Supercritical Fluid for Extraction and Isolation of Natural Compounds

K. Vidwathpriya, S. Sriranjani, P. K. Niharika, and N. V. Anil Kumar

Abstract Supercritical fluid (SCF) extraction has emerged as an effective and efficient method for separating important phytoconstituents. The extraction process is simple and environmentally friendly, generating minimal to no waste. This procedure offers various advantages over traditional extraction techniques. This chapter discusses the procedure, advantages, and different types of phytoconstituents isolated using supercritical fluids, with a preference for natural products.

Keywords Supercritical · Extraction · Phytoconstituents · Solvent · CO_2 · Dissolve · Oil · Alkaloids · Flavonoids · Terpenes

1 Introduction

Supercritical fluid (SCF) extraction is an analytical method to separate the analyte from the sample matrix using supercritical fluids as solvents (Hedrick et al. 1992). This technique is rapid, inexpensive, sustainable, and simple to execute, compared to the traditional Soxhlet extraction, where solvent costs are usually high, requiring several hours accompanied by an additional concentration step that aids pollution (Sapkale et al. 2010).

SCF extraction was initiated along with supercritical fluid chromatography in the late twentieth century for isolating forensically relevant compounds (Khaw et al. 2017). It later gained popularity when supercritical toluene was used mainly in the petroleum industry with many commercial interests.

Over the last few years, SCF extraction has gained recognition for its many established advantages, particularly supercritical carbon dioxide, because of its easy-to-use properties (2017). CO_2 has a near ambient critical temperature of 31 °C,

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allowing many biological materials and natural products to be processed around 35 °C without denaturation. It is being extensively used in decaffeination and power generation processes and is widely used to extract natural products, leaving no toxic residues behind (Khaw et al. 2017).

The advantage of supercritical CO_2 ($ScCO_2$) is that its extraction properties can be precisely varied with just minute changes in temperature and pressure. The properties can also be modified using solvents like ethanol (Camel 2001). Other than CO_2, various solvents are used to extract bioactive components from plants, namely, propane, DME, SF2, and ethanol (Bizaj et al. 2021).

2 Methodology/Mechanism

A supercritical fluid is a substance whose thermodynamic properties are higher than the critical temperature and pressure of the source compound. The maximum temperature, beyond which the gaseous state of a substance cannot be liquified, irrespective of the amount of pressure applied, is called the critical temperature of the substance. Critical pressure is the minimum pressure required to condense a gaseous substance to a liquid at its critical temperature (Alekseev et al. 2020). For carbon dioxide, the critical temperature is 304.2 K and 73.0 atm.

In the supercritical region, a homogenous fluid materializes, which has unique physiochemical properties. In this region, the surface tension of the supercritical fluid is equal to zero, the dissolving and swelling capacity increases, and the viscosity decreases (Alekseev et al. 2020). The physiochemical properties can be modulated by changing the parameters of the supercritical state. The density of supercritical fluids changes with variations in pressure and temperature; a slight increase in pressure can cause a drastic increase in the density of the supercritical fluid, which in turn causes an increase in the solubility of the supercritical solvent. Once extraction is complete, solvent recovery is relatively simple due to the volatility of the supercritical fluid leaving behind the extracted analyte (Pourmortazavi et al. 2014). Such manipulations of the physiochemical properties make SCFs an excellent solvent for extraction due to their high selectivity, solubility, and extraction efficiency (Yousefi et al. 2019).

The setup (Fig. 1) for supercritical fluid extraction involves a pump, a pressurized compartment, and a collecting vessel. The solvent is commonly stored in a tank connected to a pressurized pump. The commonly used solvent is CO_2, pumped into the system as a liquid below 5 °C and at around 50 bars of pressure. The fluid is cooled to remain a liquid but heated to critical condition after pressurization. The pressure must be maintained in the extraction cell, and heating should be provided to counteract the cooling caused by the adiabatic expansion of the CO_2. Raw material from which the natural product is extracted is placed in the extraction cell, where pressure and temperature are controlled. The raw material is also pre-treated to modulate the moisture content and particle size for optimal extraction. The supercritical fluid is allowed to enter the pressurized extraction cell, where the natural

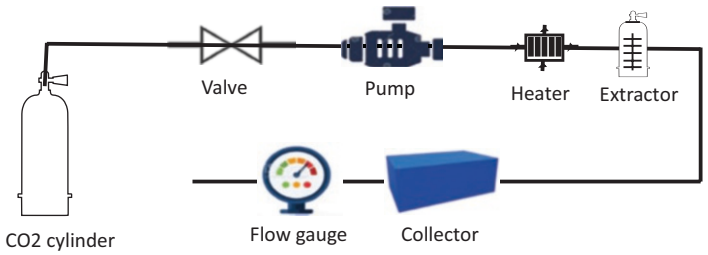

Fig. 1 Setup of $ScCO_2$ extraction

products to be extracted dissolve in the supercritical fluid based on its solubility, which in turn is dictated by its density and pressure. Once the extraction is completed, the fluid with the dissolved natural product is passed through a chamber with lesser pressure, reducing the fluid's dissolving power, and the natural product gets precipitated out. The depressurization of the supercritical CO_2 causes the fluid to become a gas and can be collected separately for further use (Sapkale et al. 2010).

Table 1 lists the chemicals/phytochemicals extracted from the species. Some of the chemicals listed in this table are generic in name, as the literature does not specify the individual compound. The table is arranged in alphabetical order of the species name.

Table 1 List of chemicals isolated from different species using $ScCO_2$

Sl no	Species name	Chemicals/phytochemicals	Ref
1	*Abelmoschus manihot*	Rutin, hyperin, isoquercetin, hibifolin, myricetin, quercetin-3′-O-glucoside, quercetin	Li et al. (2016a)
2	*Acacia dealbata*	Oxygenated triterpenes	Casas et al. (2021)
3	*Acacia dealbata*	Lupenyl acetate, lupenone, tetracosanoic acid, hexacosan-1-ol	Rodrigues et al. (2021)
4	*Acanthophoenix rubra*	Vitamin E	2018)
5	*Acanthus ilicifolius*	2-benzoxazolinone	Arumugam and Thiruganasambantham (2018)
6	*Acer nikoense*	Diarylheptanoids	Alberti et al. (2018)
7	*Alnus glutinosa*	β-Sitosterol, betulin, betulinic acid, lupeol	Felföldi-Gáva et al. (2012)
8	*Alnus hirsuta*	Diarylheptanoids	Alberti et al. (2018)
9	*Aloysia citrodora*	Phenylpropanoids, Flavonoids	Leyva-Jiménez et al. (2020)
10	*Alpinia blepharocalyx*	Diarylheptanoids	Alberti et al. (2018)
11	*Alpinia officinarum*	Diarylheptanoids	Alberti et al. (2018)

(continued)

Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
12	*Amaranthus cruentus*	Linoleic acid, decadieneal, linoleic acid propyl ester, 2.5-pentadecadiene-l-ol, 9-oxononanoic acid	Velikorodov et al. (2018)
13	*Ananas comosus*	Esters, ketones, alcohols, aldehydes, acids	Mohamad et al. (2019)
14	*Andrographis paniculata*	Rosmarinic acid, eurycomanone, andrographolide	Abd Aziz et al. (2021)
15	*Andrographis paniculata*	Andrographolide	Kumoro et al. (2019)
16	*Andrographis paniculata*	Andrographolides	Kumar et al. (2014)
17	*Annona muricata*	Flavonoids, Tannins, Phenolics, Phytate	Mesquita et al. (2021)
18	*Aquilaria malaccensis*	n-Hexadecanoic,1H-Cycloprop[e]azulene, decahydro-1,1,7-trimethyl-4-methylene	Eissa et al. (2018)
19	*Artemisia annua*	Artemisinin	Baldino and Reverchon (2018)
20	*Ascophyllum nodosum,*	Alginate, agar, carrageenan	Abdul Khalil et al. (2018)
21	*Azadirachta indica*	Terpinen-4-ol, 1,2,4-Trithiolane, 3,5-diethyl, allyl isopropyl sulphide, Cycloisolongifolene, á-Bisabolene, (−)-α-Panasinsen, Isocaryophyllene, trans-Sesquisabinene hydrate, 1-Naphthalenol	Swapna Sonale et al. (2018)
22	*Baccharis uncinella*	α-Pinene, β-pinene, limonene, (E)-caryophyllene, germacrene D, bicyclogermacrene, spathulenol, caryophyllene oxide	Minteguiaga et al. (2021)
23	*Betula platyphylla*	Diarylheptanoids	Alberti et al. (2018)
24	*Boswellia serrata*	α-Thujene, camphene, β-pinene, myrcene, limonene, m-cymene, cis-verbenol	Ayub et al. (2018)
25	*Brassica campestris*	Linolenic acid amide, linolenic acid glyceride, linolenic acid, palmitic acid	Li et al. (2016c)
26	*Brassica napus*	Phytosterols	Jafarian Asl et al. (2020)
27	*Bryonopsis laciniosa*	Linoleic acid, linolenic acid, β-sitosterol stigmasterol	Balkrishna et al. (2022)
28	*Calendula officinalis*	Bioactive pentacyclic triterpenes	Villanueva-Bermejo et al. (2019)
29	*Calluna vulgaris*	Bioactive pentacyclic triterpenes	Villanueva-Bermejo et al. (2019)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
30	*Camellia oleifera*	Palmitic acid, stearic acid, oleic acid, linoleic acid, α-tocopherol, β-carotene, squalene phytosterol. 3-hydroxytyrosol, benzoic acid, catechins, 4-hydroxybenzoic acid, chlorogenic acid	Fang et al. (2015)
31	*Cananga latifolia*	Phenolic acids, flavonoids, tannins, alkaloids	Chhouk et al. (2018)
32	*Cannabis sativa*	Tetrahydrocannabinol	Gallo-Molina et al. (2019)
33	*Cannabis sativa*	ω-6 linoleic acid, ω-3 α-linolenic acid	Devi and Khanam (2019b)
34	*Cannabis sativa*	Cannabidiol	Marzorati et al. (2020)
35	*Capsicum annuum*	γ-Tocopherol	Cvetković et al. (2020)
36	*Capsicum chinense*	Rutin, vicenin-2	de Aguiar et al. (2019)
37	*Capsicum frutescens*	Capsaicinoids	de Aguiar et al. (2018)
38	*Carica papaya*	Oleic acid	Devi and Khanam (2019a)
39	*Catharanthus roseus*	Vincristine	Karimi and Raofie (2019)
40	*Chaenomeles japonica*	α-Tocopherol, β-tocopherol, γ-tocopherol	Górnaś et al. (2019)
41	*Chenopodium quinoa*	Tocopherol	Benito-Román et al. (2018)
42	*Cinnamomum cambodianum*	Phenolic acids, flavonoids, tannins, alkaloids	Chhouk et al. (2018)
43	*Cinnamomum verum*	Cinnamaldehyde, eugenol	Masghati and Ghoreishi (2018)
44	*Cinnamomum verum*	Eugenol, eugenol acetate	Khalil et al. (2017)
45	*Citrus grandis*	7-Methoxy-8-(2-oxo-3-methylbutyl) coumarin, (6E,8E,10E)-2,6,11,15-tetramethyl-2,6,8,10,14-hexadecapentaene, γ-sitosterol, hexadecanoic acid, (E,E)-2,4-decadienal, pentacosane	Gyawali et al. (2012a)
46	*Citrus grandis*	(Z)-9-Octadecenoic acid, limonene, α-Terpineol, (E,E)-2,4-decadienal, hexadecanoic acid, pentacosane, stigmasterol, γ-sitosterol	Gyawali et al. (2012b)
47	*Citrus hassaku*	(Z)-9-Octadecenoic acid, limonene, α-Terpineol, (E,E)-2,4-decadienal, hexadecanoic acid, pentacosane, stigmasterol, γ-sitosterol	Gyawali et al. (2012b)
48	*Citrus Iyo*	(Z)-9-Octadecenoic acid, limonene, α-Terpineol, (E,E)-2,4-decadienal, hexadecanoic acid, pentacosane, stigmasterol, γ-sitosterol	Gyawali et al. (2012b)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
49	*Citrus maxima*	Terpenes, terpenoids, aldehydes, alcohols, esters	Chen et al. (2018a)
50	*Citrus reticulata*	Nobiletin, 3,5,6,7,8,3′,4′-heptamethoxyflavone, tangeretin	Long et al. (2019)
51	*Citrus sinensis*	α-Terpineol, D-Limonene, hesperidin	Barrales et al. (2018)
52	*Citrus sinensis*	Limonene, Hesperidin	Jokić et al. (2020)
53	*Colchicum speciosum*	Colchicine	Bayrak et al. (2019)
54	*Corallina officinalis*	Acyclic alkanes, branched alkanes, alkenes, organobromine compounds, organosulfur compounds, aromatic compounds, monoterpenes, sesquiterpenes, diterpenes, triterpene	Djapic (2018)
55	*Coriandrum sativum*	Linalool, camphor, linalool oxide, p-cymene, α-pinene, limonene, geranyl acetate	Choi and Lee (2018)
56	*Corylus avellana*	Diarylheptanoids	Alberti et al. (2018)
57	*Crocus sativus*	Crocetin sugar esters, picrocrocin, safranin	Kyriakoudi and Z. Tsimidou (2018)
58	*Crocus sativus*	Apocarotenoids, anthocyanins, flavonoids, anthocyanidins, phenolic compounds	Bakshi et al. (2022)
59	*Croton Polycarpus*	Flavanols, sesquiterpenoids	Aponte-Buitrago et al. (2017)
60	*Cucumis melo*	Linoleic acid, oleic acid, palmitic acid, stearic acid	Bouazzaoui et al. (2018)
61	*Cucurbita maxima*	Tocopherols	Rohman and Irnawati (2020)
62	*Cucurbita pepo*	Desmosterol, campesterol, stigmasterol, β-sitosterol, spinasterol, Δ7,22,25-stigmastatrienol, Δ7-stigmastenol, Δ7,25-stigmastadienol, Δ7-avenasterol	Hrabovski et al. (2012)
63	*Cuminum cyminum*	Cumin aldehyde, γ-terpinene, β-pinene, β-Cumic aldehyde, α-phellandrene	Fang et al. (2018)
64	*Curcuma caesia*	Beta-elemene, curzerenone, boldenone, 2-cyclohexen-1-one, 4-ethynyl-4-hydroxy-3, 5, 5-trimethyl.	Chaturvedi et al. (2020)
65	*Curcuma longa*	Tumerone, ar-turmerone, curlone	Haiyee et al. (2016)
66	*Curcuma longa*	Turmeric oil	Priyanka and Khanam (2018)
67	*Cymbopogon citronella*	Essential oil	Wu et al. (2019)
68	*Cymbopogon winterianus*	Citronella oil	Salea et al. (2018)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
69	*Cynomorium coccineum*	Glucose, Fructose, Sucrose, Alanine, Asparagine, Glutamine Proline, Valine, Acetate, Citrate, Formate, Fumarate, Malate, Malonate, Succinate, Betaine, Choline	Attia et al. (2018)
70	*Cyphomandra Betacea*	Linoleic acid, oleic acid, palmitic acid, stearic acid, linolenic acid, palmitoleic acid, squalene, β-sitosterol, cycloartenol, dihydrolanosterol, sterols, γ-tocopherol	Dorado Achicanoy et al. (2018)
71	*Dalbergia ecastophyllum*	Artepillin C, p-coumaric acid	Machado et al. (2016)
72	*Daucus carota*	Carotenoids	Miękus et al. (2019)
73	*Derris elliptica*	Rotenoids	Baldino et al. (2018b)
74	*Descurainia sophia*	Sinapic acid	Hadinezhad et al. (2015)
75	*Dialium cochinchinense*	Phenolic acids, flavonoids, tannins, alkaloids	Chhouk et al. (2018)
76	*Dipteryx odorata*	Alcohols, carbonyl compounds, acids, esters, terpenes, terpenoids, lactones, aliphatic aromatic hydrocarbons	Bajer et al. (2018)
77	*Duguetia furfuracea*	Alloaromadendrene oxide-1, β-caryophyllene oxide,(+)-Spathulenol, Spathulenol,(−)(−) Caryophyllene oxide, Methyl eladiate, Aromadendrene oxide-2,Alloaromadendrene oxide-2,(−)-Spathulenol,Isoaromadendrene epoxide, 2-methylenecholestran-3-ol, α-tocoferol,Palmitic acid,3-Deoxyestradiol,2 Methyhexadecan-1-ol	Favareto et al. (2019)
78	*Echinacea purpurea*	Caftaric acid, cichoric acid, chlorogenic acid, cynarin, echinacoside	Konar et al. (2014)
79	*Eichhornia crassipes*	Stigmasterol, cholesterol, β-sitosterol	Martins et al. 2016)
80	*Elaeagnus angustifoli*	Linoleic acid, decadieneal, linoleic acid propyl ester, 2.5-pentadecadiene-l-ol, 9-oxononanoic acid	Velikorodov et al. (2018)
81	*Elaeagnus mollis*	Linoleic acid, oleic acid, palmitic acid	Mu et al. (2021)
82	*Elaeis guineensis*	Phenolics, flavonoids, carotenoids	Bezerra et al. (2018)
83	*Elaeis guineensis*	Phenolic compounds	Chan et al. (2018)
84	*Elaeis guineensis*	Vitamin E	Damrongwattanakool and Raviyan (2018)
85	*Elaeis guineensis*	Hexadecanoic acid, octadecanoic acid	Jaafar et al. (2011)

(continued)

Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
86	*Elaeis guineensis*	α-Carotene, β-carotene	Carmona et al. (2018)
87	*Elettaria cardamomum*	1,8-cineol	Ghosh et al. (2015)
88	*Eremanthus erythropappus*	α-Bisabolol	Náthia-Neves et al. (2020)
89	*Eucalyptus globulus*	Quinolizidine alkaloids, ß- Carotenes, Saponins, tannins, steroids, flavonoids	Abd Hamid et al. (2018)
90	*Eucommia ulmoides*	Linolenic acid	Zhang et al. (2018)
91	*Eugenia involucrata*	α-Tocopherol	Barzotto et al. 2019)
92	*Eurycoma longifolia*	Rosmarinic acid, eurycomanone, andrographolide	Abd Aziz et al. (2021)
93	*Ficus hirta*	Elemicin, Psoralen, Palmitic acid, Bergapten, Linolenic acid, Medicarpin, Retinoic Acid, Maackiain, Squalene	Deng et al. (2018)
94	*Foeniculum vulgare*	Sterols	Bettaieb Rebey et al. (2019)
95	*Furcraea selloa*	Saponins	Ramli et al. (2019)
96	*Ganoderma lucidum*	Oleic acid, palmitic acid, linoleic acid, Ergosta-7, 22-dien-3β-ol, ergosterol	Li et al. (2016b)
97	*Garcinia mangostana*	Squalene, α-Cubebene	Hamid et al. (2013)
98	*Garcinia Mangostana*	α-Mangostin	Hamid et al. (2018)
99	*Gardenia angkorensis*	Phenolic acids, flavonoids, tannins, alkaloids	Chhouk et al. (2018)
100	*Glycine max*	Phytosterol, tocopherol	Han et al. (2016)
101	*Glycine max*	Polyene phosphatidyl choline	Jiang et al. (2016)
102	*Glycyrrhiza uralensis*	1-Methoxyerythrabyssin II, 6,8-diprenylgenistein, gancaonin G, isoglycyrol, licorisoflavan C, licoricidin, licorisoflavan D, licorisoflavan E	Villinski et al. (2014)
103	*Haematococcus pluvialis*	Astaxanthin	Cheng et al. (2018)
104	*Haematococcus pluvialis*	Phorbol 12-myristate 13-acetate, doxycycline	Chou et al. (2016)
105	*Haematococcus pluvialis*	Astaxanthin, lutein, fatty acids	Di Sanzo et al. (2018)
106	*Hancornia speciosa*	Amyrin, lupeol, α-amyrin, β-carotene	Maia et al. (2018)
107	*Helianthus annuus*	Chlorogenic acid	Daraee et al. (2019)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
108	*Hippophae rhamnoides*	β-Sitosterol, α-tocopherol	Dienaitė et al. (2021)
109	*Hippophae rhamnoides*	Zeaxanthin, β-carotene, lycopene, α-tocopherol, β-tocopherol, δ-tocopherol, β-sitosterol	Mihalcea et al. (2021)
110	*Humulus lupulus*	Xanthohumol, desmethylxanthohumol, bitter acids, phenolic compounds	Bizaj et al. (2021)
111	*Humulus lupulus*	Phenolic acids, ferulic acid, flavonoids, resveratrol, xanthohumol	Veiga et al. (2021)
112	*Hylocereus polyrhizus*	Linoleic acid	Abdullah et al. (2018)
113	*Ilex guayusa*	Caffeine, squalene, α-amyrin.	Cadena-Carrera et al. (2019)
114	*Inula racemose*	Alantolactone, isoalantolactone	Chi et al. (2016)
115	*Iris lactea*	Linoleic acid, oleic acid, docosahexaenoic acid.	Luan et al. (2020)
116	*Isatis tinctoria*	Isatin, tryptanthrin, deoxyvasicinone, isaindigotone, isaindigotidione, quinazolines, indolinone, benzodiazepine, glucoraphanin progoitrine, glucobrassicine, aromatic, aliphatic carboxylic acids	Hamburger (2002)
117	*Juniperus communis*	Sesquiterpene, diterpene alcohols, terpene oxides, ketones	Bogolitsyn et al. (2019)
118	*Laminaria digitata*	Alginate, agar, carrageenan	Abdul Khalil et al. (2018)
119	*Laminaria hyperborean*	Alginate, agar, carrageenan	Abdul Khalil et al. (2018)
120	*Larix sibirica*	Dehydroquercetin	Averyanova et al. (2018)
121	*Lavandula angustifolia*	Linalyl acetate	Győri et al. (2019)
122	*Lavandula angustifolia*	Tannins, flavonols, anthocyanins	Tyskiewicz et al. (2019)
123	*Leucas cephalotes*	Oleanolic acid	Kaushik et al. (2021)
124	*Linum usitatissimum*	α-Linolenic acid, lignans, proteins, dietary fibers	Tang et al. (2021)
125	*Lippia graveolens*	Flavonoids	Arias et al. (2020)
126	*Lippia origanoides*	Flavonoids	Arias et al. (2020)
127	*Lupinus luteus*	Apigenin, fisetin	Buszewski et al. (2019)
128	*Lycopodium clavatum*	Quinolizidine alkaloids, ß-Carotenes, Saponins, tannins, steroids, flavonoids	Abd Hamid et al. (2018)
129	*Macrocystis pyrifera*	Alginate, agar, carrageenan	Abdul Khalil et al. (2018)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
130	*Mangifera indica*	Pectin, phenolic compounds, carotenoids (mainly all-trans-ß-carotene), various vitamins	Sánchez-Camargo et al. (2019)
131	*Mangifera indica*	Mangiferin, isomangiferin, quercetin 3-O-galactoside, quercetin 3-O-glucoside, quercetin 3-O-xyloside, quercetin 3-O-arabinoside, quercetin, kaempferol	Meneses et al. (2015)
132	*Marrubium vulgare*	Marrubiin	Gavarić et al. (2021)
133	*Matricaria chamomilla*	Cycloalkane polyols	Al-Suod et al. (2019)
134	*Melaleuca cajuputi*	Caryophyllene, humulene	Kueh et al. (2018)
135	*Melissa officinalis*	Eugenol, geraniol, D-limonene, ortho-cresol	Zaid et al. (2020)
136	*Mitragyna speciosa*	Quinolizidine alkaloids, ß-Carotenes, Saponins, tannins, steroids, flavonoids	Abd Hamid et al. (2018)
137	*Momordica cochinchinensis*	β-Carotene, lycopene	Kha et al. (2014)
138	*Moringa oleifera*	Quinolizidine alkaloids, ß-Carotenes, Saponins, tannins, steroids, flavonoids	Abd Hamid et al. (2018)
139	*Moringa oleifera*	Gallic acid, vanillic acid, p-coumaric acid, catechin, 1-triacontanol, nonacosane, heptacosane, phytol, γ-tocopherol, α-tocopherol	da Silva et al. (2022)
140	*Morus nigra*	Phenolic acids, flavonoids	Nastić et al. (2018)
141	*Muricauda lutaonensis*	Zeaxanthin	Hameed et al. (2011)
142	*Musa paradisiaca*	Lupenone, methyl 2-hydroxy-2-(3-nitrophenyl)-2-(4-nitrophenyl)-acetate, pentacosane, 3,6,9-nonacosatriene, 10-hentriacontene, 7,23-dimethyltritriacontane	Correa et al. (2016)
143	*Myrcia blanchetiana*	Myrciaine	de Cerqueira et al. (2013)
144	*Myrica rubra*	Diarylheptanoids	Alberti et al. (2018)
145	*Myrmecodia pendans*	Gallic acid, catechin, ferulic acid, caffeic acid, p-coumaric acid, quercetin, luteolin, kaempferol	Sanjaya et al. (2014)
146	*Myrtus communis*	Quinolizidine alkaloids, ß- carotenes, Saponins, tannins, steroids, flavonoids	Abd Hamid et al. (2018)
147	*Narcissus poeticus*	Benzyl benzoate, benzyl linoleate, benzyl alcohol α-Terpineol, Limonene, (3E)-hexenol, heneicosanol, dihydroactinidiolide, 4,8,12,16-tetramethyl heptadecan-4-olide, heptanal, nonanal, (2E,4E)-decadienal, octadecanal	Baranauskienė and Venskutonis (2022)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
148	*Nelumbo nucifera*	Linoleic acid, decadieneal, linoleic acid propyl ester, 2.5-pentadecadiene-l-ol, 9-oxononanoic acid	Velikorodov et al. (2018)
149	*Nicotiana tabacum*	Nicotine, neophytadiene, 4,8,13-duvatriene-1,3-diol. Palmitic acid, stearic acid, oleic acid, linoleic acid, linolenic acid	Banožić et al. (2021)
150	*Nigella sativa*	Thymoquinone, thymol, p-cymene, chlorquinaldol, amylmetacresol, 2,4-dichlorobenzyl alcohol	Gawron et al. (2019)
151	*Ocimum basilicum*	1,8-cineole, linalool, eugenol, germacrene D, T-cadinol	Occhipinti et al. (2013)
152	*Ocimum basilicum*	Linalool, estragol	Győri et al. (2019)
153	*Ocimum sanctum*	Eugenol	Ghosh et al. (2013)
154	*Ocimum tenuiflorum*	Eugenol, eugenol acetate	Khalil et al. (2017)
155	*Odontonema strictum*	Flavonoids	Ouédraogo et al. (2018)
156	*Oenocarpus distichus*	Oleic acid, palmitic acid, linoleic acid	Cunha et al. (2019)
157	*Olea europaea*	Polyphenols	Trucillo et al. (2018)
158	*Olea europaea*	Oleuropein (OLE)	Baldino et al. (2018a)
159	*Olea europaea*	Oleuropein, luteolin-7-glucoside were the main phenolic antioxidants	Cejudo Bastante et al. (2018)
160	*Olea europaea*	Oleuropein	Uzel (2018)
161	*Olea europaea*	β-Cyclodextrin	Jaski et al. (2019)
162	*Opuntia ficus-indica*	Isorhamnetin-3-O-glucosyl-rhamnosyl--rhamnoside, isorhamnetin-3-O-glucosyl-rhamnosyl-pentoside, isorhamnetin-3-O-glucosyl-rhmanoside	Antunes-Ricardo et al. (2018)
163	*Orbignya phalerata*	Lauric acid, oleic acid, lauric acid	de Oliveira et al. (2019)
164	*Origanum majorana*	Cis-sabinene hydrate	Busatta et al. (2017)
165	*Origanum vulgare*	Cis-sabinene hydrate	Busatta et al. (2017)
166	*Origanum vulgare*	α-Linolenic acid, palmitic acid, oleic acid, linoleic acid, carvacrol, heneicosane, nonacosane, docosane, borneol, thymol	García-Pérez et al. (2019)
167	*Oroxylum indicum*	Phenolic acids, flavonoids, tannins, alkaloids	Chhouk et al. (2018)
168	*Orthosiphon aristatus*	Rosmarinic acid, eurycomanone, andrographolide	Abd Aziz et al. (2021)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
169	*Orthosiphon stamineus*	Sinensetin	Aziz et al. (2018)
170	*Orthosiphon stamineus*	Sinensetin, Isosinensetin, Rosmarinic Acid	Abdul Aziz et al. (2020)
171	*Parthenium argentatum*	Terpenoids, phenolics, alkaloids, sterols, fatty acids/triglycerides	Dehghanizadeh and Brewer (2020)
172	*Passiflora mucronate*	β-amyrin, β-sitosterol, stigmasterol, oleanolic acid	da Silva et al. (2020)
173	*Petroselinum crispum*	Apigenin	Saotome and Imai (2018)
174	*Physalis angulate*	Trinitrobenzenesulphonic acid	Almeida Jr. et al. (2017)
175	*Picea Abies*	Methyl dehydroabiatate	Burčová et al. (2018)
176	*Picea abies*	Catechin, dihydroquercetin, astringin, isorhapontin	Ferrentino et al. (2021)
177	*Pimpinella anisum*	Sterols	Bettaieb Rebey et al. (2019)
178	*Piper amalago*	Pyrrolidine Alkaloid	Carrara et al. (2017)
179	*Piper betle*	Phenolic compounds	Pise et al. (2022)
180	*Piper betle*	Tannins, quercetin, eugenol, hydroxychavicol, chavibetol	Azahar et al. (2020)
181	*Piper hispidum*	Cinnamoyl pyrrolidine amides	Lima et al. (2020)
182	*Piper klotzschianum*	Germacrene D, pipercallosidine, 14-oxy-α-muuroleno, bicyclogermacrene, (E)-caryophyllene	Lima et al. (2019)
183	*Piper nigrum*	Eugenol, eugenol acetate	Khalil et al. (2017)
184	*Piper nigrum*	Piperine, piperlonguminine, piperanine, pipercallosine, dehydropipernonaline, pipernonatine, retrofractamide B, pellitorine, guineensine	Yu et al. (2022)
185	*Pistacia lentiscus*	α-Pinene, terpinene-4-ol	Aydi et al. (2020)
186	*Pistacia vera*	α-Pinene, β-myrcene, limonene-D, α-terpinolene	Demirkoz et al. (2018)
187	*Pleurotus ostreatus*	Heteropolysaccharides, β-glucans, α-glucans, oligosaccharides	Barbosa et al. (2020)
188	*Pongamia pinnata*	Oleic acid, arachidic acid, cis-10-pentadecenoic acid, stearic acid, cis-8,11,14-Eicosatrienoic acid, linolenic acid, gamma(γ)-linolenic acid, cis-11-Eicosenoic acid	Suryawanshi and Mohanty (2018)
189	*Populus balsamifera*	Pinostrobin, tectochrysine, pinocembrin, chrysin	Adekenov et al. (2020)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
190	*Prunus armeniaca*	Tocopherols, Amygdalin, Fatty Acids	Pavlović et al. (2018)
191	*Punica granatum*	Punicic acid, tocopherols, phytosterols, triterpenes, phospholipidsquercetin, epicatechin, catechins, delphinidin, pelargonidin, cyanidin, punicalagin, punicalin, gallic acids, caffeic acids, chlorogenic acids	El-Shamy and Farag (2021)
192	*Punica granatum*	Punicic acid, linoleic acid, oleic acids	Khoddami et al. (2014)
193	*Putranjiva roxburghii*	β-Sitosterol, oleic acid, linoleic acid	Balkrishna et al. (2021)
194	*Rhodiola rosea*	Salidroside, rhodioloside B, rhodioloside C, rhodiosin, luteolin, catechin, quercetin, quercitrin, herbacetin, sacranoside A, vimalin, dihydroquercetin, acacetin, mearnsetin, taxifolin-O-pentoside, tricetin trimethyl ether 7-O-hexosyl-hexoside, tricin 7-O-glucoronyl-O-hexoside, tricin O-pentoside, tricin-O-dihexoside, eriodictyol-7-O-glucoside; flavan-3-ols: gallocatechin, hydroxycinnamic acid caffeoylmalic acid, di-O-caffeoylquinic acid, esculetin, esculin, fraxin, lignans: hinokinin, pinoresinol, L-ascorbic acid, glucaric acid, palmitic acid, linolenic acid	Zakharenko et al. (2021)
195	*Rhus punjabensis*	Dihydrofisetin	Dong et al. (2020)
196	*Rosa canina*	Linoleic acid, linolenic acid, palmitic acid, stearic acid	Jahongir et al. (2019)
197	*Rosa damascene*	Citronellol, geraniol, nerol, nonadecane, nonadecene, heneicosane, heptadecane	Antonova et al. (2021)
198	*Roselle calyces*	Anthocyanins	Idham et al. (2021)
199	*Rosmarinus eriocalyx*	β-Amyrin, camphor, tetradecenoic acid, linolenic acid	Bendif et al. (2018c)
200	*Rosmarinus officinalis*	Carnosic acid, carnosol, rosmanol, genkwanin, cirsimaritin, homoplantaginin, ursolic acid	Sharifi-Rad et al. (2020)
201	*Rosmarinus officinalis*	Carnosic acid, carnosol, methyl carnosate, rosmanol, rosmarinic acid. Moreover, carnosic acid, carnosol	Fornari et al. (2014)
202	*Rosmarinus officinalis*	Verbenone, cirsimaritin, salvigenin, carnosol, carnosic acid	Kuo et al. (2011)
203	*Rosmarinus officinalis*	Essential oils, phenolic compounds	Ali et al. (2019)
204	*Rosmarinus officinalis*	Palmitic acid, α-linolenic acid, linoleic acid, oleic acid, stearic acid, d-camphor, eicosane, 1,8-cineole, tetracosane, borneol, β-caryophyllene	García-Pérez et al. (2020)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
205	*Rubia tinctorum*	Alizarin, lucidin, rubiadin	Yekefallah and Raofie (2022)
206	*Rubus idaeus*	Fatty acids, tocopherols	Marić et al. (2020)
207	*Ruellia angustiflora*	Fatty acids, triterpenes, tetraterpenes, tocopherols, phytosterols	Pires et al. (2021)
208	*Saccharum officinarum*	Alcohols, esters, hydrocarbons, ketones, aldehydes	Ahmed Baloch et al. (2018)
209	*Saccharum officinarum*	Long-chain fatty alcohols, phytosterols	Albarelli et al. (2018)
210	*Salvia hispanica*	Linoleic acid, a-linolenic acid, tocopherols, polyphenols	Ixtaina et al. (2014)
211	*Salvia hispanica*	Squalene, sterols, tocopherols, polyphenols, carotenoids	Dąbrowski et al. (2018)
212	*Salvia officinalis*	1,8-cineole, α-/β-thujone, camphor, α-humulene, viridiflorol, manool	Jokić et al. (2018)
213	*Salvia officinalis*	Carnosic acid, carnosol	Pavić et al. (2019)
214	*Salvia Rosmarinus*	α-Pinene	Allawzi et al. (2019)
215	*Salvia Rosmarinus*	Carnosic acid, rosmarinic acid, carotenoids, chlorophyll	Lefebvre et al. (2021)
216	*Salvia viridis*	Vanillin, Ethyl syringate, Syringaldehyde (3,5-Dimethoxy-4-hydroxybenzaldehyde), Antiarol (3,4,5-Trimethoxyphenol), Indole-4-carbaldehyde, Coumarin, Coniferyl aldehyde (4-Hydroxy-3-methoxycinnamaldehyde), N-(2-Phenylethyl)acetamide, Sinapyl aldehyde (3,5-Dimethoxy-4-hydroxycinnamaldehyde), Dimethoxy-trihydroxy(iso)flavone isomer 1, Dihydroxy-dimethoxy(iso)flavone, Dimethoxy-trihydroxy(iso)flavone isomer 2, Genkwanin, Dihydroxy-trimethoxy(iso)flavone, Hydroxy-trimethoxy(iso)flavone, Hydroxy-tetramethoxy(iso)flavone, 1-Oxomicrostegiol, Viroxocin, Apigenin-4′,7-dimethyl ether (4′,7-Dimethoxy-5-hydroxyflavone), 3-Oxomicrostegiol, Hexadecanedioic acid, Viridoquinone	Zengin et al. (2019)
217	*Sambucus nigra*	Quercetin, kaempferol, rutin	Anusha Siddiqui et al. (2022)
218	*Satureja montana*	Thymol, carvacrol, γ-terpinene, p-cymene	Damjanović-Vratnica et al. (2016)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
219	*Saururus chinensis*	Aurantiamide acetate, echinuline, (−) -(7R, 8R) -7-O-acetylpolysphorin, elemicin, isoelemicin, 1, 4-bis (3, 4-dimethyoxyphenyl) 2, 3-dimethyl-1, 4-butanedione, saucerneol D, (2R) -3-(3′, 4′, 5′-trimethoxyphenyl) -1, 2-propanediol, grandisin, rel-(7R, 8R, 7′R, 8′R) 3′, 4′- methylenedioxy-3, 4, 5, 5′-tetramethoxy-7, 7 -epoxylignan, zanthopyranone, (±) -eritro-1-(3, 4, 5-trimethoxy) -1, 2 -propanodiol, threo-3, 4, 5-trimethoxy-7-hydroxy-1′-allyl-3′, 5′-dimethoxy-8. O. 4′-neolignan, (+) -(8R) -(2, 6 -dimethoxy-4-propenylphenoxy) -1-(3, 4, 5-trimethoxyphenyl) propan-1-one, meso-dihydroguaiaretic acid, (−) -galbacin, (−) - (7R, 8R) -7-O-acetylraphidecursinol B	Chen et al. (2018b)
220	*Scenedesmus almeriensis*	Lutein	Mehariya et al. (2019)
221	*Schinus terebinthifolia*	Germacrene D, sabinene, β phellandrene, α- phellandrene	Andrade et al. (2017)
222	*Schinziophyton rautanenii*	Campesterol, stigmasterol, β-sitosterol, Δ5- avenasterol, 22-dihydrospinasterol, Δ7-avenasterol, lanosterol, Δ5,23-stigmastadienol, Δ7-campesterol, clerosterol, obtusifoliol, Δ 5,24(25)-stigmastadienol, α-amyrin, gramisterol, cycloeucalenol, cycloartenol, stigmasta-8,24-dienol-3-β-ol, 28-methylobtusifoliol, 24-methylenecycloartenol, citrostadienol, β-sitosterol, Δ5-avenasterol, campesterol.	Gwatidzo et al. (2014)
223	*Serenoa repens*	Fatty acids, beta-sitosterol, fatty alcohols	Bartolomé Ortega et al. (2017)
224	*Sesamum indicum*	Sesamin, sesaminol, sesamolinol	Hu et al. (2004)
225	*Sesamum indicum*	γ-Tocopherol, lignan	Shi et al. (2018)
226	*Sesamum indicum*	Sesamin, sesamolin, tocopherols, linoleic acid, oleic acid	Buranachokpaisan et al. (2021)
227	*Sida rhombifolia*	Isoquercitin	Ferro et al. (2019)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
228	*Sideritis sipylea*	ß-Caryophyllene, α -Humulene, 9-epi-(E)-Caryophyllene, Germacrene D, Bicyclogermacrene, cis-Sesquisabinene hydrate, Spathulenol, Caryophyllene oxide, Humulene epoxide II, (E)-Sesquilavandulyl acetate, Cyclopentadecanolide, Hexahydrofarnesyl acetone, (Z)-Lanceol acetate, Isopimara-9(11),15-diene, Totarene, Beyerene, Geranyl-α-terpinene, Geranyl-p-cymene, (Z,Z)-Geranyl linalool, Dolabradiene, Sclarene, (E,Z)-Geranyl linalool, (Z,E)-Geranyl linalool, 13-epi-Dolabradiene, 13-epi-Manool oxide, (E,E)-Geranyl linalool, Manool, 13-epi-Manool, Phytol, Abienol, Abieta-8(14),13(15)-diene, Sandaracopimarinal, Sclareol, 7-α-hydroxy-Manool, 3-α-hydroxy-Manool, Isopimarol, Sideridiol, n-Hexacosane, 7-Epicandicandiol, Siderol, n-Heptacosane, n-Octacosane, n-Nonacosane, Sidol, Sesquiterpene hydrocarbons, Oxygenated sesquiterpenes, Diterpene hydrocarbons, Oxygenated diterpenes, lkanes	Axiotis et al. (2020)
229	*Solanum lycopersicum*	Polyphenols, flavonoids, lycopenes, carotenoids	Haddadin and Haddadin (2015)
230	*Solanum lycopersicum*	Lycopene	Inakuma (2015)
231	*Solanum lycopersicum*	Lycopene, β-carotene	Cante et al. (2022)
232	*Solanum lycopersicum*	Lycopene	Reverchon et al. (2022)
233	*Solanum lycopersicum*	α-Tocopherol, γ-tocopherol, lycopene, β-carotene	Romano et al. (2020)
234	*Solanum viarum*	1,2-Benzenedicarboxylic acid, quinic acid, octadecenoic acid, solasodine	Confortin et al. (2019)
235	*Sophora flavescens*	Genistein	Han and Kang (2015)
236	*Sorbus aucuparia*	Linoleic acid, oleic acid, palmitic acid	Bobinaitė et al. (2020)
237	*Sorghum bicolor*	Linoleic acid, decadieneal, linoleic acid propyl ester, 2.5-pentadecadiene-l-ol, 9-oxononanoic acid	Velikorodov et al. (2018)
238	*Spina gleditsiae*	Saponins	Liu (2018)
239	*Spinacia oleracea*	Lutein, chlorophyll	Derrien et al. (2018)
240	*Spinacia oleraecea*	Phenolics	Lee et al. (2018)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
241	*Stellera chamaejasme*	Hexanedioic acid, bis(2-ethylhexyl) ester, πsitosterol, 7-methyl-Z-tetradecen-1-ol acetate, 9-hexadecenoic acid-hexadecyl ester (Z), 1,2- benzenedicarboxylic acid-diisooctyl ester, (3π24Z) stigmasta-5,24(28)-dien-3-ol, stigmastan-3,5-diene, squalene	Bai et al. (2012)
242	*Stevia rebaudiana*	Polyphenols, chlorophylls, carotenoids	Bursać Kovačević et al. (2018)
243	*Sucupira branca*	Alpha-humulene, beta-caryophyllene, alpha-copaene, (−)-beta-elemene, (E)-germacrene D(−)-gamma-elemene, spathulenol	Chañi-Paucar et al. (2022)
244	*Swietenia mahagoni*	Linoleic acid	Hartati et al. (2018)
245	*Syzygium aromaticum*	Eugenol, eugenol acetate	Idowu et al. (2021)
246	*Syzygium aromaticum*	Eugenol, chavicol, n-pentacosane, hexacosanal, vitamin E	Frohlich et al. (2019)
247	*Syzygium aromaticum*	Eugenol, caryophyllene, eugenol acetate	Győri et al. (2019)
248	*Syzygium aromaticum*	Eugenyl acetate, β-caryophyllene, α-humulene	Haro-González et al. (2021)
249	*Syzygium campanulatum*	Flavanones, chalcone, triterpenoids	Memon et al. (2016)
250	*Tagetes erecta*	Lutein	Pal and Bhattacharjee (2018)
251	*Tanacetum parthenium*	Parthenolide, sudachitin, aceronin, nevadensin	Végh et al. (2018)
252	*Teucrium polium*	Germacrene D, β-eudesmol, shyobunol, δ-cadinene	Bendif et al. (2018b)
253	*Theobroma cacao*	Polyphenols, mainly procyanidins, flavan-3-ols	Hernández et al. (2019)
254	*Thymus mastichina*	Thymol, α-terpinene, p-cymene	Kessler et al. (2022)
255	*Thymus munbyanus*	Tocopherol	Bendif et al. (2018a)
256	*Thymus vulgaris*	Chlorophyll b, chlorophyll a	Hamdan and Daood (2011)
257	*Trachyspermum ammi*	Thymol, o-Cymene, γ-Terpinene, 2-methyl-5-(1-methylethyl)-phenol	Bhatt et al. (2018)
258	*Trifolium pratense*	Isoflavonoids (3-phenyl chromones), flavonoids (2-phenyl chromones)	Klejdus et al. (2005)
259	*Triticum Vulgare*	Tocopherol	Özcan and Ören (2019)

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Table 1 (continued)

Sl no	Species name	Chemicals/phytochemicals	Ref
260	*Vaccinium Meridionale*	Anthocyanins (ACNs)	Colorado et al. (2020)
261	*Vaccinium myrtillus*	Anthocyanins, flavonols, tocopherols. Polyunsaturated fatty acids, vitamin E.	Gustinelli et al. (2018)
262	*Viburnum opulus*	β-Sitosterol, α-tocopherol	Dienaitė et al. (2021)
263	*Viburnum opulus*	Phenolic acids, iridoids, quercetin, (epi) catechina, flavalignans, procyanidins, anthocyanins	Dienaite et al. 2020)
264	*Virola surinamensis*	Steroids, terpenes, coumarins, phenolics	Cordeiro et al. (2019)
265	*Vitis vinifera*	1-Hexacosanol, 1-octacosanol,1-triacontanol, α-tocopherol, β-sitosterol, β-amyrin	de Melo et al. (2020)
266	*Xanthium strumarium*	Linoleic acid, decadieneal, linoleic acid propyl ester, 2.5-pentadecadiene-l-ol, 9-oxononanoic acid	Velikorodov et al. (2018)
267	*Xinjiang jujube*	Quercetin-3-O-robinobioside, Rutin (Quercetin-3-O-rutinoside), Hyperoside (Quercetin-3-O-β-d-galactoside), Quercetin-3-O-β-d-glucoside, Kaempferol-3-O-robinobioside, Kaempferol-3-O-glucoside, Quercetin-3-O-β-l-arabinosyl-(1 → 2)-α-l-rhamnoside, Quercetin-3-O-β-d-xylosyl-(1 → 2)-α-l-rhamnoside.	Song et al. (2019)
268	*Zingiber officinale*	α-Zingiberene	de Souza Junior et al. (2020)
269	*Zingiber officinale*	6-Gingerol	Gan et al. (2016)

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