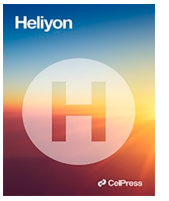
Heliyon 10 (2024) e29707

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon



Review article

A comprehensive account on ethnobotany, phytochemistry and pharmacological insights of genus *Celtis*

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ARTICLE INFO

Keywords:
Celtis
Cannabaceae
Ethnopharmacology
Phytochemistry
Biological activities

ABSTRACT

The plants of *Celtis* L. genus have been traditionally used to cure aches, sore throats, fevers, cancer, sexually transmitted diseases, sexual weakness, diarrhea, stomach problems, amenorrhea, menstrual disorders, kidney stones, and pain. The review aims to give a comprehensive account of the current state of ethnopharmacology, phytochemistry, and biological activities of the *Celtis* genus, as well as to describe the potential area of future avenues. Information on the *Celtis* genus was obtained from internet sources such as Google Scholar, Web of Science, PubMed, ScienceDirect, and so on by using appropriate keywords, including ethnobotanical, pharmacological, pharmaceutical, bioactivity, phytochemistry, and botanical features of the *Celtis* genus. This review identified 14 species in the genus *Celtis* that have a phytopharmacological investigation, including *C.africana* Burm. f., *C. australis* L., *C. occidentalis* L., *C. sinensis* Pers., *C. philippensis* Blanco., *C. tetrandra* Roxb., *C. tessmannii* Rendle., *C. jessoensis* Koidz., *C. adolfi-friderici* Engl., *C. iguanaea* (Jacq.) Sarg., *C. laevigata* Wild., *C. pallida* Torr., *C. zenkeri* Engl., and *C. tournefortii* Lam. This genus contains many classified phytoconstituents, such as terpenoids, organic acids, flavonoids, and volatile compounds. Their extracts and pure substances have been shown to have the same anticancer, antibacterial, anti-inflammatory, antioxidant, hepatoprotective, cardioprotective, urease-inhibiting, and antidiarrheal properties as their traditional uses. In terms of current information on ethnopharmacology, phytochemicals, and pharmacological uses, the data acquired in this review could be beneficial and needed for future research. Some phytoconstituents (for instance, kaempferol, myricetin, quercetin, and eugenol) and extracts (for example, leaves, seeds, and ripe fruits extracts of *C. australis*) showed tremendous results in preliminary testing with promising antimicrobial, anticancer, and urease inhibitory effects. Further research and clinical investigations are needed to develop them as lead compounds and neutraceuticals, which may provide an advance over traditional medicinal systems.

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https://doi.org/10.1016/j.heliyon.2024.e29707
Received 21 December 2022; Received in revised form 19 October 2023; Accepted 14 April 2024
Available online 25 April 2024

Abbreviations

2D-NMR	Two-dimensional Nuclear Magnetic Resonance
A2780	Human Ovarian Cancer
A549	Adeno-Carcinomic Human Alveolar Basal Epithelial Cells
ACF	Aberrant Crypt Foci
AGS	Human Gastric Adenocarcinoma Cells
Bcl2	B-Cell Leukemia 2
CAT	Catalase
C-NMR	Carbon-13 Nuclear Magnetic Resonance
COX-2	Cyclooxygenase-2
CYP-1A1	Cytochrome P450 Family 1 Subfamily A Member 1
DAD	Diode-Array Detection
DPPH	2,2-Diphenyl-1-Picrylhydrazyl
ESI-MS	Electrospray Ionization Mass Spectroscopy
ERK1/2	Extracellular Signal-Regulated Kinase ½
EI-MS	Electron Ionization Mass Spectroscopy
FID	Flame Ionization Detector
FT-IR	Fourier Transform Infrared Spectroscopy
FRAP	Ferric Reducing Ability of Plasma
GC-MS	Gas Chromatography Mass Spectroscopy
GSH	Glutathione
HCT-116	Human Colon Cancer Cell line
H-NMR	Proton Nuclear Magnetic Resonance
HPLC	High-Performance Liquid Chromatography
HR-FAB-MS	High-Resolution Fast Atom Bombardment Mass Spectroscopy
HRESIMS	High-Resolution Electrospray Ionization Mass Spectrometry
HREIMS	High-Resolution Electron Ionization Mass Spectrometry
HMG-CoA Reductase	3-Hydroxy-3-Methyl-Glutaryl-Coenzyme A Reductase
iNOS	Inducible Nitric Oxide Synthase
IR	Infrared Spectroscopy
JNK	Jun N-Terminal Kinases
KAS	Beta-Ketoacyl-[acyl Carrier Protein]-Synthase
LC-MS	Liquid Chromatography Mass Spectroscopy
LDL	Low-Density Lipoprotein
MIC	Minimum Inhibitory Concentration
MBC	Minimum Bactericidal Concentration
mir-26b	MicroRNA 26b
mir-146a	MicroRNA 146a
MRSA	Methicillin-Resistant *Staphylococcus aureus*
MS	Mass Spectroscopy
mRNA	Messenger RNA
NMDAR	N-Methyl-D-Aspartate-Receptor
PC-3	Human Prostate Cancer Cell line
QS	Quorum Sensing
RSH	Reactive Thiol Group,
SFE-CO2	Supercritical Fluid Extraction of CO2
SOD	Superoxide Dismutase
TBARS	Thiobarbituric Acid Reactive Substances
TOF/MS	Time of Flight Mass Spectroscopy
TRAIL	Tumor Necrosis Factor-Related Apoptosis-Inducing Ligand,
TNF-α	Tumor Necrosis Factor-Alpha
UHPLC	Ultra High-Pressure Liquid Chromatography
UV	Ultraviolet Spectroscopy
QqQ-MS	Triple Quadrupole Mass Spectroscopy
BHT	Butylated Hydroxytoluene
BHA	Butylated Hydroxyanisole
MAPK	Mitogen-Activated Protein Kinase
SHP2	Src Homology Region 2 (SH2)-Containing Protein Tyrosine Phosphatase 2
STAT	Signal Transducers and Activators of Transcription

Scientific names
B. cereus *Bacillus cereus*
B. megaterium *Bacillus megaterium*
B. subtilis *Bacillus subtilis*
C. albicans *Candida albicans*
C. freundii *Citrobacter freundii*
C. neoformans *Cryptococcus neoformans*
C. parapsilosis *Candida parapsilosis*
C. tropicalis *Candida tropicalis*
E. aerogenes *Enterobacter aerogenes*
E. coli *Escherichia coli*
K. pneumonia *Klebsiella pneumonia*
L. ivanovii *Listeria ivanovii*
L. monocytogenes *Listeria monocytogenes*
M. avium *Mycobacterium avium*
M. tuberculosis *Mycobacterium tuberculosis*
P. aeruginosa *Pseudomonas aeruginosa*
P. falciparum *Plasmodium falciparum*
P. mirabilis *Proteus mirabilis*
P. vulgaris *Proteus vulgaris*
R. mucilaginosa *Rhodotorulamucilaginosa*
S. aureus *Staphylococcus aureus*
P. aeruginosa *Pseudomonas aeruginosa*

1. Introduction

Scientists have explored natural sources for discovering novel therapeutic compounds throughout the ages [1–3]. This effort has resulted in the discovery of several therapeutic plants that can potentially cure various diseases [4–6]. Interestingly, almost 80 % of the world's population relies heavily on natural approaches to health care needs [7–9]. These medicinal plants' ability to promote recovery is due to their varied chemical compounds, which have abundant biological impacts on living beings [10,11]. In particular, these biologically active phytomolecules are the source of many pharmacological medicines [12]. For instance, medicinal plants feature antimalarial molecules like quinine, cardioactive drugs like digoxin, narcotic pain relievers like morphine, and anti-neoplastic therapies like vincristine and vinblastine [13]. Therefore, potent medicinal plant genus may play a vital role in discovering new lead medicinal molecules.

The *Celtis* genus is one of the potential sources of medicinal compounds that exhibit prosperous ethnopharmacological properties. Almost every portion of these plants (leaves, barks, roots, saps, etc.) historically utilized in traditional treatments for a wide array of diseases such as diabetics, venereal, gastrointestinal, amenorrhea, pain, headache, and fever [14–26]. A wide range of biochemical activities have been revealed by preliminary biological and therapeutic assessments of extracts and secondary metabolites of *Celtis* species. These encompass anti-cancer, anti-inflammatory, antimicrobial, analgesic, antifungal, antidiabetic, and antioxidant features [25,27–38].

Identified chemicals from *Celtis* plants show potential in the fight against antimicrobial resistance (AMR), while AMR is an urgent problem that led to almost 3.57 million deaths worldwide in 2019 [39]. For the managing such AMR threats, the antimicrobial activity of the medicinal plants poses a new hope [40]. Moreover, the antibacterial efficacy of the *Celtis* plant's molecules, including eugenol, palmitic acid, and stearic acid has been noted against resistant strains [41,42]. These phytoconstituents could be used as a starting point to find novel antibiotic compounds that can reduce AMR cases.

However, the therapeutic details of *Celtis*'s compounds is still limited, especially in regard to their efficacy, mode of action, therapeutic index, and probable toxicity. A thorough analysis of the *Celtis* genus is required to clarify its present status and inform future investigation scope to the researcher, because most of the findings made until now are in the preliminary stage. While one review has concentrated on a single *Celtis* species, *Celtis australis* [43], many other species of the *Celtis* genus have not been rigorously reviewed. This comprehensive review of the *Celtis* genus is required to fill this knowledge gap.

Celtis is the genus of hackberries or nettle trees belonging to the Cannabaceae family, is mainly distributed in Africa, Asia, northern Australia, and South and North America [44,45]. Formerly, *Celtis* plants were allocated as either Ulmaceae or a new family, Celtidaceae. However, *Celtis* is now classified under the Cannabaceae family [46]. According to the Plant List 2022, 349 scientific names of the genus *Celtis* are documented, including 69 accepted names, 222 synonym species, and 55 unaccessible data (www.theplantlist.org). This unique genus can be separated from other genera of its family, especially by leaf characteristics: deciduous, alternate, and distichous with three veins rather than one vein. Flowers are small, greenish, and either unisexual or bisexual. Fruits are fleshy and one-seeded [47].

From this comprehensive review, considering the botanical, pharmacological, biological, and phytochemistry aspects of species from the genus *Celtis*, only 14 species have been evaluated for the extensive analyses as per our knowledge, which include *C. africana* Burm. f., *C. australis* L., (synonym: *Celtis australis* var. *eriocarpa* Decne.),*C. occidentalis* L., *C. sinensis* Pers.,*C. philippensis* Blanco.,

C. tetrandra Roxb.,*C. tessmannii* Rendle.,*C. jessoensis* Koidz., (Synonym: *C. choseniana* Nakai), *C. adolfi-friderici* Engl.,*C. iguanaea* (Jacq.) Sarg. (synonym: *C. ehrenbergiana* (Klotzsch) Liebm.),*C. laevigata* Wild., *C. pallida* Torr., *C. zenkeri*Engl., and*C. tournefortii* Lam. (synonym: *C. aetnensis* (Tornab.) Strobl). Among them, *C. africana* Burm. f., *C. australis* L., and *C. sinensis* Pers. were the most often evaluated species across a broad range of ailments. This review aims to gather the present state knowledge from the ethnopharmacological to the phytopharmacological value of the genus *Celtis* for future studies. The existing knowledge of phytochemical components with their characterization data and medicinal uses of this genus is reviewed to accelerate the discovery of new lead compounds.

2. Methods

2.1. The search strategy

The relevant data of the genus *Celtis* was collected via electronic resources such as Google Scholar, PubMed, Web of Science, and ScienceDirect using search terms "ethnobotanical use of *Celtis*", "pharmacological use of *Celtis*", "pharmaceutical use of *Celtis*", "bioactivity of *Celtis*", "phytochemistry of *Celtis*", and "botanical characteristics of *Celtis*". This review included the relevant websites, journal articles, Ph.D. thesis, and books.

2.2. Inclusion and exclusion criteria

From 1881 to 2023, a total of 2514 articles were collected by searching keywords rigorously. Where, only 1479 abstracts were matched with this study's title and aims. Relevant websites, journal articles, books, and Ph.D. thesis were collected, while 202 pertinent sources were short-listed (Fig. 1). Duplicates, lack of full text, abstract not available in English, withdrawn or retracted articles, lack of ethnopharmacology and phytochemical investigation were eliminated (n = 899) (Fig. 1). The details of this review methodology based on Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) were sketched in Fig. 1.

2.3. Software and database

All chemical synonyms were taken from the PubChem database, while synonymous scientific names were taken from the Plant List 2022 website (www.theplantlist.org). Chemical structures of the phytoconstituents were drawn with ChemDraw 16.0 (PerkinElmer Informatics, in Waltham, MA).

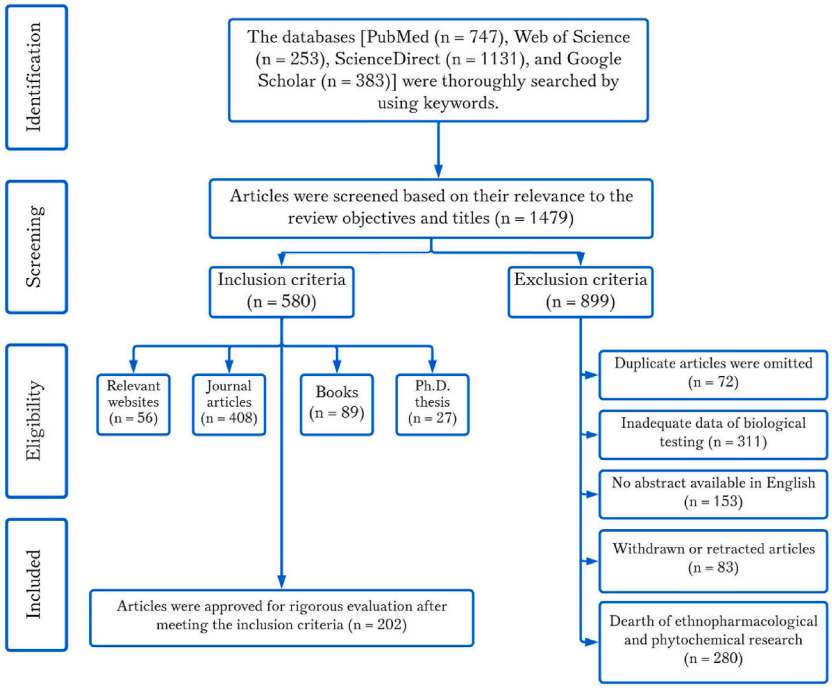

Fig. 1. The article selection procedure following the preferred reporting items for systematic review and meta-analysis (PRISMA) protocols.

Table 1
Botany and distribution of *Celtis* genus.

Scientific name	Distribution	Leaves	Fruits	Flowers	References
C. adolphi-friderici	Togo, Benin, Democratic Republic of Congo, Uganda, Guinea, Ivory Coast, Ghana	Alternate, simple, broadly elliptic, mesophyll, entire, glabrous	Fleshy, sub-globose	The flowers are small with a white corolla.	[49]
C. africana	From West Africa to Sudan, Arabia, Angola, and the Cape Province of South Africa.	Simple alternate, egg-shaped, soft hairy, asymmetrical and has three veins raised from the base.	Yellowish-colored fruits are found from October to February.	Unisexual, greenish, small, and raised in springs.	[27,50,51]
C. australis	From West Asia to the Mediterranean, including Morocco, Spain, Syria, the Caucasus, and Central and Northern Europe.	Simple, cauline, alternate, stipulate, and hairy stipules and petiolate.	Harvested in the autumn and with a single seed	From March to April, green, small, unisexual flowers bloom.	[52–54]
C. choseniana	North Korea, and South Korea.	Pale green, deciduous, narrow or wide ovate, papery, glabrous upper, and glaucous lower leaves.	Orange-yellow, ellipsoidal to globose, and solitary fruit	Flowers placed in tightly packed cymes	[55]
C. iguanaea	From New Mexico east to Virginia, Illinois south to Florida, and New Mexico west to Virginia.	The tops of the leaves are pale greenish-yellow, and the bottoms are pale green.	Ovid shaped, orange or brownish-red colored long fruit comes from September to October.	Flowers bloom in mid-May and grow in separate or small clusters.	[47, 56–58]
	Native to South America, Central America, and North America	Oval to broadly elliptic, wide, acute or attenuate at the apex, obtuse to subcordate at the base.		Greenish-yellow, bisexual, cylindrical ovary, hairy, staminate flowers.	
C. occidentalis	In North America, east of Mississippi, Ontario, and eastern Canada; the Southeastern US; the Southern Appalachian States; and Northwest Italy.	The leaves have three principal veins. oblong or lanceolate in shape.	Reveal in September to October. Purple or brownish, fleshy, thin skin, one seed, globular fruit.	In bloom in April and May	[47,56]
C. pallida	From the south to the middle of America, Arizona, Florida, New Mexico, and Texas.	Ovate to ovate-oblong shape, rounded apex, rough surfaces.	It may be yellow, orange, or red.	It blooms from March to May.	[59]
C. philippensis	Madagascar, India, Myanmar, Southeast China, Taiwan, Thailand, Malaysia, Northeast and West Australia, and the Solomon Islands.	Elliptical to lanceolate, ovate-elliptical shape	The color ranges from orange to red, and the shape ranges from globose to ellipsoid, with an obtusely rounded base.	Cluster cyme has five bisexual flowers and five or more male flowers.	[60,61]
C. sinensis	China, Taiwan, Korea, and Japan	Ovate or ovate-elliptic, hair scatters from major veins.	Fasciculate in the leaf axils and at the stem bases. Style branches are linear and undivided, and bloom in March or April.	Stone white flowers bloom in September or October.	[61,62]
C. tessmanni	Native to Gabon, Cameroon, Congo, Central Republic of Africa.	Elliptic-shaped leaves	Fruits may be orange or black	Hermaphrodites stay at the apex of cymes crowded with male flowers.	[45]
C. tournefortii	Ukraine, Croatia, Greece, Cyprus, northwestern Iran, northern Iraq, Turkey, and the Caucasus region, Azerbaijan.	Oval to narrowly oval, acute to sub acuminate leaves	Matured fruits are yellow to orange in color.	Blooms March–April	[33,63]
C. zenkeri	From Ivory Coast to Angola, Uganda, Tanzania	Oblong-elliptic to ovate, shortly acuminate, 3-nerved from the base	Sub-globose or ovoid, red, pubescent or subglabrous.	Lower with clustered male flowers, often with 1–2 female or hermaphrodite flowers at the top.	[64]

3. Botany

3.1. Taxonomy

The *Celtis* genus is a member of the Plantae kingdom, Viridiplantae subkingdom, Streptophyta infrakingdom, Embryophytasuperdivision, Tracheophyta division, Spermatophytina subdivision, Magnoliopsida class, Rosanae superorder, Rosales order, and Cannabaceae family [48].

Table 2
The traditional uses of *Celtis*genus.

Species	Part used	Method of preparation	Medicinal uses	Region	References
C. adolphi-friderici	Barks	Decoction	General malaise, severe cough, fever and headache, and as an emetic	N/A	[65]
	Barks	Pulp	Relieve costal and side pains of chest	Democratic republic of Congo	[65]
	Barks, fruits, and leaves	N/A	Tuberculosis, severe cough, headache, fever, and sore eyes	Cameroon	[49]
	Fruits	N/A	Tuberculosis	Democratic republic of Congo	[65]
	Leaves	Decoction	Sore eyes	N/A	[65]
	Roots	N/A	Sexual impotence	Ghana	[66]
C. africana	Bark and roots	Dry powder Infused in water or milk	Cancer	South Africa	[16]
	Ground Bark	N/A	General pain, headache, and fever	Nigeria	[15]
	Leaves	Direct Consumption	Trypanosomiasis edema (Cattle)	Kenya	[14]
	Leaves	Pounded leaves	Indigestion (Cattle)	Mali	[14]
	Leaves	N/A	Pleurisy	Lesotho	[15]
	Leaves	N/A	Indigestion, edema	South Africa	[67]
	N/A	N/A	Rheumatism, pains, syphilis, cancer	South Africa	[17,18]
C. australis	Bark	Decoction	Astringent for peptic ulcers, dysentery, and diarrhea	India	[23]
	Barks	Paste	Bones, pimples, contusions, sprains and joint pains	India	[19]
	Fruits	N/A	Amenorrhea, colic, heavy menstrual and intermenstrual bleeding	India	[20,21]
	Leaves and fruits	Decoction	Peptic ulcers, dysentery, diarrhea, heavy menstrual and intermenstrual bleeding, and amenorrhea	India	[19]
	Roots	Boiling	Colic and other stomach troubles	India	[23,24]
	Stems & Leaves	Crushing	Leprosy	India	[22]
	N/A	N/A	Gastrointestinal problems	Morocco	[25]
C. choseniana	Leaves	N/A	Inflammation exposure	Korean	[68]
C. ehrenbergiana	Leaves	Infusion	Indigestion	N/A	[69]
C. eriocarpa	Bark	Grounded powder	Sprain, pimples and Joint pain	India	[70]
	Barks	Powdered bark	Tumor, scabies and skin problems	Kashmir	[71]
	Seeds	Dry seeds	Dysentery	Kashmir	[71]
	Fruits	N/A	Amenorrhea and colic	India	[72]
	Leaves	Decoction	Amenorrhea	Pakistan	[73]
C. iguanaea	Bark	N/A	Fever	Brazil	[74]
	Fruits	Decoction	Dysentery and intestinal catarrh	Brazil	[75]
	Fruits	Sap	Eye diseases	N/A	[76]
	Leaves	Infusion	Used as a vaginal douche to treat leucorrhea	Brazil	[75]
	Leaves and fruits	Aqueous infusion	Kidney pain	Ecuador	[77]
	Leaves and flowers	Infusion	Diabetes mellitus	Mexico	[78]
	Leaves and roots	Decoction	Urinary tract infections	Brazil	[79]
	N/A	Use as tea	Body aches, rheumatism, chest pain, asthma, cramps, poor digestion, diuretics	Brazil	[80]
C. laevigata	Barks	Boiling liquor	Sore throats	America	[81]
	Barks	Powdered shells	Venereal diseases	America	[81]
C. occidentalis	Barks	Decoction	Menses and sore throat	America	[81]
	Barks	Decoction & powdered shells	Venereal Diseases	America	[81]
	Wood	Extracts	Jaundice	Canada	[26]
C. pallida	Stems and Leaves	Dry Powder	Stomach aches, diarrhea, inflammation, wounds, cholera, pain, coughing, and skin infections	Mexico	[36]
C. philippensis	Leaves	Saps	Parasitic infections	N/A	[82]
	Roots	N/A	Ulcer	Tanzania	[83]
C. sinensis	Barks	Decoction	Lumbago, menstruation irregularity, gastric problems, abdominal pain	Korea	[84]
	Leaves	Decoction, paste	Lacquer sore, urticaria, eczema	Korea	[84]
	Root barks	N/A	Dyspepsia, poor appetite, shortness of breath, and swollen feet	China	[21]
C. tessmannii	Bark	Decoction	Diabetes and hypertension problem	Cameroon	[85]
	Stem bark	Decoction	Diabetes mellitus	Gabon	[86]
		N/A	Malaria, gangrene, sexual weakness, insomnia, and nervosity	Cameroon	[85]
		N/A	Tachycardia, anemia, respiratory inflammation, analgesics, fever, and diarrhea	Cameroon	[85]

(*continued on next page*)

Table 2 (*continued*)

Species	Part used	Method of preparation	Medicinal uses	Region	References
C. tetrandra	Excluding root, plants	N/A	Used as a contraceptive for semen coagulation properties	N/A	[87]
	Seeds	Juice	Indigestion	Nepal	[88]
	Shoots and leaves	N/A	Loss of appetite	N/A	[82]
	Roots	N/A	Laxative	N/A	[82]
	Tender leaves	Vegetables	Reducing postpartum pains	India	[89]
C. tournefortii	Seeds	N/A	Kidney sand	Turkey	[33]
	Leaves	N/A	Stomach pain, cessation of bleeding, inducing sedation, and digestion	Turkey	[33]
	Fruits	N/A	Diarrhea, dysentery, and ulcer	Turkey	[33]
C. zenkeri	Stem-bark	Decoction	Cough, arthritis, fever	Nigeria	[90–92]
	Steam-bark	Powdered	Analgesic	Nigeria	[90–92]
	Wood	Macerated	Cuts on the skin	Nigeria	[92]

3.2. Study on flora and distribution

Celtis plants have axillary spines and can be evergreen or deciduous, polygamo-monoecious, or monoecious. The leaves are alternate and have a whole or toothed margin and three veins from the base. Inflorescences might be clustered into cymelets, racemes, or paniculates. Flowers are small, and either unisexual or bisexual. The inflorescences are made up of branched racemes or panicles. Flowers are 4–5 merous, with basally slightly connate tepals in male flowers, caducous, and sessile ovaries. The fruit is fleshy with a wild, foliaceous, and variably folded seed leaf that ranges in size from 3 to 25 mm [45]. Characteristics of flowers, fruits, leaves and distribution of the *Celtis* plants are given in Table 1.

4. Ethnopharmacology

Celtis species are being used to treat a variety of diseases almost all around the world. Approximately all parts of *Celtis* plants are traditionally used to treat various ailments. These parts are processed as decoctions, powdered shells, extracts, and boiling liquor for medicinal purposes (Table 2).

Almost all investigated *Celtis* species are used to treat pains, sore throats, fevers, diarrhea, and stomach problems (Table 2). The stems and leaves of *C. australis* and *C. pallida*, as well as the leaves of *C. philippensis,* are applied in various forms to treat skin-related problems [36,82,93]. Furthermore, venereal diseases such as sexually transmitted diseases and sexual weakness are treated with *C. africana* and the barks of *C. occidentalis* in the forms of decoction and powdered shells [81,94]. Decoctions of the barks of *C. occidentalis* and fruits of *C. australis* are used to treat menstrual problems such as menses, amenorrhea, heavy menstrual, and intermenstrual bleeding [20,21,81]. The dried barks and roots of *C. africana* are applied in powder form and infused in water or milk to treat cancer [16]. In Cameroon, the barks, fruits, and leaves of *C. adolphi-friderici* are used to treat tuberculosis, sore eyes, fever, cough, and headaches [49]. Another species, *C. ehrenbergiana* leaves' infusion is used to treat indigestion [69]. Additionally, the leaves and fruits of *C. iguanaea* and the seeds of *C. tournefortii* are also used to make aqueous infusions for treating kidney problems such as pain and sand [33,77]. These traditional uses suggested that *Celtis* plants may contain compounds with a wide range of biological activities such as analgesic, antimicrobial, anti-inflammatory, anticancer, antioxidant (protective), anti-fibrinolytic, and anti-diarrhea.

5. Phytochemistry

Among the numerous species of *Celtis* plant, only a few have been studied for their phytoconstituents. Although phytochemicals can be found in various parts of the plant, they are mainly found in three principal segments: leaves, stems, and roots. The percentage composition of every plant varies based on preparation techniques, ecological factors, and variety [95]. Flavonoids, tannins, alkaloids, and phenolic constituents are the most common molecules found in phytochemical investigations [96]. Other compounds such as terpenoids, fatty acids, esters, aldehydes, alcohols, and their glycosides are also reported to be present in these plants (Table 3).

Diverse phytochemicals are found in the aerial parts, fruits, leaves, stems, barks, roots, seeds, and twigs of these plants. A study in Saudi Arabia identified amide, fatty acids, terpenoids, sterol [102], and flavonoids [123]in the aerial parts of *C. africana*, while alcohols, aldehydes, ketones, and esters were found in the leaves, fruits, and stems in a South African study in addition to fatty acids, terpenoids, and sterol [27].

C. australis leaves, fruits, barks, and stems contain phytochemical elements that are substantially similar to those found in *C. africana,* such as phenolic acids, fatty acids, flavonoids, terpenoids, and sterols [31,32,111,122,127]. The ripe fruits and seeds of *C. australis* contain various types of esters, and fatty acids [31,32], while the fruits of *C. tournefortii* contain phenolic acid, benzoic acid, fatty acids, esters, tannins, terpenoids, and flavonoids [33,113,114]. *C. pallida* possess alcohol, fatty acids, esters, terpenoids, sugars [36], phenolic acids, and flavonoids [117].

In a Hungarian study of dried extract of *C. occidentalis*, amides were identified in the twigs [100], while an Egyptian study of ethanol extract identified several flavonoid compounds [122]. Dichloromethane-ethanol extracts of *C. iguanaea* leaves contain

Table 3
Phytochemistry of *Celtis* genus.

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
Amides								
1.	Ceramide	Celtisamide A	*C. tessmannii*	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
2.	Ceramide	Celtisamide B	*C. tessmannii*	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
3.	Fatty acid derivatives	Oleamide	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
			C. zenkeri	Leaves		GC-MS	Nigeria	[99]
4.	Hydroxycinnamic acid derivatives	2-trans-3-(4-hydroxyphenyl)- N-[2-(4-hydroxyphenyl)-2- oxoethyl] prop-2-enamide	*C. occidentalis*	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]
5.	Hydroxycinnamic acid derivatives	*cis*-N-coumaroyltyramine	*C. sinensis*	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV	Korea	[101]
6.	Hydroxycinnamic acid derivatives	*trans*-N-caffeoyltyramine	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. occidentalis	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]
			C. sinensis	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV	Korea	[101]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
7.	Hydroxycinnamic acid derivatives	*trans*-N-coumaroyloctopamine	*C. occidentalis*	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
8.	Hydroxycinnamic acid derivatives	*trans*-N-coumaroyltyramine	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
			C. africana	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. occidentalis	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]
			C. sinensis	Twigs	Methanol extract	EI-MS, H-NMR, C-NMR	Korea	[104]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
			C. zenkeri	Stem barks	Methanol extract	HREIMS, C-NMR, H-NMR		[90]
9.	Hydroxycinnamic acid derivatives	*trans*-N-feruloyloctopamine	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
			C. occidentalis	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]
			C. tessmannii	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
10.	Hydroxycinnamic acid derivatives	*trans*-N-feruloyltyramine	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
			C. africana	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. occidentalis	Twigs	Methanol extract	UHPLC-Orbitrap-MS, H-NMR, C-NMR,	Hungary	[100]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. tessmannii	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
11.	Iso-benzo-furanone propanamide	Zenkeramide	*C. zenkeri*	Stem-barks	Methanol	H-NMR, C-NMR, HREIMS	Nigeria	[90]
Esters								
12.	Anthraquinone ester	6-hydroxy-5,7,8-trimethoxy-9,10-dioxo-9,10-dihydroanthracen-2-yl acetate	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[105]
13.	Carboxylic ester	2-Propenoic acid, butyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
14.	Carboxylic ester	Benzyl benzoate	*C. africana*	Stems	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
15.	Carboxylic ester	Malic acid, 4-ethyl ester	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
16.	Carboxylic ester	Methyl salicylate	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
17.	Ester	Sulfurous acid, dibutyl ester	*C. africana*	Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
18.	Fatty acid ester	1,2-Benzenedicarboxylic acid, butyl oxtyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
19.	Fatty acid ester	2-Methylstearoate	*C. australis*	Ripe Fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
20.	Fatty acid ester	Acetic acid n-octadcyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
21.	Fatty acid ester	Arachidic acid methyl ester	*C. tourneforti*	Leaves and fruits	Hexane extract	GC-MS	Iraq	[106]
22.	Fatty acid ester	Capric acid methyl ester	*C. tourneforti*	Leaves and fruits	Hexane extract	GC-MS	Iraq	[106]
23.	Fatty acid ester	Dibutyl phthalate	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
24.	Fatty acid ester	Diethyl phthalate	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
25.	Fatty acid ester	Ethyl linolenate	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
26.	Fatty acid ester	Ethyl palmitate	*C. africana*	Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
27.	Fatty acid ester	Glycerol 1-stearate	*C. adolphi-friderici*	Roots	Acetone extract	FAB-MS, EI-MS, H-NMR	Cameroon	[103]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
28.	Fatty acid ester	Hexadecanoic, 2-hydroxyethyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
29.	Fatty acid ester	Hexacosyl heptafluorobutyrate	*C. zenkeri*	Leaves	Methanol	GC-MS	Nigeria	[107]
30.	Fatty acid ester	Lignoceric acid methyl ester	*C. tourneforti*	Leaves and fruits	Hexane extract	GC-MS	Iraq	[106]
31.	Fatty acid ester	Linoleic acid-, 2-hydroxy-1-(hydroxymethyl) ethyl ester	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
32.	Fatty acid ester	Linolenic acid, methyl ester	*C. africana*	Fruits	Ethyl acetate Extract	2D-GC-TOF/MS	South Africa	[27]
33.	Fatty acid ester	Methyl 13-methyltetradecanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
34.	Fatty acid ester	Methyl 14-acetyl hydroxy palmitate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
35.	Fatty acid ester	Methyl 1-dotriacontanoate	*C. australis*	Ripe Fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
36.	Fatty acid ester	Methyl 1-tetradecanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
37.	Fatty acid ester	Methyl 2,4-dimethyl heneicosanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
38.	Fatty acid ester	Methyl dotriacentanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
39.	Fatty acid ester	Methyl linoleate	*C. australis*	Ripe Fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
40.	Fatty acid ester	Methyl oleate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
			C. zenkeri	Leaves		GC-MS	Nigeria	[31]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
41.	Fatty acid ester	Methyl Palmitate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
			C. iguanaea	Leaves	Dichloromethane and ethanol extract	GC-MS	Brazil	[108]
42.	Fatty acid ester	Methyl pentachloro stearate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
43.	Fatty acid ester	Methyl stearate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
			C. iguanaea	Leaves	Dichloromethane and ethanol extract	GC-MS	Brazil	[108]
44.	Fatty acid ester	Methyl tetradecanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
45.	Fatty acid ester	Methyl tricosanoate	*C. australis*	Ripe fruits	Ethanol extract	FT-IR, GC-MS	India	[31]
			C. tourneforti	Leaves and fruits	Hexane extract	GC-MS	Iraq	[106]
46.	Fatty acid ester	Monolinolenin	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
47.	Fatty acid ester	Phthalic acid, butyl 2-ethylhexyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
48.	Fatty acid ester	Phthalic acid, butyl tetradecyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
49.	Fatty acid ester	Phthalic acid, di-isobutyl ester	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
50.	Fatty acid ester	Stigmast-5-en-3-ol oleate	*C. ehrenbergiana*	Leaves	Crude methanolic extract	GC-MS	Brazil	[109]
51.	Hydroxycinnamic acid ester	Chlorogenic acid	*C. australis*	Fruits	Methanol extract	HPLC	Iran	[110]
			C. australis	Leaves		RP-HPLC, UV	Italy	[111]
			C. iguanaea	Leaves	70 % ethanol	HPLC	Brazil	[112]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Fruits & Leaves	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
52.	Phenolic ester	Protocatechuic acid, ethyl ester	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
53.	Triterpene ester	3β-trans-sinapoyloxylup-20(29)-en-28-ol	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
54.	Triterpene ester	3β-trans-feruloyloxy-16β-hydroxylup-20(29)-ene	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
Flavonoids								
55.	Anthocyanin	Cyanidin-3,5-di-O-glucoside	*C. australis*	fruits & Leaves	Water and ethanol extract	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
56.	Anthocyanin	Delphinidin-3,5-di-O-glucoside	*C. australis*	fruits & Leaves	Water extract	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
57.	Anthocyanin	Pelargonidin-3,5-di-O-glucoside	*C. australis*	fruits & Leaves	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
58.	Flavanol	Afzelechin	*C. tetrandra*	Barks	Ethyl acetate extract	MS, H-NMR, C-NMR, HRESIMS	Thailand	[116]
59.	Flavanol	Catechin	*C. pallida*	Leaves & Fruits	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
			C. tetrandra	Barks	Ethyl acetate extract	MS, H-NMR, C-NMR, HRESIMS	Thailand	[116]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
60.	Flavanol	Epiafzelechin	*C. tetrandra*	Barks	Ethyl acetate extract	MS, H-NMR, C-NMR, HRESIMS	Thailand	[116]
61.	Flavanol	Epicatechin	*C. australis*	Leaves	Ethanol extract	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. pallida	Leaves & Fruits	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
62.	Flavanol	Gallocatechin	*C. pallida*	Leaves	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
63.	Flavanol dimer	Epiafzelechin-(4α→8)-catechin	*C. tetrandra*	Barks	Ethyl acetate extract	MS, H-NMR, C-NMR, HRESIMS	Thailand	[116]
64.	Flavanol dimer	Epiafzelechin-(4α→8)-epicatechin	*C. tetrandra*	Barks	Ethyl acetate extract	MS, H-NMR, C-NMR, HRESIMS	Thailand	[116]
65.	Flavanone	Naringenin	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Fruits, Leaves & Young twigs	methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
66.	Flavanone glycoside	Eriodictyol acetyl-glucoside- pentoside	*C. eriocarpa*	leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
67.	Flavanone glycoside	Hesperidin	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
68.	Flavanone glycoside	Naringenin glucuronide glucoside	*C. eriocarpa*	Leaves	methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
69.	Flavanone glycoside	Naringin	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Fruits, Leaves &Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
70.	Flavanone glycoside	Neohesperidin	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
71.	Flavanonol	Taxifolin	*C. tournefortii*	Fruits	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
72.	Flavone	Acacetin	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
73.	Flavone	Apigenin	*C. australis*	Fruits	Ethanol extract	EIMS, IR, H-NMR, C-NMR	India	[119]
			C. australis	Fruits	Methanol extract	HPLC	Iran	[110]
			C. tournefortii	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey, Iraq	[106, 114]
74.	Flavone	Diosmetin	*C. tournefortii*	Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
75.	Flavone	Hispidulin	*C. australis*	Leaves	Methanol extract	LC-MS	Montenegreo	[120]
76.	Flavone	Luteolin	*C. choseniana*	Leaves	Methanol extract	HPLC	Korea	[68]
77.	Flavone	Wogonin	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
78.	Flavone glycoside	2"-O-α-L-rhamnopyranosyl-7-O-methylvitexin	*C. australis*	Leaves		RP-HPLC, UV	Italy	[111]
79.	Flavone glycoside	2-O-pentosyl-8-C-hexosyl-apigenin	*C. iguanaea*	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
80.	Flavone glycoside	2″-O-β-D-galactopyranosyl orientin	*C. australis*	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
81.	Flavone glycoside	2″-O-β-galactopyranosyl vitexin	*C. australis*	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
82.	Flavone glycoside	2-α-rhamnopyranosyl vitexin	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
83.	Flavone glycoside	4‴-rhamnosyl-2″-O-β-D-galactopyranosyl vitexin	*C. australis*	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
84.	Flavone glycoside	Acacetin 7-O-glucoside	*C. australis*	Leaves		RP-HPLC, UV	Italy	[111]
85.	Flavone glycoside	Acacetin-8-C-rutinoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
86.	Flavone glycoside	Apigenin 6-C-glucoside	*C. australis*	Leaves		RP-HPLC, UV	Italy	[111]
87.	Flavone glycoside	Apigenin 7-O-galloylrhamnoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
88.	Flavone glycoside	Apigenin-6,8-di-C-glucoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
89.	Flavone glycoside	Apigenin-6,8-di-C-rhamnoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
90.	Flavone glycoside	Apigetrin	*C. australis*	Leaves	Methanol extract	LC-MS	Montenegreo	[120]
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
91.	Flavone glycoside	Baicalein dipentosidehexoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
92.	Flavone glycoside	Baicalein-8-C-glucoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
93.	Flavone glycoside	Baicalin	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
94.	Flavone glycoside	Celtiside A	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
95.	Flavone glycoside	Celtiside B	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
96.	Flavone glycoside	Dihydroluteolin-7-O-glucoronide	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
97.	Flavone glycoside	Diosmin	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
98.	Flavone glycoside	Isoorientin	*C. australis*	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
99.	Flavone glycoside	Isoswertiajaponin	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
100.	Flavone glycoside	Isoswertisin	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
101.	Flavone glycoside	Isovitexin	*C. australis*	Leaves		RP-HPLC, UV	Italy	[111]
			C. australis		Ethanol extract	UV, HRESIMS, H-NMR, C-NMR	Egypt	[122]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. sinensis	Leaves	Ethanol extract		China	[124]
102.	Flavone glycoside	Isovitexinhydroxyferuloyl glucoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
103.	Flavone glycoside	Luteolin-4 -O-rhamnosyl (1 → 2) glycoside	*C. iguanaea*	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
104.	Flavone glycoside	Luteolin-6-C-acetyl pentoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
105.	Flavone glycoside	Orientin	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
			C. australis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. iguanaea	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
106.	Flavone glycoside	Scutellarin	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
107.	Flavone glycoside	Tetrahydroxy isoflavone-O-hexoside	*C. iguanaea*	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
108.	Flavone glycoside	Vitexin	*C. africana*	Aerial parts	Ethanol & water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
			C. australis	Leaves		RP-HPLC, UV	Italy	[111]
			C. australis		Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. eriocarpa	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
			C. iguanaea	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
109.	Flavone glycoside	Vitexin 2″-O-rhamnoside	*C. africana*	Aerial parts	Ethanol and water extract	1D NMR, 2D NMR	Saudi Arabia	[123]
			C. eriocarpa	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
110.	Flavonol	Fisetin	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
111.	Flavonol	Galangin	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
112.	Flavonol	Kaempferol	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
			C. choseniana	Leaves	Methanol extract	HPLC	Korea	[68]
113.	Flavonol	Morin	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
114.	Flavonol	Myricetin	*C. tournefortii*	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
115.	Flavonol	Quercetin	*C. australis*	Fruits	Ethanol extract	EIMS, IR, H-NMR, C-NMR	India	[119]
			C. choseniana	Leaves	Methanol extract	HPLC	Korea	[68]
			C. ehrenbergiana	Leaves	Lyophilized aqueous, and crude methanolic extract	GC-MS	Brazil	[109]
			C. iguanaea	Leaves	70 % Ethanol	HPLC	Brazil	[112]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
116.	Flavonol glycoside	Isorhamnetin hexosidepentoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
117.	Flavonol glycoside	Kaempferol 3-O-glucoside	*C. australis*	Leaves	Methanol extract	LC-MS	Montenegreo	[120]
118.	Flavonol glycoside	Quercetin rhamnosidedipentoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
119.	Flavonol glycoside	Quercetin-3-β-D-glucoside	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
120.	Flavonol glycoside	Rutin	*C. australis*	Fruits	Methanol extract	HPLC	Iran	[110]
			C. australis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]

(*continued on next page*)

Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. iguanaea	Leaves	70 % Ethanol extract	HPLC	Brazil	[112]
			C. occidentalis	Leaves	Ethanol extract	UV, HRESIMS, 1D-NMR, 2D-NMR	Egypt	[122]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Fruits, Leaves & Young twigs	Methanolic solution with 1 % acetic acid	HPLC	Iraq	[106]
			C. tournefortii	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
			C. iguanaea	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
121.	Flavonolignan	Silibinin	*C. tournefortii*	Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
122.	Isoflavone	Biochanin A	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
			C. tournefortii	Leaves	Methanol extract	LC-MS/MS	Mardin	[125]
123.	Isoflavone glycoside	Genistin	*C. iguanaea*	Leaves	Dichloromethane extract	ESI-MS	Brazil	[121]
Organic acids								
124.	Aliphatic carboxylic acid	5-hydroxypipecolic acid	*C. ehrenbergiana*	Leaves	Crude methanolic extract	GC-MS	Brazil	[109]
125.	Aliphatic carboxylic acid	Azelaic acid	*C. adolphi-friderici*	Roots	Acetone extract	ESIHRMS, EI-MS, H-NMR	Cameroon	[103]
126.	Aliphatic carboxylic acid	Fumaric acid	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
127.	Aliphatic carboxylic acid	Methyl quinic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
128.	Aliphatic dicarboxylic acid	Quinic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
129.	Aliphatic dicarboxylic acid	Sebacic acid	*C. adolphi-friderici*	Roots	Acetone extract	EI-MS, H-NMR	Cameroon	[103]
130.	Aliphatic dicarboxylic acid	Shikimic Acid	*C. tournefortii*	Leaves	Methanol extract	LC-MS/MS	Mardin	[125]
131.	Aliphatic dicarboxylic acid	Succinic acid	*C. tessmannii*	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
132.	Benzoic acid	4-Hydroxybenzoic acid	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
133.	Benzoic acid	Hydroxybenzoic acid	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
134.	Carboxylic acid metabolites	Allantoin	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
135.	Dicarboxylic acid	Tartaric acid quinylhydroxybenzoylglucoronide	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
136.	Dihydroxy-benzoic acid	Gentisic acid	*C. laevigata*	Leaves	Aqueous extract	UV, Chromatographed	United States	[126]
			C. tournefortii	Fruits, Leaves &	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
137.	Dihydroxy-benzoic acid	Protocatechuic acid	*C. tournefortii*	Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
			C. australis	Leaves	Methanol extract	LC-MS	Montenegreo	[120]
138.	Dihydroxy-benzoic acid	Vanillic acid	*C. australis*	Leaves	Ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. australis	Leaves	Hydro-methanolic extract	H-NMR, C-NMR,	Morocco	[127]
			C. adolphi-friderici	Roots	Acetone extract	H-NMR, C-NMR,	Cameroon	[103]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
139.	Fatty acid	2-hydroxy linoleic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
140.	Fatty acid	Behenic acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
141.	Fatty acid	Heptacosanoic acid	*C. adolphi-friderici*	Roots	Acetone extract	EI-MS, H-NMR	Cameroon	[103]
142.	Fatty acid	Hexacosanoic acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
143.	Fatty acid	Hydroxy linolenic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
144.	Fatty acid	Lacceroic acid	*C. adolphi-friderici*	Roots	Acetone extract	EIHRMS, EI-MS, H-NMR	Cameroon	[103]
145.	Fatty acid	Lauric acid	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
146.	Fatty acid	Lignoceric acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
147.	Fatty acid	Linoleic acid	*C. africana*	Leaves, Fruits & Stems	Hexane extract, Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. australis	Seeds	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33]
148.	Fatty acid	Linolenic acid	*C. africana*	Fruits, Leaves & Stems	Hexane extract, Ethyl acetate extract, dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. ehrenbergiana	Leaves	Crude methanolic extract	GC-MS	Brazil	[109]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33]
149.	Fatty acid	Margaric acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
150.	Fatty acid	Myristic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
151.	Fatty acid	Nonadecanoic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
152.	Fatty acid	Octacosanoic acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
153.	Fatty acid	Oleic acid	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. australis	Seeds	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
154.	Fatty acid	Palmitic acid	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. africana	Leaves, Fruits & Stems	Hexane extract, Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. australis	Seeds	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. ehrenbergiana	Leaves	Crude methanolic extract	GC-MS	Brazil	[109]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. sinensis	Leave & Stems	SFE-CO_2	GC-MS	China	[98]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33]
155.	Fatty acid	Palmitoleic acid	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33]
156.	Fatty acid	Stearic acid	*C. australis*	Seeds	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. sinensis	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	GC, FID	Turkey	[33])
157.	Hydroxycinnamic acid	Aesculetin	*C. australis*	Leaves	Methanol extract	LC-MS	Montenegreo	[120]
158.	Hydroxycinnamic acid	Benzoyl sinapic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
159.	Hydroxycinnamic acid	Caffeic acid	*C. australis*	Fruits	Methanol extract	HPLC	Iran	[110]
			C. laevigata	Leaves	Aqueous extract	UV, Chromatographed	United states	[126]
			C. pallida	Fruits	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
160.	Hydroxycinnamic acid	Cinnamic acid	*C. australis*	Fruits	Methanol extract	HPLC	Iran	[110]
			C. pallida	Fruits	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
			C. tournefortii	Leaves	Methanol solution with 1 % acetic acid	HPLC	Turkey	[106]
161.	Hydroxycinnamic acid	Hydroxy-caffeic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
162.	Hydroxycinnamic acid	*p*-coumaric acid	*C. australis*	Fruits	Methanol extract	HPLC	Iran	[110]
			C. laevigata	Leaves	Aqueous extract	UV, Chromatographed	United states	[126]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. tournefortii	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
163.	Hydroxycinnamic acid	*p*-Coumaric acid-O-glucoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
			C. eriocarpa	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
164.	Hydroxycinnamic acid	Phenyl caffeic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
165.	Hydroxycinnamic acid	Sinapic acid	*C. tournefortii*	Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
166.	Hydroxycinnamic acid glycoside	Rosmarinic acid	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
167.	Phenolic acid	Dehydro-acacetin dihydroxybenzoic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
168.	Phenolic acid	Quinic acid phenol	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
169.	Phenolic acid	Quinoyl galloyl tartaric acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
170.	Phenolic acid	Quinyl malic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
171.	Phenolic acid	Quinylvanilyl malic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
172.	Phenolic acid	Syringic acid quinylrhamnoside	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
173.	Trihydroxy- benzoic acid	Gallic acid	*C. australis*	Fruits & leaves	Water extract	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. australis	Fruits	Methanol extract	HPLC	Iran	[110]
			C. ehrenbergiana		Lyophilized aqueous and crude methanolic extract	GC-MS	Brazil	[109]
			C. iguanaea	Leaves	70 % Ethanol	HPLC	Brazil	[112]
			C. pallida	Leaves & Fruits	Methanol, methanol-water or acetone extract	HPLC	Mexico	[117]
			C. tournefortii	Fruits, Leaves, & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
Terpenoids								
174.	Bacterial pentacyclic triterpenoid	3β-hydroxy-35-(cyclohexyl-50-propan-70-one)-33-ethyl-34-methylbactereohopane	*C. australis*	Barks	Ethanol extract	IR, 2D NMR, ESI-MS, n LCMS QTOF	India	[128]
175.	Carotenoid	Lutein	*C. australis*	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
176.	Carotenoid	Zeaxanthin	*C. australis*	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
177.	Carotenoid	β-carotene	*C. australis*	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
178.	Diterpene	Phytol	*C. africana*	Leaves	Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. iguanaea	Leaves	Dichloromethane and ethanol extract	GC-MS	Brazil	[108]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. zenkeri	Leaves, Stem-bark		GC-MS	Nigeria	[99]
179.	Diterpene	Retinol	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
180.	Tocopherol	ç-Tocopherol	*C. africana*	Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
181.	Tocopherol	α-Tocopherol	*C. africana*	Stems & Leaves	Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. australis	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. ehrenbergiana	Leaves	Crude methanolic extract	GC /MS	Brazil	[109]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
182.	Tocopherol	γ-tocopherol	*C. australis*	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
183.	Tocopherol	δ-tocopherol	*C. australis*	Fruits	Water and ethanol extracts	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
			C. tournefortii	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
184.	Triterpenoid	(3β)-3-hydroxy-30-propylhopan-31-one	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[105]
185.	Triterpenoid	(3β)-oleanan-3-ol	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[105]
186.	Triterpenoid	(9β,31R)-9,25-cyclo-30-propylhopan-31-ol	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[105]
187.	Triterpenoid	20-epibryonolic acid	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
188.	Triterpenoid	3β-O-(E)-coumaroylbetulin	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
189.	Triterpenoid	3β-O-(E)-feruloylbetulin	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
190.	Triterpenoid	Betulin	*C. philippinensis*	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
191.	Triterpenoid	Betulinic acid	*C. tessmannii*	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
192.	Triterpenoid	Epifriedelanol	*C. iguanaea*	Barks	Ethanol extract	H-NMR, C-NMR	Brazil	[129]
			C. sinensis	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV,	Korea	[101]
193.	Triterpenoid	Friedelin	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
			C. africana	Stems	Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. iguanaea	Barks	Ethanol extract	H-NMR, C-NMR	Brazil	[129]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
194.	Triterpenoid	Friedelinol	*C. africana*	Stems	Hexane extract, Ethyl acetate extract, Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
195.	Triterpenoid	Germanicol	*C. sinensis*	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV,	Korea	[101]
196.	Triterpenoid	Lupeol	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
197.	Triterpenoid	Oleanolic acid	*C. africana*	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
198.	Triterpenoid	Platanic acid	*C. tessmannii*	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
199.	Triterpenoid	Squalene	*C. africana*	Leaves	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. ehrenbergiana		Crude methanolic extract	GC-MS	Brazil	[109]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
200.	Triterpenoid	Ursolic acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. philippinensis	Twigs	Methanol extract	FT-IR, HR-FAB-MS, H-NMR, C-NMR	Indonesia	[115]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
201.	Triterpenoid glycoside	(3β,9β)-9,25-cycloolean-12-en-3-yl β-D-glucofuranoside	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[105]
Miscellaneous compounds								
202.	Acid anhydrate	2-Dodecen-1-yl (−) succinic anhydride	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
203.	Acid anhydrate	Hydroxy-benzoyl *p*-coumaric acid anhydride	*C. tessmannii*	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
204.	Alcohol	1,2-Epoxylinalool	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
205.	Alcohol	1-Eicosanol	*C. africana*	Leaves	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
206.	Alcohol	1-Hexacosanol	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
207.	Alcohol	1-Hexadecanol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
208.	Alcohol	1-Propanol, 2-(dimethyl-amino)-2-methyl	*C. africana*	Fruits	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
209.	Alcohol	1-Tetracosanol	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
210.	Alcohol	2,2,3,4-Tetramethylhex-5-en-3-ol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
211.	Alcohol	2-Ethyl-1-hexanol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
212.	Alcohol	2-Hexen-1-ol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
213.	Alcohol	2-Methyl-1-hexadecanol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
214.	Alcohol	3,4,4-Trimethyl-3-pentanol	*C. africana*	Fruits	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
215.	Alcohol	3,7,11,15-Tetramethyl-2-hexadecen-1-ol	*C. iguanaea*	Leaves	Dichloromethane and ethanol extract	GC-MS	Brazil	[108]
216.	Alcohol	3,7-Dimethyl-2,6-octadien-1-ol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
217.	Alcohol	3-Hexanol,4,4-dimethyl-	*C. africana*	Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
218.	Alcohol	3-Hexen-1-ol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
			C. africana	Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
219.	Alcohol	Docosanol	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
220.	Alcohol	Mome inositol	*C. africana*	Leaves, Fruits & Stems	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]

(*continued on next page*)

Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
221.	Alcohol	ND2H-1-Benzopyran-6-ol,3,4-dihydro-2,7,8-trimethyl- 2-(4,8,12-trimethyltridecyl)	*C. africana*	Fruits	Ethyl acetate extracts	2D-GC-TOF/MS	South Africa	[27]
222.	Alcohol	n-Tridecan-1-ol	*C. africana*	Stems	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
223.	Alcohol	Sapiol	*C. adolphi-friderici*	Roots	Acetone extract	NMR and MS	Cameroon	[103]
224.	Alcohol	*trans*-9-Hexadecen-1-ol	*C. sinensis*	Leaves and Stems	SFE-CO_2	GC-MS	China	[98]
225.	Aldehyde	14-Hexadecenal	*C. sinensis*	Leaves and Stems	SFE-CO_2	GC-MS	China	[98]
226.	Aldehyde	2,4-Heptadienal	*C. africana*	Stems	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
227.	Aldehyde	2-Heptenal	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. africana	Stems	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
228.	Aldehyde	2-Propylhexanal	*C. africana*	Fruits	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
229.	Aldehyde	3,5-Dihydroxybenzaldehyde	*C. australis*	Fruits & Leaves	Ethanol extract	UHPLC–QqQ-MS/MS, UV	Croatia	[32]
230.	Aldehyde	4-Hydroxybenzaldehyde	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
231.	Aldehyde	Benzaldeyde	*C. sinensis*	Leaves and Stems	SFE-CO_2	GC-MS	China	[98]
232.	Aldehyde	Benzeacetaldehyde	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
233.	Aldehyde	Deca-2,4-dienal	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. africana	Stems	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
234.	Aldehyde	Hexanal	*C. africana*	Stems	Ethyl acetate extract	2D-GC-TOF/MS	South Africa	[27]
235.	Aldehyde	Indole-3-carboxaldehyde	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
236.	Alkane	(−)-trans-Pinane	*C. zenkeri*	Leaves	Methanol	GC-MS	Nigeria	[107]
237.	Alkane	(R)-1-Methyl-4-(1-methylethyl)-cyclohexene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
238.	Alkane	1-Docosene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
239.	Alkane	1α,2α,4α-1, 2,4-Trimethyl-cyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
240.	Alkane	2,6,10,15-Tetramethyl-heptadecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
241.	Alkane	2,6,10-trimethyl-tetradecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
242.	Alkane	6-Tridecene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
243.	Alkane	7-Tetradecene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
244.	Alkane	Benzedrex	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
245.	Alkane	bicyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
246.	Alkane	*cis*-1,2-Dimethyl-cyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]

(*continued on next page*)

Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
247.	Alkane	*cis*-1-Ethyl-2-methyl-cyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
248.	Alkane	Decane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
249.	Alkane	Dodecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
250.	Alkane	Ethyl-cyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
251.	Alkane	Heptadecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
252.	Alkane	Hexadecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
253.	Alkane	Nonadecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
254.	Alkane	Nonane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
255.	Alkane	Octadecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
256.	Alkane	Pentyl-cyclohexane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
257.	Alkane	Tetradecane	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
258.	Alkene	2,4-Dimethylpenta-1,3-diene	*C. zenkeri*	Leaves		GC-MS	Nigeria	[99]
259.	Alkene	3,5-Dimethyl-1,6-heptadiene	*C. zenkeri*	Leaves		GC-MS	Nigeria	[99]
260.	Alkene	Nonadecene	*C. zenkeri*	Stem bark		GC-MS	Nigeria	[99]
261.	Amino acid	2-Aminooctanoic acid	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
262.	Amino acid	Aspartic acid	*C. adolphi-friderici*	Roots	Acetone extract	EI-MS, H-NMR, C-NMR	Cameroon	[103]
263.	Benzene	1,2,4,5-Tetramethyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
264.	Benzene	1,3,5-Trimethyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
265.	Benzene	1,3-Diethyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
266.	Benzene	1,4-Diethyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
267.	Benzene	1-Ethyl-3-methyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
268.	Benzene	1-Isocyano-2-methyl-benzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
269.	Benzene	Ethylbenzene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
270.	Benzene	Naphthalene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
271.	Benzene	p-Xylene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
272.	Benzopyrone	Scopoletin	*C. laevigata*	Leaves	Aqueous extract	UV, Chromatographed	United States	[126]

(*continued on next page*)

Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
273.	Benzopyrone glycoside	Scopolin	*C. laevigata*	Leaves	Aqueous extract	UV, Chromatographed	United States	[126]
274.	Dimer	Quinic acid-O- Malic acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
275.	Dimer	Quinic acid-O-tartaric acid	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
276.	Hydroxy pyrone	3-hydroxy-2-methyl-4H-pyran-4-one	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
277.	Ketone	2-Pyrrolidinone, 1-methyl-	*C. zenkeri*	Leaves	Methanol extract	GC-MS	Nigeria	[107]
278.	Ketone	1-(4-hydroxy-3-methoxyphenyl) ethanone	*C. africana*	Stems	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
279.	Ketone	2,3-Heptanedione	*C. africana*	Stems & Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
280.	Ketone	2,3-Pentanedione	*C. africana*	Fruits, Leaves & Stems	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
281.	Ketone	3,4-Dimethyldihydrofuran-2,5-dione	*C. africana*	Stems	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
282.	Ketone	3,5,6,7,8,8a-hexahydro-4,8a-dimethyl-6-(1-methylethenyl- 2(1H)naphthalenone	*C. africana*	Stems	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
283.	Ketone	3-Hydroxy-5,6-epoxy-â-ionone	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
284.	Ketone	Cyclohexanone	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MC	China	[98]
285.	Ketone	Jasmone	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
286.	Lignan glycoside	Pinoresinol-4-O-glucoside	*C. sinensis*	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV	Korea	[101]
287.	Lignan glycoside	Pinoresinol-4-O-rutinoside	*C. sinensis*	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV	Korea	[101]
288.	Lipid (glucosphingolipid)	1-O-(β-D-glucopyranosyl) -(2S,3S,4R,5E)-2N-([2′R,6′E]-2′-hydroxyoctadeca-6′-enoylamino)-5-pentadecaene-1,3,4-triol	*C. africana*	Aerial parts	Ethanol-water extract	2D-NMR, MS	Saudi Arabia	[37]
289.	Lipid (glucosphingolipid)	Eloundemnoside	*C. adolphi-friderici*	Roots	Acetone extract	H-NMR, C-NMR, HRESIMS, UV, IR	Cameroon	[103]
290.	Nitrogeneous base	2-Amino-9-(3,4-dihydroxy-5-hydroxymethyl-tetrahydrofuran-2-yl)-3,9 dihydro-purin-6-one	*C. africana*	Leaves, Fruits & Stems	Dichloromethane: methanol	2D-GC-TOF/MS	South Africa	[27]
291.	Nitrogeneous base	2,4(1H,3H)-pyrimidinedione,5-methyl	*C. africana*	Stems	Dichloromethane: methanol	2D-GC-TOF/MS	South Africa	[27]
292.	Phenol	2,2′-Methylenebis[6-(1,1-dimethylethyl)-4-methyl]-phenol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
293.	Phenol	2,4-bis(1,1-dimethylethyl)-Phenol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
294.	Phenol	2-Methoxy-6-(2-propenyl)-phenol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
295.	Phenol	5-Pentyl-1,3-benzenediol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
296.	Phenol	Butylated hydroxytoluene	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
297.	Phenol	Eugenol	*C. sinensis*	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
298.	Phenolic aldehyde	Ferulaldehyde	*C. eriocarpa*	Leaves	Methanol extract	UHPLC-DAD, ESI-MS	Pakistan	[118]
299.	Steroid	(3β,9β,14β)-14-hydroxy-9,19-cyclocholan-3-yl β-D-glucopyranoside	*C. australis*	Stem barks & Fruits	Ethanol extract	H-NMR, C-NMR, IR, MS	India	[119]

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Table 3 (*continued*)

Compound Number	Chemical class	Compound	Species	Organs	Extract	Structure elucidation	Collection site	Rf no.
300.	Sterol	α-Sitosterol	*C. africana*	Fruits	Dichloromethane: methanol extract	2D-GC-TOF/MS	South Africa	[27]
			C. africana	Stems & Leaves	Hexane extract	2D-GC-TOF/MS	South Africa	[27]
			C. sinensis	Leaves and stems	SFE-CO_2	GC-MS	China	[98]
301.	Sterol	β-sitosterol	*C. adolphi-friderici*	Roots	Acetone extract	H-NMR, C-NMR, HRESIMS, UV, IR	Cameroon	[103]
			C. africana	Aerial parts	Ethanol-water extract	H-NMR, C-NMR, EIMS, HREIMS	Saudi Arabia	[102]
			C. australis	Leaves	Hydro-methanolic extract	H-NMR, C-NMR,	Morocco	[127]
			C. pallida	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
			C. sinensis	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV	Korea	[101]
			C. tessmannii	Stem barks	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
			C. zenkeri	Stem barks	Methanol	HREIMS, H-NMR, C-NMR	Nigeria	[90]
302.	Sterol	Gamma-sitosterol	*C. ehrenbergiana*	Leaves	Crude methanolic extract	GC-MS	Brazil	[109]
			C. iguanaea	Leaves	Dichloromethane & ethanol extract	GC-MS	Brazil	[108]
303.	Sterol glycoside	β-sitosterol-3-O-β-glucoside	*C. australis*	Leaves	Hydro-methanolic extract	H-NMR, C-NMR,	Morocco	[127]
			C. sinensis	Twigs	Methanol extract	H-NMR, C-NMR, FT-IR, UV,	Korea	[101]
304.	Sterol glycoside	β-sitosterol-3-O-β-D-glucopyranoside	*C. adolphi-friderici*	Roots	Acetone extract		Cameroon	[103]
			C. zenkeri	Stem bark	Methanol extract	HREIMS, H-NMR, C-NMR	Nigeria	[90]
305.	Stilbene	Resveratrol	*C. tournefortii*	Fruits	Water, ethanol and methanol extract	RP-HPLC-DAD, UV	Turkey	[33]
			C. tournefortii	Leaves	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
306.	Stilbenoid glycoside	Polydatine	*C. tournefortii*	Fruits, Leaves & Young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]
307.	Sugar	*cis*-1-O-methylinositol	*C. tessmannii*	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
308.	Sugar	Sucrose	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
309.	Sugar	D-Turanose	*C. pallida*	Aerial parts	Ethanol extract	GC-MS	Mexico	[36]
310.	Tannin	Glucosyringic acid	*C. tessmannii*	Roots	Methanol extract	NMR, UV, IR, MS, GC-MS	Cameroon	[97]
311.	Tannin	Ellagic acid	*C. iguanaea*	Leaves	70 % ethanol	HPLC	Brazil	[112]
			C. tournefortii	Fruits	Methanol extract	HPLC, UV	Turkey	[113]
			C. tournefortii	Leaves & young twigs	Methanol–dichloromethane extract	HPLC-TOF/MS	Turkey	[114]

terpenoids, alcohol, esters, and sterol [108] as well as flavonoids [121]. However, only flavonoid compounds were reported in the leaves of *C. choseniana* [68] and the barks of *C. tetrandra* [116]. The twigs of *C. philippinensis* contain several terpenoids and terpenoid esters [115]. Phytochemical analysis of the methanol extract of *C. eriocarpa* leaves revealed the existence of acid anhydrate, fatty acids, phenolic acids, esters, flavonoids, and glycosides [118]. In addition to phenolic acids, benzopyrone and glycoside were isolated from the leaves of *C. laevigata* as chief cytotoxic compounds [126]. Amides, terpenoids, sterols, and glycosides are also present in the twigs of *C. sinensis* [101]. Furthermore, amides, terpenoids, and sterols were also discovered in the stem bark of *C. tessmannii,* along with acid anhydrate, tannin, and sugar in the roots [97].

Phytochemicals (primary and secondary metabolites) have been known for their wide range of therapeutic advantages for plants and humans [130]. Plant metabolic reactions such as photosynthesis and respiration are controlled by primary metabolites such as chlorophyll, lipids, carbohydrates, proteins, nucleic acids, and amino acids [95,131,132]. Secondary metabolites include terpenoids, flavonoids, alkaloids, phenols, saponins, tannins, steroids, and glycosides, all of which play critical roles in shielding plants from degradation and boosting plant fragrance, appearance and texture [95,132].

Numerous molecules from these classes have been found and evaluated for pharmacological effects in *Celtis* plants. Despite the ample papers on phytochemical analysis among many species of *Celtis*, the structure identification procedure of molecules from these species needs to be explicitly stated in all articles. The compounds were identified using two dimensional time of flight mass spectroscopy (2D-GC-TOF/MS), proton nuclear magnetic resonance (^{1}H-NMR), carbon-13 nuclear magnetic resonance (^{13}C-NMR), electrospray ionization mass spectrometry (ESI-MS), high-resolution fast atom bombardment mass spectroscopy (HR-FAB-MS), gas chromatrography mass spectrometry (GC-MS), reversed-phase high performance liquid chromatography (RP-HPLC), triple quadrupole mass spectroscopy (QqQ-MS), infrared (IR), reversed-phase high performance liquid chromatography diode-array detection (RP-HPLC-DAD), liquid chromatography mass spectrometry (LC-MS), ultra high-pressure liquid chromatography diode-array detection (UHPLC-DAD), high-resolution electron ionization mass spectrometry (HREIMS), high-resolution electrospray ionization mass spectrometry (HRESIMS), flame ionization detector (FID), and ultra high-pressure liquid chromatography-orbitrap mass spectrometry (UHPLC-Orbitrap-MS).

5.1. Amide compounds

Till now, very few amide compounds have been found in *Celtis* species plants. The majority of them are hydroxycinnamic acid derivatives (compounds **4**–**10**), with only two being ceramides (compounds **1**–**2**) (Table 3) (Fig. 1). Hydroxycinnamic acid derivatives are primarily found in aerial parts, roots, and twigs of *Celtis* plants, while ceramides are present in the stem barks only. The frequently reported amides in *Celtis* species is compound **8**, which is obtained from the aerial parts of *C. africana* [102], roots of *C. adolphi-friderici* [103], stem barks of *C. zenkeri* and *C. tessmannii* [90,97], and twigs of *C. sinensis* and *C. occidentalis* [100,101]. Two new ceramides compounds **1**–**2** were detected as pure compounds from a methanol extract of *C. tessmannii* stem barks using NMR, ultra violet spectroscopy (UV), IR, MS, and GC-MS methods [97], while a noble iso-benzo-furanone propenamide (compound **11**) was discovered from Central African plant *C. zenkeri* [90]. Compound **3** is the only fatty acid derivative amide found in this study noted from the supercritical fluid extraction of carbon di-oxide (SFE-CO_2) extraction of *C. sinensis* leaves and stems and leaves of *C. zenkeri* [98,99]. All the amide compounds obtained from the genus *Celtis* are sketched in Fig. 2.

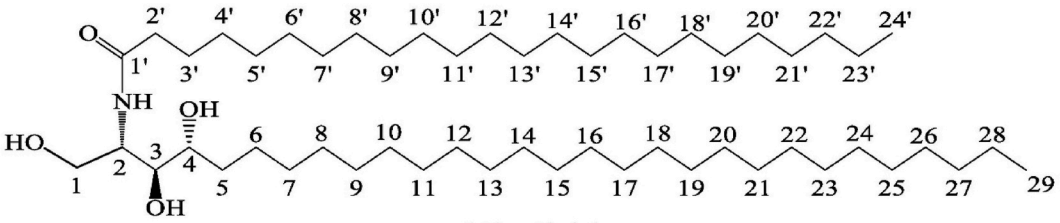
5.2. Esters

In addition to organic acids, various ester compounds such as carboxylic esters (compounds **13**–**16**), fatty esters (compounds **18**–**50**), and triterpene esters (compounds **53**–**54**) have been documented from *Celtis* plants (Table 3). These constituents are mainly identified in leaves, fruits, and stems. Compounds **53** and **54** (triterpene esters) are found for the first time in a methanolic extract of *C. philippinensis* twigs through fourier-transform infrared spectroscopy (FT-IR), HR-FAB-MS, H-NMR, and C-NMR techniques [115]. Most isolated esters from the *Celtis* plants come from a species, but some molecules, including compounds **27**, **40**, **41**, **43**, **45**, and **51**, have been detected from more than one species (Table 3). Among them, only the compound **51** has been noted in three different species, including *C. australis*, *C. iguanaea*, and *C. tournefortii* [111–113]. Various types of fatty acid esters are reported from the ripe fruits of *C. australis* via the GC-MS method, where methyl ester of these fatty acids is the most dominating compound (71.60 %) of the total fatty acid composition (95.45 %) [31]. Another compound **49** was the main identified compound among the seventy-three different identified volatile compounds of *C. sinensis*, isolated from both leaves and stems at 20.79 % and 23.76 % of total contents, respectively [98]. The only isolated anthraquinone ester of these species, compound **12** is reported from an Indian study of *C. australis* stem barks and fruits using H-NMR, C-NMR, IR, and MS techniques [105]. Solely phenolic ester, compound **52**, is detected from fruits, leaves, and young twigs of *C. tournefortii* via HPLC-TOF/MS methods [114], while the only steroid and fatty acid derivative ester, compound **50**, is reported from crude methanolic extract of *C. ehrenbergiana* through GC-MS manner [109]. A Cameroonian investigation of acetone extract of *C. adolphi-friderici* roots isolated 3.3 mg of compound **27**, the only reported ester of this species [103]. All the organic esters compounds obtained from the genus *Celtis* are sketched in Fig. 3.

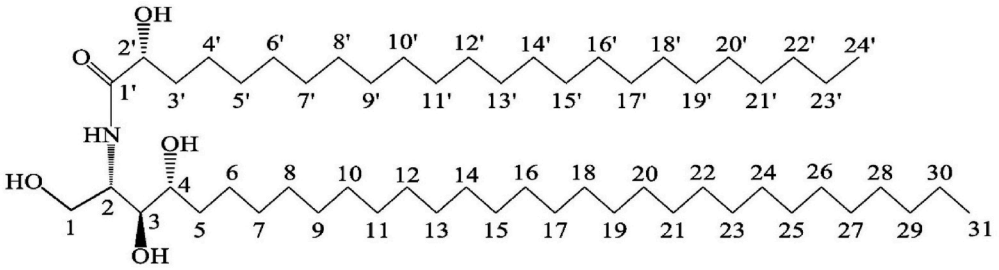
5.3. Flavonoids

Flavonoids are the most documented components in *Celtis* species classified into flavanonol (compound **71**), flavanol (compounds **58**–**64**), flavonol (compounds **110**–**120**), flavone (compounds **72**–**109**), flavanone (compounds **65**–**70**) , and anthocyanins (compounds **55**–**57**) (Table 3). Leaves and fruits are the main reservoirs of these molecules, but they are also detected in the bark, young

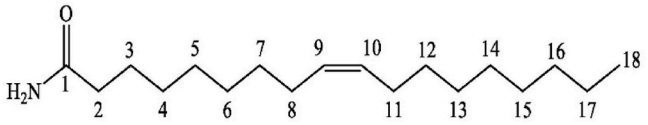
twigs, and aerial parts (Table 3). Compound **59** is the most frequently reported flavanol in the *Celtis* species, isolated from various parts of *C. pallida*, *C. tetrandra*,*and C. tournefortii* [113,114,116,117], while the other flavanols are mainly epimers of compounds **58** and **59** (Table 3). However, compounds **108**, **115**, and **120** are the most commonly detected flavonoid molecules of the *Celtis* genus isolated from the various extracts of different parts of the five distinct species (Table 3). Compound **105**, a flavone glycoside, was also isolated from four distinct *Celtis* species (*C. africana, C. australis, C. occidentalis*, and *C. iguanaea*) [121–123]. Among the conjugate molecules of



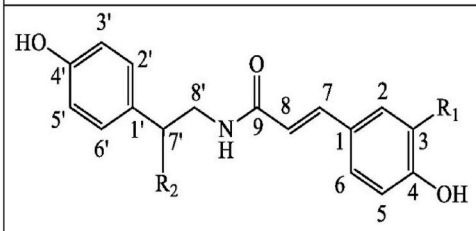
Celtisamide A **1**

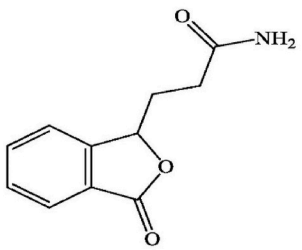


Celtisamide B **2**



Oleamide **3**

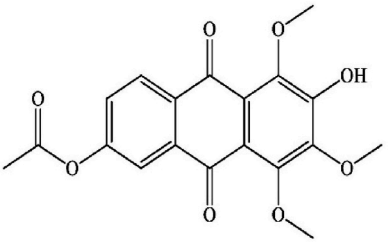
General Structure	Compound name	R_1	R_2
	2-trans-3-(4-hydroxyphenyl)- N-[2-(4-hydroxyphenyl)-2- oxoethyl] prop-2-enamide **4**	H	O
	trans-N-caffeoyltyramine **6**	OH	OH
	trans-N-coumaroyloctopamine **7**	H	OH
	trans-N-coumaroyltyramine **8**	H	H
	trans-N-feruloyloctopamine **9**	OCH_3	OH
	trans-N-feruloyltyramine **10**	OCH_3	H



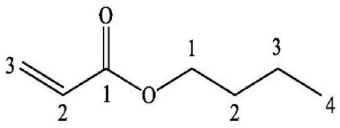
Zenkeramide **11**

Fig. 2. Amides from the genus *Celtis*.

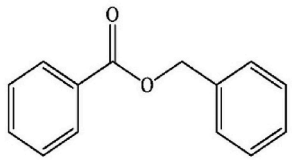
flavonoids, flavones and flavanone glycosides are the most extracted compounds (Table 3), while two new flavanol dimers (compounds **63,** and **64**) are identified from the ethyl acetate extract of *C. tetrandra* barks using MS, H-NMR, C-NMR, and HRESIMS [116]. Ten flavonoids' glycosides are attributed to compound **108** and its derivatives, discovered in the five following different species, *C. africana, C. australis*, *C. eriocarpa, C. occidentalis*, and *C. iguanaea* [111,118,121–123]. In this study, all flavonoids of *C. occidentalis* [118,122] and almost all of *C. eriocarpa* were identified as glycoside compounds, while most of the *C. ericocarpa* flavonoids were the



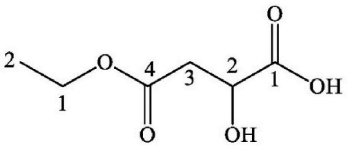
6-hydroxy-5,7,8-trimethoxy-9,10-dioxo-9,10-dihydroanthracen-2-yl acetate **12**



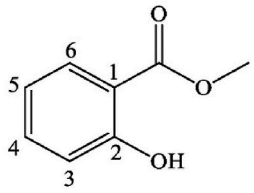
2-Propenoic acid, butyl ester **13**



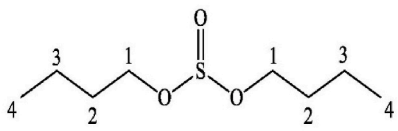
Benzyl benzoate **14**



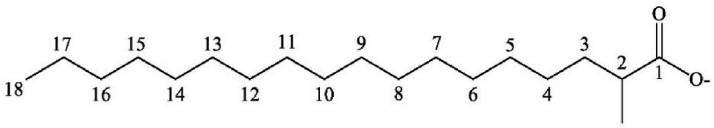
Malic acid, 4-ethyl ester **15**



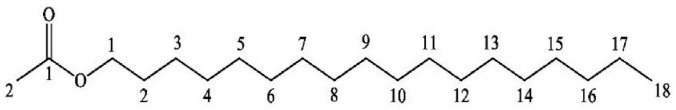
Methyl salicylate **16**



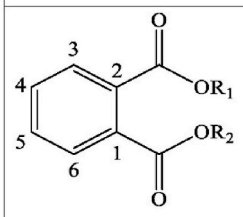
Sulfurous acid, dibutyl ester **17**



2-Methylstearoate **19**



Acetic acid, n-octadcyl ester **20**

General Structure	Compound name	R_1	R_2
	Dibutyl phthalate **23**	butyl	butyl
	Diethyl phthalate **24**	ethyl	ethyl
	Phthalic acid, di-isobutyl ester **49**	isobutyl	isobutyl
	Phthalic acid, butyl tetradecyl ester **48**	butyl	tetradecyl
	Phthalic acid, butyl 2-ethylhexyl ester **47**	butyl	2-ethylhexyl

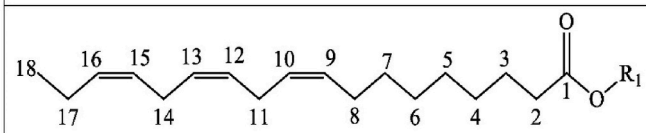
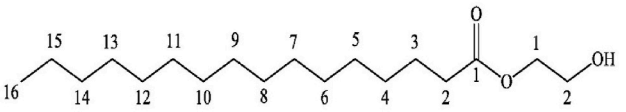
General Structure	Compound name	R_1
	Ethyl linolenate **25**	CH_3-CH_3
	Linolenic acid, methyl ester **32**	CH_3
	Monolinolenin **46**	Glycerol

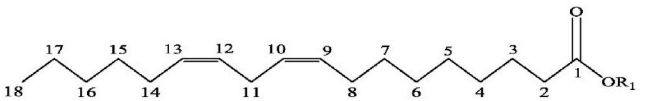
Fig. 3. Esters from the genus *Celtis*.

General Structure	Compound name	R_1
	Ethyl palmitic **26**	CH_3-CH_3
	Methyl palmitate **41**	CH_3

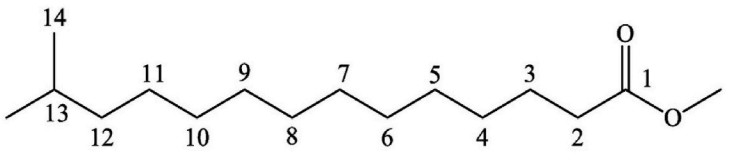
General Structure	Compound name	R_1
	glycerol 1-stearate **27**	Glycerol
	Methyl stearate **43**	CH_3



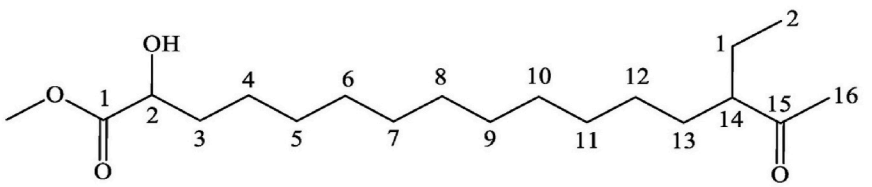
Hexadecanoic, 2-hydroxyethyl ester **28**



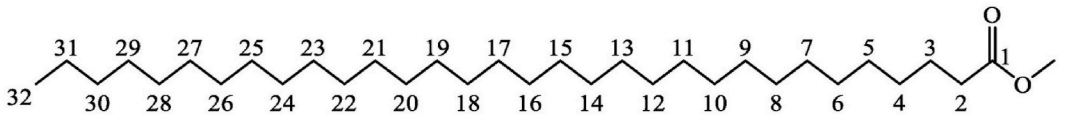
Compound name	R_1
Linoleic acid-, 2-hydroxy-1-(1hydroxymethyl) ethyl ester **31**	2-hydroxy-1-(1hydroxymethyl) ethyl
Methyl linoleate **39**	CH_3



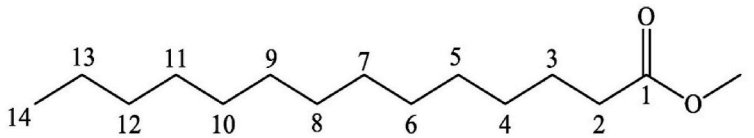
Methyl 13-methyltetradecanoate **33**



Methyl 14-acetylhydroxypalmitate **34**

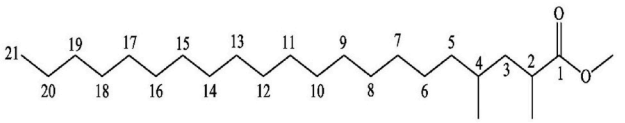


Methyl 1-dotriacontanoate **35**

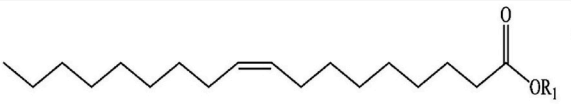


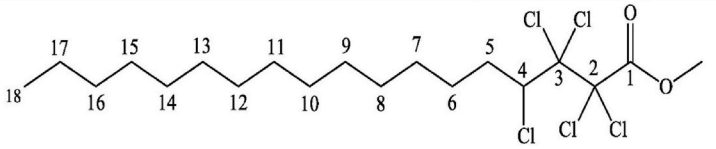
Methyl 1-tetradecanoate **36**

Fig. 3. (*continued*).

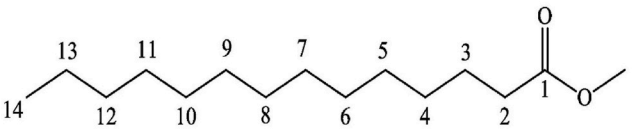


Methyl 2,4-dimethyl heneicosanoate **37**

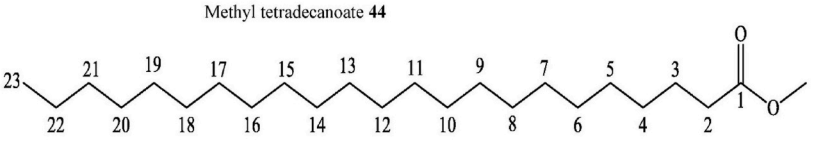
General Structure	Compound name	R_1
	Methyl Oleate **40**	CH_3
	Stigmast-5-en-3-ol Oleate **50**	Stigmast-5-en-3-ol



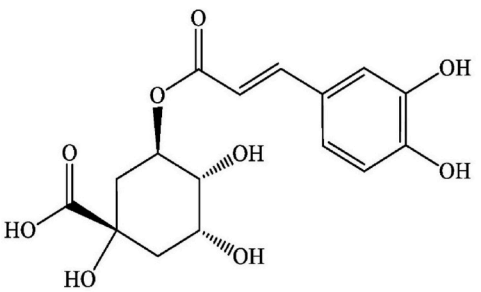
Methyl pentachloro stearate **42**



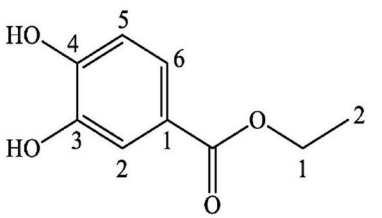
Methyl tetradecanoate **44**



Methyl tricosanoate **45**



Chlorogenic acid **51**



Protocatechuic acid, ethyl ester **52**

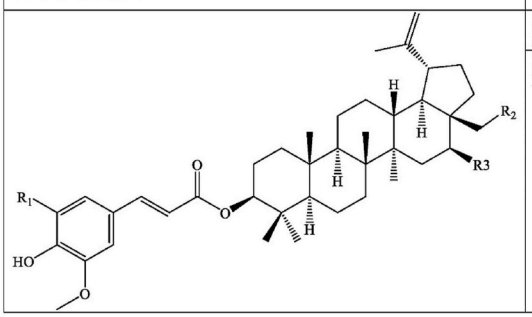
General Structure	Compound name	R_1	R_2	R_3
	3β-trans-sinapoyloxylup-20(29)-en-28-ol **53**	OCH_3	OH	H
	3β-trans-feruloyloxy-16β-hydroxylup-20(29)-ene **54**	H	H	OH

Fig. 3. (*continued*).

first time reported molecules [118]. Three different anthocyanins have been reported from the fruits and leaves of *C. australis* [32]. A new C-triglycoside, compound **83**, is obtained from the leaves of *C. australis* and *C. occidentalis*, whereas compound **81** is the primary isolated component of the n-butanol fraction of the same species' leaves [122]. Compounds **94** and **95**, two novel C-glycosylflavonoids, were discovered in ethanol and water extracts of *C. africana* aerial parts using HR-FAB-MS, H NMR, C-NMR, GC-MS, and EI-MS techniques [123]. All the organic acid compounds obtained from the genus *Celtis* are sketched in Fig. 4.

5.4. Organic acids

Among the various types of phytochemical molecules of *Celtis* species, organic acids and their derivatives are the second most reported compounds that can be divided into phenolic acids (compounds **167**–**172**), hydroxycinnamic acids and glycoside (compounds **157**–**166**), benzoic acids and derivatives (compounds **132**–**133, 135**–**138**), fatty acids (compounds **139**–**156**), as well as aliphatic carboxylic acids (compounds **124**–**131**) (Table 3). Most of these compounds were identified in the aerial parts, roots, fruits, and leaves of *Celtis* plants. The most frequently documented organic acid in the *Celtis* species is compound **154**, which is obtained from various parts of six different species, including *C. tournefortii*, *C. africana*, *C. australis*, *C. pallida*,*C. ehrenbergiana*, and *C. sinensis* [27,32,33,36,98,102,109]. Furthermore, compound **156** is reported from four different *Celtis* species namely: *C. australis, C. pallida, C. sinensis,* and *C. tournefortii* [32,33,36,98], while compound **153** is noted from three distinct species: *C. africana*,*C. australis*, and *C. tournefortii* [32,33,102].Compound **148** is extracted from hexane, ethyl acetate, and dichloromethane: methanol extract of *C. africana* leaves, fruits, and stems [27], while compound **145** is isolated from the only ethanol-water extract of aerial parts of the same species [102]. Along with compounds **139** and **143**, **150**–**151**, two different types of fatty acids are identified through UHPLC-DAD and ESI-MS techniques from the crude methanolic extract of leaves of *C. eriocarpa* [118]. Seven fatty acids (compounds **140**, **142**, **146**, **149**, **148**, **152**, and **154**) were reported from the ethanol-water extract of *C. pallida* aerial parts via the GC-MS method [36]. A saturated fatty acid compound **155**, was solely isolated from the fruits of *C. tournefortii* [33].

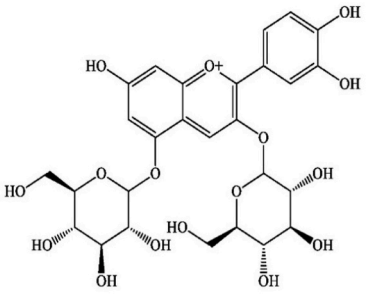
In addition, six distinct phenolic acids (compounds **167**–**172**), methanolic extracts of leaves of *C. eriocarpa* represent about 40 % of the total reported hydroxycinnamic acids among the *Celtis*s pecies (compounds **158**, **161**, **163**, and **164**) [118]. Among the hydroxycinnamic acids, compound **159** is the most frequently isolated acid of the *Celtis* genus and was reported from three distinct species (*C. australis*, *C. laevigata*, *C. pallida*, and*C. tournefortii*) [78,113,114,126]. Two hydroxycinnamic acid compounds, **162** and **165**, were discovered using high performance liquid chromatography and time of flight mass spectrometry (HPLC-TOF/MS) techniques in methanol–dichloromethane extracts of *C. tournefortii* leaves and young twigs [114]. Compound **166** is solely reported from the fruits of *C. tournefortii* [33]. Besides various kinds of organic acids, different types of aliphatic carboxylic acids (compounds **124**–**131)** were separated from five individual species (*C. adolphi-friderici*, *C. eriocarpa*, *C. ehrenbergiana*, *C. tessmannii*, and *C. tournefortii*) through various mass spectrometry techniques in different types of alcoholic or acetone extracts [36,97,103,109,118]. Compound **134** is the only carboxylic acid metabolite noted in this study, which was isolated from acetone extract of roots of *C. adolphi-friderici* [103]. All the organic acid compounds obtained from the genus *Celtis* are sketched in Fig. 5.

5.5. Terpenoids

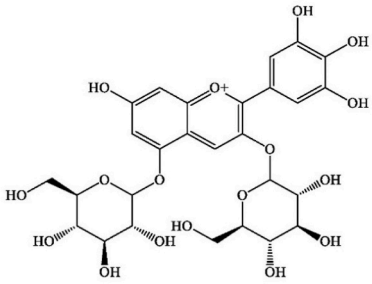
The plants of the *Celtis* genus are also documented to possess a variety of terpenoid molecules (Table 3). Most of these molecules were discovered in aerial parts, barks, fruits, leaves, stem barks, and twigs. Among them, triterpenoids (compounds **184**–**201**) are the most dominating terpenoids, with two of their esters (compounds **53**–**54**). Apart from triterpenoids, compounds **178**–**179** are diterpenes, while the remainders are carotenoids (compounds **175**–**177**) and tocopherols (compounds **180**–**183**) (Table 3). Compound **181** is the often-reported terpene among the *Celtis* plants, detected in five individual species such as, *C. africana*,*C. australis*, *C. ehrenbergiana*,*C. pallida*,*and C. tournefortii* [27,32,33,36,109]. However, among the triterpenoids, compound **193** is the most reported compound that has been found in four individual plants, including *C. adolphi-friderici*, *C. africana*,*C. tessmannii*, and *C. iguanaea* [27,97,103,129]. Along with three triterpenoids (compounds **184**–**186**), a triterpenoid glycoside, compound **201**, was identified in the ethanol extract of *C. australis* [105]. Several derivatives (compounds **188**–**190**) were recorded from *Celtis* species, while compound **191** was found in from methanolic extracts of stem barks of *C. tessmannii* [97], and the rest of compounds **188**–**190** were isolated from *C. philippinensis* twigs and characterized via NMR and MS techniques [115]. Compound **194** is identified from the various extracts of *C. africana* stems [27], while its epimer, compound **192**, is reported from twigs of *C. sinensis* [101] as well as the barks of *C. iguanaea* [129]. Among the triterpenoids, compound **199** and **200** are found in three distinct species (Table 3), while diterpene compound **178** is also revealed in four different species (*C. africana*,*C. iguanaea*,*C. pallida*,*and C. zenkeri*) [27,36,99,108]. A novel bacteriohopanoid compound **174** has been isolated from the ethanol extract of *C. australis* bark [128]. Three different carotenoids (compounds **175**–**177**), were isolated from the Croatian study on fruits of *C. australis*, where compounds **175** and **176** are two isomers [32]. The compound **179**, a derivative of compound **177** [133], has been identified in the fruits of *C. tournefortii* [33]. Along with compound **181**, three different tocopherols were detected in *Celtis* plants, including *C. africana*, *C. australis*, and *C. tourneforttii* [27,32,33]. However, terpenoids were not reported from several *Celtis* species. Thus, further research is necessary to identify more terpenoid derivatives from other *Celtis* plants (Table 3). All the terpenoid compounds obtained from the genus *Celtis* are sketched in Fig. 6.

5.6. Miscellaneous compounds

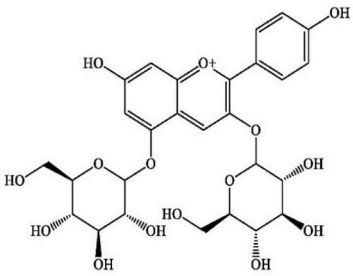
Along with amides, organic acids, terpenoids, flavonoids, and esters, *Celtis* species have been found to possess a variety of additional volatile chemicals such as acid anhydrates, lipids, aldehydes, esters, alkanes, benzopyrone, ketones, alcohols, sterols, tannins,



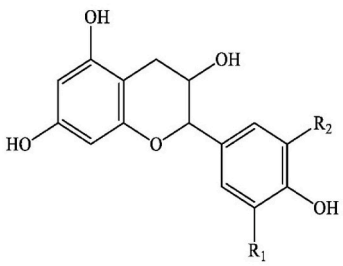
Cyanidin-3,5-di-O-glucoside **55**



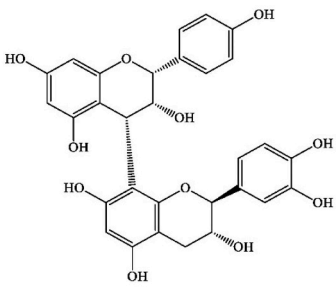
Delphinidin-3,5-di-O-glucoside **56**



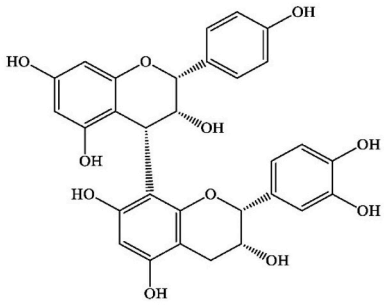
Pelargonidin-3,5-di-O-glucoside **57**



General Structure	Compound Name	R_1	R_2
	Afzelechin **58**	H	H
	Catechin **59**	OH	H
	Gallocatechin **62**	OH	OH



Epiafzelechin-(4α→8)-catechin **63**



Epiafzelechin-(4α→8)-epicatechin **64**

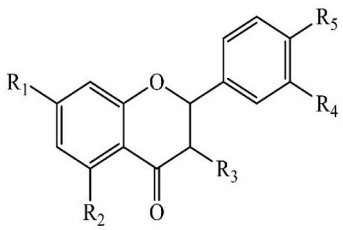
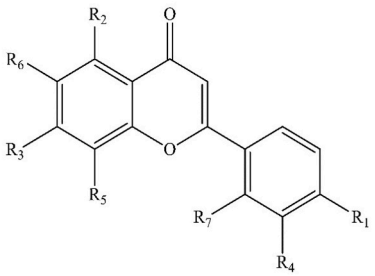


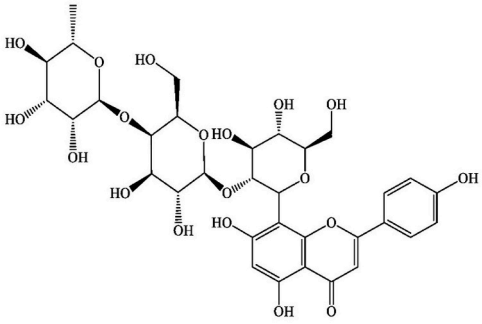
Fig. 4. Flavonoids from the genus *Celtis*.

Compound name	R_1	R_2	R_3	R_4	R_5	R_6
Naringenin **65**	OH	OH	H	H	OH	H
Hesperidin **67**	7-O-rhamnoglucoside	OH	H	H	$O\text{-}CH_3$	OH
Naringin **69**	7-O-rhamnoglucoside	OH	H	H	OH	H
Neohesperidin **70**	7-O-neohesperidoside	OH	H	OH	$O\text{-}CH_3$	H
Taxifolin **71**	OH	OH	OH	OH	OH	H

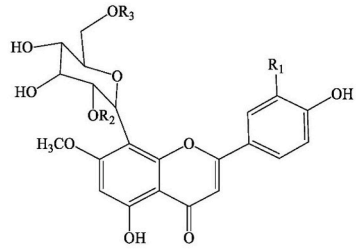


Compound name	R1	R2	R3	R4	R5	R6	R7
Acacetin **72**	$O\text{-}CH_3$	OH	OH	H	H	H	H
Apigenin **73**	OH	OH	OH	H	H	H	H
Diosmetin **74**	$O\text{-}CH_3$	OH	OH	OH	H	H	H
Luteolin **76**	OH	OH	OH	OH	H	H	H
Wogonin **77**	H	OH	OH	H	$O\text{-}CH_3$	H	H
2"-O-α-L-rhamnopyranosyl-7-O- methylvitexin **78**	OH	OH	$O\text{-}CH_3$	H	2"-O-α-L-rhamnopyranoside	H	H
Acacetin-7-O-glucoside **84**	$O\text{-}CH_3$	OH	O-glucoside	H	H	H	H
Acacetin-8-C-rutinoside **85**	$O\text{-}CH_3$	C-rutinoside	OH	H	H	H	H
Apigenin 6-C-glucoside **86**	OH	OH	OH	H	H	C-glucoside	H
Apigetrin **90**	OH	OH	O-glucoside	H	H	H	H
Baicalein-8-C-glucoside **92**	H	OH	OH	H	C-glucoside	OH	H
Baicalin **93**	H	OH	O-glucuronide	H	H	OH	H
Diosmin **97**	$O\text{-}CH_3$	OH	O-rutinoside	OH	H	H	H
Isoorientin **98**	OH	OH	OH	OH	H	C-glucoside	H
Isoswertiajaponin **99**	OH	OH	$O\text{-}CH_3$	OH	C-glucoside	H	H
Isoswertisin **100**	OH	OH	$O\text{-}CH_3$	H	C-glucoside	H	H
Isovitexin **101**	OH	OH	OH	H	H	C-glucoside	H
Orientin **105**	OH	OH	OH	OH	C-glucoside	H	H
Scutellarin **106**	OH	H	OH	H	OH	O- glucuronide	H
Vitexin **108**	OH	OH	OH	H	C-glucoside	H	H
Vitexin-2"-O-rhamnoside **109**	OH	OH	OH	H	C-glucoside	H	O-rhamnoside

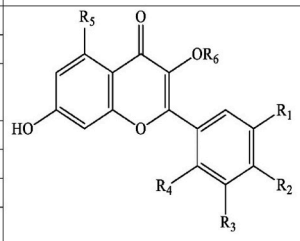
Fig. 4. (*continued*).

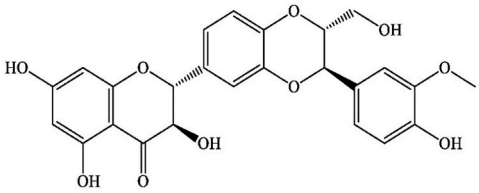


4'''-Rhamnosyl-2''-O-β-D-galactopyranosyl vitexin **83**

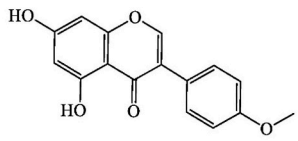


Compound name	R_1	R_2	R_3
Celtiside A **94**	H	H	Rhamnose
Celtiside B **95**	OH	Rhamnose	H

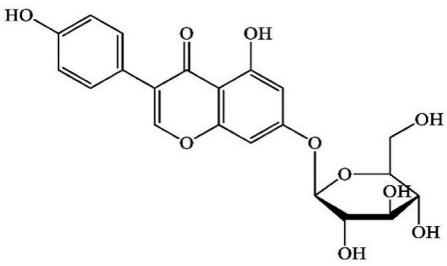
Compound name	R_1	R_2	R_3	R_4	R_5	R_6	General Structure
Fisetin **110**	H	OH	OH	H	H	H	
Galangin **111**	H	H	H	H	OH	H	
Kaempherol **112**	H	OH	H	H	OH	H	
Morin **113**	H	OH	H	OH	OH	H	
Myricetin **114**	OH	OH	OH	H	OH	H	
Quercetin **115**	H	OH	OH	H	OH	H	
Quercetin-3-β-D-glucoside **119**	H	OH	OH	H	OH	3-β-D-glucose	
Rutin **120**	H	OH	OH	H	OH	3-rutinoside	



Silibinin **121**



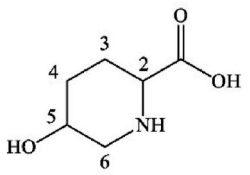
Biochanin A **122**



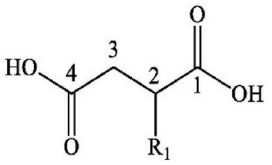
Genistin **123**

Fig. 4. (*continued*).

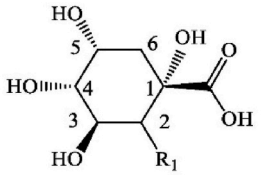
sugars, and others (Table 3). These chemicals have been found in various plant parts, including leaves, fruits, stems, roots, twigs, and aerial parts. Many of these compounds are identified through phytochemical detection using different spectroscopic methods. Almost all aldehydes and ketone molecules from *C. africana* have been determined using 2D-GC-TOF/MS [27], while alcohol, sterol, sugar, and amino acid of *C. pallida* were detected by GC-MS techniques [36]. The majority of the alcohol molecules have been identified from three species: *C. pallida*, *C. africana*, and *C. sinensis* [27,36,98]. In addition to two sterol glycosides, compounds **303**–**304**, three individual sterols, compounds **300**–**302**, are noted from *Celtis* plants, while the compound **301** is the dominating among them, is found in seven different species (*C. africana, C. australis, C. sinensis, C. tessmannii*, *C. adolphi-friderici, C. zenkeri*, and *C. pallida*) [36,97,101–103, 127,134]. A cytotoxic novel glucosphingolipid, compound **288**, is detected from the ethanol-water extracts of *C. africana* aerial parts



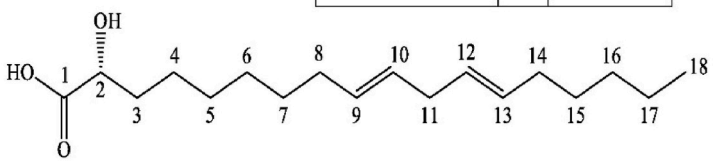
5-Hydroxypipecolic acid **124**



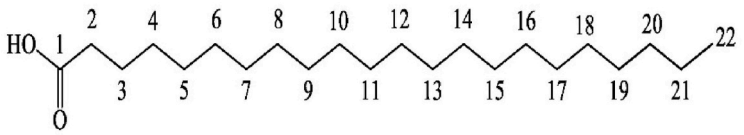
Compound name	R_1	2-3 Carbon bonds
Fumaric acid **126**	H	Double bond
Succinic acid **131**	H	Single bond



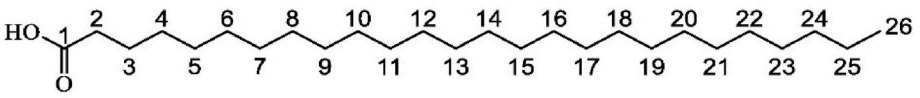
Compound name	R_1
Methyl quinic acid **127**	CH_3
Quinic acid **128**	H



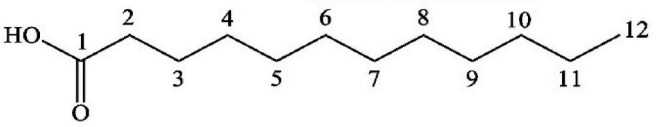
2-hydroxy linoleic acid **139**



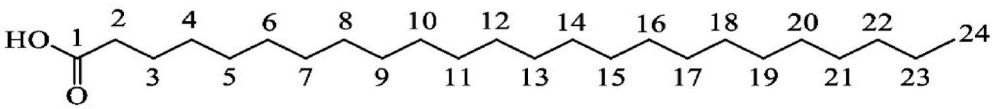
Behenic Acid **140**



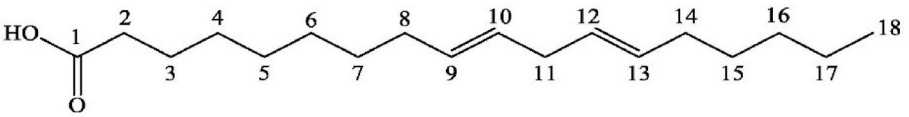
Hexacosanoic acid **142**



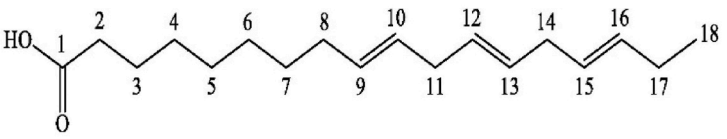
Lauric acid **145**



Lignoceric acid **146**

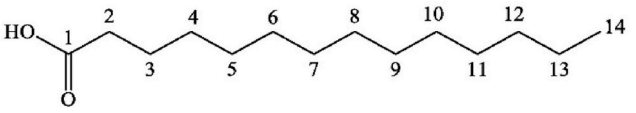


Linoleic acid **147**

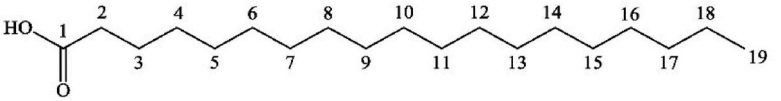


Linolenic Acid **148**

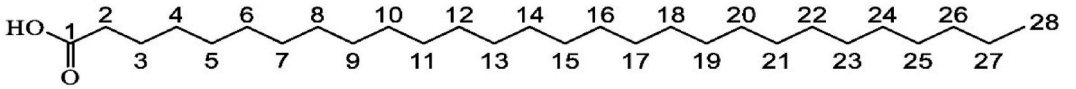
Fig. 5. Organic acids from the genus *Celtis*.



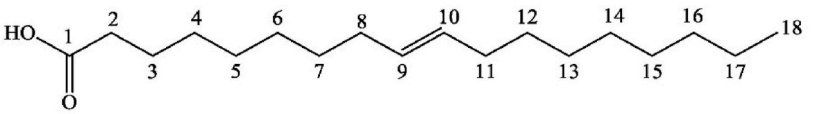
Myristic Acid **150**



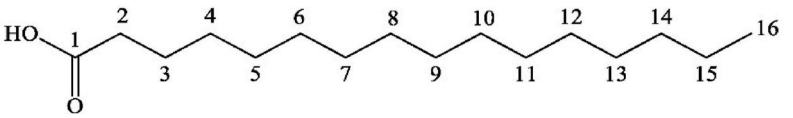
Nonadecanoic Acid **151**



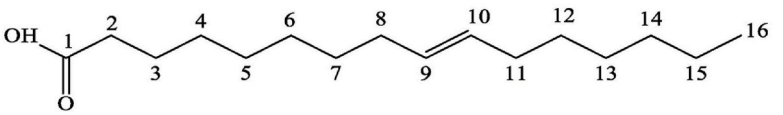
Octacosanoic acid **152**



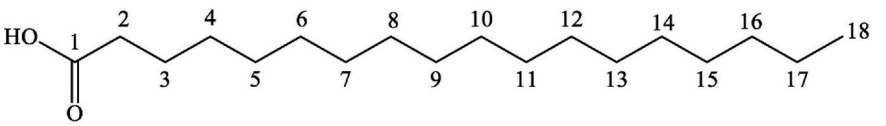
Oleic Acid **153**



Palmitic Acid **154**



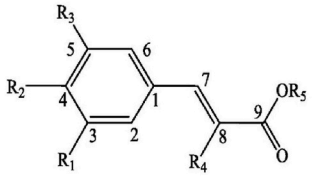
Palmitoleic Acid **155**



Stearic Acid **156**

Fig. 5. (*continued*).

General structure



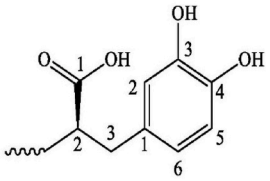
Compound Name	R_1	R_2	R_3	R_4	R_5
Caffeic acid **159**	OH	OH	H	H	H
Cinnamic acid **160**	H	H	H	H	H
Hydroxy caffeic acid **161**	OH	OH	H	OH	H
p-Coumaric acid **162**	H	OH	H	H	H
Rosmarinic acid **165**	OH	OH	H	H	
Sinapic acid **166**	OCH_3	OH	OCH_3	H	H

Fig. 5. (*continued*).

[37], whereas another glucosphingolipid, compound **289**, is identified from acetone extracts of *C. adolphi-friderici* roots through H-NMR, C-NMR, HRESIMS, UV, IR techniques [103]. Moreover, some minor compounds, including tannin, sugar, stilbene, nitrogenous base, lignan, and benzopyrone, are also identified in *Celtis* plants (Table 3). Two phytotoxic benzopyrones, compounds **272** and **273**, are documented in the aqueous extract of *C. laevigata* leaves [126]. The miscellaneous compounds found from the genus *Celtis* are sketched in Fig. 7.

6. Biological activities

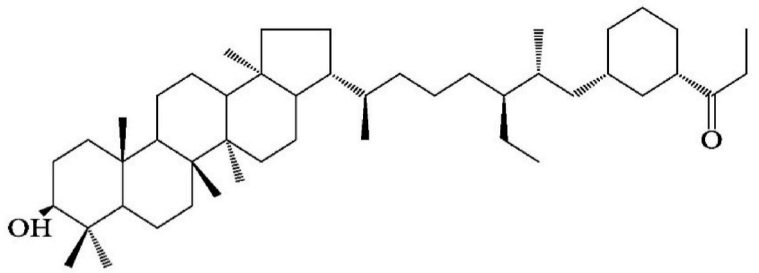
Numerous bioactive constituents such as amides, organic acids, terpenoids, flavonoids, ester and several compounds present in *Celtis* species may account for their various health benefits, and therefore responsible for the vast pharmacological properties (Tables 4 and 5). However, only few species have been extensively studied for bioactivities.

6.1. Antimicrobial activities

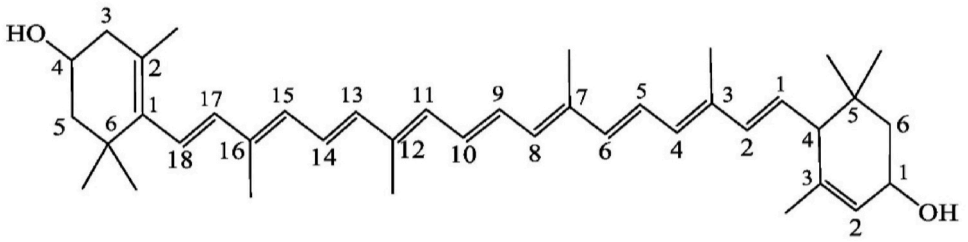
Based on the Antimicrobial Resistance Collaborators study, the six bacteria pathogens causing resistance-related mortality, including *Acinetobacter baumannii*, *Escherichia coli*, *Staphylococcus aureus*, *Streptococcus pneumoniae*, *Klebsiella pneumoniae*, and *Pseudomonas aeruginosa*, were responsible for 929,000 AMR-related deaths, while total AMR deaths in 2019 were 3.57 million [39]. This figure was higher than the mortality from AIDS and malaria [145]. However, the antibacterial capabilities of medicinal plants provide a possible option for addressing the growing challenges of AMR [40].

The species of *Celtis* genus may play some significant role because various parts of many *Celtis* species demonstrated a prominent antimicrobial activity, especially against *S. aureus* and *P. aeruginosa* (Table 4). Enormous reports have been noted on the antimicrobial activity of various parts of *C. australis* such as leaves [32,118,138], ripe fruits [31], and seeds [138]. Dichloromethane extracts of *C. laevigata* demonstrated antimicrobial activity against two *Mycobacteria* organisms, including *Mycobacterium tuberculosis* and *Mycobacterium avium*, which were more active against *Mycobacterium tuberculosis* than *Mycobacterium avium* [35]. The ethanol extracts of aerial parts of *C. pallida* were tested against several types of bacteria (*Escherichia coli*, *S. aureus*, *Bacillus subtilis*, and *P. aeruginosa*), and fungus (*Candida albicans*); and showed low anti-microbial activity compared with the standard (Cefotaxime) [36].

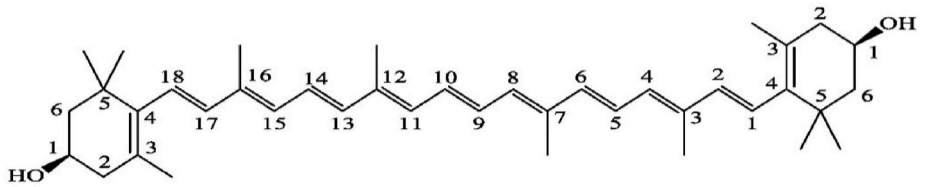
In *C. africana*, various extracts of leaves, fruits, and stems exhibit tremendous antimicrobial activity against 2 gram-positive (*Bacillus cereus* and *S. aureus*) as well as 5 gram-negative bacteria (*Klebsiella pneumoniae*,*Enterobacter aerogenes*,*P. aeruginosa*,*Proteus mirabilis*, and *E. coli*). Among them, high potency was recorded from the hexane extract of fruits against *S. aureus*, while ethyl acetate extract of stems demonstrated a mild growth inhibitory effect against *K. pneumonia*, *P. aeruginosa*, *S. aureus*, *P. mirabilis*, and *E. coli* [27]. Hexane extracts of fruits and leaves demonstrated mild potency against only two organisms *E. aerogenes* and *P. aeruginosa* [27]. However, these extracts did not exhibit any activity against *M. tuberculosis*,*B. subtilis*,*Klebsiella oxytoca*,*Enterobacter cloacae*,*Proteus vulgaris*, and *Staphylococcus epidermidis* [27]. Intriguingly, an acetone extract of leaves of *C. africana* also showed potent antifungal activity against *Cryptococcus neoformans* (Minimum inhibitory concentrations (MIC) 0.22 mg/ml) [28].



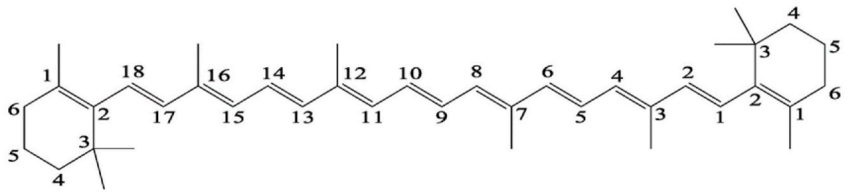
3β-hydroxy-35-(cyclohexyl-50-propan-70-one)-33-ethyl-34-methylbactereohopane **174**



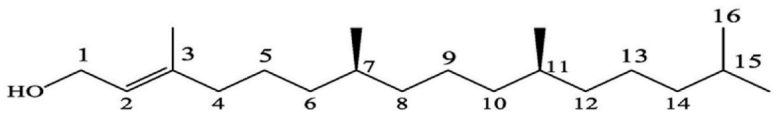
Lutein **175**



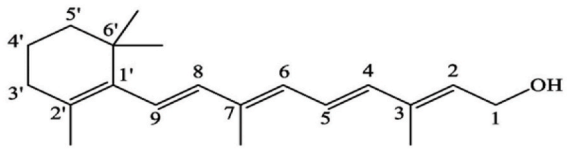
Zeaxanthin **176**



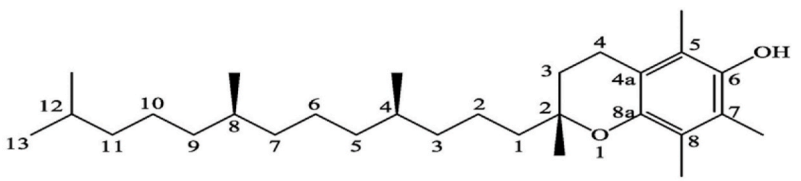
β-carotene **177**



Phytol **178**

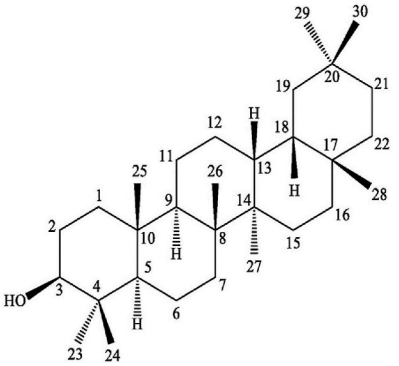


Retinol **179**

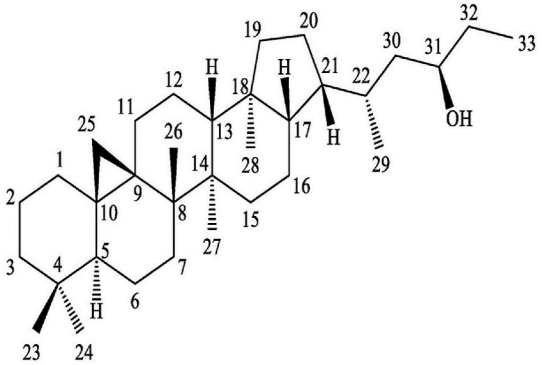


α-tocopherol **181**

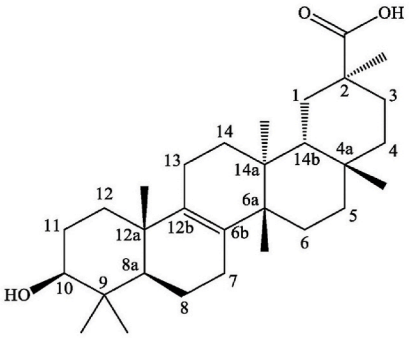
Fig. 6. Terpenoids from the genus *Celtis*.



(3β)-oleanan-3-ol **185**



(9β,31R)-9,25-cyclo-30-propylhopan-31-ol **186**



20-epibryonolic acid **187**

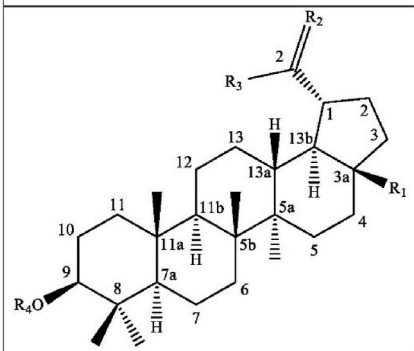
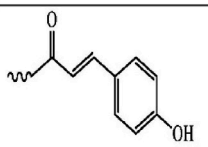
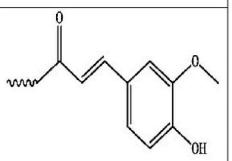
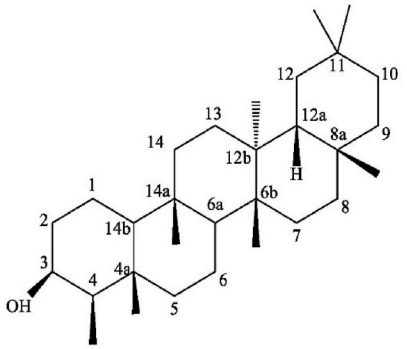
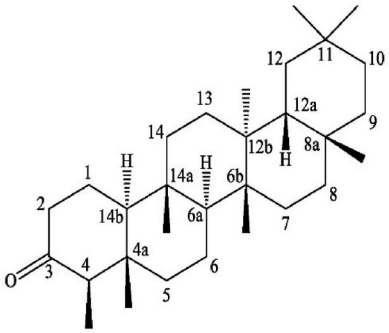
General Structure	Compound name	R_1	R_2	R_3	R_4
	3β-O-(E)-coumaroylbetulin **188**	CH_2OH	CH_2	CH_3	
	3β-O-(E)-feruloylbetulin **189**	CH_2OH	CH_2	CH_3	
	Betulin **190**	CH_2OH	CH_2	CH_3	H
	Betulinic acid **191**	COOH	CH_2	CH_3	H
	Lupeol **196**	CH_3	CH_2	CH_3	H
	Platanic acid **198**	COOH	O	CH_3	H

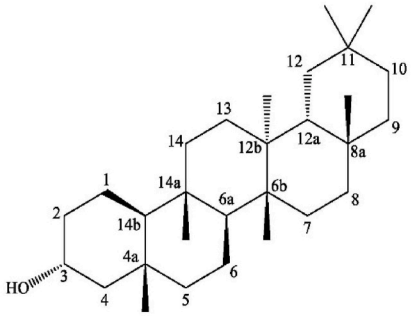
Fig. 6. (*continued*).



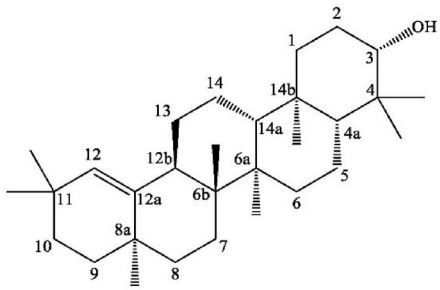
Epifriedelanol **192**



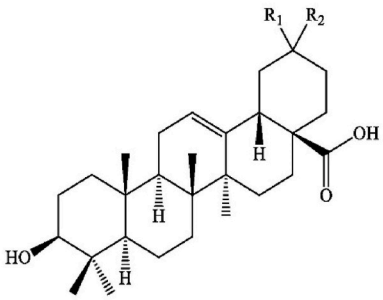
Friedelin **193**



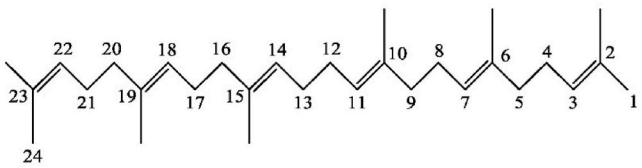
Friedelinol **194**



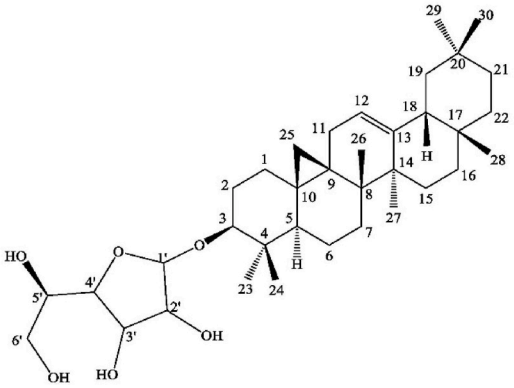
Germanicol **195**



Compound name	R_1	R_2
Oleanolic acid **197**	CH_3	CH_3
Ursolic acid **200**	CH_3	H



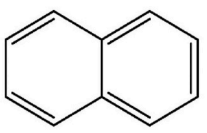
Squalene **199**



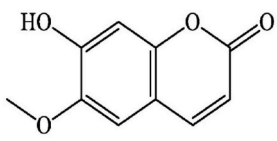
(3β,9β)-9,25-cycloolean-12-en-3-yl β-D-glucofuranoside **201**

Fig. 6. (*continued*).

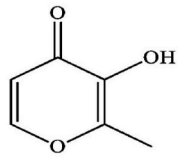
Three different extracts of *C. tournefortii* fruits displayed the growth inhibition of *B. subtilis*,*Bacillus megaterium*,*S. aureus*,*E. coli*, *P. aeruginosa*,*Listeria monocytogenes*,*K. pneumonia*,*P. vulgaris*, and *C. albicans* [33]. Its water extract exhibited a narrow spectrum of activity and only showed inhibition against gram-positive bacteria (*B. subtilis*, *B. megaterium*, and *S. aureus*), while both ethanol and



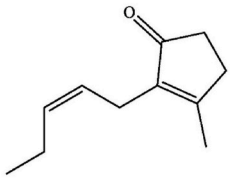
Naphthalene **270**



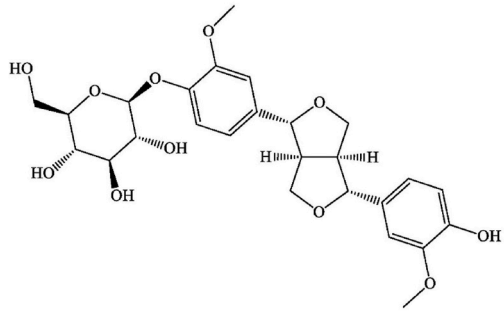
Scopoletin **272**



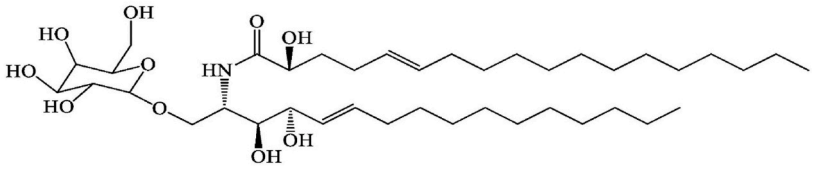
3-hydroxy-2-methyl-4H-pyran-4-one **276**



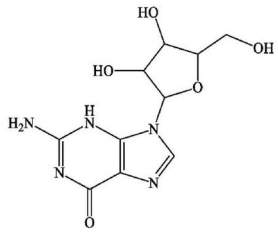
Jasmone **285**



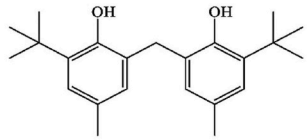
Pinoresinol 4-O-glucoside **286**



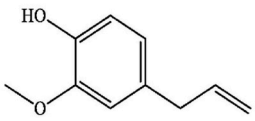
1-O-(β-D-glucopyranosyl) -(2S,3S,4R,5E)-2N-([2'R,6'E]-2'-hydroxyoctadeca-6'-enoylamino)-5-pentadecaene-1,3,4-triol **288**



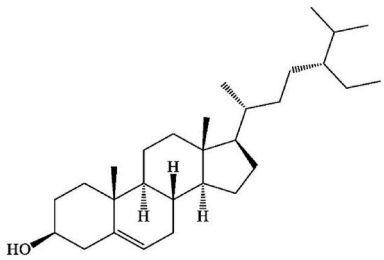
2-Amino-9-(3,4-dihydroxy-5-hydroxymethyl-tetrahydrofuran-2-yl)-3,9 dihydro-purin-6-one **290**



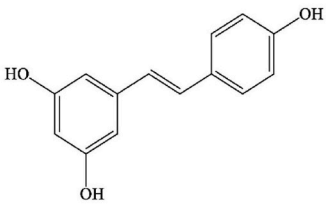
2,2'-Methylenebis[6-(1,1-dimethylethyl)-4-methyl]-phenol **292**



Eugenol **297**



β-sitosterol **301**



Resveratrol **305**

(caption on next page)

Fig. 7. Miscellaneous compounds from the genus *Celtis*.

methanol extracts demonstrated broad-spectrum antibacterial activity, and methanol extract further showed antifungal activity against *C. albicans* [33]. In comparison to the growth inhibition activity of standard (10 mg/disc streptomycin sulfate and 30 mg/disc nystatin), methanol extract demonstrated superior antibacterial action against *L. monocytogenes* and *B. subtilis* [33]. Further studies are needed to identify the antimicrobial components of the methanol extract.

Among the plants of the *Celtis* genus, various extracts of different parts (leaves, seeds, and ripe fruits) of *C. australis* have notable antimicrobial activity against bacteria and fungus, even on resistance strains (Table 4). Leaf methanolic extract showed good antimicrobial potency against *S. aureus* and *P. aeruginosa* despite their resistance to Cefuroxime, Ampicillin, and Tetracycline. So, it is predictable that methanolic extract may have antibacterial components that show potency against resistant strains [30]. Another study on ripe fruits of *C. australis* revealed that ethanol extract had potent antimicrobial effect against *B. subtilis* and *P. aeruginosa* (250 μg/ml and 125 μg/ml MICs, respectively) [31]. Furthermore, the ethanolic leaf (harvested at the end of October) extract has antifungal action against *C. albicans*, *Candida parapsilosis* (MIC = 0.156 mg/mL), and *R. mucilaginosa* (MIC = 0.313 mg/mL) [32], whereas the hydromethanol and ethyl acetate extracts of leaves and seeds have antifungal activity against *C. albicans*, *Candida tropicalis*, and *Aspergillus niger* [138]. Among them, hydromethanol extract outperforms ethyl acetate extract in antifungal activity. In the case of *A. niger*, hydromethanol extract of both seeds and leaves showed greater activity than the standard fluconazole. However, compared to nystatin, only leaves hydromethanol extract is as effective as nystatin [138]. Further hydromethanol extract of leaves study is needed to find out what the antifungal compound in them is. Along with anti-fungal action, ethyl acetate extract has remarkable anti-bacterial activity. The ethyl acetate extracts of the leaves and seeds are active against both gram-positive (*Bacillus. spp*,*Bacillus cereus*,*Listeria ivanovii*,*and S. aureus*) and gram-negative (*C. freundii*,*E. coli*, and *S. sp*) bacteria [138]. In particular, leaves ethyl acetate extract strongly reduced the growth of *Citrobacter freundii* and *E. coli*, while seeds ethyl acetate extract was more potent against *Bacillus. spp*, *L. ivanovii*, and *Staphylococcus* spp. [138].

In the *Celtis* genus, various types of fatty acids are isolated from the species that may be involved in broad-spectrum antimicrobial activities. Recent biological research on fatty acids has found possible antibacterial mechanisms, such as inhibiting protein synthesis, DNA/RNA replication, cell wall, metabolic route, and quorum sensing (QS), as well as horizontal gene transfer (HGT), cytoplasmic membrane disruption, and efflux pumps, that may help reduce bacterial growth, even in resistant strains [146]. Compounds **154** and **156** are two familiar saturated plant-fatty acids also detected in these *Celtis* plants, both of which exert antibacterial action against gram-positive and gram-negative bacteria. Their nanostructure arrays successfully suppress the growth of *P. aeruginosa* and *S. aureus* [147], which are inhibited by the majority of various plant extracts of the *Celtis* genus (Tables 4 and 5).

They showed bactericidal action against vancomycin-resistant *Enterococcus faecalis* (VREF) and multidrug-resistant *Staphylococcus epidermidis* (MRSE) while encapsulated in liposome carriers [41]. Additionally, Parsons et al., stated that unsaturated fatty acid including compound **155** is noxious to metabolism because it is not good enough for phospholipid biosynthesis and accumulates in the cells of bacteria [148]. In this way, it affects the cell membrane and its functions, such as the proton gradient, and inhibits macromolecular synthesis, which ultimately leads to energy loss [148]. Another phyto-fatty acid, compound **147,** also alters the bacterial metabolic pathways of *S. aureus* [149] through its ability to alter gene expression in glycolytic and fermentative systems that are essential for energy production [146]. Furthermore, compounds **155** and **147** selectively inhibit bacterial enoyl-acyl carrier protein reductase (FabI), a key molecule in bacterial fatty acid generation [150]. The liposomal form of unsaturated fatty acid (compound **148**) exhibits minimum bacteriacidal concentration (MBC) against *Helicobacter pylori* at 200 μg/mL through increasing the permeability of the outer membrane [151].

The presence of phenolic compounds in the *Celtis* genus may also be responsible for the enhancement of antibiotic activity even against resistant pathogens. Compound **297** displays antimicrobial activity on several microorganisms such as *A. niger*,*Aspergillus fumigatus*,*Aspergillus flavus*,*Aspergillus ochraceus*,*Alternaria alternata*,*Botrytis cinerea*,*Candida. spp*,*Penicillium citrinum*,*Penicillium chrysogenum*,*Fusarium oxysporum*, and *Rhizopus oryzae* through cell membrane disturbance [152]. The compound has bactericidal activity against *H. pylori* at low pH levels. However, the organism remained susceptible to the compound even after undergoing ten successive generations of growth at concentrations below their inhibitory levels, without developing any resistance [153]. Furthermore, this phytoconstituent also inhibits biofilm formation as well as breaks cell-to-cell communication in Methicillin-resistant *Staphylococcus aureus* (MRSA) at 0.04 % v/V concentration [42]. Compounds **71** and **65** inhibit vancomycin-resistant *E. faecalis* by binding to Beta-Ketoacyl-[acyl carrier protein]-synthase (KAS) III, which is required for bacterial fatty acid synthesis [154]. Other compounds, such as Genistein (aglycone of compound **123**), compounds **112**, **115**, **114**, **76**, **122**, and **305**, exhibit activity against various microorganisms, even on resistant strains, at various concentrations [155–159]. Another mechanism of action, "inhibition of d-Alanine: d-alanine ligase," is shown by compounds **115** and **73** against *H. pylori* and *E. coli* [160]. Though compound **113** cannot affect bacterial growth, it can restrain the virulence of pathogenic bacterial strains, like *S. aureus* via Sortase A and B inhibitors [161].

Some terpenoids and their derivatives that have antimicrobial activity are also detected in *Celtis* genus plants (Table 3). Terpenes are more susceptible to gram-positive than gram-negative bacteria. Their lipophilic feature is mainly responsible for their antimicrobial response [162]. Compound **190**, a pentacyclic triterpenoid, has anti-staphylococcal activity against *S. aureus*. However, their individual actions are weaker than the common antibiotics. They produce a synergistic effect with the combination of beta-lactam and glycopeptide class antibiotics through cell wall inhibition. Among them, compound **191** and methicillin are the most effective combinations [163]. Another familiar phyto-triterpenoid of *Celtis* species, compound **200**, has broad-spectrum antibacterial activity. In the Langmuir monolayer technique, this phytoconstituent displayed a disorganizing effect on the applied model of the *E. coli* membrane [164].

Table 4
Biological activities of extracts of *Celtis* genus.

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
Anti-diabetic activity	*C. philippensis*	Crude, Ethyl acetate, Ethanol, and Aqueous extracts	Leaves	In vivo	Various solvent extract-treated groups of Wistar albino rats saw a considerable reduction in their peak blood glucose levels around day 14 of the experiment. However, the extract improved HDL levels relative to the glycemic group, indicating antilipidemic potential.	Glibenclamide	[135]
Anti-diarrheal activity	*C. africana*	Aerial parts	Organic fraction	In vivo	At a high dose, fractioned showed spasmolytic activity in rabbits through the Ca^{++} antagonist induced gut relaxation.	Loperamide	[136]
	C. pallida	Aerial parts	Ethanol extract	In vivo	Inhibited diarrheic defecation in BALB/c mice in a dose-dependent manner	Loperamide	[36]
Anti-inflammatory/ Analgesic activity	*C. australis*	Barks, fruits, fatty acids (fruits)	Ethanol extracts of barks and fruits, fatty acids from ethyl acetate extracts	In vivo	On Swiss albino mice, 500 mg/kg extracts of barks and fruits and fatty acids showed a moderate analgesic effect against acetic acid-induced writhes. On adult female Sprague-Dawley rats, crude extracts and fatty acids suppressed carrageenan-induced paw edema was significant at all concentrations (100 mg/kg, 250 mg/kg, and 500 mg/kg) compared to the standard phenylbutazone.	Paracetamol and Phenylbutazone	[137]
	C. *choseniana*	Leaves	Methanol extract	In vivo, In vitro	In both in vivo and in vitro studies, it suppressed nitric oxide generation as well as mRNA expression of inducible nitric oxide synthase, tumor necrosis factor-alpha, and cyclooxygenase-2.	Prednisolone	[68]
	C. pallida	Aerial parts	Ethanol extract	In vivo	Decreased 30 % in ear inflammation of mice	Indomethacin	[36]
Anti-microbial activity	*C. africana*	Fruit	Hexane extract	In vitro	Against four types bacteria including *E. coli*, *P. mirabilis, S. aureus*, and *B. cereus* (MIC 32 mg/ml). Lowest MIC 4 mg/ml was recorded against *S. aureus*.	Streptomycin	[27]
	C. africana	Leaves	Acetone extract	In vitro	Showed inhibition activity against *C. neoformans* (MIC = 0.22 mg/ml)	Amphotericin B	[28]
	C. africana	Leaves	Hexane extract	In vitro	Against *P. aeruginosa,* and *E. aerogenes* (MIC 32 mg/ml)	Streptomycin	[27]
	C. africana	Stem	Ethyl acetate extract	In vitro	Against *K. pneumonia, P. aeruginosa*, *S. aureus*,	Streptomycin	[27]

(*continued on next page*)

Table 4 (*continued*)

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
					P. mirabilis, and *E. coli* (MIC 32 mg/ml).		
	C. africana	Stem bark	Ethanol extract	In vitro	Showed moderate anti-plasmodic activity against *P. falciparum* 3D7 strain (IC_{50} = 29.05 μg/ml)	Artemisinin	[29]
	C. australis	Leaves	Ethanol extracts	In vitro	More efficient against *C. albicans*, *C. parapsilosis* (MICs = 0.156 mg/ml) than *R. mucilaginosa*(MIC = 0.313 mg/ml).	N/A	[32]
	C. australis	Leaves and seeds	Hexane, and ethyl acetate extract	In vitro	Demonstrated better activity against *Bacillus. sp*, *B. cereus*, *L. ivanovii*, *C. freundii*, and *E. coli* than *S. aureus*. *C. freudii* and *E. coli* were significantly inhibited by leaf ethyl acetate, whereas *B. sp*, *L. ivanovii*, and *Salmonella* sp were more sensitive to seed ethyl acetate.	Tetracyclin and Penicillin G	[138]
	C. australis	Leaves and seeds	Hydro-methanol and ethyl acetate extract	In vitro	Extract of leaves showed inhibition against *A. niger* and *C. albicans* (hydromethanol) and *C. tropicalis* (ethyl acetate). Both leaves and seeds ethyl acetate and hydromethanol (leaves and seeds) showed inhibitory effects on *Candida albicans*, while fluconazole and nistatine had no effect on them. Hydromethanol > Ethyl acetate. Nystatin > Hydromethanol > Fluconazole (*A. Niger*)	Nistatine and Fluconazole	[138]
	C. australis	Leaves	Water and methanol extracts	In vitro	Against *P. aeruginosa* and *S. aureus*. Between the two extracts, methanol showed the highest antibacterial activity. Activity was also recorded against the resistance strains of cefuroxime, ampicillin, and tetracycline. Methanol > Water. Can be used in the case of resistance	Cephotaxime	[30]
	C. australis	Ripe fruits	Ethanol extract	In vitro	Activity against *P. aeruginosa* and *B. subtilis*. MICs were 250 μg/ml and 125 μg/ml, respectively	Ampicillin	[31]
	C. laevigata	Plant materials	Dichloromethane extract	In vitro	Showed better efficiency against *Mycobacterium tuberculosis* (99 %) than *Mycobacterium avium* (39 %)	Rifampin	[35]
	C. pallida	Aerial parts	Ethanol extract	In vitro	Mild antimicrobial activity against *B. subtillis,*	Cefotaxime	[36]

(*continued on next page*)

Table 4 (*continued*)

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
					E. coli, *P. aeruginosa, S. aureus*, and *C. albicans* (MICs = 400 μg/ml).		
	C. tournefortii	Fruits	Ethanol extract	In vitro	Extract showed activity against *L. monocytogenes*, *E. coli*, *S. aureus*, *P. aeruginosa*, *K. pneumonia*, *B. megaterium*, *P. aeruginosa*, *B. subtilis* bacteria, and *C. albicans* fungus.	Streptomycin sulfate (10 mg/ disc) and Nystatin (30 mg/disc)	[33]
	C. tournefortii	Fruits	Methanol extract	In vitro	Activity was recorded against *P. vulgaris, B. megaterium, E. coli*, *L. monocytogenes, P. aeruginosa*, *K. pneumonia*, *B. subtilis*, *S. aureus* bacteria and *C. albicans* fungus. Better than standard (streptomycin and nystatin) against *L. Monocytogenes*, and *B. Subtilis*.	Streptomycin sulfate (10 mg/ disc) and Nystatin (30 mg/disc)	[33]
	C. tournefortii	Fruits	Water extract	In vitro	Activity was noted against *S. aureus*, *B. subtilis*, and *B. megaterium*.	Streptomycin sulfate (10 mg/ disc) and Nystatin (30 mg/disc)	[33]
	C. tournefortii	Leaves	Aqueous extract (Silver Nanoparticles)	In vitro	Silver nanoparticles at doses of 0.06–0.13 μg/mL and 0.50–1.00 μg/mL showed effective inhibitory action against gram-positive bacteria *S. aureus* and *B. subtilis*, while gram-negative bacteria *E. coli*, and *P. aeruginosa*. Silver nanoparticles were also effective against *C. albicans* growth at 0.03 g/mL, a significantly lower dosage than antibiotics.		[34]
Antiulcerogenic activity	*C. iguanaea*	Ethanolextract	Leaves	In vivo	The activity was shown to protect from indomethacin, ethanol, and pyloric ligation-induced gastric ulcers in male Swiss mice. The hexane fraction of this extract reduced indomethacin-induced ulcers by suppressing the release of gastric acid, increasing pH, and decreasing acidity without interrupting intestinal motility through the anticholinergic mechanism.	Ranitidine	[139]
	C. iguanaea	Hexane extract	Leaves	In vivo	The activity of this species reduced indomethacin and pyloric ligation-	Ranitidine	[140]

(*continued on next page*)

Table 4 (*continued*)

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
					induced gastric ulceration and lesion index in the experimental models. It blocked the histamine and cholinergic receptors that hindered the cell molecular events of gastric secretion as well as suppressed the total H+ excretion.		
Cytotoxic /Anticancer activity/ Antiproliferative activity/Anti-tumor activity	*C. aetnensis*	Twigs	Chloroform extract	In vitro	Extract reduced human colon cancer cell line (Caco2) cells by apoptosis at the low dose (5 μM) and necrosis at high dose (250 μg/ml). This extract increased ROS levels, decreased RSH levels, and increased heme oxygenase (HO-1) expression.	Untreated control group	[38]
	C. africana	Aerial parts	Ethyl acetate extract	In vitro	Showed the highest cytotoxicity (EC_{50} = 8.3 μg/ml) among the other extracts such as petroleum-ether, chloroform, and n-butanol against mouse lymphoma cells L5178Y, while positive control Kahalalide F exhibited an EC_{50} of 6.3 μg/ml.	Kahalalide F	[37]
	C. eriocarpa	Leaves	Methanolic extract, n-Hexane fraction, Chloroform fraction, Ethyl acetate fraction, and Aqueous fraction	In vitro	The highest cytotoxin LC_{50} was noted from ethyl acetate fraction against Brine shrimp larva at 243.61 μg/ml, while positive control potassium dichromate revealed LC_{50} at 7.04 μg/ml. Among them, the LC_{50} value ranged from 243.61 μg/ml to 1015 μg/ml. The n-hexane fraction produced the lowest activity. Ethyl acetate fractions > methanol extracts > chloroform fractions > Aqueous fractions > n-Hexane.	Potassium Dichromate	[118]
	C. eriocarpa	Leaves	Methanolic extract, n-Hexane fraction, Chloroform fraction, Ethyl-acetate fraction, and Aqueous fraction	(In vivo/ In vitro)	Compared with camptothecin (positive control), activity was shown against *Agrobacterium tumefaciens* induced tumors on potato discs, but the result was insignificant. Camptothecin showed an IC_{50} value of 3.67 μg/ml, while leaf extracts' IC_{50} values ranged from 372 μg/ml to 1057 μg/ml. Ethyl acetate fraction > Methanol extract >	Camptothecin	[118]

(*continued on next page*)

Table 4 (*continued*)

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
					Chloroform fraction > Aqueous fraction > Hexane fraction		
	C.iguanaea	Leaves	Dichloromethane, and Hexane extract	In vitro	Dichloromethane showed activity against human ovarian (OVCAR-3), lung (NCI–H460), and glioblastoma (U-251) tumour cells, with GI_{50} values of 28.46 μg/ml, 32.31 μg/ml, and 37.99 μg/ml, respectively. On the other hand, hexane extract showed activity against human glioblastoma (U-251), ovarian (OVCAR-3), and colon (HT-29) tumour cells, with GI_{50} values of 6.40 mg/ml, 3.99 mg/ml, and 3.16 mg/ml, respectively. Hexane extract > Dichloromethane extract	Doxorubicin	[108]
	C. tournefortii	Fruits	Ethanol extracts	In vitro	Ethanol extract demonstrated better activity than water and methanol extracts against PC-3.	Cell were treated with DMSO (Solvent-control group)	[33]
	C. tournefortii	Fruits	Methanol extracts	In vitro	Methanol extract exhibited better activity than water and ethanol extracts against A2780.	Cell were treated with DMSO (Solvent-control group)	[33]
	C. tournefortii	Fruits	Water extracts	In vitro	Water extract showed better activity than ethanol and methanol extracts against MCF-7, HCT-116.	Cell were treated with DMSO (Solvent-control group)	[33]
	C. tourneforti	Leaves	Aqueous extract (Silver-nanoparticle)	In vitro	Silver nanoparticles of leaves extract showed effective on CaCo-2 cell line. Morever, low activity was detected against healthy cell line HDF.		[34]
Healing wounded	*C. australis*	Seeds	Ethyl acetate extract	In vivo	In Sprague-Dawley rats, the wound healing rate was as same as the standard ointment rates.	Madécassol®	[141]
Hepatoprotective	*C. tournefortii*	Fruits	Aqueous, 25 % ethanol, and 75 % ethanol	In vivo	Activity was shown to protect against Cu-induced hepatic cell damage in Wistar Albino rats. Fruit extracts significantly emaciated the degenerative and necrotic destruction of the Cu-induced hepatic damage in the rats. It may increase the antioxidant activity that assuages the destruction of the Cu-induced toxicity.	N/A	[142]
	C. tournefortii	Leaves	Aqueous, ethanol-aqueous (1:3 v/v), and ethanol-aqueous (3:1 v/v)	In vivo	Activity was shown to protect against CCl_4-induced hepatic cells damage in Wistar albino	N/A	[143]

(*continued on next page*)

Table 4 (*continued*)

Activity	Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
					rats. Results revealed that the leaf extract tremendously lessened the CCl_4-induced degenerative and necrotic destruction of the rat's hepatic tissue by enhancing the antioxidant activity. It has the potential to be used as a hepatoprotective agent.		
Laxative (prokinetic)	*C. africana*	Aerial parts	Aqueous fraction	In vivo	Rabbits demonstrated dose-dependent spasmogenic action at low dosages of 0.03–3 mg/ml, which contracted the rabbit's jejunum. It displayed atropine-sensitive prokinetic and laxative actions.	Carbachol	[136]
Rumen fermentation	*C. pallida*	Leaves	Hydroalcoholic extract	N/A	Significantly improvement of rumen fermentation at doses 1.2–1.8 ml/g dry matter of diets	N/A	[144]

After the aforementioned, it can be concluded that the various mechanisms of antimicrobial activity of *Celtis* species depend on the plant compounds as well as the types of extract solvent (polar and non-polar). Furthermore, *Celtis* may show some hope for antimicrobial resistance disaster, because of some isolated compound of *Celtis* showed positive effect on the VREF, MRSE, and MRSA. However, the majority of the published articles are based on in vitro tests, which may not assure the same results in animal models or clinical conditions. With the increase of antibiotic-resistant pathogenic bacteria, there is an urgent need to find novel antimicrobial drugs, while phytoconstituents from plants such as *Celtis* could be promising alternatives.

6.2. Anticancer, antitumor, and antiproliferative activities

Cancer is among the ailments that kill large numbers of people every year throughout the world. A study shows that in southern Thailand raw seed consumption has remarkable healing properties in the occurrence of esophageal cancer [165]. Among three different extracts of *C. tournefortii* fruits, the water extract showed better activity against human breast cancer (MCF-7) and human colon cancer (HCT-116) than the ethanol and methanol extracts. However, ethanol extract showed superiority against human prostrate cancer (PC-3), while methanol extract was more efficient against human ovarian cancer (A2780) cell lines [33]. A new glucosphingolipid (compound **235**), isolated from *C. africana*, displayed potent cytotoxicity against mouse lymphoma cells L5178Y, nearly the same as the positive control Kahalalide F and better than other extracts such as ethyl acetate, petroleum-ether, chloroform, and n-butanol extract [37] (Table 5). Methanolic extract and its various fractions of *C. eriocarpa* leaves exhibited cytotoxicity against Brine shrimp larvae, while the ethyl acetate fraction showed more efficiency than the other fractions (n-Hexane, chloroform, and aqueous) and the methanolic extract [118]. Another chloroform extract of *C. aetnensis* twigs induced apoptosis in a Human Colon Cancer (Caco2) cell lines at a low dose, and necrosis at a high dose through the increase of reactive oxygen species (ROS) levels, heme oxygenase (HO-1) expression, and decreasing reactive thiol group (RSH) levels [38].

Some familiar plant bioactive compounds are also identified from investigated *Celtis* species to have tremendous anticancer activity. Compound **147** is such a bioactive compound and one of the frequently occurring fatty acids in *Celtis* species (Table 3), that in high doses decreases the proliferation of Caco-2 cell line [166], with a protective effect against cancer growth [167]. Another fatty acid of *Celtis* species, compound **154**, demonstrated selective cytotoxicity by promoting apoptosis in the human leukemic (MOLT-4) cell line. Compound **154** exerts an anticancer effect in mice by targeting tumor cell DNA topoisomerase I. Surprisingly, it does not affect DNA topoisomerase II, indicating that compound **154** can be used as an anti-cancer medicine [168]. Furthermore, conjugation of N-acylhydrazones, with compounds **149, 153,** and **147** displays activity against human breast cancer (MCF-7), leukemia (HL-60), cervix (KB–V1/Vbl), and melanoma (518A2) carcinomas, while conjugation with compounds **149** is three times better than Doxorubicin [169]. A familiar plant's flavone glycoside, compound **105**, isolated from four distinct *Celtis* species (*C. africana*,*C. australis*, *C. occidentalis*, and *C. iguanaea*) suppresses cell growth, invasion, and migration. In Adeno-carcinomic human alveolar basal epithelial (A549) cell lines, it reduces Cyclooxygenase-2 (COX-2) messenger RNA (mRNA) expression by upregulating MicroRNA 26b (miR-26b) and MicroRNA 146a (mir-146a) [170]. Furthermore, the compound **105** and celecoxib combination demonstrate a synergistic impact

Table 5
Biological activites of the phytoconstituents of *Celtis* genus.

Activity name	Comp. Number	Plants	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref. no
Anticholinergic activity	Compound 8	*C. sinensis*	In vivo	Exhibited a dose-dependent acetylcholinesterase inhibitory effect in a dose-dependent response at male ICR mice	Berberine	[104]
	Compound 8, compound 10, compound 6	*C. africana*	In vitro	Three of them showed moderate acetylcholinesterase inhibitors effects. Compound 10 > compound 6 > compound 8	Galanthamine	[102]
Anti-inflammatory/ analgesic activity	Compound 125	*C. adolphi-friderici*	In vitro	Compound 125 (IC_{50} = 16.3 μM) showed high potent anti-inflammatory activity, even better than standard Baicalein.	Baicalein	[103]
	Compound 131	*C. tessmannii*	In vitro	Activity against lipoxygenase was more than the standard (Baicalein). (IC_{50} = 12.9 μM)	Baicalein	[97]
	Compound 101	*C. sinensis*	In vivo	In vivo, compound 101 decreased inflammatory molecules (IFN-α, TNF-α, IL-2, and IL-17A) in the lymphatic system, inhibited cytokine release into the serum, and increased apoptosis-related protein production in ginkgo acid-induced contact dermatitis in ICR mice. Additionally, in vitro, Con A-activated T cells showed death and decreased inflammatory cytokines. This chemical blocked MAPK and STAT signaling and phosphorylated SHP2.	Dexamethasone	[124]
	Compound 8, compound 10, compound 6	*C. africana*	In vivo	In rats' carrageenan induced paw edema, compound 8 exhibited remarkable action, whereas compounds 3 and 4 exhibited only mild action. compound 8 > compound 10 > compound 6	Diclofenac sodium	[102]
Anti-microbial activity	Compound 138	*C. australis*	In vitro	Activity was shown against gram positive bacteria including *B. sp*, *B. cereus*, *L. ivanovii*, and *S. aureus*. (MICs = 25–100 μg/ml). Most active against *B. cereus* (MICs = 25 μg/ml) Demonstrated activity against gram negative bacteria such as *C. freundii*, *E. coli*, and *S. sp*. (MICs = 25–100 μg/ml)	Tretracycline	[127]
	Compound 191	*C. tessmannii*	In vitro	Showed potency anti-plasmodium activity against various chloroquine-sensitive and resistant *P. falciparum* strains. (IC_{50} = 2.38–1.7 μg/ml)	N/A	[97]
	Compound 301	*C. australis*	In vitro	Against gram positive bacteria such as *B. sp*, *B. cereus*, *L. ivanovii*, and *S. aureus*. (MICs = 100–200 μg/ml) Against gram negative bacteria including *E. coli* and *S. sp*. (MICs = 200 μg/ml)	Tretracycline	[127]
	Compound 303	*C. australis*	In vitro	Showed activity against gram positive bacteria such as *B. sp*, *B. cereus*, *L. ivanovii*, and *S. aureus*. (MICs = 50–200 μg/ml) Activity was demonstrated against gram negative bacteria such as *C. freundii*, *E. coli*, and *S. sp*. (MICs = 100–200 μg/ml)	Tretracycline	[127]
Cytotoxicity/Anti-cancer activity/ Anti-proliferative activity/Anti-tumor activity	Compound 200	*C. philippinensis*	In vitro	Activity showed better against oral epidermoid than other such as against human lung, colon, oral epidermoid, and hormone-dependent prostate cancer. oral epidermoid > hormone-dependent prostate > colon > lung	Paclitaxel and Camptothecin	[115]
	Compound 53	*C. philippinensis*	In vitro	Activity showed better against oral epidermoid than other such as against human lung, colon, oral epidermoid, and hormone-dependent prostate cancer. oral epidermoid > hormone-dependent prostate > colon > lung	Paclitaxel and Camptothecin	[115]
	Compound 54	*C. philippinensis*	In vitro	Activity showed better against oral epidermoid than others such as human lung, colon, oral epidermoid, and hormone-dependent prostate cancer. oral epidermoid > hormone-dependent prostate > lung > colon	Paclitaxel and Camptothecin	[115]

(*continued on next page*)

Table 5 (*continued*)

Activity name	Comp. Number	Plants	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref. no
	Compound 288	*C. africana*	In vitro	Demonstrated better cytotoxicity (EC_{50} = 7.8 μg/ml) than other extracts, such as ethyl acetate, petroleum-ether, chloroform, and n-butanol extract, against mouse lymphoma cells L5178Y, as well as near to the standard Kahalalide F.	Kahalalide F	[37]
	Compound 302	*C. iguanaea*	In vitro	Activity was shown against human liver, breast, colon, and lung tumor cell lines through cell cycle arrest and apoptosis.	Doxorubicin	[108]
	Compound 58, compound 60, compound 59	*C. tetrandra*	In vitro	Compounds demonstrated remarkable activity in overcoming TRAIL (Tumor necrosis factor (TNF)-related apoptosis-inducing ligand) resistance in AGS (human gastric adenocarcinoma) cells. It can be used to treat the TRAIL resistance AGS cell.	Luteolin	[116]
	Compound 63, compound 64	*C. tetrandra*	In vitro	These two flavanol dimers showed low potency to overcome TRAIL resistance in AGS cells.	Luteolin	[116]
Urease inhibitory	Compound 131	*C. tessmannii*	In vitro	Compound 53 was reported as having the most potent anti-urease activity even more than the standard thiourea.	Thiourea	[97]
	Compound 193	*C. adolphi-friderici*		Compound 77 showed the very high potent anti-urease activity even more than thiourea (standard).	Thiourea	[103]
	Compound 301	*C. zenkeri*	In vitro	It was more potent inhibitor against the Jack bean urease (IC_{50} = 20.3 μM), than the standard (thiourea- IC_{50} = 21.5 μM)	Thiourea	[90]
	Compound 304	*C. zenkeri*	In vitro	In comparison to the standard (thiourea- IC_{50} = 21.5 μM), it was high moderate inhibitor of the Jack bean urease (IC_{50} = 27.6 μM).	Thiourea	[90]
	Compound 108, compound 100, compound 99, compound 105,	*C. africana*	In vitro	Compound 108, compound 105, compound 99 and compound 100 showed potent urease inhibitory activity. Compound 105 > compound 108 > compound 99 > compounds 100	Thiourea	[123]

*Compound number indicates the compound's serial number of Table 3.

on cell invasion and migration in A549 cell lines through the inhibition of COX-2, inducible nitric oxide synthase (iNOS), and B-Cell Leukemia 2 expression with the activation of the apoptosis-inducing gene "Cytochrome P450 Family 1 Subfamily A Member 1" [170]. The results show that both compound **105** and its combination could be a potentially effective medicine that kills cells by causing inflammation.

Cytotoxic terpenoids are also detected from *Celtis* genus. For example, compound **199**, which is separated from fruits of *C.africana* [27], can reduce a significant portion of rats' aberrant crypt foci (ACF) in the colon. The possible mechanism is that it may be able to stop "3-Hydroxy-3-Methyl-Glutaryl-Coenzyme A Reductase" or bile acids that lead to colonic tumors or ACF [171]. Compounds **58** and **60**, two flavanol epimers of the bark of *C. tretranda*, contribute to human gastric adenocarcinoma (AGS) cells regain from Tumor Necrosis Factor Related Apoptosis-Inducing Ligand (TRAIL) resistance-overcoming properties much more than their dimers, compounds **63** and **64** [116].

Because of their ability to block the expression of numerous tumor-and angiogenesis-associated genes, phytoconstituents may also enhance apoptotic signaling channels by reducing activating caspases, as demonstrated by analogous molecules from other plant genera [172], along with significant downregulation of DNA synthesis. Additional investigation is needed to put emphasis on the probable pharmacological mechanisms that are involved in anticancer activity. Also, the results of the experiments need to be backed up by a lot of research on human carcinoma cell lines.

6.3. Anti-inflammatory activity

Almost every clinical manifestation is accompanied by a proinflammatory response. As a result, the anti-inflammatory properties of *Celtis* plant materials may be useful. Various kinds of inflammation have been used to test the anti-inflammatory activities of *C. australis* barks and fruits [137], *C. pallida* aerial parts [36], as well as *C. choseniana* leaf extracts [68].

The anti-inflammatory properties of ethanolic extracts of barks and fruits of *C. australis* were reported via their remarkable reduction of carrageenan-induced paw edema. The same study also revealed the analgesic effects of *C. australis* by inhibition of acetic acid-induced writhes in Swiss albino mice [137]. However, the extracts' outcomes against inflammation were better than the fatty acid experiment [137]. Leaves of *C. choseniana* decrease nitric oxide generation as well as mRNA expression of iNOS, COX-2, and tumor necrosis factor-alpha (TNF-α) [68]. Further investigation revealed that this extract contained anti-inflammatory flavonoids such as

compounds **112**, **115**, and **76** [68].

Compound **25**, an isolated phytoconstituent from *C. africana* fruits, leads to anti-inflammatory effect by suppressing iNOS and COX-2 [173], whereas compound **131** of *C. tessmannii* acid shows activity by inhibiting lipoxygenase [97] (Table 5). Compound **148** also reduces lipoxygenase induced interleukin-1 (IL), IL-6, and TNF-α [97]. Additionally, TNF-α production is also inhibited by *C. sinensis* lignan glycoside [101].

From the aforementioned, it is apparent that *Celtis* genus bioactive molecules decrease inflammatory components through the interrupting cyclooxygenase, and lipoxygenase pathway, which may lead to reduce the generation of inflammatory mediators such as IL and TNF-α.

6.4. Anti-diarrheal and prokinetic activity

The antidiarrheal effect of the *Celtis* genus has been investigated through many animals' model, such as rabbits and BALB/c mice. The chloroform fraction of ethanol: water (8:2) extract of *C. africana* aerial parts reduced the frequency of stooling in rabbits at a high dose [136]. An ethanol extract of *C. pallida* aerial parts exhibited dose-dependent antidiarrheal activity via diarrheic defecation in BALB/c mice [36]. Conversely, the aqueous fraction of ethanol: water (8:2) extract of *C. africana* aerial parts demonstrated atropine-sensitive prokinetic activity at lower dose by contracting rabbits' jejunum [136]. Medicinal plants are generally known to have antidiarrheal properties through stimulating the intestinal K^+ channels and activating Na^+/K^+- ATPase activity, as well as reducing intracellular Ca^{++} concentration, facilitating gastrointestinal smooth muscle relaxation as well as reducing diarrhea [174–176]. Further studies are necessary to isolate the potential anti-diarrheal compounds from *Celtis* species extracts, which may lead to get a new gut relaxation agent.

6.5. Acetylcholinesterase inhibitory activity

Acetylcholinesterase is responsible for the cessation of signal transduction of several cholinergic systems in the central and peripheral nervous systems by efficiently breaking down the neurotransmitter acetylcholine [177]. From the *Celtis* genus, different hydroxycinnamic acid derivative amide compounds, **8**, **10**, and **6,** were detected in the ethanol-water extract of *C. africana* aerial parts, which showed a weak to moderate acetylcholinesterase inhibition activity [102]. Compound **8** is also isolated from twigs of *C. sinensis* [104]. As per their structure, compound **8** has a hydroxy group at the 4th position, while compound **10** has an extra methoxy group at the 3rd position that may be accountable for its better activity. However, the most active constituent among them, compound **6**, has two additional hydroxy groups at the 3rd and 4th positions, which may be responsible for the strongest activity [102]. As per our knowledge, despite their structure-activity-relationship, the exact mechanism of action against acetylcholinesterase is still obscure. Additional investigation is needed to learn about their mechanism of action, which may lead to the invention of a novel acetylcholinesterase inhibitory molecule.

6.6. Anti-urease inhibitory activity

The nickel-containing enzyme, urease, plays a vital role in the breakdown of urea to generate ammonia and CO_2 [178]. The urease activity of *H. pylori* plays a crucial role in the etiology of gastric and peptic ulcers [179]. So, plant-urease inhibitors are potent compounds that can be used as anti-ulcer medications. The urease inhibitory effect of *Celtis* plants was revealed in several isolated compounds of three species including *C. adolphi-friderici*, *C. tessmanii,* and *C. africana* (Table 4). A triterpene, compound **193**, detected from the roots of *C. adolphi-friderici* exhibited more potent anti-urease activity (50 % inhibitory concentration (IC_{50}) = 15.36 μM) than other isolated compounds from this species, even more, effective than standard thiourea (IC_{50} = 21.6 μM) [103]. Compound **131**, another phytoconstituent, that was isolated from *C. tessmanii*, also had more efficacy anti-urease activity (IC_{50} = 12.9 μM) than thiourea [97] (Table 5). Four constituents, including compound **108**, compound **105**, **99**, and **100** of *C. africana* demonstrated potent anti-urease activity, while the other three compounds **94**, **95**, and **109** were not as efficacious as the previous four constituents [123]. As per their structure, the presence of a sugar moiety might reduce their potential anti-urease activity [37].

Isolated compounds of *Celtis* species have tremendous potential as urease inhibitory constituents. Despite their remarkable activity against the urease enzyme, their precise mechanism of action remains unknown. Moreover, all investigation has been done under an in vitro test. A clinical trial is necessary to evaluate their in vivo potency, which may lead to the establishment of a new potent anti-urease medication.

6.7. Other medicinal properties

Aside from the previously mentioned activities, the isolated phytoconstituents and extracts have several protective functions. For example, compounds **148** and **199** have neuro- and hepatoprotective effects, respectively [180,181]. Ethyl acetate extract of *C. australis* seeds had remarkable wound healing efficacy comparable to that of standard ointment [141]. Furthermore, detected flavonoids such as compounds **106**, **67**, and **69** have cardioprotective properties due to their immunosuppressive and antioxidant properties [182–184]. More research is needed to investigate the various processes involved in the aforementioned positive benefits.

7. Antioxidant properties

Besides performing several biological functions, extracts and compounds of *Celtis* plants exhibit remarkable antioxidant activity (Tables 6 and 7). Their abilities to quench singlet oxygen and react with a variety of radical species may help to reduce oxidative stress in humans. So, it may help protect against diseases like heart disease and cancer [185]. Leaves and fruits extracts of *Celtis* plants display antioxidant activities in various tests (Table 6).

In a 2,2-Diphenyl-1-Picrylhydrazyl (DPPH) scavenging test, methanolic extract of *C. africana* stems showed better antioxidant activity than leaves [186]. Another hackberry (*C. australis*) showed different antioxidant properties at DPPH, and ferric reducing antioxidant power assay (FRAP) based on their different genotpes. The varying antioxidant potential estimated using FRAP and DPPH tests was 44.35–117.87 mg Fe^{2+}/100 g and 14.12–88.24 %, respectively [110]. Furthermore, Synergism activity is also noticed in the *Celtis* genus. For instance, the n-butanol fraction of *C. africana* aerial parts exhibited an IC_{50} value of 40.5 μM, which is better than the other isolated compounds of this fraction >42 μM [123]. Water extract of *C. tournefortii* fruit showed more efficacious in hydroxyl radical (OH^-) scavenging test than the standard butylated hydroxytoluene (BHT) [33]. Also, hydroalcoholic extracts of *C. iguanaea* leaves showed antioxidant activity in a rat model by lowering the levels of thiobarbituric acid reactive substances (TBARS) (byproducts of lipid peroxidation) in the plasma and raising the levels of nonprotein thiols (CI-600) [121].

Almost all investigated *Celtis* plants contain a variety of flavonoids, including flavanol, flavone, isoflavone, flavonol, and flavanonol, which have been known for their antioxidant activity due to their ability to act as hydrogen donors as well as reducing agents [188]. Flavonoids suppress the enzymes that produce superoxide anions, such as protein Kinase-C and xanthine oxidase. They can also inhibit microsomal monooxygenase, cyclooxygenase, mitochondrial succinoxidase, lipoxygenase, glutathione S-transferase, and nicotinamide adenine dinucleotide oxidase, all of which are involved in the generation of ROS. Furthermore, flavonoids effectively chelate trace metals that are needed in oxygen metabolism [189]. Three flavanols, compounds **59**, **61**, and **62**, are reported from the *Celtis* plants (Table 3), where compounds **59** and **62** demonstrated similar antioxidant properties in the DPPH scavenging test (nearly

Table 6
Antioxidant properties of various extractives of *Celtis* genus.

Species	Part	Extract	In vitro/ In vivo	Key findings	Positive control/ Standard	Ref no.
C. africana	Aerial parts	Ethanol extract (n-butanol fraction)	In vitro	Showed anti-oxidant activity while IC_{50} value was 40.5 μM (DPPH scavenging test). That was better than the other isolated compounds > 42 μM. Maybe it's a synergism effect of isolated compounds from this extract	BHA	[123]
C. africana	Leaves and stems	Methanol extract	In vitro	At 0.1 mg/ml concentration, stem showed better activity than leaves (DPPH testing). It is less effective than the standard ascorbic acid and butylated hydroxytoluene (BHT). Stems > Leaves	Ascorbic acid, BHT	[186]
C. australis	Leaves	Hydroalcoholic extract	In vitro	Comparison to the Ascorbic acid (IC_{50} = 14.3 μg/ml), it showed lower activity (IC_{50} = 80.5 μg/ml) in DPPH scavenging test.	Ascorbic acid	[187]
C. eriocarpa	Leaves	Methanol extracts and sub fraction	In vitro	Ethyl acetate fraction showed greater activity than others including hexane, chloroform, aqueous fractions and methanol extracts (DPPH testing). Ethyl acetate fractions (EC_{50} = 324.81 μg/ml) > methanol extracts (EC_{50} = 593.68 μg/ml) > chloroform fractions (EC_{50} = 1058.18 μg/ml) > aqueous fractions (EC_{50} = 1155.0 μg/ml) > hexane fractions (EC_{50} = 2981.03 μg/ml).	Ascorbic acid	[118]
C. iguanaea	Leaves	Hydroalcoholic extract	In vivo	Activity was observed in rats' plasma by the decrease of TBARS (Thio-barbituric acid reactive substances) and an increase in nonprotein thiol levels (CI-600).	Simvastatin	[121]
C. pallida	Leaves	Methanol, methanol: water (80:20), and acetone extract	In vitro	In the DPPH scavenging test, acetone extract showed better activity than other two including methanol, and methanol: water (80:20). acetone > methanol > methanol: water (80:20)	BHA, α-tocopherol	[117]
C. tournefortii	Fruits	Water, ethanol and methanol extracts	In vitro	In the DPPH radical scavenging testing, activity was lower than standard BHT. However, in the OH^- scavenging testing fruits water extract (84.12 %) exhibited higher antioxidant activity than BHT (75.77 %).	BHT	[33]
C. zenkeri	Leaves and stem barks	Essential oils	In vitro	At 250 μg/ml, leaves showed tremendous antioxidant activity compared to standard ascorbic acid and BHA, while being higher than α-tocopherol (DPPH testing). Stem barks showed the same potent activity as standards (ascorbic acid and BHA) at any concentration, more than α-tocopherol.	Ascorbic acid and BHA	[99]

Table 7
Antioxidant properties of the new phytoconstituents of *Celtis* genus.

Comp. Number	Plants	Invitro/ In vivo	Key findings	Positive control/ Standard	Ref. no
Compound 138	*C. australis*	In vitro	In the DPPH scavenging test, the IC_{50} value was 8.2 μg/ml, while the BHT IC_{50} was 12.0 μg/ml.	BHT	[127]
Compound 131	*C. tessmannii*	In vitro	In the DPPH radical scavenging test, compound 53 was better antioxidants than the standard.	BHA	[97]
Compound 81	*C. australia* & *C. occidentalis*	In vitro	Showed greater activity against superoxide radical (induced by xanthine oxidase) as well as DPPH radical scavenging testing than the standard.	α-tocopherol, and BHT	[52]
Compound 8, Compound 10, Compound 6	*C. africana*	In vitro	In the DPPH scavenging test, compound 6 is more active than others two compounds. Compound 6 and compound 10, were better than standard BHA (26.3 μm and 33.2 μm, respectively). Compound 6 > compound 10 > compound 8	BHA	[102]
Compound 6, compound 10, compound 9, compound 7, compound 4, compound 8	*C. occidentalis*	In vitro	In the DPPH scavenging testing, compound 6 and 10showed remarkable antioxidants activity. Compound 6 > compound 10 > compound 9 > compound 7 > compound 4 > compound 8	Caffeic acid (IC_{50} = 4.6 ± 0.3)	[100]
Compound 138, compound 141, compound 125	*C. adolphi-friderici*	In vitro	In the DPPH scavenging test, compound 125 showed tremendous activity compound 141, and compound 138. While all compounds demonstrated good antioxidant as well as better than the standard BHA Compound 125 > compound 141 > compound 138 > standard BHA.	BHA	[103]

Note: Compound number indicates the serial number of the compounds displayed in Table 3.

80 % effective), while compound **61** was greater than them (85 % effective). But low-density lipoprotein (LDL) oxidation and FRAPassays showed that compounds **59** and **61** were equally effective (Table 7) [190].

Compound **104**, a flavonol glycoside, is isolated from four different *Celtis* species (*C. australis, C. tournefortii, C. occidentalis*, and *C. iguanaea*) (Table 7), and exhibits a variety of protective actions via an antioxidant mechanism. For example, it acts as a ROS scavenger where it increases glutathione production as well as improves cellular oxidative defense mechanisms by upregulating numerous antioxidant enzymes, including catalase and superoxide dismutase [191]. Additionally, compound **104** inhibits xanthine oxidase, which is also responsible for the production of ROS [191]. It also displays several neuroprotective activities in various in vitro and in vivo studies, through the reduction of ROS, lipid peroxidation, and iNOS [191]. Another apigenin flavone glycoside of the *Celtis* genus, compound **114** and its various derivatives (Table 3) also have remarkable antioxidant as well as protective activity where it reduces the growth of lipid peroxidation, nitrite levels, and neuronal degeneration. It recovers the acetylcholinesterase–monoamine enzyme to its normal range and reduces the expression of mRNA of the metabotropic glutamate receptor 1, N-methyl--D-aspartate-receptor, and metabotropic glutamate 5 [192]. Another study of compound **114** (15 mg/kg, i. v.) showed that it improved the neurological dysfunction in cerebral ischemia/reperfusion by boosting extracellular signal-regulated kinase ½ and BCL-2 protein levels in the cortex and hippocampus while diminishing BCL-2 associated X protein expression, jun N-terminal kinases, and p38 phosphorylation [193].

Because of having conjugated double bonds, terpenoid compounds have the ability to quench singlet oxygen, hydrogen or electron transfer. Such as isolated terpenoids of *C. australis* fruits, compound **83** showed greater antioxidant activity than compound **82** due to the presence of additional double bonds in compound **83** [185]. Along with oxygen radicals, terpenoids also scavenge several radicals. Compound **82**, for instance, scavenges sulfur radicals, whereas compound **84** scavenges sulfonyl, nitrogen, and glutathione radicals [185]. Tocopherols (compounds **85**–**88**) can move hydrogen atoms from one molecule to another, which changes lipids and peroxyl radicals into more stable substances [194].

8. Other uses

Along with traditional and pharmacological uses, *Celtis* plants are also known for their decorative [195], furniture, millwork, and box manufacturing purposes [195,196]. Apart from decorative use, *C. africana* wood is used for flooring, construction, fuel, and charcoal manufacturing [27]. *C. occidentalis* roots are used to make dye [197], while the bark of *C. australis* is used to make yellow dye [198]. Furthermore, the woods of *C. australis* are used as fuel [199], agriculture equipment, and handle manufacturing [88]. Malleable thin shoots are used as walking sticks [197]. The timber of *C. tetranda* is strong, and durable and is used for manufacturing handle ores as well as fuel [199]. Roots of *C. pallida* are much strong to use in erosion problems [200]. However, the timber of *C. laevigata* and *C. pallida* is not good enough. They are used only for fencing and fuel [199,201,202].

9. Limitations

The review could be more flawless. The specified phytoconstituents of the genus or delve into their intricate mechanisms of action were not thoroughly examined primarily due to insufficient evidence regarding precise mechanistic details. In addition, the review

lacks the crucial ethnopharmacological information. The ethnopharmacology section would benefit from enhancements by incorporating specific criteria for interpreting ethnobotanical data. This could involve utilizing qualitative citation metrics like Relative Frequency Citation (RFC), Fidelity Level (FL), Relative Importance (RI), and Frequency Index (FI). However, since the article is primarily a narrative review, its main emphasis lies in presenting the current understanding of the ethnopharmacological and phytopharmacological significance of the *Celtis* genus. This focus is intended to facilitate future research and the acquisition of data for characterizing the genus and exploring its medicinal uses, with the potential to expedite the discovery of novel bioactive compounds.

10. Conclusion and futuristic prospects

Numerous findings show that plants of the *Celtis* genus have remarkable ethnopharmacological properties, thanks to their biologically active compounds. The three most investigated species, *C. africana*, *C. australis*, and *C. tournefortii*, have antibacterial, antioxidant, anticancer, and anti-inflammatory properties. Phytochemical studies revealed that the primary constituents occurring in this genus are amides, organic acids (phenolic acids, hydroxycinnamic acids, fatty acids, and aliphatic carboxylic acids), terpenoids (diterpenoids, triterpenoids, tocopherols, and carotenoids), flavonoids (flavanol, flavone, flavonol, and their glycosides), and esters (fatty acid esters).

Despite the important biological activities (antimicrobial, anticancer, and overall urease inhibition activities) of the genus *Celtis*, thanks to their potential new therapeutic molecules, this have not fully confirmed them because the studies were not fully established with scrutiny. Moreover, preliminary research has been limited to a few animal trials and is not widely accepted because it may behave differently in extensive studies.

To promote the therapeutic active compounds and as nutraceuticals of the *Celtis* genus, the research community may take some following steps.

i. Because the activity of bioactive compounds in the *Celtis* genus is connected to their ethnopharmacological activity, retrace and organize traditional information about the *Celtis* species to understand how effective bioactive molecules may have been discovered.
ii. Further phytochemical analysis is needed to isolate compounds from the bio-active extracts and bioassay tests of the isolated compounds are also needed for the determination of the responsible phytochemicals. For example, the extracts *C. australis* and *C. africana* showed some hope of having effective antimicrobial agents.
iii. Designing a new pathway to collect or synthesize target molecules noticed in Table 5 may lead to finding a novel medicinal molecule.
iv. In addition to the study of pharmacological activity, a pharmacokinetic study to evaluate the absorption, metabolism, distribution, and elimination of *Celtis* extract and its bioactive phytoconstituents is required.
v. An accurate toxicology and dose-response graph are needed to indicate the therapeutic range which was missed in the maximum study.
vi. Clinical trials are required to evaluate the further biological consequences of these substances that have already been examined in vitro and in vivo.
vii. The bioactive agents' safety and efficacy and the potential pathways of protection must also be evaluated before introducing such molecules for further studies in human and animals.

Because of the up to date comprehensive information on the *Celtis* genus' ethnopharmacological to potent bioactive molecules and phytochemistry, as well as the future prospects of the scope of *Celtis* genus research, this review article will be helpful to those who have an interest in the *Celtis* genus especially for its important ethnopharmacology and bioactive molecules.

Data availability statement

All the data involved in the review are explained in the manuscript.

CRediT authorship contribution statement

Md Abdus Samadd: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Visualization, Writing – original draft. **Md Jamal Hossain:** Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Miss Sharmin Zahan:** Investigation, Methodology, Validation, Visualization, Writing – review & editing. **Md Monirul Islam:** Resources, Software, Validation, Visualization, Writing – review & editing. **Mohammad A. Rashid:** Investigation, Methodology, Supervision, Validation, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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