **169** | (+)-Bursehernin | *C. camphora* | Leaves | [42] |
| **170** | Dimethylmatairesinol | *C. camphora* | Leaves, Bark | [42,51] |
| **171** | (−)-4-*epi*-Lyoniresinol | *C. cassia* | Leaves | [52] |
| **172** | (6*R*,7*R*,8*R*)-7a-[(*β*-D-glucopyranosyl)oxy] lyoniresinol | *C. cassia* | Bark | [52] |
| **173** | (6*R*,7*S*,8*S*)-7a-[(*β*-D-glucopyranosyl)oxy] lyoniresinol | *C. cassia* | Bark | [52] |

(*continued on next page*)

**Table 2** (*continued*)

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **174** | (−)-Isolariciresinol | *C. cassia* | Bark | [41] |
| **175** | (6*S*,7*R*,8*R*)-7a-[(*β*-D-glucopyranosyl)oxy] lyoniresinol | *C. cassia* | Bark | [52] |
| **176** | (+)-Isolariciresinol | *C. cassia* | Bark | [49] |
| **177** | Polystachyol | *C. cassia* | Bark | [41] |
| **178** | Lariciresinol | *C. cassia* | Bark | [52] |
| **179** | 5′-Methoxylariciresinol | *C. cassia* | Bark | [49] |
| **180** | (+)-(7′*R*,8*R*,8′*R*)-5,5′-Dimethoxylariciresinol | *C. cassia* | Bark | [49] |
| **181** | (+)-(7′*S*,8*R*,8′*R*)-5,5′-Dimethoxylariciresinol | *C. cassia* | Bark | [49] |
| **182*** | Cinnacassins G | *C. cassia* | Twig | [50] |
| **183*** | Cinnacassins H | *C. cassia* | Twig | [50] |
| **184** | Magnolone | *C. camphora* | Bark, Leaves | [43] |
| **185** | (+)-Episesaminone | *C. camphora* | Aerial parts | [44] |
| **186** | Ciwujiatone | *C. cassia* | Bark | [41] |
| **187** | (−)-Secoisolariciresinol | *C. cassia* | Bark | [41,49] |
| **188** | (7*S*,8*R*)-Dihydrodehydrodi coniferyl alcohol 9'-*O*-*β*-D-apiofuranosyl-(1 → 6)-*O*-*β*-D-glucopyranoside | *C. cassia* | Bark | [52] |
| **189** | (−)-(7*S*,8*R*)-Dihydrodehydrodi conifery alcohol | *C. cassia* | Bark | [41,49] |
| **190*** | Cinncassins D | *C. cassia* | Bark | [49] |
| **191** | ( ± )-Subaveniumins A | *C. subavenium* | Bark | [53] |
| **192** | ( ± )-Subaveniumins B | *C. subavenium* | Bark | [53] |
| **193** | 1,2,3-Propanetriol,1-{4-[(1*R*,2*R*)-2-hydroxy-2-(4-hydroxy-3-methoxyphenyl)-1-(hydroxymethyl)ethoxy]-3-methoxyphenyl]-, (1*R*,2*R*)- | *C. cassia* | Bark | [52] |
| **194** | *threo*-1-(4-Hydroxy-3-methoxyphenyl)-2-{4-[(*E*)-3-hydroxy-1-propenyl]-2-methoxyphenoxy}-1,3-propanedoil | *C. cassia* | Bark | [41] |
| **195** | (*E*)-2-Hydroxy-phenylpropionic acid cinnamoyl ester | *C. cassia* | Bark | [48] |
| **196*** | Cinnacassin I | *C. cassia* | Twig | [50] |
| **197*** | Cinnacassin J | *C. cassia* | Twig | [50] |
| **198*** | Cinnacassin K | *C. cassia* | Twig | [50] |
| **199*** | Cinnacassin L | *C. cassia* | Twig | [50] |
| **200*** | Cinnacassin M | *C. cassia* | Twig | [50] |
| **201*** | Cinncassins E | *C. cassia* | Bark | [49] |
| **202** | (+)-*threo*-(7*S*,8*S*)-Guaiacylglycerol-*β*-coniferyl aldehyde ether | *C. cassia* | Bark | [49] |
| **203** | (+)-*erythro*-(7*S*,8*R*)-Guaiacylglycerol-*β*-coniferyl aldehyde ether | *C. cassia* | Bark | [49] |
| **204** | (−)-*erythro*-(7*R*,8*S*)-Guaiacylglycerol-*β*-*O*-4′-sinapoyl ether | *C. cassia* | Bark | [49] |
| **205** | (−)-*erythro*-(7*S*,8*R*)-Syringylglycerol-8-*O*-4′-(sinapoyl alcohol) ether | *C. cassia* | Bark | [49] |
| **206** | Picrasmalignan A | *C. cassia* | Bark | [49] |
| **Flavonoids** | | | | |
| **207** | 7,4′-Di-*O*-methyl-(+)-catechin | *C. cassia* | Bark | [41] |
| **208** | 5,7,3′-Tri-*O*-methyl-(−)-epicatechin | *C. cassia*<br>*C. camphora* | Bark | [42] |
| **209** | (−)-(2*R*,3*R*)-5,7-dimethoxy-3′,4′-methylenedioxy-flavan-3-ol | *C. chartophyllum*<br>*C. camphora*<br>*C. cassia* | Aerial part<br>Aerial part<br>Bark | [20,40]<br>[43,44]<br>[48] |
| **210** | (2*S*,3*S*)-3'-Hydroxy-5,7,4′-trimethoxy-flavan-3-ol | *C. camphora* | Aerial part | [43,44] |
| **211** | 3′, 4′-Dihydroxy-5,7-dimethoxy-flavan-3-ol | *C. camphora* | Leaves | [42] |
| **212** | Quercetin-3-*O*-*α*-L-rhamnoside | *C. porrectum* | Leaves | [20,54] |
| **213** | Kaempferol-3-*O*-*α*-L-rhamnoside | *C. porrectum* | Leaves | [20,54] |
| **214** | Kaempferol | *C. chartophyllum*<br>*C. cassia* | Aerial part<br>Bark | [40]<br>[20] |
| **215** | Quercetin | *C. chartophyllum*<br>*C. camphora* | Aerial part | [40]<br>[43,44] |
| **216** | Herbacetin | *C. porrectum* | Leaves | [54] |
| **217*** | Cinnamomoside A | *C. cassia* | Twig | [50] |
| **218** | 6,7,4′-Trimethoxyflavone | *C. camphora* | Aerial part | [43,44] |
| **219** | 3′,4′,5,7-Tetrahydroxyflavanone | *C. chartophyllum* | Aerial part | [40] |
| **220** | 5,7,4′-Trihydroxy-dihydroflavonol | *C. chartophyllum* | Aerial part | [40] |
| **221** | Dihydrokaempferol | *C. camphora* | Aerial part | [43,44] |
| **222** | Proanthocyanidin A | *C. verum* | Bark | [47] |
| **223** | Proanthocyanidin B | *C. verum* | Bark | [47] |
| **Aromatic compounds** | | | | |
| **224** | Syringaldehyde | *C. cassia*<br>*C. camphora* | Bark<br>Aerial part | [20,41]<br>[43,44] |

(*continued on next page*)

**Table 2** (*continued*)

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **225** | Vanillin | *C. cassia* | Bark | [20] |
| | | *C. subavenium* | Bark | [37] |
| | | *C. camphora* | Aerial part | [43,44] |
| **226** | Protocatechualdehyde | *C. cassia* | Bark | [20] |
| | | *C. camphora* | Aerial part | [43,44] |
| **227** | Isovanillin | *C. subavenium* | Bark | [37] |
| **228** | Veratraldehyde | *C. subavenium* | Bark | [37] |
| **229** | 4-Hydroxybenzaldehyde | *C. porrectum* | Leaves | [54] |
| **230** | Benzoic acid | *C. cassia* | Twig | [46] |
| **231** | Vanillic acid | *C. cassia* | Bark | [20] |
| | | *C. subavenium* | Bark | [37] |
| **232** | Protocatechuic acid | *C. cassia* | Bark | [20] |
| | | *C. chartophyllum* | Aerial part | [40] |
| | | *C. camphora* | Aerial part | [43,44] |
| **233** | Isovanillic acid | *C. cassia* | Bark | [20] |
| | | *C. chartophyllum* | Aerial part | [40] |
| **234** | *p*-Hydroxybenzoic acid | *C. cassia* | Bark | [20] |
| | | *C. camphora* | Aerial part | [43,44] |
| **235** | Syringic acid | *C. cassia* | Bark | [41] |
| **236** | Ethyl protocatechuate | *C. chartophyllum* | Aerial part | [40] |
| **237** | 5-Hydroxyethyl salicylate | *C. cassia* | Bark | [20] |
| | | *C. camphora* | Aerial part | [43,44] |
| **238** | Icariside DC | *C. cassia* | Twig, Buds | [39] |
| **239** | Styrene glycol | *C. cassia* | Bark | [41] |
| **240** | 2-Phenylethyl-*O*-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **241** | 2-*O*-*β*-D glucosyl-(1*S*)-phenylethylene glycol | *C. cassia* | Buds | [39] |
| **242** | 1,3,5-Trimethoxybenzene | *C. chartophyllum* | Aerial part | [40] |
| **243** | 3-Hydroxy-4,5-dinethoxyphenyl-*β*-D-glucopyranoside | *C. subavenium* | Leaves | [34] |
| **244** | 3,4,5-Trimethoxyphynol-1-*O*-*β*-D-glucoside | *C. subavenium* | Leaves | [34] |
| **245** | Kelampayoside A | *C. cassia* | Bark | [31] |
| **246** | Tachioside | *C. cassia* | Leaves | [14] |
| **247** | 3,4-Dimethoxyphenol-*β*-D-apiofuranosyl (1 → 6)-*O*-*β*-D-glucopyranoside | *C. cassia* | Bark | [31] |
| **248** | 1,2,4-Trihydroxybenzene | *C. porrectum* | Leaves | [54] |
| **249** | Isotachioside | *C. cassia* | Buds | [39] |
| **250** | Cinnacasside A | *C. cassia* | Bark | [30,55] |
| **251** | Cinnacasside B | *C. cassia* | Bark | [55] |
| **252** | Cinnacasside C | *C. cassia* | Bark | [55] |
| **253*** | Cinnacassides F | *C. cassia* | Buds, Bark | [39,55] |
| **254*** | Cinnacassides G | *C. cassia* | Bark | [55] |
| **255** | Glycerin-1-benzoatel benzoate | *C. cassia* | Bark | [41] |
| **256** | Methyl homovanillate | *C. cassia* | Bark | [41] |
| **257** | Phenylmethanol *O*-*α*-L-arabinofuranosyl (1 → 6)-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **258** | Phenylmethanol *O*-*α*-L-arabinopyranosyl (1 → 6)-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **259** | 5,7-Dihydroxychromone | *C. chartophyllum* | Aerial part | [40] |
| **260** | 5,7-Dimethoxychromone | *C. camphora* | Bark | [42] |
| **261** | 4-Hydroxy-4,7-dimethyl-1-tetralone | *C. chartophyllum* | Aerial part | [40] |
| **262** | (−)-Gynuraone | *C. cassia* | Bark | [41] |
| **263** | 3ζ-(1ζ-Hydroxyethyl)-7-hydroxy-1-isobenzofuranone | *C. cassia* | Bark | [41] |
| **264** | *rel*-(3*R*,3′*S*,4*R*,4′*S*)-3,3′,4,4’-Tetrahydro-6,6′-dimethoxy[3,3′-bi-2H-benzopyran]-4,4′-diol | *C. chartophyllum* | Aerial part | [40] |
| **265** | (3*R*,4*R*,3′*R*,4′*R*)-6,6′-Dimethoxy-3,4,3′,4′-tetrahydro-2H,2′H-[3,3′]bichromenyl-4,4′-diol | *C. porrectum*<br>*C. camphora* | Leaves<br>Aerial part | [20,54]<br>[43,44] |
| **266** | 3,3′,4,4’-Tetrahydroxy diphenyl | *C. chartophyllum* | Aerial part | [40] |
| | | *C. cassia* | Bark | [48] |
| **267*** | 2,2′,7a,7a’,7b,7b’-Hexamethyldiphenyl ether | *C. subavenium* | Bark | [37] |
| **268** | (−)-(7*R*,8*R*,8′*R*)-Acuminatolide | *C. camphora* | Aerial part | [44] |
| **269** | Zhebeiresinol | *C. cassia* | Bark | [41] |
| **270*** | Cinncassins B | *C. cassia* | Bark | [49] |
| **271*** | Cinncassins C | *C. cassia* | Bark | [49] |
| **272*** | (3*R*,4*S*,6*R*)-4,6-Dihydroxy-de-*O*-methyllasiodiplodin | *C. cassia* | Bark | [31] |
| **273** | Methylstictic acid | *C. cassia* | Bark | [48] |
| **274** | 1-Hydroxy-3,6-dimethoxy-8-methyl-anthraquinone | *C. camphora* | Aerial part | [43,44] |
| **275*** | Cinnaburmanin A | *C. burmannii* | Bark | [56] |
| **276** | (+)-Leptolepisol C | *C. cassia* | Bark | [49] |
| **Coumarins** | | | | |
| **277** | Scopoletin | *C. camphora* | Aerial part | [43,44] |

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**Table 2** (*continued*)

| No. | Compound | Species Resource | Parts Used | Ref. |
|---|---|---|---|---|
| **278** | 6,7-Dimethoxycoumarin | *C. camphora* | Aerial part | [43,44] |
| **279** | Coumarin | *C. osmophloeum* | Leaves | [8] |
| | | *C. cassia* | Bark, Twig | [20,46,48] |
| **280** | *cis*-4-Hydroxymellein | *C. cassia* | Bark | [20,48] |
| **Aliphatic compounds** | | | | |
| **281** | *n*-Eicosanic acid | *C. chartophyllum* | Aerial part | [40] |
| **282** | Lignoceric acid | *C. chartophyllum* | Aerial part | [40] |
| **283** | Hexacosanoic acid | *C. chartophyllum* | Aerial part | [40] |
| **284** | Heptacosanoic acid | *C. chartophyllum* | Aerial part | [40] |
| **285** | Octacosyl palmitate | *C. chartophyllum* | Aerial part | [40] |
| **286** | Octacosanyl arachidate | *C. chartophyllum* | Aerial part | [40] |
| **287** | Linoleic acid | *C. camphora* | Bark | [51] |
| **288** | Ethyl-*β*-D-Glucoside | *C. cassia* | Leaves | [34] |
| **289** | *epi*-Boscialin | *C. cassia* | Bark | [48] |
| **290** | 4-Oxo-heptadecanoica acid | *C. camphora* | Twig, Leaves | [43,44] |
| **291** | (2*S*)-Butan-2-*O*-*β*-D-glucopyranoside | *C. cassia* | Buds | [39] |
| **292** | (2*S*)-2-Butan-2-*O*-*β*-D-apiofuranosyl (1 → 6)-glucopyranoside | *C. cassia* | Buds | [39] |
| **293** | 6-Hydroxy-6-methyl-4,7-octadien-2-one | *C. camphora* | Aerial part | [43,44] |
| **294** | *n*-Dotriacontane | *C. chartophyllum* | Aerial part | [40] |
| **295** | *n*-Octacosanol | *C. chartophyllum* | Aerial part | [40] |
| **296** | *n*-Dotriacontanol | *C. chartophyllum* | Aerial part | [40] |
| **297** | Hexacosane | *C. camphora* | Bark | [51] |
| **Steroids** | | | | |
| **298** | *β*-Sitosterol | *C. cassia* | Bark | [20] |
| | | *C. camphora* | Bark | [43,51] |
| | | *C. chartophyllum* | Aerial part | [40] |
| | | *C. porrectum* | Leaves | [20,54] |
| | | *C. subavenium* | Bark | [37] |
| **299** | Daucosterol | *C. porrectum* | Leaves | [20,54] |
| **Other constituents** | | | | |
| **300** | 5*R*-Methyl-3-heptatriacontyl-2(5H)-furanone | *C. cassia* | Twig | [57] |
| **301** | Decumbic acid | *C. cassia* | Bark | [20] |
| **302** | 3-Hydroxy-4,4-dimethyl-4-butyrolactone | *C. porrectum* | Fruit | [21] |
| **303** | *n*-Butyl-*β*-D-fructofur-anoside | *C. cassia* | Leaves | [14] |
| **304** | (1*R*,2*S*,3*S*,4*S*)-2,3-Epoxy-1,4-dihydroxy-5-methyl-5-cyelohexene | *C. cassia* | Bark | [48] |
| **305** | 4,5-Dihydroxy-3-methylcyclohex-2-enone | *C. cassia* | Bark | [48] |
| **306** | 3-Mevalonolactone | *C. cassia* | Bark | [41] |

* They are new compounds isolated from the genus *Cinnamomum*.

### 5.2. Anti-oxidative activity

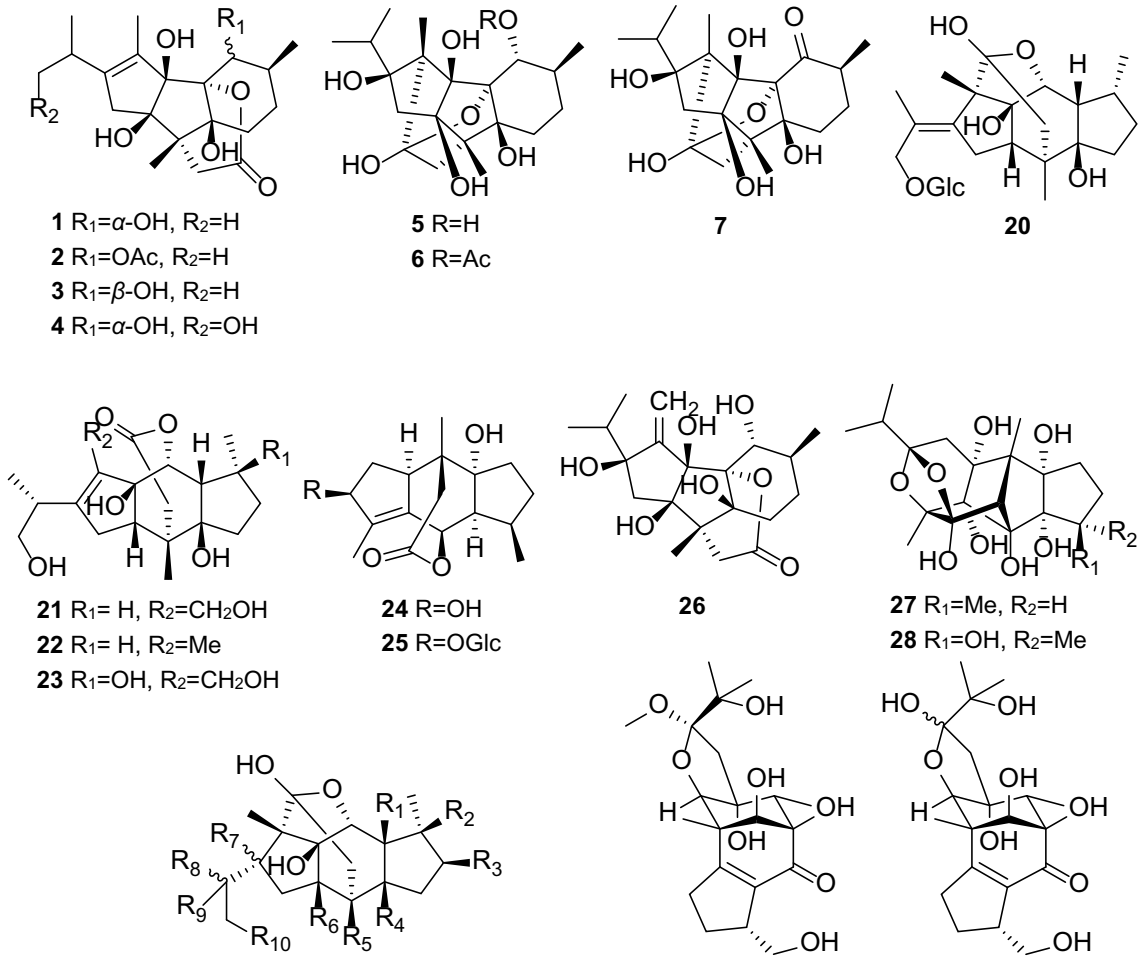
Fu et al. [77] found for the first time that *C. camphora* seed kernel oil exerted antioxidative effect in diet-induced obese rats, which was achieved by inhibiting the activities of serum glutamic oxaloacetic transaminase and glutamate-pyruvate transaminase to reduce fat deposition in rats. Besides, Liu et al. [78] evaluated the anti-oxidative property of the flavonoids from *C. camphora* leaves. The flavonoids exhibited DPPH free radical scavenging activity similar to the positive control of vitamin C with increasing concentration, although relatively low DPPH free radical scavenging activity at low concentrations; the reducing ability also increased significantly with the increase of concentration and was very close to the three positive control sets of vitamin C, BHT, and BHA. However, the authors did not link the profound activity to a particular compound.

It turned out that the flavonoids of *C. septentrionale* also exhibited good effects on scavenging free radicals with increasing concentrations and was seen as a natural antioxidant. The study of Lu et al. [79] showed that 86% of DPPH·, 68% of hydroxyl radicals (·OH), and 59% of superoxide anion free radical ($O^{2-}$·) were scavenged with the concentration of 0.15 mg/mL.

Cong et al. [35] confirmed that the essential oil of *C. longipaniculatum* leaves also had certain anti-oxidative activity in a time- and concentration-dependent manner, indicating that the extract of *C. longipaniculatum* leaves presented great developmental potential as a natural antioxidant. Liu et al. [80] found that the proanthocyanidins from *C. longipaniculatum* leaves were compounds that had a good ability to scavenge DPPH radical, although only slightly lower than that of vitamin C. The experimental data of ferric scavenging activity test displayed a higher reducing activity of the proanthocyanidins compared to vitamin C and BHT but lower than BHA; the findings of potassium ferricyanide reduction method confirmed a higher antioxidant activity than vitamin C (0.125 mg/mL), BHT (0.125 mg/mL), and BHA (0.094 mg/mL) when the concentration was 0.156 mg/mL. In addition, the total polysaccharides and flavonoids of *C. longipaniculatum* leaves were verified to have strong antioxidant effects on oils such as lard and colza oil; they were more natural and safer compared with synthetic antioxidants [81,82]. However, the authors in above studies didn't discuss the anti-oxidative mechanism of *C. longipaniculatum*.

One investigation [83] into the flavonoids of *C. cassia* showed good antioxidant activity. The flavonoids, obtained by fractional extraction of ethyl acetate and *n*-butanol, and column purification, had different abilities to scavenge DPPH and ABTS free radicals. The results of the study illustrated that the purified *C. cassia* flavonoids had similar effects on scavenging DPPH free radical compared with vitamin C ($IC_{50}$ was 6.37 μg/mL of ethyl acetate-extracted flavonoids, 6.13 μg/mL of *n*-butanol-extracted flavonoids, 5.07 μg/mL of vitamin C, respectively); the ethyl acetate-extracted cinnamon flavonoids had better ability to scavenge ABTS free radical than that of *n*-butanol-extracted, but the capacities were lower than vitamin C ($IC_{50}$ = 205, 270 and 166 μg/mL).

Abeysekera et al. [13] showed for the first time that antioxidant capacity was related to different maturity stages (immature, partly




**8** $R_1$=$R_3$=$R_4$=$R_6$=$R_9$=H, $R_2$=$R_{10}$=OH, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**9** $R_1$=$R_2$=$R_{10}$=OH, $R_3$=$R_4$=$R_6$=$R_9$=H, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**10** $R_1$=$R_2$=$R_{10}$=OH, $R_3$=$R_4$=$R_6$=$R_9$=H, $R_5$=Me, $R_7$=*α*-H, $R_8$=*α*-Me
**11** $R_1$=$R_3$=$R_6$=$R_9$=$R_{10}$=H, $R_2$=$R_4$=OH, $R_5$=$R_8$=Me, $R_7$=*β*-OH
**12** $R_1$=$R_2$=$R_6$=$R_9$=H, $R_3$=$R_4$=$R_{10}$=OH, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**13** $R_1$=$R_2$=$R_3$=$R_6$=$R_9$=H, $R_4$=$R_{10}$=OH, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**14** $R_1$=$R_2$=$R_3$=$R_6$=$R_9$=H, $R_4$=OH, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me, $R_{10}$=OGlc
**15** $R_1$=$R_6$=$R_{10}$=OH, $R_2$=$R_3$=$R_4$=$R_9$=H, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**16** $R_1$=$R_2$=$R_3$=$R_9$=H, $R_4$=$R_6$=$R_{10}$=OH, $R_5$=Me, $R_7$=*α*-H, $R_8$=*β*-Me
**17** $R_1$=$R_4$=$R_6$=OH, $R_2$=$R_3$=$R_9$=$R_{10}$=H, $R_5$=$R_8$=Me, $R_7$=*β*-OH
**18** $R_1$=$R_4$=$R_6$=OH, $R_2$=$R_3$=$R_9$=$R_{10}$=H, $R_5$=$CH_2OGlc$, $R_7$=*β*-OH, $R_8$=Me
**19** $R_1$=$R_4$=$R_6$=$R_9$=OH, $R_2$=$R_3$=$R_{10}$=H, $R_5$=$R_8$=Me, $R_7$=*β*-OH

**Fig. 1.** Chemical structures of diterpenes (**1** − **30**).

mature, and mature) of *C. zeylanicum* leaves. The antioxidant properties were tested by evaluating the DPPH and ABTS radical scavenging activities, oxygen radical absorbance capacity, together with ferric reducing antioxidant power. The findings of these assays illustrated that mature *C. zeylanicum* leaves exhibited the highest antioxidant, and immature leaves showed the lowest. Soon after, Kallel et al. [84] investigated the antioxidant capacity of *C. zeylanicum* essential oil with its principal compositions (cinnamaldehyde 77.34% and *trans*-cinnamyl acetate 4.98%). The authors showed that the ammonium phosphomolybdate potency was about 108.75 ± 32.63 mg of essential oil (equivalent to 1 mg of vitamin C in terms of antioxidant power), and the scavenging rates of DPPH and $H_2O_2$ free radicals were 21.3% and 55.2%, respectively. The results indicated the potential of *C. zeylanicum* essential oil as an antioxidant.

In a word, most of the above studies on the antioxidant activity of the *Cinnamomum* taxa only evaluated the free radicals scavenging abilities of the extracts, however, these simple chemical assays were of no therapeutic relevance in animals or humans. Therefore, further research on the detailed mechanism of these activities based on animal models or humans is necessary.

### 5.3. Anti-inflammatory and analgesic activities

The anti-inflammatory effect of *C. subavenium* has been reported previously. Lai et al. [53] evaluated the *in vitro* anti-inflammatory activity of ( ± )-subaveniumins A and B (**191, 192**), two pairs of racemic

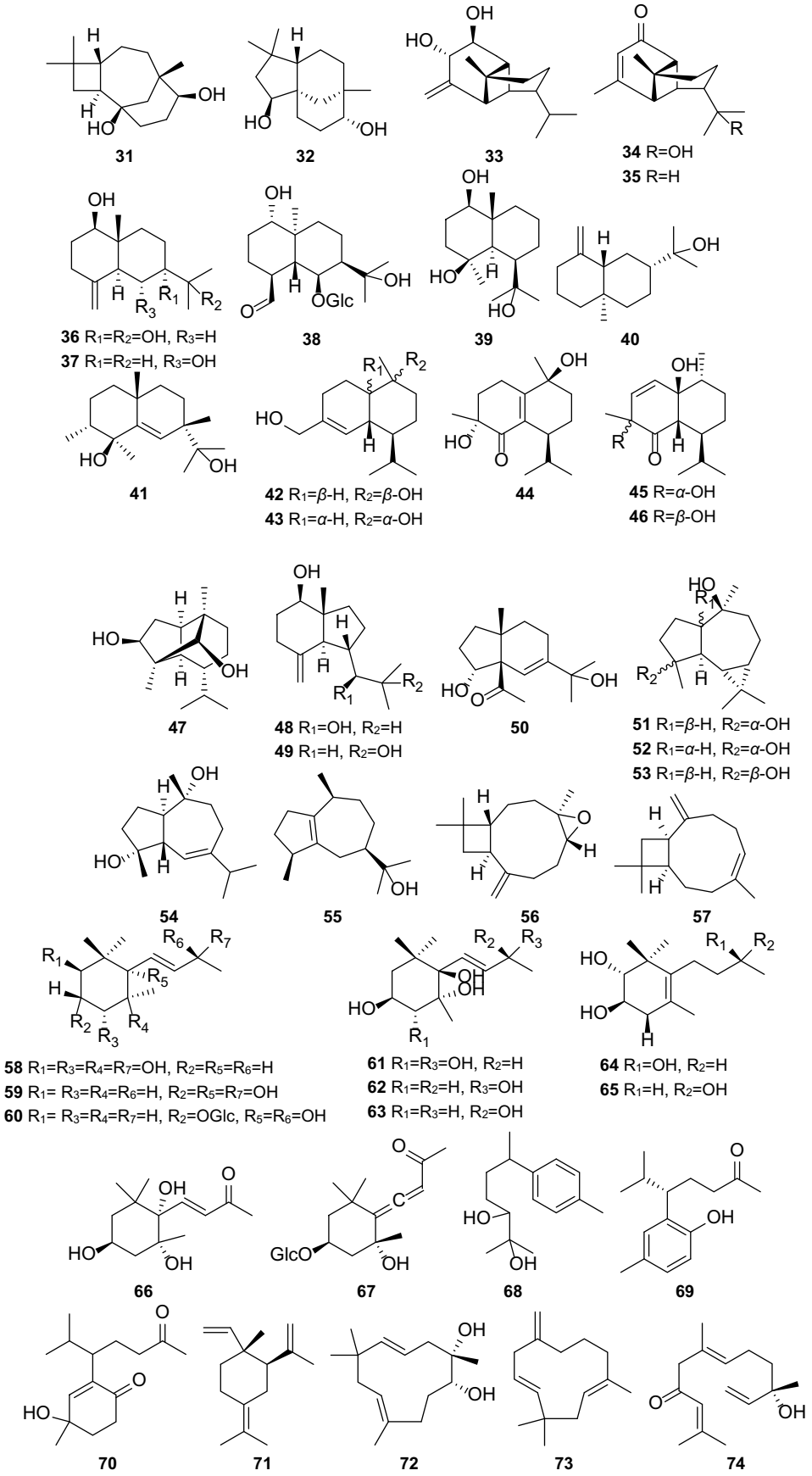



**Fig. 2.** Chemical structures of sesquiterpenes (**31–74**).

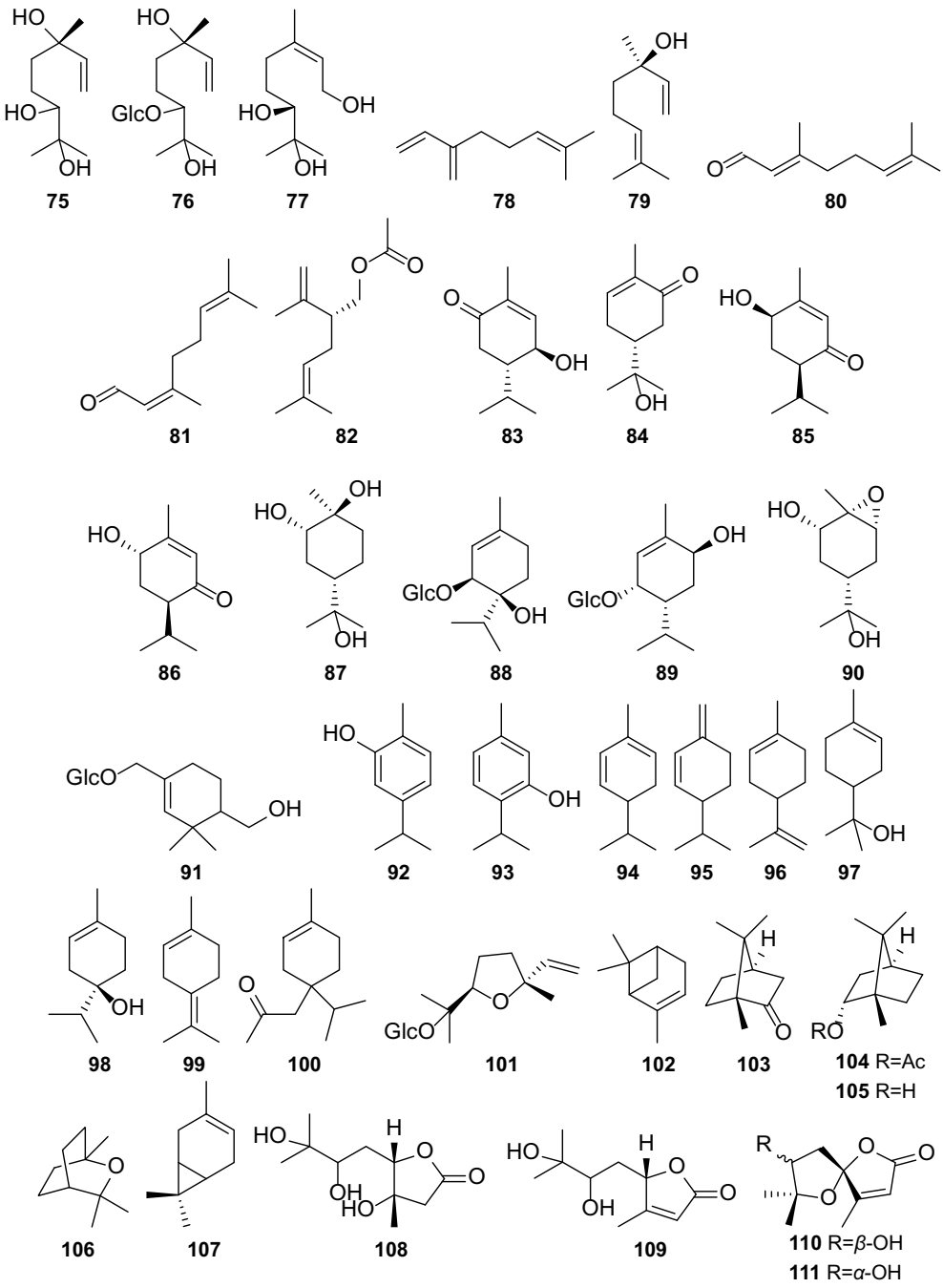
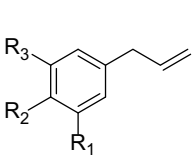


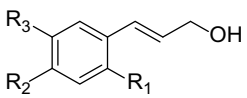

**Fig. 3.** Chemical structures of monoterpenes (**75–111**).

spirodienone neolignans isolated from the bark of *C. subavenium*. The authors studied the moderate influence of the isolated compounds on the production of NO in RAW264.7 mouse macrophages induced by lipopolysaccharide with $IC_{50}$ values of 17.9, 5.6, 15.1, and 4.3 μM, respectively. Interestingly, compound (−)-**191** showed a much stronger inhibitory effect than (+)-**191**, and (−)-**192** also exhibited an inhibitory effect more potent than that of (+)-**192**. Later, Hao et al. [22] investigated the anti-inflammatory property of *C. subavenium* leaf oil (CS-LO) *in vitro* and *in vivo* by evaluating the LPS-stimulated RAW264.7 cells and the Carr-induced hind mouse paw edema model. The authors indicated that the anti-inflammatory effects of CS-LO might attribute to the inhibitory to the expression of iNOS, COX-2, IL-1*β*, IL-6, and TNF-*α* as well as the production of NO and PGE2, and the inactivation of NF-*κ*B.

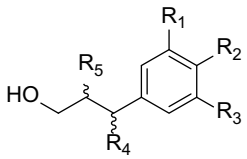
A 2016 report [85] demonstrated that essential oil from the twigs of *C. cassia* (15, 30, and 60 mg/kg) have good analgesic activity. The current study also revealed that *C. cassia* essential oil not only reduced the amount of writhing induced by acetic acid or oxytocin but also blocked the formalin-induced or Complete Freund's adjuvant (CFA) paw flinching and licking. Moreover, it was also found that *C. cassia* essential oil suppressed carrageenan-induced mechanical hyperalgesia and paw edema, and decrease the levels of cytokines (TNF-*α*, and IL-1*β*), NO, and PGE2 in carrageenan-induced mice paw skin tissue. In 2017, Shin et al. [86] confirmed that ethanol extract of *C. cassia* had a noticeable anti-inflammatory effect, which significantly suppressed NLRP3, AIM2 as well as NLRC4 inflammasome activation and improved the survival rate in the LPS-induced septic shock and murine gout model. In 2018, Sharma et al. [87] reported that *C. cassia* bark extract



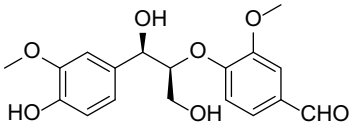
**112** $R_1$=OMe, $R_2$=OH, $R_3$=H
**113** $R_1$=H, $R_2$=$R_3$=OMe
**114** $R_1$=H, $R_2$+$R_3$=$OCH_2O$
**115** $R_1$= $R_3$=H, $R_2$=OMe



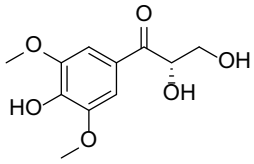
**116** $R_1$=$R_2$=$R_3$=H
**117** $R_1$=OH, $R_2$=$R_3$=H
**118** $R_1$=H, $R_2$+$R_3$=$OCH_2O$
**119** $R_1$=H, $R_2$=$R_3$=OMe



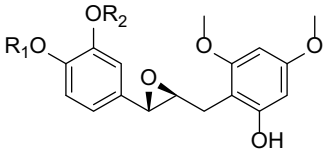
**135** $R_1$=H, $R_2$=OH, $R_3$=OMe, $R_4$=α-OGlc, $R_5$=β-OH
**136** $R_1$=$R_2$=OMe, $R_3$=H, $R_4$=$R_5$=OH
**137** $R_1$=$R_3$=OMe, $R_3$=H, $R_4$=$R_5$=OH
**138** $R_1$=$R_3$=OMe, $R_2$=OH, $R_4$=$R_5$=α-OH
**139** $R_1$=$R_2$=$R_3$=H, $R_4$=$R_5$=OH
**140** $R_1$=$R_2$=$R_3$=$R_5$=H, $R_4$=OH
**141** $R_1$=OMe, $R_2$=OH, $R_3$=H, $R_4$=α-OH, $R_5$=α-OGlc
**142** $R_1$=$R_2$=$R_3$=H, $R_4$=α-OH, $R_5$=α-OGlc



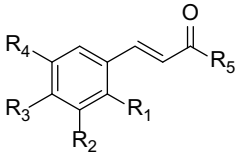
**152**



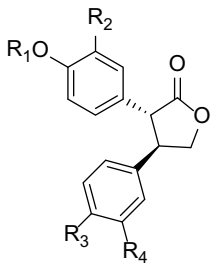
**153**



**154** $R_1$=H, $R_2$=Me
**155** $R_1$+$R_2$=$CH_2$



**120** $R_1$=$R_2$=$R_3$=$R_4$=$R_5$=H
**121** $R_1$=OMe, $R_2$=$R_3$=$R_4$=$R_5$=H
**122** $R_1$=OH, $R_2$=$R_3$=$R_4$=$R_5$=H
**123** $R_1$=$R_2$=$R_5$=H, $R_4$=OMe，$R_3$=OH
**124** $R_1$=OMe, $R_2$=OH, $R_3$=$R_4$=$R_5$=H
**125** $R_1$=OH, $R_2$=$R_4$=$R_5$=H, $R_3$=OMe
**126** $R_1$=$R_5$=H, $R_2$=$R_4$=OMe, $R_3$=OH
**127** $R_1$=$R_5$=H, $R_2$=OH, $R_3$=$R_4$=OMe
**128** $R_1$=$R_4$=$R_5$=H, $R_2$+$R_3$=$OCH_2O$
**129** $R_1$=$R_4$=$R_5$=H, $R_2$=$R_3$=OMe
**130** $R_1$=$R_2$=$R_3$=$R_4$=H, $R_5$=OH
**131** $R_1$=OMe, $R_2$=$R_3$=$R_4$=H, $R_5$=OH
**132** $R_1$=$R_2$=$R_3$=$R_4$=H, $R_5$=OMe
**133** $R_1$=$R_2$=H, $R_3$=$R_4$=$R_5$=OMe
**134** $R_1$=$R_2$=$R_4$=H, $R_3$=OMe, $R_5$=O-phenethyl



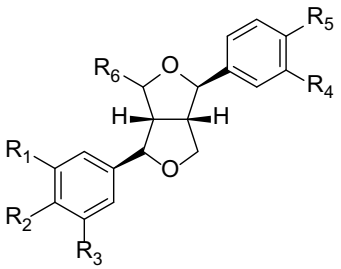
**143** $R_1$=$R_2$=H, $R_3$=OH, $R_4$=OMe
**144** $R_1$=$R_2$=H, $R_3$=$R_4$=OH
**145** $R_1$=H, $R_2$=$R_4$=OMe, $R_3$=OH
**146** $R_1$=Me, $R_2$=H, $R_3$=$R_4$=OH
**147** $R_1$=Me, $R_2$=H, $R_3$=OH, $R_4$=OMe
**148** $R_1$=H, $R_2$=OMe, $R_3$=$R_4$=OH
**149** $R_1$=Me, $R_2$=H, $R_3$+$R_4$=$OCH_2O$
**150** $R_1$=$R_2$=H, $R_3$+$R_4$=$OCH_2O$
**151** $R_1$=H, $R_2$=OMe, $R_3$+$R_4$=$OCH_2O$

**Fig. 4.** Chemical structures of phenylpropanoids (**112–155**).

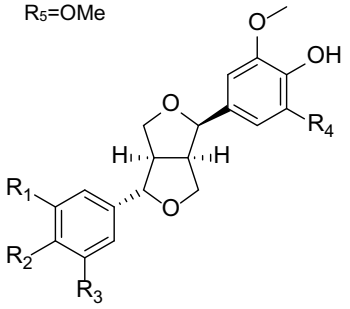
showed notable anti-arthritic activity *via* reducing IL-1, MDA, TNF-α levels and joint swelling levels in rats with CFA-induced and formaldehyde-induced arthritis. Later in 2019, cinnamic acid, a primary compound of *C. cassia*, was reported to provide relief against oxaliplatin-induced neuropathic pain through inhibiting spinal pain transmission [88].

The anti-inflammatory activity of the essential oil from *C. longipaniculatum* has been evaluated. Cong et al. [78] reported that *C. longipaniculatum* essential oil had a specific anti-inflammatory activity, it could not only downregulate the inhibition rate and NO production of the LPS-induced RAW264.7 macrophage but also reduce carrageenan-induced rat paw swelling along with a dose-dependent manner.

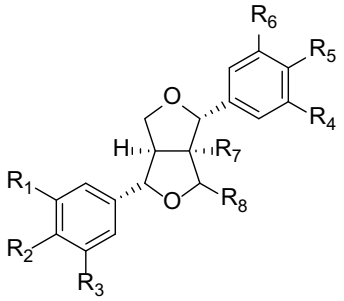
Fu et al. [77] previously assessed that *C. camphora* seed kernel oil demonstrated a positive anti-inflammatory impact on high-fat-diet-induced obese rats. The authors indicated its mechanism of action was to reduce the activities of serum glutamic oxaloacetic transaminase and glutamate-pyruvate transaminase, as well as the levels of inflammatory markers (TNF-α, IL-6, and P65) *via* up-regulation of PPAR-γ. Li et al. [44] illustrated the combined *in vitro* anti-inflammatory activity of phenylpropanoid (**112**), lignan (**160 and 185**), flavonoid (**209, 210 and 221**), coumarin (**265**), as well as a terpenoid (**74**) from ethanol extracts of *C. camphora*. The authors studied the influence of the isolated compounds on Lipopolysaccharide (LPS)-stimulated RAW 264.7 macrophages. Furthermore, it was also found compounds **74** and **185** to



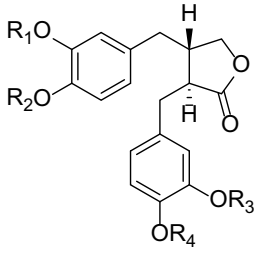
**156** $R_1+R_2=R_4+R_5=OCH_2O$, $R_3=R_6=H$
**157** $R_1+R_2=OCH_2O$, $R_3=H$, $R_4=R_6=OH$, $R_5=OMe$



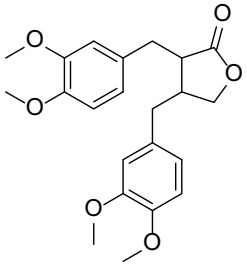
**166** $R_1+R_2=OCH_2O$, $R_3=R_4=H$
**167** $R_1=R_4=H$, $R_2=OH$, $R_3=OMe$



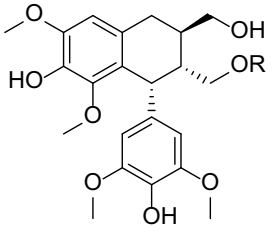
**158** $R_1=R_3=R_4=R_6=OMe$, $R_2=R_5=OH$, $R_7=R_8=H$
**159** $R_1=R_6=OMe$, $R_2=R_5=OH$, $R_3=R_4=R_7=R_8=H$
**160** $R_1+R_2=OCH_2O$, $R_3=R_6=R_7=R_8=H$, $R_4=OMe$, $R_5=OH$
**161** $R_1+R_2=OCH_2O$, $R_3=R_6=R_7=H$, $R_4=R_8=OH$, $R_5=OMe$
**162** $R_1=R_2=R_6=OMe$, $R_3=R_4=R_7=R_8=H$, $R_5=OH$
**163** $R_1=R_4=R_8=H$, $R_2+R_3=R_5+R_6=OCH_2O$, $R_7=OH$
**164** $R_1=R_2=R_6=OMe$, $R_3=R_4=R_7=R_8=H$, $R_5=OH$
**165** $R_1=R_3=R_6=OMe$, $R_2=R_4=R_5=OH$, $R_7=R_8=H$



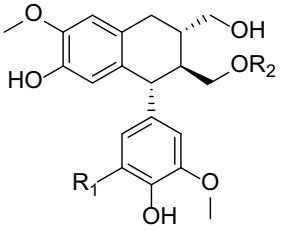
**168** $R_1=R_2=Me$，$R_3+R_4=CH_2$
**169** $R_1+R_2=CH_2$，$R_3=R_4=Me$



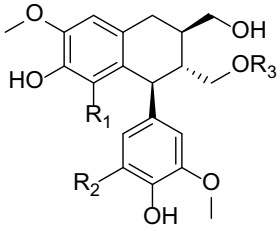
**170**



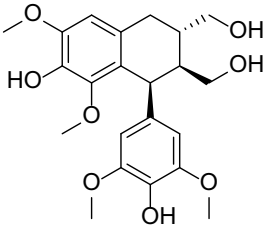
**171** R=H
**172** R=Glc



**173** $R_1=OMe$, $R_2=Glc$
**174** $R_1=R_2=H$



**175** $R_1=R_2=OMe$, $R_3=Glc$
**176** $R_1=R_2=R_3=H$



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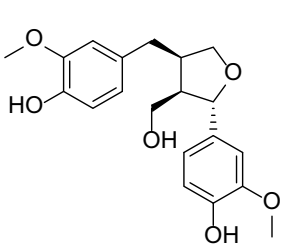

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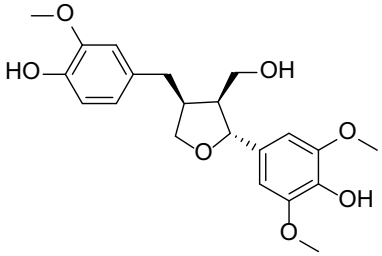

**179**

**Fig. 5.** Chemical structures of lignans (**156–206**).

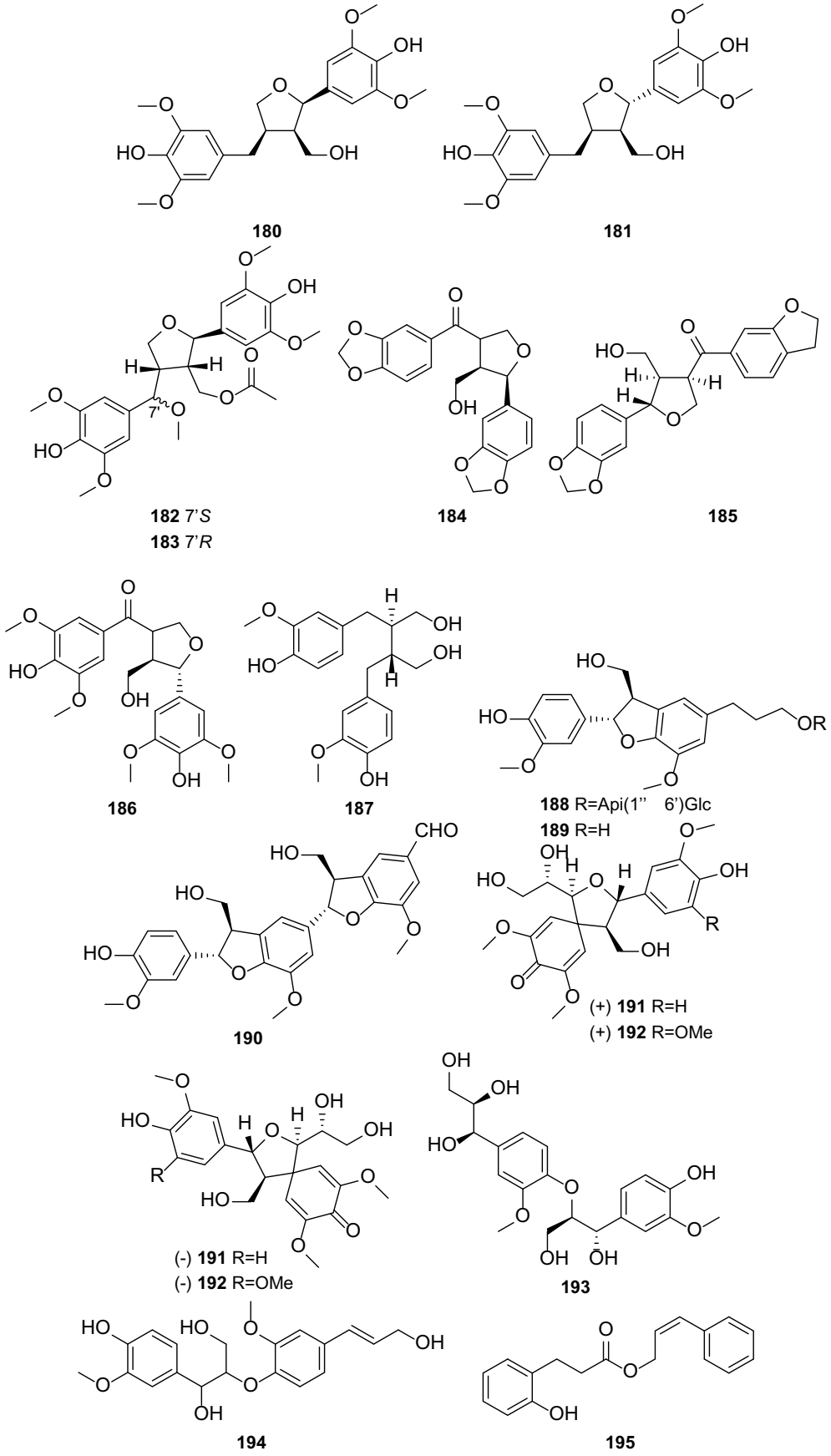


**Fig. 5.** (*continued*)

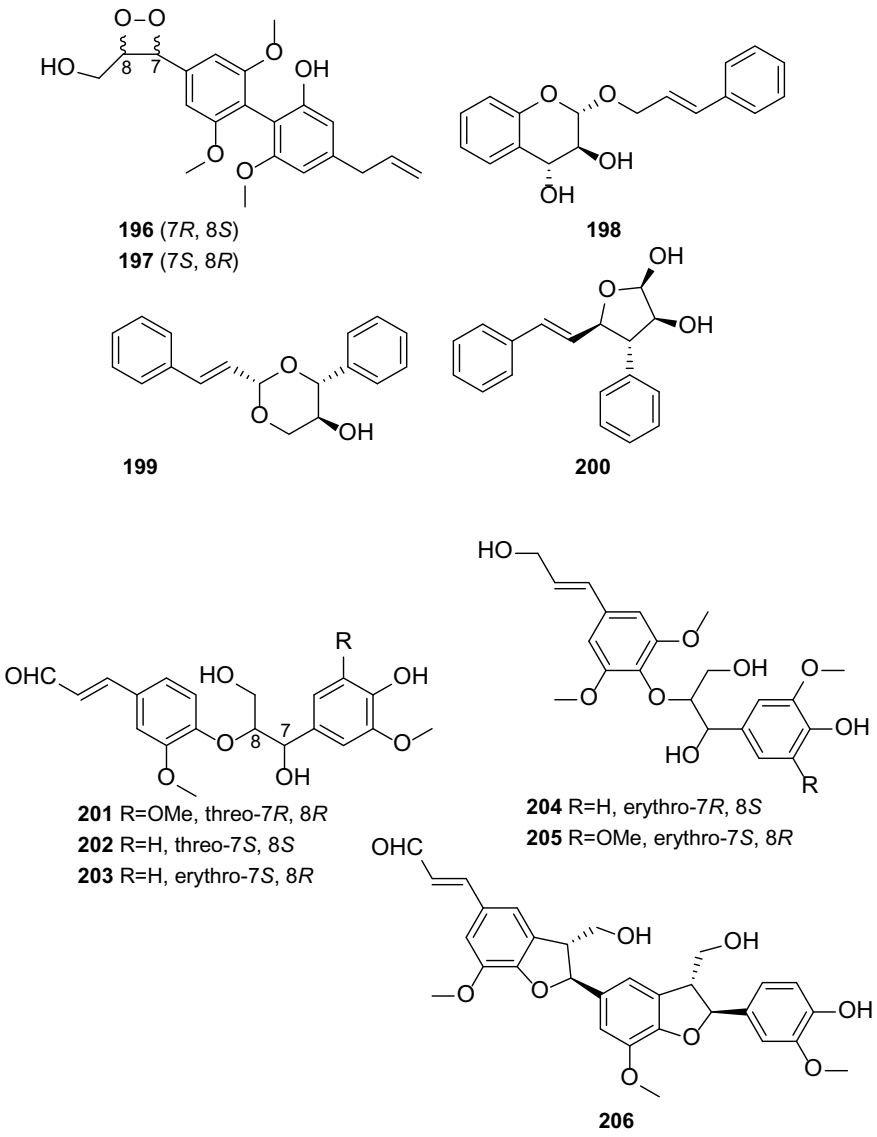


**Fig. 5.** (*continued*)

be new molecules with *in vitro* anti-inflammatory activities, which mechanism was to suppress the release of pro-inflammatory cytokines (TNF-*α*, IL-6, and PGE2), and alleviate increased mRNA and protein levels of inducible nitric oxide synthase (iNOS), cyclooxygenase (COX-2), and matrix metallopeptidase-9 (MMP-9) *via* blocking NF-*κ*B activation. Other research found that the ethanol extract of *C. camphora* leaves had good effects on treating allergic dermatitis such as atopic dermatitis [89]. The result showed notable anti-inflammatory property of *C. camphora* leaves in human adult low-calcium high-temperature keratinocytes, which was achieved by inhibiting the phosphorylation of janus kinase signal transducer, an activator of transcription 1, and extracellular signal-regulated kinase 1/2. Moreover, the authors suggested the significant therapeutic potential of *C. camphora* leaves on atopic dermatitis in mice induced by 2,4-dinitrochlorobenzene, which was achieved by improving atopic dermatitis symptoms.

The anti-inflammatory activity of *C. zeylanicum* bark essential oil (CBEO) in a validated human dermal fibroblast system has been evaluated by Han et al. [25]. The authors elucidated that CBEO, which can be seen a promising anti-inflammatory agent, had a significant effect on inhibiting the production of several inflammatory biomarkers, covering vascular cell adhesion molecule-1 (VCAM-1), intercellular cell adhesion molecule-1 (ICAM-1), monocyte chemoattractant protein-1 (MCP-1), interferon-gamma induced protein 10 (IP-10), interferon-inducible T-cell alpha chemoattractant (I-TAC), and monokine induced by gamma interferon (MIG).

HelmyAbdou et al. [90] reported *C. burmannii* anti-inflammatory activity in the hepatic histopathological lesions caused by a multi-walled carbon nanotube. The aqueous extract of *C. burmannii* at a dose of 75 mg/kg notably improved the antioxidant system. It decreased the rate of pro-inflammatory cytokines including interleukin-6 (IL-6), interleukin-1*β* (IL1*β*), cyclooxygenase-1 (COX-1), and tumor necrotic factor-α in comparison with the control group.

Kim et al. [91] indicated that *C. japonicum* water extract (CSWE) could inhibit inflammation of the intestines. It was shown that the protein and expression levels of nitrite, PGE2, IL-6, IL-8, TNF-*α*, NF-*κ*B activity, and the phosphorylation of the factors of the NF-*κ*B pathway had been significantly reduced with CSWE-treated. Subsequently, cinnamic acid (**130**) and cinnamaldehyde (**120**) were found to be responsible for the anti-inflammation properties of this fraction.

### 5.4. Anti-diabetic and anti-obesity activities

Fu et al. [92] evaluated the effect of *C. camphora* seed kernel oil (CKO) on body fat deposition and blood lipids in rats for the first time.

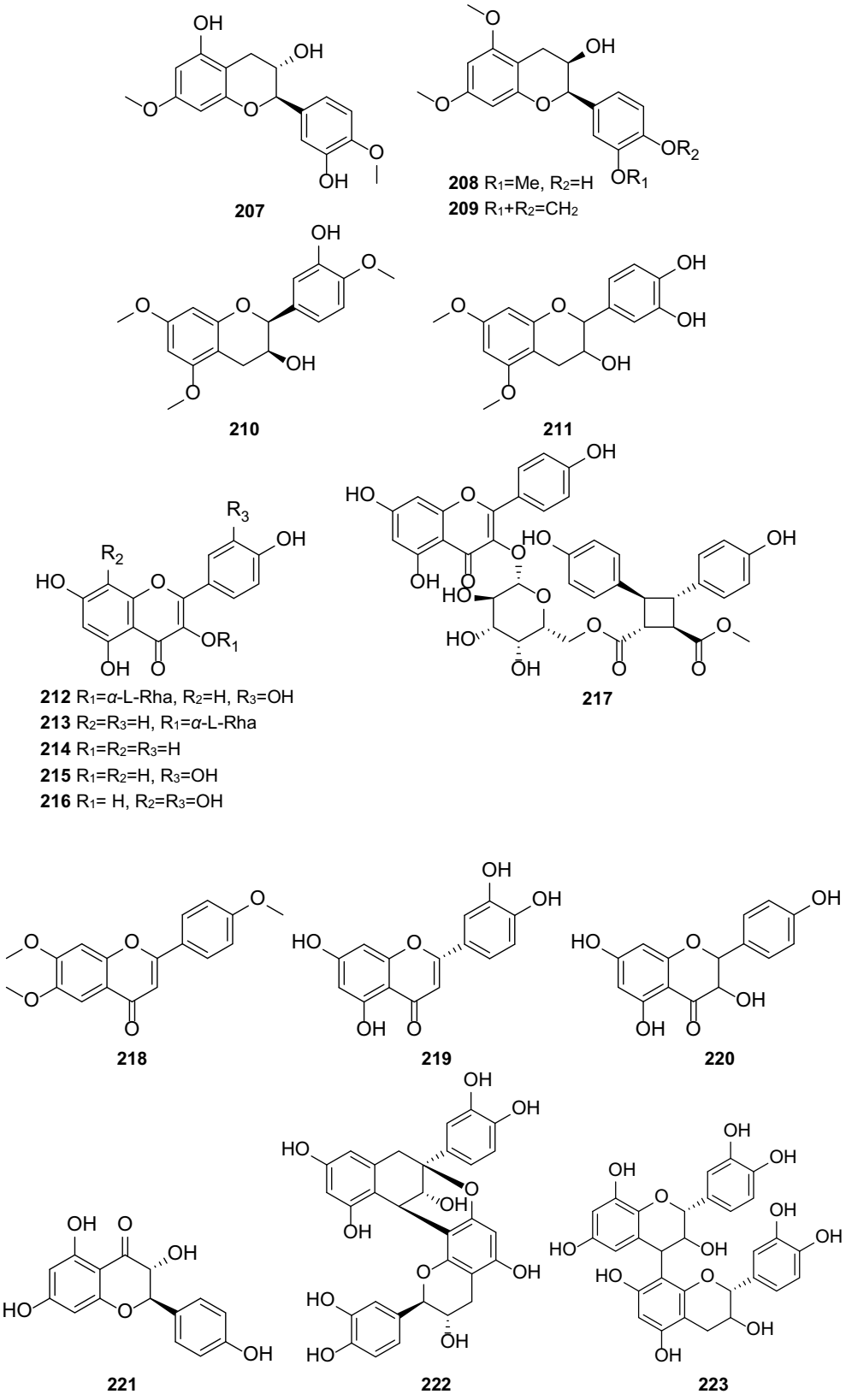


**Fig. 6.** Chemical structures of flavonoids (**207–223**).

The authors found that the final body weight and abdominal fat weight in mice treated with CKO was significantly lower than the mice treated with lard and soybean; in addition, the levels of blood triglyceride (TG) as well as low-density lipoprotein cholesterol (LDL-C) were greatly improved.

Pharmacological studies illustrated that *C. zeylanicum* extract could enhance the hypoglycemic properties of insulin or oral diabetes medications, and could be used as an adjuvant remedy in diabetic patients' daily regimen. A report [93] showed that *C. zeylanicum* bark water extract has a mild effect on lowering blood glucose levels in alloxan-induced diabetic mice (serum glucose levels were 322 ± 7.5 mg/dL).

Song et al. [94] demonstrated that *C.cassia* extract (100 or 300 mg/kg) consumption led to an inhibitory of weight gain in high-fat diet

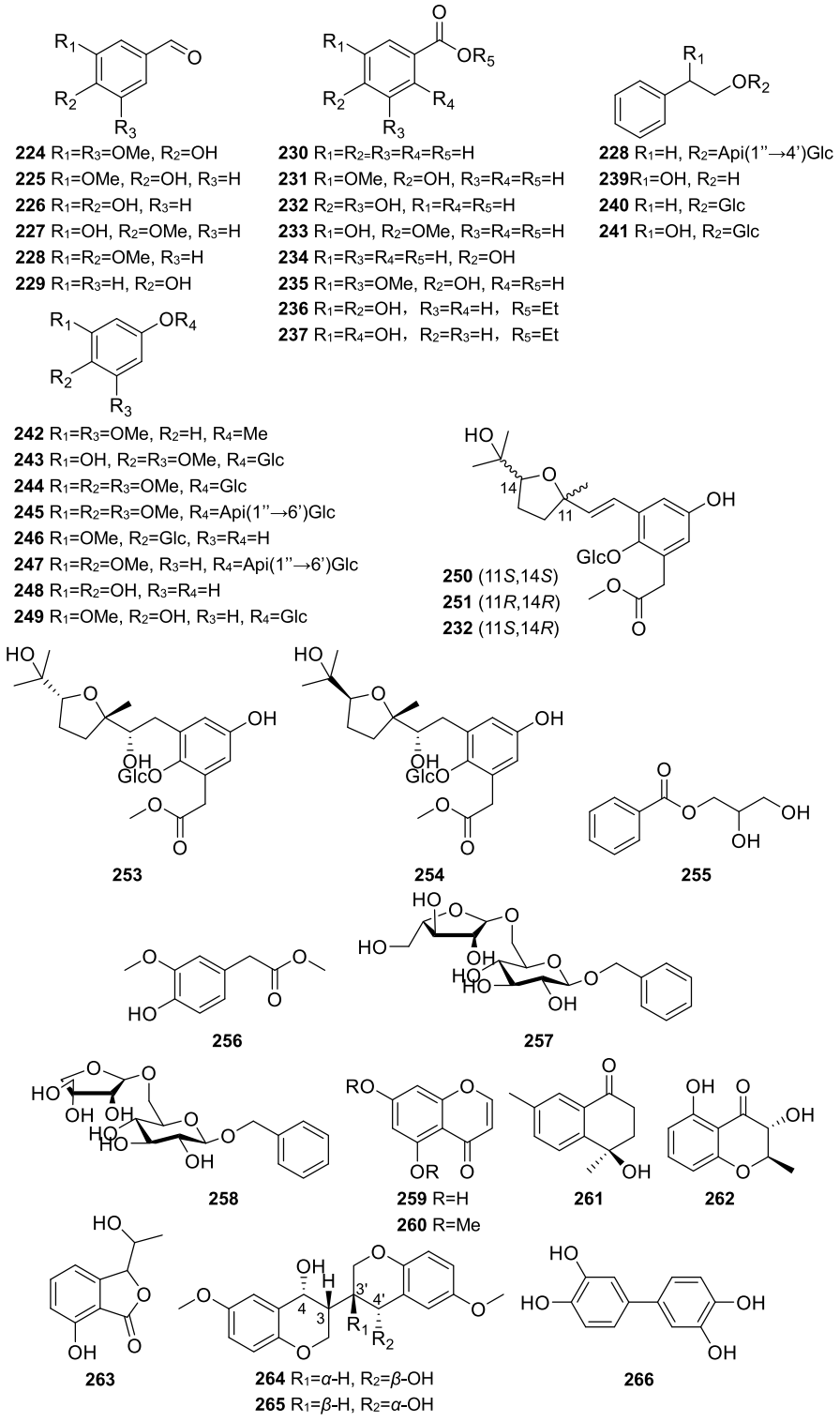


**Fig. 7.** Chemical structures of aromatic compounds (**224–276**).

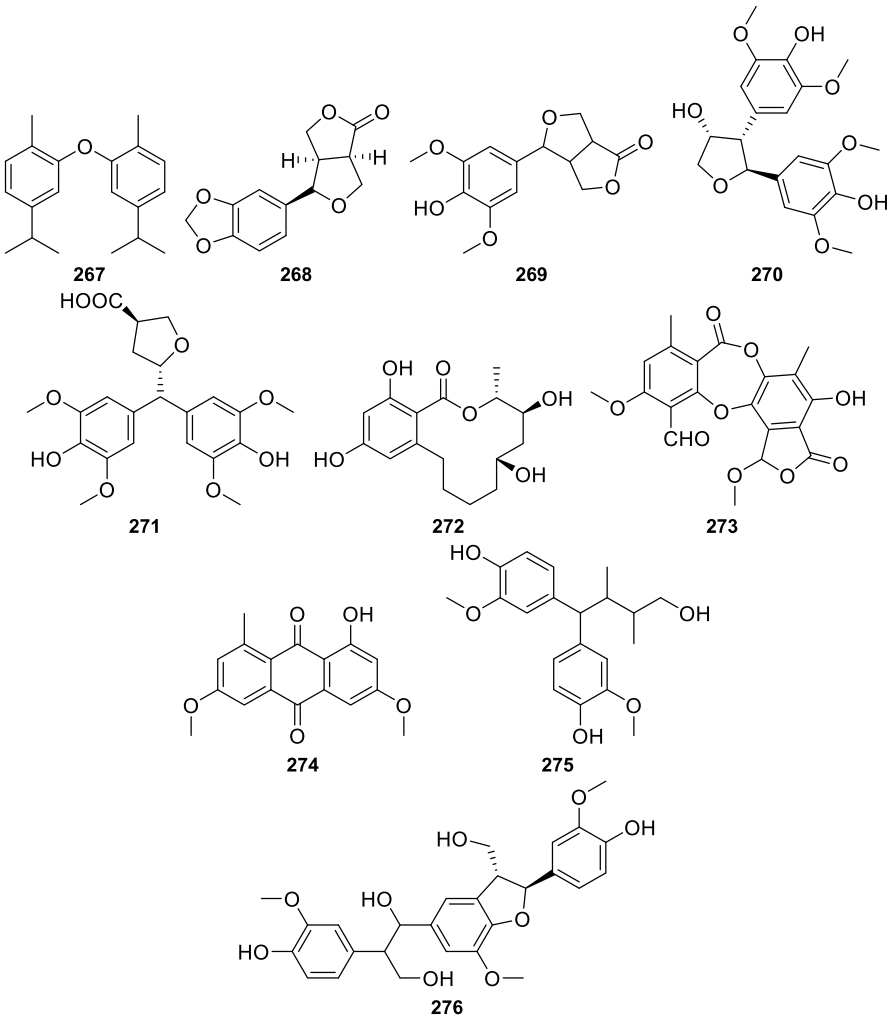


**Fig. 7.** (*continued*)

(HFD)-induced obese mice *via* suppressing lipid accumulation and increasing energy expenditure, which mechanism was to upregulating the biological activity of mitochondria in skeletal muscle cells to reducing blood lipids and avoiding lipids accumulation in the liver. Moreover, the findings of Zheng [95] showed that polyphenols from *C. cassia* effectively improved lipid metabolism in Hep G2 cells and inhibited the expression of SREBP-1 and its downstream target genes (FAS, SCD1), suggesting that the effect of *C. cassia* polyphenols on improving liver disease might be achieved by inhibiting the *de novo* synthesis of lipids through the SIRT1-AMPK-ACC pathway.

The essential oil of *C. osmophloeum* ct. linalool leaves (LEO) and its main component *S*-(+)-linalool have been confirmed to exhibit weight-controlling and hypolipidemic effects. Cheng et al. [96] found that LEO and *S*-(+)-linalool played an essential role in inhibiting the production and accumulation of lipids without side effects, the bodyweight change rate in mice treated with *S*-(+)-linalool and LEO was 2.5%, which was lower than the control group of 3.9%. Also, the TG, TC, and blood glucose levels remained normal in mice treated with LEO and *S*-(+)-linalool compared with the control group, and the level of aspartate aminotransferase (AST) and alanine aminotransferase (ALT) remained unchanged. Moreover, it was also showed that *S*-(+)-linalool controlled intracellular lipid in 3 T3-L1 adipocytes.

### 5.5. Anti-tumor activity

The antitumor potential of *C. verum* (*C. zeylanicum*) has been reported previously. 2-methoxycinnamaldehyde (2-MCA, **121**), which was found in very high concentrations in *C. verum*, was discovered to be an underlying agent for anti-lung cancer treatment. One research of Liu et al. [5] reported that 2-MCA not only reduced the size of human lung squamous cell carcinoma NCI-H520 cells *in vivo*, but also has an *in vitro* antiproliferative effect accompanied by suppressing cell growth markers, topoisomerase I as well as II, and increasing in proapoptotic molecules, related to elevated lysosomal vacuolation. The anti-lung cancer potential of 2-MCA was also confirmed by Wong et al. [97]. It was implied that 2-MCA to be inhibitory to the growth of human lung adenocarcinoma A549 cells as indicated by downregulation of NF-κB binding activity and inhibition of topoisomerase I and II activities, together with an upregulation of lysosomal vacuolation and VAC. Similar results that cuminaldehyde, also the main component of *C. verum*, exhibited *in vitro* antitumor activity against human lung adenocarcinoma A549 cells [98]. In addition, Ishrat et al. [24] endeavored to evaluate the antitumor activity of ethanol extract from *C. zeylanicum*. The *in vitro* cytotoxic properties of ethanol extract of *C. zeylanicum* against human breast carcinoma cell line MDA-MB-231 and normal kidney epithelial cell line Vero were tested. The results illustrated the ethanolic extract had a strong cytotoxic effect on MDA cells with $IC_{50}$ values of 25 μg/mL, whereas non-toxic to Vero cells even at 100 μg/mL ($IC_{50}$ > 100 μg/mL), indicating the potential benefit in treating breast cancer.

Lin et al. [99] suggested that *C. cassia* extract has *in vivo* anti-metastatic activities in human lung A549 and H1299 cells, which was

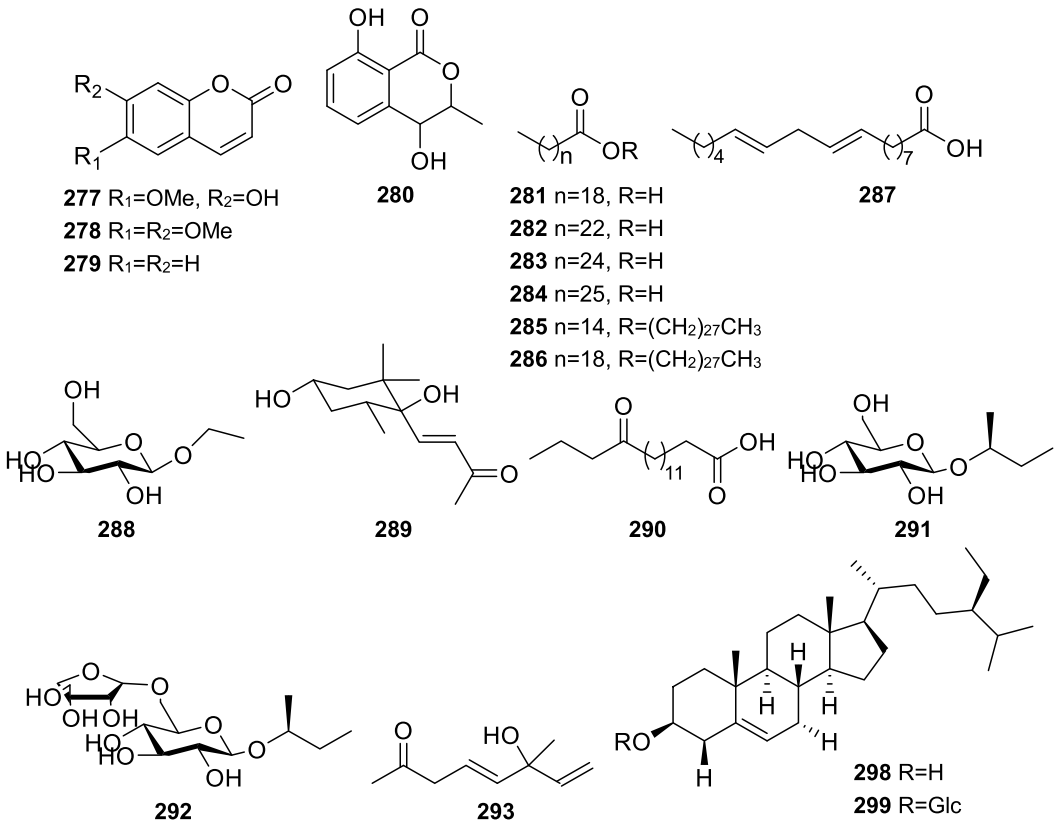


**Fig. 8.** Chemical structures of coumarins (**277–280**), partial aliphatic compounds (**281–293**), and steroids (**298–299**).

mediated by reducing the TGF-b1-induced epithelial-mesenchymal transition (EMT) in human lung adenocarcinoma cells and blocking tumor growth. One study of Chang et al. [100] confirmed that *C. cassia* essential oil and its main component cinnamaldehyde (**120**) had anti-oral cancer properties, they could significantly reduce the viability of human oral squamous cell carcinoma HSC-3 cells, and induce DNA damage as well as G2/M cell cycle arrest and apoptosis. Another research of Park et al. [101] showed that the twigs of *C. cassia* played an essential role in treating human colorectal cancer cells, and its mechanism might be inhibiting cell proliferation through down-regulating cyclin D1 *via* proteasomal degradation and transcriptional suppression, and inducing apoptosis through ROS-dependent NF-κB and ATF3 activation.

Cinnamaldehyde (**120**), has been reported to exhibit anticancer properties. Wang et al. [102] revealed that cinnamaldehyde at doses of 3.13, 1.56, 0.78, 0.39, 0.20, 0.10 g/L when given to human liver cancer cells HepG2 restrained the cells proliferation in a dose- and time-dependent manner. It also increased the expression of p21 protein and decreased the expression of CDK4 proteins. Also, cinnamaldehyde exhibited anti-tumor biological activity against cervical cancer cells by participating in the regulation of the PI3K/Akt/mTOR signaling pathway in cells [124]. Furthermore, Chen et al. [103] found that cinnamaldehyde played an anti-endometrial cancer role in RL95–2 cells, which was mediated by reducing the expression of NF-κB·p65, IL-6 and IGF-R proteins and promoting the apoptosis of RL95–2 cells.

### 5.6. Immunoregulation activity

Previously, Liu et al. have evaluated several chemical ingredients isolated from *C. cassia* bark responsible for the immunoregulation effect. The suppression effects of cinnacassides F (253) (400 μM) on T cells and B cells proliferation (36.1 and 20.3%) were slightly weaker than that of the positive control (60.6% and 33.5%), cinnacassides A–C (**250–252**) showed weak inhibitory effects on the proliferation of T cells and B cells [80]. In addition, Zhou et al. [32] found that cinnamomols A (**27**) and B (**28**) (0.391 to 100 μM), isolated from the leaves of *C. cassia*, enhanced the proliferation of ConA-induced murine T cells with enhancement rates varying from 29 to 64%.

Two alcohol (EtOH and MeOH) extracts of *C. verum* were investigated for their immunoregulation effects against collagen type-II induced arthritic (CIA) and Rheumatoid Arthritis (RA) by Qadir et al. [104]. The experimental data showed that the EtOH and MeOH extracts (1, 2, and 4 mg/kg BW) exhibited a good therapeutic effect on CIA mice, and the better effect was observed for the MeOH extract at a dose of 4 mg/kg BW. The extracts also had inhibitory effects on all RA-related proteins including NFATc3, TNF-α, CAII, and mCalpain.

### 5.7. Insecticidal and Acaricidal activities

Recently, investigations into the insecticidal and acaricidal activities of *C. camphora* have been conducted. Chen and Dai [105] confirmed that in comparison with the other seven experimental plant extracts, the crude ethanol extract of *C. camphora* displayed significantly acaricidal capacity against *T. cinnabarinus*, which demonstrated corrected mortality of almost 97% at a basal concentration of 1500 mg/kg. Additionally, the authors indicated that 2,4-di-tert-butylphenol and ethyl oleate , which were the significant constituents of *C. camphora* extract, exhibited acaricidal effect with the $LC_{50}$ values of 1850.94 and 2481.65 mg/kg, respectively. Jiang et al. [106] investigated the insecticidal potential of *C. camphora* essential oils from different parts covering leaves, twigs, and seeds. The result showed that the three essential oils all had potent insecticidal activity against cotton aphids after 48 h of treatment ($IC_{50}$ = 245.79, 274.99, 146.78 mg/L); the essential seed oil with a concentration of 20 μL / mL exhibited the highest repellent rate of 89.86% (after 24 h of treatment). Linalool was identified as a main insecticidal component. Later, the insecticidal

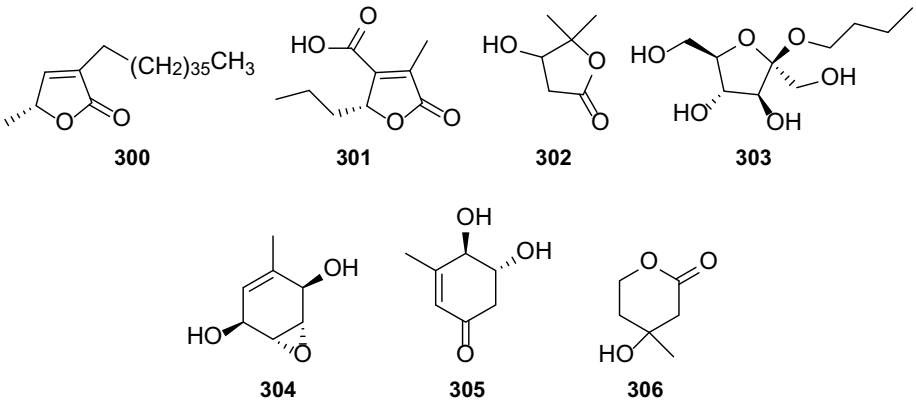


**Fig. 9.** Chemical structures of other compounds (**300–306**).

activity of *C. camphora* essential oils from stem barks (EB), leaves (EL), and fruits (EF) was measured by seal-spaced fumigation [107]. The findings of assay suggested EB and EL exhibited strong fumigant toxicity against *T. castaneum* and L. *serricorne* adults ($LC_{50}$ < 3.2 mg/L air); meanwhile, EB and EL displayed contact toxicity against L. *serricorne* adults ($LD_{50}$ = 7.6, 21.3 μg/adult) but not so effective against *T. castaneum*, while EF showed contact toxicity against *T. castaneum* and *L. serricorne* adults with ($LD_{50}$ = 19.0, 10.1 μg/adult).

### 5.8. Cardiovascular protective activity

*C. cassia* has been studied for its notable cardiovascular protective effects and has demonstrated promising results. Kwon et al. [108] found that *C. cassia* bark extract (10, 30 and 50 μg/mL) suppressed the proliferation of platelet-derived growth factor (PDGF)-BB-induced VSMC *via* G0/G1 blockade, and blocked the transduction of early signal stimulated by PDGF, as well as up-regulated the protein levels of p21 and p27, and restrained the expression of proliferating cell nuclear antigen (PCNA). Also, cinnamic acid (**130**), eugenol (**112**) and cinnamyl alcohol (**116**) were identified as the active components of cardiovascular protective. Soon after, the water extract of *C. cassia* was confirmed to be a potent angiogenesis inhibitor, which restrained vascular endothelial growth factor (VEGF)-induced proliferation, migration, invasion, tube formation, and intracellular signaling events (phosphorylation of ERK, p38 and VEGFR2, and activation of matrix metalloproteinases) in cultured human umbilical vein endothelial cells (HUVECs) [109]. Subsequently, Wei et al. [110] indicated that the water extract of *C. cassia* (750 mg/kg) had preventive and protective effects on diabetic cardiomyopathy through significantly increasing the content of PCR, ATP, and ADP in myocardial tissue, as well as improving cardiac energy metabolism to a certain extent so as to slow heart damage.

### 5.9. Cytoprotective activity

The cytoprotective potential of *C. cassia* has been reported by ElKady and Ramadan previously [111]. It was suggested that the aqueous extract of *C. cassia* (10–50 μg/mL) inhibited the *in vitro* cytotoxic effect of *cis*-diammine dichloroplatinum (CDDP), which was achieved by suppressing the increased expression of CDDP-induced mitochondrial Bax protein, releasing mitochondrial cytochrome *c*, activating caspase-3, making DNA fragmentation and generating ROS, and up-regulating expression of the cytoprotective gene (heme oxygenase (HO)-1).

In recent research, two novel Nrf2 activators, 3*S*-(+)-9-oxonerolidol (NLD, **74**) and 3,3′,4,4′-tetrahydroxydiphenyl (THD, **266**), isolated from *C. chartophyllum*, have been studied the underlying use to prevent oxidative insults in human lung epithelial cells [112]. The authors concluded that Nrf2 and its downstream genes including NADPH: quinone oxidoreductase 1 (NQO-1) and γ-glutamylcysteine synthetase (γ-GCS) in human lung epithelial cells were noticeably activated, and the nuclear translocation and stabilization of Nrf2 was enhanced with the administration of NLD and THD. Moreover, NLD and THD protected human lung epithelial cells from sodium arsenite [As(III)]-induced cytotoxicity.

### 5.10. Neuroprotective activity

Upadhyay et al. [113] previously indicated that the aqueous extract of *C. tamala* (CT) leaves (400 mg/kg) demonstrated a positive impact on the anxiolytic, antidepressant, and anti-stress actions. The experimental data suggested that the CT extract produced an anxiolytic effect comparable to that of Laurazepam, and also induced antidepressant activity equivalent to imipramine, and produced an anti-stress effect similar to *Withania somnifera*, indicating it had a therapeutic effect on mental diseases.

### 5.11. Other pharmacological activity

Kim et al. [46] investigated that cinnamomulactone (**143**), which was isolated from the twigs of *C. cassia*, restrained the gene expression of MMP-3, (IL)-1*β* and MMP-1 on FLS cells with no cytotoxicity up to 100 μM , indicating it was a candidate for a potential lead to develop new RA drug.

Choi et al. [114] found that *C. cassia* water extract showed an underlying therapeutic effect on benign prostatic hyperplasia (BPH), which was achieved by inhibiting protein expression of prostate-specific antigens, estrogen receptor *α* (ER*α*), androgen receptor (AR), 5*α*-reductase (5AR), and steroid receptor coactivator 1. Moreover, administration of *C. cassia* water extract (500 and 1000 μg/ml) restrained the proliferation of RWPE-1 cells by inhibiting 5AR and AR.

Recently, the water extract of *C. osmophloeum* (COK) leaves was confirmed to be used to treat hair loss and demonstrated promising results [115]. The *in vitro* bioassays suggested that COK water extract significantly promoted the proliferation of human hair dermal papilla cells (hDPCs) *via* up-regulating mRNA levels of some hair growth-related factors covering vascular endothelial growth factor, keratinocyte growth factor (KGF) and transforming growth factor-*β*2. Besides, the *in vivo* assays showed that COK leaf extract promoted the anagen phase in the hair growth cycle in hair removal C57BL/6 mouse model.

## 6. Conclusions and future perspectives

The genus *Cinnamomum* is considered to be of excellent economic and medicinal value. This genus has an irreplaceable role in the fields of the chemical industry, agriculture, food industry, and pharmaceutical industry. Its industrialization and application prospects are extensive.

A great variety of chemical components are widely distributed in plants of *Cinnamomum* taxa, among them, terpenes, phenylpropanoids and aromatics are relatively abundant. Various types of chemical components make this genus high medicinal value. Contemporary pharmacological researches have been confirmed that *Cinnamomum* has a wide range of pharmacological properties, including antimicrobial activity, antioxidant activity, anti-inflammatory and analgesic activity, antitumor activity, anti-diabetic and anti-obesity activities, immunoregulation activity, insecticidal and acaricidal activities, cardiovascular protective activity, cytoprotective activity, neuroprotective activity as well as other effects, which make the genus have irreplaceable application value in the fields of chemical industry, agriculture, food industry and pharmaceutical industry. For instance, *C. cassia* extracts can be used in postharvest citrus storage and preservation [81]. The volatile oil of cinnamon and *C. japonicum*[116] has a good preservation effect on fruits and meat. The water extract of *C. camphora* is applied not only for wood preservation [117] but also for air disinfection [118]. The tincture containing 4% volatile oil of *C. longipaniculatum* leaves is of great effect on air disinfection, and it can replace sodium hypochlorite disinfectant [119]. Cinnamaldehyde, the antibacterial substance of *C. zeylanicum* bark essential oil, is an active inhibitor of bacterial growth and is used as natural antimicrobial agents against periodontal disease [3,4,76]. Numerous systematic studies on the genus *Cinnamomum* confirmed that cinnamaldehyde is an indispensable active ingredient for its diverse biological activities. Cinnamaldehyde can be used to prevent and attenuate diabetes [120], atherosclerosis [121], cancer [122], inflammation [123], and heart disease [124].

At present, more research has been conducted on commonly used medicinal plants such as *C. cassia*, *C. camphora* and *C. subavenium* in *Cinnamomum*. In spite of other species have been studied, they mainly focused on the researches of essential oils, and there is a lack of systematic studies of the extraction or separation. Besides, many constituents remain unknown, and further investigations are required to confirm the medicinal properties of *Cinnamomum.* When it comes to the studies of biochemical activities, a small number of monomer compounds have been reported, whereas, in other pharmacological activities, the total plant extracts or essential oils were generally used for research, and few attempts were made to isolate the bioactive constituents and to identify the molecular mechanisms. Additionally, quality control is poorly researched, and no direct clinical evidence has been reported. Therefore, we need to strengthen the research on the biological activity of different types of monomer compounds *in vitro* and *in vivo* in future, in order to benefit the plants of this genus to serve human health better. Moreover, well-developed methods should be established to ensure the consistency, safety and efficacy of the *Cinnamomum* herbs. To sum up, the research on the genus *Cinnamomum* has crucial economic value and theoretical significance, and needs to be further systematically and deeply studied on the basis of existing research to promote the modernization process of traditional medicine.

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**Conflicts of Interest:** The authors declare no conflicts of interest.

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