REVIEW

The Genus *Terminalia* (Combretaceae): An Ethnopharmacological, Phytochemical and Pharmacological Review

Xiao-Rui Zhang\(^1\,2\) · Joseph Sakah Kaunda\(^1\,2\) · Hong-Tao Zhu\(^1\) · Dong Wang\(^1\) · Chong-Ren Yang\(^1\) · Ying-Jun Zhang\(^1\,3\)

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Abstract

*Terminalia* Linn, a genus of mostly medium or large trees in the family Combretaceae with about 250 species in the world, is distributed mainly in southern Asia, Himalayas, Madagascar, Australia, and the tropical and subtropical regions of Africa. Many species are used widely in many traditional medicinal systems, e.g., traditional Chinese medicine, Tibetan medicine, and Indian Ayurvedic medicine practices. So far, about 39 species have been phytochemically studied, which led to the identification of 368 compounds, including terpenoids, tannins, flavonoids, phenylpropanoids, simple phenolics and so on. Some of the isolates showed various bioactivities, in vitro or in vivo, such as antitumor, anti HIV-1, antifungal, antimicrobial, antimalarial, antioxidant, diarrhea and analgesic. This review covers research articles from 1934 to 2018, retrieved from SciFinder, Wikipedia, Google Scholar, Chinese Knowledge Network and Baidu Scholar by using “*Terminalia*” as the search term (“all fields”) with no specific time frame setting for the search. Thirty-nine important medicinal and edible *Terminalia* species were selected and summarized on their geographical distribution, traditional uses, phytochemistry and related pharmacological activities.

Keywords *Terminalia* · Combretaceae · Ethnomedicine · Traditional uses · Phytochemistry · Hydrolyzable tannins · Pharmacology

Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| A. | Aspergillus |
| BCG | Bacillus Calmette Guerin |
| BMM | Broth microdilution method |
| Ca. | Candida |
| Cr. | Cryptococcus |
| CC\(_{50}\) | Cytotoxic concentration of the extracts to cause death to 50% of host’s viable cells |
| DPPH | 2,2-Diphenyl-1-picrylhydrazyl |
| E. | Escherichia |
| EC\(_{50}\) | Half maximal effective concentration |
| FRAP | Ferric reducing/antioxidant power |
| GABA | Neurotransmitter gamma-aminobutyric acid |
| IC\(_{50}\) | Minimum inhibition concentration for inhibiting 50% of the pathogen |
| K. | Klebsiella |
| MIC | Minimum inhibitory concentration |
| MTT | 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide |
| Ps. | Pseudomonas |
| Sa. | Salmonella |
| Sta. | Staphylococcus |
| Str. | Streptomyces |

1 Introduction

*Terminalia* Linn, comprising about 250 species in the world mostly as medium or large trees, is the second largest genus in the family Combretaceae. The name “*Terminalia*” is derived from Latin word “terminus”, which means the leaves are located at the tip of the branch. The bark of *Terminalia* plants usually has cracks and branches tucked into layers. Most of the *Terminalia* plants’ leaves are large, leathery
with solitary or clustered small green white flowers. Their fruits are yellow, dark red or black; drupe, usually angular or winged. Some fruits are edible, highly nutritious and possess medicinal values.

Terminalia species are widely distributed in the southern Asia, Himalayas, Madagascar, Australia, and the tropical and subtropical regions of Africa. Terminalia plants in southern Asia have been intensively studied phytochemically due to their wide usage in Asian (India, Tibetan, and Chinese) traditional medicine systems [1]. For example, the fruits of Terminalia bellirica and Terminalia chebula, together with Phyllanthus emblica (Euphorbiaceae) which form the herbal remedy, Triphala, in Tibetan medicine, have received much attention because of its extensive and remarkable effectiveness in the treatment of anticancer, antifungal, antimicrobial, antimalarial, antioxidant.

So far, 39 Terminalia species have been investigated for their phytochemical constituents, which resulted in the identification of terpenes, tannins, flavonoids, lignans and simple phenols, amongst others. Pharmacological studies suggest that they have exhibited activity on liver and kidney protection, antibacterial, antiinflammatory, anticaner, and have displayed a positive effect on immune regulation, cardiovascular disease and diabetes, and acceleration of wound healing.

This paper features 39 important medicinal and edible Terminalia species and summarizes their traditional usage, geographical distribution, structures of isolated chemical constituents and pharmacological activities.

2 Species’ Description, Distribution and Traditional Uses

So far, 50 Terminalia species have been documented, 39 of which have been reported to possess medicinal properties and/or being edible. Among them, eight species and four varieties including T. argyrophylla, T. bellirica, T. catappa, T. chebula, T. franchetii, T. hainanensis, T. myriocarpa, T. intricate, T. chebula var. tomentella, T. franchetii var. membranifolia, T. franchetii var. glabra, and T. myriocarpa var. hirsuta are distributed in China (Yunnan, southeast Tibet, Taiwan, Guangdong, south Guangxi and southwest Sichuan). Their distribution and traditional applications are shown in Table 1.

Terminalia species are broadly used in many aspects. Some are employed as drugs, while others can provide high quality wood, tannin or dyes. For example, fruits of T. ferdi-nandiana, a species largely distributed in Australia, are rich in vitamin C, and possess strong antioxidant activity [25]. T. bellirica and T. chebula are not only recorded in every version of Chinese pharmacopoeia, but are also the important and most commonly applied drugs in Han, Tibetan, Mongolian and many other folk medicinal systems in India, Burma, Thailand, Malaysia, Vietnam and other southeast asian countries. T. catappa is a commonly used medicinal plant for liver protection in China [20].

3 Chemical Composition

Since 1930s, the chemical compositions of the genus Terminalia have been vastly studied. T. arjuna, T. bellirica, T. catappa and T. chebula, having been frequently used in the Ayurvedic, Chinese and Tibetan medicines, attracted scholars’ attention. To date, 368 compounds, largely terpenoids (1–104), tannins (105–196), flavonoids (197–241), lignans (242–265), phenols and glycosides (268–318) were reported from the genus (Tables 2, 3).

3.1 Terpenoids

So far, 104 terpenoids (Fig. 1) including 86 triterpenes (1–86), 14 monoterpenes (87–100), 4 sesquiterpenes (101–104) have been reported from the genus Terminalia. The triterpenoids are mainly oleanane, ursane and lupine types, and their glycosides. Particularly, Atta-ur-Rahman et al. isolated a new seco-triterpene terminalin A (81) possessing a novel rearranged seco-glutanine structure with a pyran ring-A and an isopropanol moiety from the stem barks of T. glaucescens [129]. Ponou et al. found two dimeric triterpenoid glucosides, ivorenosides A and B (49–50) possessing an unusual skeleton [131], and two new oleane type triterpenes, 3-oxo-type ivorenigenin A (41) and 3,24-dinor-2,4-secooleanane-type ivorenigenin B (53) from the barks of T. ivorenis [132]. Compounds 41, 49 and 53 showed significant anticancer activities. Wang et al. isolated five new 18,19-secooleanane type triterpene glycosyl esters, namely arjunasides A–E (82–86) from the MeOH extract of T. arjuna’s barks, TaBs [68]. Moreover, five ursane type triterpene glucosyl esters (64–68) were also obtained for the first time [76]. From the fruits of T. chebula, 23-O-neochebuloylarjungenin 28-O-β-d-glycosyl ester (21) and 23-O-4’-epi-neochebuloylarjungenin (22) with novel substituents at C-23 were reported, in addition to compounds 23–24, 30–32 and 63, whose C-23 substituents were gallate. Compounds 30 and 31 had strong hypoglycemic effect [146]. Furthermore, compound 40 was obtained from the barks of T. arjuna [85], while friedelin (79) with 3-oxo moiety was reported from the fruits of T. arjuna [83], the root barks of T. avicennioides [93], and the stem barks of T. glaucescens [130] and T. mollis [35].
Table 1 Local names, distributions and traditional uses of *Terminalia* plants

| No. | Plants          | Local names                          | Distributions                          | Traditional uses                                                                 |
|-----|----------------|--------------------------------------|----------------------------------------|----------------------------------------------------------------------------------|
| T1  | *T. alata*     | Unknown                              | Southern Vietnam [2, 3]                | Anti-diarrhea, ulcer, diuretics, supplements [3]                                 |
| T2  | *T. amazonia*  | White olive                          | Southern Costa Rica [4]                | Wood                                                                             |
| T3  | *T. arborea*   | Jaha Kling                           | Indonesia                              | Cardiovascular disease, myocardial infarction, atherosclerosis, diabetes, cancer, stroke, cataract, shoulder stiffness, cold allergy, hypertension, senile dementia, inflammation, gum disease (e.g. gingivitis, pneumonia), Alzheimer’s, skin conditions [5] |
| T4  | *T. arjuna*    | Arjuna, White Marudah, Koha          | India, South Asia, Sri Lanka [6]       | Cardiotonic, sores, bile infection, poison antidote [6]                          |
| T5  | *T. argyrophylla* | Silver leaves Chebula, Xiao Chebula (Yunnan), Manna (Yunnan Dai language) | China (Yunnan) [7]                     | Autoimmune diseases [7]                                                          |
| T6  | *T. australis* | Tanimbu, palo amarillo               | Punta Lara, Argentina (Buenos Aires) [8] | Hemostasis                                                                      |
| T7  | *T. avicennioides* | kpai, Kpace, buashe               | Nigeria [9, 10]                        | Malaria, worms, gastric peptic ulcer [9], scorpion bites [10], tuberculosis, cough [90] |
| T8  | *T. bellirica* | Beleric                               | China (southern Yunnan), Vietnam, Laos, Thailand, Cambodia, Myanmar, India (except West), Malaysia, Indonesia | Laxative, edible |
| T9  | *T. bentzoe*   | Unknown                              | Rodrigues [13]                         | Edema, diarrhea, leprosy, bile congestion, indigestion, headache [11]           |
| T10 | *T. bialata*   | Indian silver greywood              | India, South Asia                      | Fever, diarrhea, cough, dysentery, skin diseases [12]                            |
| T11 | *T. brachystemma* | Kalahari cluster leaf            | Southern Africa                        | Wine, palm sugar [23]                                                            |
| T12 | *T. brownii*   | Kuuku, muwuku (Kamba, Kenya), koloswa (northern region, Kenya), weba (Ethiopia), Ibu-ko (Samburu, Kenya), orbuko (Masai, Tanzania), and mbarao or mwalambe, in Kiswahili | Southern and central Africa            | Diarrhea [94]                                                                   |
| T13 | *T. bursarina* | Yellow wood                         | Australia, South Asia [17]             | Essential oil [13]                                                               |
| T14 | *T. calamansanai* | Philippine almond, Anarep         | Philippines, Southeast Asia             | Wood [14]                                                                       |
| T15 | *T. calcicola* | Unknown                             | Madagascar Rain Forest [19]            | Schistosomiasis, gastrointestinal disorders [15]                                 |
| T16 | *T. catappa*   | Indian almond, umbrella tree, tropical almond | Australia and SE Asia, Africa, South America Tropical Coast | Diarrhea, stomach pain, gastric ulcer, colic, heartburn                          |
|     |                |                                      |                                        | Genitourinary infection, urethral pain, endometritis, cystitis, leucorrhea, syphilis, gonorrhea, malaria, dysmenorrhea, nervousness, hysteria, epilepsy, athlete’s foot, indigestion, stomach pain, gastric ulcer, colitis, cough, vomiting, hepatitis, jaundice, cirrhosis, yellow fever [16] |

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*Note:* The table includes local names, distributions, and traditional uses of *Terminalia* plants. The traditional uses are diverse, ranging from anti-diarrhea and ulcer treatments to cardiovascular disease prevention and additional health benefits.
| No. | Plants                  | Local names                      | Distributions                                                                 | Traditional uses                                                                 |
|-----|-------------------------|----------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------------------|
| T17 | *T. chebula*            | Black Myrobalan, Inknut, Chebulic Myrobalan | Nepal, northern India, Myanmar, Sri Lanka, Thailand, Bangladesh, China (Yunnan), Himalayan | Digestion appetizers, vomiting, infertility, asthma, sore throat, vomiting, diarrhea, dysentery, bleeding, ulcers, gout, bladder disease |
| T18 | *T. chebula* var. tomentella | Weimaohezi (variant)           | China (western Yunnan), Myanmar | Unknown                                                                             |
| T19 | *T. citrina*            | Manahei, Yellow myrobalan       | India, Bangladesh, Laos, Myanmar, Nepal, Thailand, Cambodia, Vietnam | Unknown                                                                             |
| T20 | *T. elliptica*          | Indian arali | SE Asia, Bangladesh, Laos, Myanmar, Nepal, Thailand | Ulcers, fractures, bleeding, bronchitis, diarrhoea | [23] |
| T21 | *T. franchetii*         | Unknown                          | SW China | Unknown                                                                             |
| T22 | *T. franchetii* var. membranifolia | Baoyedianlanren (variant) | China (western Guangxi (Longlin), central to SE Yunnan) | Unknown                                                                             |
| T23 | *T. franchetii* var. glabra | Guang yedianlanren (variant) | Unknown | Unknown                                                                             |
| T24 | *T. ferdinandiana*      | Gubinge, Bbillygoat plum, Kakadu plum, green plum | Australia | Dietary supplements, skin care | [25] |
| T25 | *T. glaucescens*        | Unknown                          | Nigeria | Amenorrhea, vaginal infections, syphilis, sore, neurological disorders, Anti-plasma, antiparasitic, antiviral, antimicrobial |
| T26 | *T. hainanensis*        | Ji zhenmu, Hainan lanren       | China (Hainan) | Unknown                                                                             |
| T27 | *T. intricate*          | Cuozhilanren                     | China (NW Yunnan and SW Sichuan) | Unknown                                                                             |
| T28 | *T. ivorensis*          | Idigbo, Black Afara, Shingle Wood, Brimstone Wood, Black bark | Cameroon, West Africa, Ivory Coast, Liberia, Nigeria, Sierra Leone, Ghana | Rheumatism, gastroenteritis, psychiatric, syphilis, burns and bruises, Malara, cough, diarhoea, dysentery, wound, hepatitis, malaria, fever, cough, diarhoea, tuberculosis, skin diseases |
| T29 | *T. kaernbachii*        | Okari Nai                        | Unknown | Unknown                                                                             |
| T30 | *T. kaiserana*         | Unknown                          | Tanzania | West Africa, Sudan Savanna | [32] |
| T31 | *T. laxiflora*          | Unknown                          | West Africa | Unknown                                                                             |
| T32 | *T. macroptera*         | Bayankada                        | Unknown | Unknown                                                                             |
| T33 | *T. mantaly*            | Unknown                          | Africa | Unknown                                                                             |
| T34 | *T. mollis*             | Quangolaren                      | Indonesia, SE Asia, South Asia, China (Guangxi (Li-oung), Yunnan (central to the south), and Tibet (Medog), northern Vietnam, Thailand, Laos, northern Myanmar, Malaysia, NE India, Sikkim) | Antimicrobial, Antioxidant, liver protection, Antioxidant, liver protection, Antioxidant, liver protection, |
| T35 | *T. myriocarpa*         | Unknown                          | Quangolaren | Unknown                                                                             |
| T36 | *T. myriocarpa* var. hirsuta | Yingmaoqiangularen (variant) | Unknown | Unknown                                                                             |
Table 1 (continued)

| No. | Plants         | Local names                               | Distributions                                                                 | Traditional uses                                                                 |
|-----|----------------|-------------------------------------------|-------------------------------------------------------------------------------|--------------------------------------------------------------------------------|
| T38 | *T. oblongata* | Rose wood, yellow wood                    | Central Queensland [39]                                                       | Unknown [39]                                                                    |
| T39 | *T. paniculata*| Vellamaruth                               | India                                                                         | Cholera, mumps, menstrual disorders, cough, bronchitis, heart failure, hepatitis, diabetes, obesity [40] |
| T40 | *T. parviflora*| Tropical almond, umbrella tree, Indian almond | Sri Lanka and India [41]                                                      | Diarrhea [41]                                                                   |
| T41 | *T. prunioides*| Hareri, Sterkbos, Purple pod Terminalia, Mwangati | Southern Africa                                                               | Postnatal abdominal pain                                                         |
| T42 | *T. sambesiaca*| Unknown                                   | Southern Africa                                                               | Cancer, gastric ulcer, appendicitis                                             |
| T43 | *T. schimperiana*| Idi odan                                 | Africa, Sierra Leone, Guinea, Uganda, Ethiopia                                | Bloody diarrhea [45]                                                            |
| T44 | *T. sericea*   | Monakanakane, Mososo, Mogonono, Amangwe, Vaalboom, Mangwe, Silver clutter-leaf | Northern South Africa, Botswana (except central Kalahari), southern Mozambique, Tanzania, Namibia, Zimbabwe, Northern Democratic Republic of Congo, tropical Africa [43] | Local burns, bronchitis, dysentery [42] Diarrhea, sexually transmitted infections, rash, tuberculosis [43] Fever, high blood pressure [44] |
| T45 | *T. spinosa*   | Musosahwai, spiny cluster leaf, Kasansa   | Southern Africa                                                               | Malaria, fever [46]                                                            |
| T46 | *T. stenostachya*| Rosette leaf Terminalia                   | Southern Africa                                                               | Epilepsy, poisoning [47]                                                        |
| T47 | *T. stuhlmannii*| Unknown                                   | Acacia [48]                                                                   | Epilepsy, poisoning [47]                                                        |
| T48 | *T. superba*   | Limba                                     | Tropical Western Africa                                                       | Unknown                                                                        |
| T49 | *T. triflora*  | Lanza, lanza amarilla, amarillo derío, paloamarillo | Tropical (South America)                                                      | Gastroenteritis, diabetes, female infertility, abdominal pain, bacteria/fungi/viral infections [49], diabetes remedies, anesthetic, hepatitis [50] |
| T50 | *T. tropophylla*| Unknown                                   | Madagascan [51]                                                              | Making posts, furniture, weapons, fuel [149]                                    |

SE southeastern, NE northeastern, SW southwestern, NW northwestern
| No. | Compounds                                                                 | Plants  | Organs | References       |
|-----|----------------------------------------------------------------------------|---------|--------|-----------------|
|     | **Triterpenes (86)**                                                       |         |        |                 |
| 1   | 2α,3β,19α-Trihydroxyolean-12-en-20-oic acid 3-O-β-d-galactosyl-(1→3)-β-d-glucoside | T1      | R      | [3]             |
| 2   | 2α,3β,19α-Trihydroxyolean-12-en-28-oic acid methylester 3β-O-rutinoside    | T1      | R      | [53]            |
| 3   | 2α,3β,19β,23-Tetrahydroxyolean-12-en-28-oic acid 3β-O-β-d-galactosyl-(1→3)-β-d-glucoside-28-O-β-d-glucoside | T1      | R      | [52]            |
| 4   | 3-Acetylmasinic acid                                                       | T1      | RB     | [54]            |
| 5   | Arjunic acid                                                              | T1      | B      | [55, 74]        |
|     |                                                                             | T4      | SB, F  | [60, 79, 124]   |
|     |                                                                             | T17     | F      | [146]           |
|     |                                                                             | T25     | SB     | [130]           |
|     |                                                                             | T28     | B      | [132]           |
|     |                                                                             | T32     | B      | [145]           |
|     |                                                                             | T44     | R      | [133]           |
| 6   | Arjunoside I                                                               | T4      | SB     | [61]            |
| 7   | Arjunoside II                                                              | T4      | SB     | [61]            |
| 8   | Arjunoside III                                                             | T4      | R      | [62, 63]        |
| 9   | Arjunoside IV                                                              | T4      | R      | [62, 63]        |
| 10  | Arjunetin                                                                  | T1      | B      | [55, 74]        |
|     |                                                                             | T4      | B, L, S, R, F | [23, 67] |
|     |                                                                             | T8, T16, T17, T20, T39 | B, L, S, R, F | [23] |
| 11  | Oleanolic acid                                                             | T1      | H      | [56]            |
|     |                                                                             | T9      | L      | [97]            |
|     |                                                                             | T4, T16, T20 | B, L, S, R, F | [23] |
|     |                                                                             | T8, T17 | B, L, S, R | [23] |
|     |                                                                             | T39     | L, S, R, F | [23] |
|     |                                                                             | T28     | B      | [132]           |
|     |                                                                             | T36     | B      | [140]           |
| 12  | Ursolic Acid                                                               | T4, T16, T20 | B, L, S, R, F | [23] |
|     |                                                                             | T8, T17 | L, S, R | [23] |
|     |                                                                             | T39     | B, L, S, F | [23] |
| 13  | Maslinic acid                                                              | T1      | H      | [56]            |
|     |                                                                             | T9      | L      | [97]            |
|     |                                                                             | T17     | F      | [21, 116]       |
|     |                                                                             | T36     | B      | [140]           |
| 14  | 2α,3α,24-Trihydroxyolean-11,13(18)-dien-28-oic acid                       | T33     | SB     | [158]           |
| 15  | Terminoside A                                                              | T4      | B      | [58]            |
| 16  | Arjungenin                                                                 | T4      | SB, L, R, F | [23, 60, 70, 74] |
|     |                                                                             | T25     | R      | [60]            |
|     |                                                                             | T12     | B      | [99]            |
|     |                                                                             | T8, T16, T20, T39 | B, L, S, R, F | [23] |
|     |                                                                             | T17     | B, L, S, R, F | [23, 146] |
|     |                                                                             | T25     | R, SB  | [69, 130]       |
|     |                                                                             | T28     | B      | [132]           |
|     |                                                                             | T32     | B      | [145]           |
|     |                                                                             | T33     | SB     | [158]           |
|     |                                                                             | T44     | RB     | [133, 152]      |
| 17  | Hypatic acid                                                               | T25     | R      | [69]            |
| 18  | Arjunglucoside I                                                           | T4      | B, R   | [70, 74, 78]    |
|     |                                                                             | T17     | F      | [146]           |
|     |                                                                             | T50     | R      | [72]            |
|     |                                                                             | T32     | B      | [145]           |
Table 2 (continued)

| No. | Compounds                                      | Plants | Organs | References |
|-----|-----------------------------------------------|--------|--------|------------|
| 19  | Sericoside                                     | T4     | B      | [71]       |
|     |                                               | T25    | SB     | [130]      |
|     |                                               | T28    | B      | [76, 131]  |
|     |                                               | T44    | R, L, SB | [43, 133, 149] |
|     |                                               | T32    | B      | [145]      |
|     |                                               | T50    | R      | [72]       |
| 20  | Crataegioside                                  | T4     | B      | [75]       |
|     |                                               | T17    | F      | [146]      |
| 21  | 23-O-neochebuloylarjungenin 28-O-β-D-glucosyl ester | T17    | F      | [146]      |
| 22  | 23-O-4′-epi-neochebuloylarjungenin             | T17    | F      | [146]      |
| 23  | 23-O-galloylarjunic acid                      | T39    | B      | [144]      |
|     |                                               | T32    | B      | [145]      |
|     |                                               | T17    | F      | [146]      |
| 24  | Quercotriterpenoside I                        | T32    | B      | [145]      |
|     |                                               | T17    | F      | [146]      |
| 25  | Sericic acid                                  | T28    | B      | [132]      |
|     |                                               | T32    | B      | [145]      |
|     |                                               | T44    | R      | [150]      |
| 26  | 24-Deoxy-sericoside                           | T32    | B      | [138]      |
| 27  | Arjunolic acid                                 | T1     | B, H   | [55, 56, 74] |
|     |                                               | T4     | B, H, L, S, R, F | [23, 77, 78, 91] |
|     |                                               | T7     |       | [97]       |
|     |                                               | T9     | L      | [23]       |
|     |                                               | T8     | B, L, S, R | [23]       |
|     |                                               | T16, T17, T20, T39 |       | [23, 144] |
|     |                                               | T32    | H, R   | [128]      |
|     |                                               | T34    | H, B   | [128, 145] |
|     |                                               | T36    | H      | [140]      |
| 28  | Terminolic acid                                | T1     | H      | [56]       |
|     |                                               | T17    | F      | [146]      |
|     |                                               | T7, T16, T31 |       | [128]      |
|     |                                               | T25    | H, R1  | [128]      |
|     |                                               | T32    | H, B   | [128, 145] |
| 29  | Arjunglucoside II                             | T4     | B      | [70, 74]   |
|     |                                               | T17    | F      | [146]      |
| 30  | 23-O-galloylarjunic acid                      | T17    | F      | [146]      |
| 31  | 23-O-galloylarjunic acid 28-O-β-D-glucosyl ester | T17    | F      | [146]      |
| 32  | 23-O-galloyl terminolic acid 28-O-β-D-glucosyl ester | T17    | F      | [146]      |
| 33  | Arjunolitin                                    | T4     | SB     | [80]       |
| 34  | Terminolitin                                  | T4     | F      | [80]       |
| 35  | Arjunglucoside III                            | T4     | B      | [74]       |
| 36  | Methyl oleanate                                | T4     | R, F   | [80, 124]  |
| 37  | Olean-3α,22β-diol-12 en-28-oic acid 3-O-β-D-glucosyl-(1→4)-β-D-glucoside | T4     | B      | [81, 84]   |
| 38  | Arjunetoside                                   | T4     | R, SB  | [82]       |
| 39  | Olean 3β,6β,22α-triol-12en-28-oic acid-3-O-β-D-glucosyl-(1→4)-β-D-glucoside | T4     | B      | [84]       |
| 40  | 2α,19α-Dihydroxy-3-oxoolean-12-en-28-oic acid 28-O-β-D-glucoside | T4     | R      | [85]       |
| 41  | Ivorengenin A (2α,19α,24-trihydroxy-3-oxoolean-12-en-28-oic acid) | T28    | B      | [132]      |
| 42  | Chebuloside I                                 | T17    | F      | [115]      |
| 43  | Chebuloside II                                | T17    | F      | [115]      |
|     |                                               | T32    | B      | [138]      |
| No. | Compounds                                                                 | Plants | Organs | References |
|-----|---------------------------------------------------------------------------|--------|--------|------------|
| 44  | Arjunglucoside                                                            | T17    | F      | [115]      |
|     |                                                                           | T44    | R, SB  | [133]      |
|     |                                                                           | T33    | SB     | [158]      |
| 45  | Glaucescic acid (2α,3α,6α,23-tetrahydroxyolean-2-en-28-oic acid)          | T25    | R      | [69]       |
| 46  | Glaucinoic acid (2α,3β,19α,24-tetrahydroxyolean-12-en-30-oic acid)        | T25    | SB     | [130]      |
| 47  | Termiarjunoside I (olean-1α,3β,9α,22α-tetraol-12-en-28-oic acid-3β-T-n-    | T4     | SB     | [156]      |
|     | glucoside)                                                                |        |        |            |
| 48  | Termiarjunoside II (olean-3α,5α,25-triol-12-en-23,28-dioic acid-3α-T-n-    | T4     | SB     | [156]      |
|     | glucoside)                                                                |        |        |            |
| 49  | β-Amyrin                                                                  | T25    | SB     | [129]      |
|     |                                                                           | T36    | B      | [140]      |
| 50  | Ivorenoside A                                                             | T28    | B      | [131]      |
| 51  | Ivorenoside B                                                             | T28    | B      | [131]      |
| 52  | Ivorenoside C                                                             | T28    | B      | [131]      |
| 53  | Ivorengenin B (4-oxo-19α-hydroxy-3,24-dinor-2,4-secoolean-12-ene-2,28-    | T28    | B      | [132]      |
|     | dioic acid)                                                               |        |        |            |
| 54  | 1α,3β-Hydroxyimberbic acid 23-O-α-l-4-acetylrhamnoside                     | T47    | SB     | [48]       |
| 55  | 1α,3β,3,23-Trihydroxy-olean-12-en-29-oate-23-O-α-[4-acetoxyrhamnosyl]-29-| T47    | SB     | [48]       |
|     | α-rhamnoside                                                              |        |        |            |
| 56  | 2α,3β-Dihydroxyolean-12-en-28-oic acid 28-O-β-n-glucoside                 | T48    | SB     | [49]       |
| 57  | 2α,3β,21β-Trihydroxyolean-12-en-28-oic acid 28-O-β-n-glucoside            | T48    | SB     | [49]       |
| 58  | 2α,3β,29-Trihydroxyolean-12-en-28-oic acid 28-O-β-n-glucoside             | T48    | SB     | [49]       |
| 59  | 2α,3β,23,27-Tetrahydroxyolean-12-en-28-oic acid 28-O-β-n-glucoside        | T48    | SB     | [49]       |
| 60  | Terminaliaside A ((3β,21β,22α)-3-O-(3′-O-angeloylglucosyl)-21,22-dihydroxy| T50    | R      | [72]       |
|     | 28-O-sophorosyl-16-oxoolean-12-ene)                                        |        |        |            |
| 61  | 2, 3, 23-Trihydroxyolean-12-ene                                           | T7     | RB     | [91]       |
| 62  | 2α,3β,23-Trihydroxyolean-12-en-28-oic acid                               | T48    | SB     | [49]       |
| 63  | 23-O-galloylpinaenoic acid 28-O-β-n-glucosyl ester                        | T17    | F      | [146]      |
| 64  | Pinaenoic acid 28-O-β-n-glucosyl ester                                     | T4     | B      | [76]       |
|     |                                                                           | T17    | F      | [146]      |
| 65  | 2α,3β-Dihydroxysurs-12,18-dien-28-oic acid 28-O-β-n-glucosyl ester        | T4     | B      | [76]       |
| 66  | Quadranoside VIII                                                          | T4     | B      | [76]       |
| 67  | Kajiichigoside F1                                                          | T4     | B      | [76]       |
| 68  | 2α,3β,23-Trihydroxyurs-12,19-dien-28-oic acid 28-O-β-n-glucosyl ester     | T4     | B      | [76]       |
| 69  | α-Amyrin                                                                  | T7     | RB     | [91]       |
| 70  | 2α,3β,23-Trihydroxy-urs-12-en-28-oic acid                                | T34    | L      | [35]       |
| 71  | 2α-Hydroxyursolic acid                                                    | T34    | L      | [35]       |
|     |                                                                           | T17    | F      | [115, 116] |
| 72  | Ursolic acid                                                              | T11    | L      | [35]       |
| 73  | 2α-Hydroxymicromeric acid                                                 | T17    | F      | [115, 116] |
| 74  | Betulinic acid                                                            | T1     | B      | [55]       |
|     |                                                                           | T11    | L      | [35]       |
|     |                                                                           | T12    | B      | [99]       |
|     |                                                                           | T4, T16, T17, T20, T39          | B, L, S, R, F | [23] |
|     |                                                                           | T8     | SB     | [129]      |
|     |                                                                           | T25    | B      | [132]      |
|     |                                                                           | T28    | B      | [140]      |
|     |                                                                           | T36    |        |            |
| 75  | Terminic acid                                                             | T4     | R, H   | [57, 62]   |
Table 2 (continued)

| No. | Compounds            | Plants | Organs | References |
|-----|----------------------|--------|--------|------------|
| 76  | Lupeol               | T4     | SB     | [80]       |
|     |                      | T25    | SB     | [129]      |
|     |                      | T44    | SB, R  | [43]       |
| 77  | Monogynol A          | T12    | B      | [99]       |
| 78  | Triterpenes          | T25    | SB     | [129]      |
|     |                      | T44    | R, SB  | [133]      |
| 79  | Friedelin            | T4     | F      | [83]       |
|     |                      | T7     | RB     | [93]       |
|     |                      | T25    | SB     | [129, 130] |
|     |                      | T34    | SB     | [35]       |
| 80  | Maslinic lactone     | T1     | H      | [56]       |
| 81  | Terminalin A         | T25    | SB     | [129]      |
| 82  | Arjunaside A         | T4     | B      | [68]       |
| 83  | Arjunaside B         | T4     | B      | [68]       |
| 84  | Arjunaside C         | T4     | B      | [68]       |
| 85  | Arjunaside D         | T4     | B      | [68]       |
| 86  | Arjunaside E         | T4     | B      | [68]       |
|     | Mono- (14) and sesqui- (4) terpendoids |
| 87  | α-Pinene             | T9     | L      | [13]       |
| 88  | Sabinene             | T9     | L      | [13]       |
| 89  | Myrcene              | T9     | L      | [13]       |
| 90  | β-Pinene             | T9     | L      | [13]       |
| 91  | 1,8-Cineole          | T9     | L      | [13]       |
| 92  | Linalool             | T9     | L      | [13]       |
| 93  | Menthone             | T9     | L      | [13]       |
| 94  | γ-Terpineol          | T9     | L      | [13]       |
| 95  | α-Terpineol          | T9     | L      | [13]       |
| 96  | Limonene             | T9     | L      | [13]       |
| 97  | Neral                | T9     | L      | [13]       |
| 98  | Geraniol             | T9     | L      | [13]       |
| 99  | Thymol               | T9     | L      | [13]       |
| 100 | Isomenthone          | T9     | L      | [13]       |
| 101 | β-Copaene            | T9     | L      | [13]       |
| 102 | β-Caryophyllene      | T9     | L      | [13]       |
| 103 | Caryophyllene        | T9     | L      | [13]       |
| 104 | α-Humulene           | T9     | L      | [13]       |
|     | Hydrolysable (89) and condensed tannins (2) |
| 105 | 1,2,3,6-Tetra-O-galloyl-β-D-glucose | T17   | F      | [159]      |
| 106 | Gallotannin (1,2,3,4,6 pentagalloyl glucose) | T4    | SB, L  | [86]       |
|     |                      | T17    | F      | [21, 118, 119] |
|     |                      | T19    | F      | [120]      |
|     |                      | T30    | R      | [133]      |
|     |                      | T45, T46 | L     | [133]      |
| 107 | 1,3,4,6-Tetra-O-galloyl-β-D-glucose | T17   | F      | [159]      |
| 108 | 2,3,4,6-Tetra-O-galloyl-β-D-glucose | T3    | F      | [154]      |
|     |                      | T4    | SB, L  | [86]       |
| 109 | 1,2,6-Tri-O-galloyl-β-D-glucose | T31   | R      | [101]      |
| 110 | Sanguin H-1          | T14    | L      | [102]      |
| 111 | 1,6-Di-O-galloyl-β-D-glucose | T3    | F      | [154]      |
|     |                      | T17    | F      | [21, 119]  |
|     |                      | T40    | B      | [41]       |
Table 2 (continued)

| No. | Compounds                                      | Plants | Organs | References |
|-----|------------------------------------------------|--------|--------|------------|
| 112 | 1,3,6-Tri-O-galloyl-β-D-glucose                | T3     | F      | [154]      |
|     |                                               | T40    | B      | [41]       |
|     |                                               | T19    | F      | [120]      |
|     |                                               | T17    | F      | [159]      |
| 113 | Methyl 3,6-di-O-galloyl-β-D-glucoside          | T40    | B      | [41]       |
| 114 | 4,6 Bis hexahydroxydiphenyl-1-galloyl-glucose  | T14    | L      | [18, 102]  |
| 115 | Sanguin H-4                                    | T3     | F      | [154]      |
| 116 | Corilagin                                      | T3     | F      | [101]      |
|     |                                               | T31    | R      | [41, 106, 107] |
|     |                                               | T16    | L, B   | [41, 106, 107] |
|     |                                               | T17    | F      | [21, 118, 119, 159] |
|     |                                               | T19    | F      | [120]      |
|     |                                               | T24    | F      | [126]      |
|     |                                               | T32    | L      | [135, 136] |
| 117 | Tercatain                                      | T16    | B, L   | [41, 106, 107] |
|     |                                               | T17    | F      | [159]      |
| 118 | 1,3-Di-O-galloyl-β-D-glucose                   | T17    | F      | [159]      |
| 119 | 2,3-O-(S)-HHDP-β-D-glucose                    | T3     | F      | [154]      |
|     |                                               | T14    | L      | [102]      |
|     |                                               | T4     | B      | [104]      |
|     |                                               | T16    | B, L   | [41, 107]  |
|     |                                               | T40    | B      | [41]       |
|     |                                               | T36    | L      | [38]       |
| 120 | 2,3-(S)-HHDP-6-O-galloyl-β-D-glucose           | T3     | F      | [154]      |
|     |                                               | T4     | B      | [104]      |
|     |                                               | T40    | B      | [41]       |
|     |                                               | T32    | B      | [137]      |
| 121 | 3,6-Di-O-galloyl-β-D-glucose                   | T3     | F      | [154]      |
|     |                                               | T40    | B      | [41]       |
|     |                                               | T17    | F      | [159]      |
| 122 | 3,4-Di-O-galloyl-β-D-glucose                   | T3     | F      | [154]      |
| 123 | 6-O-galloyl-β-D-glucose                       | T17    | F      | [159]      |
| 124 | 3,4,6-Tri-O-galloyl-β-D-glucose               | T17    | F      | [159]      |
| 125 | Tellimagrandin I                              | T35    | L      | [139]      |
|     |                                               | T17    | F      | [159]      |
| 126 | Gemin D                                       | T17    | F      | [159]      |
| 127 | Arjunin                                        | T4     | L      | [65, 86]   |
|     |                                               | T17    | F      | [115]      |
| 128 | Punicalin                                      | T3     | F      | [154]      |
|     |                                               | T4     | L, B   | [65, 86, 104] |
|     |                                               | T14    | L      | [102]      |
|     |                                               | T40    | B      | [41]       |
|     |                                               | T16    | L      | [106, 107] |
|     |                                               | T17    | L, F   | [21, 155]  |
|     |                                               | T28    | SB     | [29]       |
|     |                                               | T49    | L      | [149]      |
| 129 | Casuarinin                                     | T4     | L, B   | [88, 104]  |
|     |                                               | T16    | B      | [41]       |
|     |                                               | T17    | F      | [21, 118, 119] |
| 130 | Casuariin                                      | T4     | B      | [90, 104]  |
| 131 | Terchebulin                                    | T3     | F      | [154]      |
|     |                                               | T4     | B      | [90, 104]  |
|     |                                               | T7     | SB     | [92]       |
|     |                                               | T12    | B      | [100]      |
|     |                                               | T17    | F      | [21]       |
|     |                                               | T31    | W      | [134]      |
### Table 2 (continued)

| No. | Compounds                           | Plants     | Organs | References            |
|-----|-------------------------------------|------------|--------|-----------------------|
| 132 | Castalagin                          | T4         | B      | [90, 104]             |
|     |                                     | T16, T40   | B      | [41]                  |
| 133 | Grandinin                           | T16, T40   | B      | [41]                  |
| 134 | Castalin                            | T16, T40   | B      | [41]                  |
| 135 | α/β-Punicalagin                      | T3         | F      | [154]                 |
|     |                                     | T7         | SB     | [92]                  |
|     |                                     | T4         | B      | [104]                 |
|     |                                     | T11        | L      | [35]                  |
|     |                                     | T12        | B      | [100]                 |
|     |                                     | T31        | R      | [101]                 |
|     |                                     | T14        | L      | [18, 103]             |
|     |                                     | T16        | B      | [41]                  |
|     |                                     | T17        | L, F   | [21, 106, 119, 155]   |
|     |                                     | T40        | B      | [41]                  |
|     |                                     | T19        | F      | [120]                 |
|     |                                     | T28        | SB     | [29]                  |
|     |                                     | T32        | B      | [137]                 |
|     |                                     | T35        | L      | [139]                 |
|     |                                     | T36        | L      | [38]                  |
|     |                                     | T38        | L      | [39]                  |
| 136 | 1-α-O-galloylpunicalagin             | T14        | L      | [18, 102, 103]        |
| 137 | 6′-O-methyl neochebulagate           | T17        | F      | [159]                 |
| 138 | Dimethyl neochebulagate              | T17        | F      | [159]                 |
| 139 | Neochebulagic acid                   | T17        | F      | [159]                 |
| 140 | Dimethyl 4′-epi-neochebulagate       | T17        | F      | [159]                 |
| 141 | Methyl chebulagate                   | T17        | F      | [159]                 |
| 142 | Chebulagic acid                      | T3         | F      | [154]                 |
|     |                                     | T4         | B, L, S| [23]                  |
|     |                                     | T8         | F, B, L,S| [23]                  |
|     |                                     | T17        | F, B, L,S,R| [23, 96]             |
|     |                                     | T16        | F, B, L,S,R| [3, 4, 9, 21, 110]   |
|     |                                     | T39        | F, B, L,S,R| [23]                  |
|     |                                     | T20        | F, B, L,R | [23]                  |
|     |                                     | T19        | F      | [120]                 |
|     |                                     | T32        | L      | [135, 136]            |
|     |                                     | T35        | L      | [139]                 |
| 143 | Chebulinic acid                      | T3         | F      | [154]                 |
|     |                                     | T4, T8, T16, T20, T39 | F, B, L, S,R | [3, 4, 21, 110, 119, 155] |
|     |                                     | T17        | F      | [23]                  |
|     |                                     | T32        | L      | [23]                  |
|     |                                     | T35        | L      | [110, 135, 139]       |
| 144 | Chebulanin                           | T34, T11   | L      | [35]                  |
|     |                                     | T17        | F      | [21, 119, 155, 159]   |
| 145 | 1,3-Di-O-galloyl-2,4-chebuloyl-β-D-glucose | T3 | F | [154] |
| 146 | 1,6-Di-O-galloyl-2,4-chebuloyl-β-D-glucose | T17 | F | [155, 159] |
| 147 | 2-O-galloylpunicalin                 | T14        | L      | [18]                  |
|     |                                     | T40        | B      | [41]                  |
|     |                                     | T32        | B      | [137]                 |
|     |                                     | T49        | L      | [149]                 |
| 148 | 1-Desgalloyleugenin                  | T14        | L      | [102]                 |
|     |                                     | T16        | L      | [107]                 |
| 149 | Eugeniin                            | T14        | L      | [102]                 |
| 150 | Rugosin A                            | T14        | L      | [102]                 |
| 151 | 1(α)-O-galloylpedunculagin           | T14        | L      | [102]                 |
| 152 | Praecoxin A                          | T14        | L      | [102]                 |
| 153 | Calamansanin                         | T14        | L      | [102]                 |
| No. | Compounds                                                                 | Plants | Organs | References |
|-----|---------------------------------------------------------------------------|--------|--------|------------|
| 154 | Calamanin A                                                               | T14    | L      | [102]      |
| 155 | Calamanin B                                                               | T14    | L      | [102]      |
| 156 | Calamanin C                                                               | T14    | L      | [102]      |
| 157 | Terflavin C                                                               | T4     | B      | [104]      |
|     |                                                                           | T14    | L      | [103]      |
|     |                                                                           | T17    | L      | [21]       |
| 158 | Terflavin A                                                               | T16    | L      | [106, 107] |
|     |                                                                           | T17    | F      | [21]       |
|     |                                                                           | T32    | B      | [137]      |
| 159 | Terflavin B                                                               | T16    | L      | [106, 107] |
|     |                                                                           | T17    | L, F   | [21, 155]  |
|     |                                                                           | T32    | B      | [137]      |
| 160 | 3-Methoxy-4-hydroxyphenol-1-O-β-(6′-O-galloyl)-glucoside                   | T16    | B      | [41]       |
| 161 | 3,5-Di-methoxy-4-hydroxyphenol-1-O-β-(6′-O-galloyl)-glucoside              | T16    | B      | [41]       |
| 162 | Acutissimin A                                                             | T16    | B      | [41]       |
| 163 | Eugenigrandin A                                                           | T16    | B      | [41]       |
| 164 | Catappanin A                                                              | T16    | B      | [41]       |
| 165 | Castamollinin                                                             | T40    | B      | [41]       |
| 166 | Tergallagin                                                               | T16    | L      | [106, 107] |
| 167 | Geraniin                                                                  | T16    | L      | [107]      |
| 168 | Granatin B                                                                | T16    | L      | [107]      |
| 169 | Gallotannic (tannic acid)                                                 | T17, T8| F      | [113]      |
|     |                                                                           | T38    | L      | [141]      |
| 170 | Chebulin                                                                  | T17    | F      | [113, 114] |
| 171 | Terchebin                                                                 | T17    | F      | [113, 119] |
| 172 | Neochebulinic acid                                                        | T3     | F      | [154]      |
|     |                                                                           | T17    | F      | [21, 119, 155] |
| 173 | Chebumeinin A                                                             | T17    | F      | [118]      |
| 174 | Chebumeinin B                                                             | T17    | F      | [118]      |
| 175 | Isoterchebulin                                                            | T32    | B      | [137]      |
| 176 | Punicacortein C                                                           | T3     | F      | [154]      |
|     |                                                                           | T32    | B      | [137]      |
|     |                                                                           | T17    | F      | [159]      |
| 177 | Punicacortein D                                                           | T17    | F      | [159]      |
| 178 | 4,6-O-Isoterchebuloyl-β-glucose                                           | T32    | B      | [137]      |
| 179 | Trigalloyl-β-β-glucose                                                    | T35    | L      | [139]      |
| 180 | Tetragalloyl-β-β-glucose                                                  | T35    | L      | [139]      |
| 181 | Pentagalloyl-β-β-glucose                                                  | T35    | L      | [139]      |
| 182 | 1,2,3-Tri-O-galloyl-6-O-cinnamoyl-β-β-glucose                             | T17    | F      | [159]      |
| 183 | 1,2,3,6-Tetra-O-galloyl-4-O-cinnamoyl-β-β-glucose                         | T17    | F      | [159]      |
| 184 | 1,6-Di-O-galloyl-2-O-cinnamoyl-β-β-glucose                               | T17    | F      | [159]      |
| 185 | 1,2-Di-O-galloyl-6-O-cinnamoyl-β-β-glucose                               | T17    | F      | [159]      |
| 186 | 4-O-(2′, 4′-di-O-galloyl-α-β-rhamnosyl) ellagic acid                      | T17    | F      | [159]      |
| 187 | 4-O-(4′-O-galloyl-α-β-rhamnosyl) ellagic acid                             | T17    | F      | [159]      |
| 188 | 4-O-(3′, 4′-di-O-galloyl-α-β-rhamnosyl) ellagic acid                      | T17    | F      | [159]      |
| 189 | 1′-O-methyl neochebulanin                                                 | T17    | F      | [159]      |
| 190 | Dimethyl neochebulinate                                                   | T17    | F      | [159]      |
| 191 | Phyllanembelin E                                                          | T17    | F      | [159]      |
| 192 | 1′-O-methyl neochebulinate                                                | T17    | F      | [159]      |
| 193 | Phyllanembelin F                                                          | T17    | F      | [159]      |
| 194 | Procyanidin B-1                                                           | T16    | B      | [41]       |
| 195 | 3′-O-galloyl procyanidin B-2                                               | T16    | B      | [41]       |
| No. | Compounds                                      | Plants | Organs | References |
|-----|-----------------------------------------------|--------|--------|------------|
| 196 | 5,7,2'-Tri-O-methylflavanone 4'-O-α-l-rhamnosyl-(1→4)-β-D-glucoside | T1     | R      | [52]       |
| 197 | Arjunone                                      | T4     | B, F   | [83, 89]   |
| 198 | 8-Methyl-5,7,2',4'-tetramethoxy-flavanone     | T1     | R      | [53]       |
|     |                                              | T39    | B      | [144]      |
| 199 | Naringin                                      | T4     | L, S, F| [23]       |
|     |                                              | T8     | B, F   | [23]       |
|     |                                              | T17    | L, R, F| [23]       |
|     |                                              | T39    | R, F   | [23]       |
|     |                                              | T20    | B, L, S, R | [23] |
| 200 | Eriodictyol                                   | T4, T8, T17, T20, T39 | B, L, S, R, F | [23] |
|     |                                              | T16    | L, S, R, F | [23] |
| 201 | Hesperitin                                    | T24    | F      | [122]      |
| 202 | Flavanone                                     | T24    | F      | [122]      |
| 203 | Arjunolone (6,4-dihydroxy-7-methoxy flavone)  | T4     | SB     | [64]       |
| 204 | Bicalein (5,6,7-trihydroxy flavone)           | T4     | SB     | [64]       |
| 205 | Scutellarein                                  | T4     | B, R   | [23]       |
|     |                                              | T8, T17, T20 | B, L, S, R, F | [23] |
|     |                                              | T16    | L, F   | [23]       |
|     |                                              | T39    | B, L, R, F | [23] |
| 206 | Luteolin                                      | T4     | B, L   | [23, 65]   |
|     |                                              | T8, T20 | L, S   | [23]       |
|     |                                              | T17    | R, L   | [23]       |
|     |                                              | T16    | L      | [23]       |
|     |                                              | T39    | L, S, F| [23]       |
|     |                                              | T24    | F      | [122]      |
| 207 | Apigenin                                      | T4     | B, L, S, R, F | [23, 66] |
|     |                                              | T8, T16, T17, T20, T39 | B, L, S, R, F | [23] |
| 208 | Isoorientin                                   | T11    | L      | [35]       |
|     |                                              | T4, T8, T17, T16, T20, T39 | B, L, S, R, F | [23] |
|     |                                              | T16    | L      | [139]      |
|     |                                              | T35    | L      | [38]       |
|     |                                              | T36    | L      | [38]       |
| 209 | Orientin                                      | T11    | L      | [35]       |
|     |                                              | T4     | L, F   | [23]       |
|     |                                              | T8     | B, S   | [23]       |
|     |                                              | T17    | B, L, S, R, F | [23] |
|     |                                              | T16    | L, R, F| [23]       |
|     |                                              | T39    | B, S, F| [23]       |
|     |                                              | T20    | L, S, F| [23]       |
|     |                                              | T35    | L      | [139]      |
|     |                                              | T36    | L      | [38]       |
| 210 | Isovitexin                                    | T11    | L      | [35]       |
|     |                                              | T4     | L, F   | [23]       |
|     |                                              | T17    | L, R, F| [23]       |
|     |                                              | T16    | L      | [23, 105]  |
|     |                                              | T39    | S, F   | [23]       |
|     |                                              | T20    | L, S, F| [23]       |
|     |                                              | T35    | L      | [139]      |
|     |                                              | T36    | L      | [38]       |
| 211 | Apigenin-6-C-(2"-O-galloyl)-β-D-glucoside     | T16    | L      | [105]      |
| 212 | Apigenin-8-C-(2"-O-galloyl)-β-D-glucoside     | T16    | L      | [105]      |
|     |                                              | T34    | L      | [35]       |
Table 2 (continued)

| No. | Compounds                          | Plants  | Organs   | References |
|-----|------------------------------------|---------|----------|------------|
| 213 | Vitexin                            | T4, T17, T20 | B, L, S, R, F | [23]       |
|     |                                    | T8      | B, L, S, R | [23]       |
|     |                                    | T16     | L, S, R, F | [23]       |
|     |                                    | T39     | B, L, S, F | [23]       |
|     |                                    | T35     | L         | [139]      |
|     |                                    | T36     | L         | [38]       |
| 214 | Amentoflavone                      | T8      | L         | [23]       |
|     |                                    | T17     | L, R, F   | [23]       |
|     |                                    | T20     | L         | [23]       |
| 215 | Neosaponarin                       | T36     | L         | [38]       |
| 216 | (−)-Epicatechin                    | T4      | B         | [76]       |
| 217 | Epicatechin                        | T4, T8, T17, T20, T39 | B, L, S, R, F | [23]       |
|     |                                    | T16     | L, S, R, F | [23]       |
|     |                                    | T34     | SB        | [35]       |
| 218 | Catechin                           | T34     | SB        | [35]       |
|     |                                    | T11     | L         | [35]       |
|     |                                    | T4, T8, T16, T17, T20, T39 | B, L, S, R, F | [23]       |
|     |                                    | T44     | R         | [133]      |
| 219 | Catechin–epicatechin               | T44     | R         | [43]       |
| 220 | Catechin–epigallocatechin          | T44     | R         | [43]       |
| 221 | Epigallocatechin                   | T34     | SB        | [35]       |
| 222 | (−)-Epicatechin-3-O-gallate        | T16     | B         | [41]       |
| 223 | (−)-Epigallocatechin-3-O-gallate  | T16     | B         | [41]       |
| 224 | Flavanol                           | T24     | F         | [122]      |
| 225 | Gallicatechin                      | T34     | SB        | [35]       |
|     |                                    | T24     | F         | [126]      |
| 226 | Quercetin                          | T4      | B, L, R   | [23]       |
|     |                                    | T8      | R         | [23]       |
|     |                                    | T17     | S, R, F   | [23]       |
|     |                                    | T16     | L, S, F   | [23]       |
|     |                                    | T39     | L, B      | [23, 142]  |
|     |                                    | T20     | F         | [23]       |
|     |                                    | T24     | F         | [124]      |
|     |                                    | T49     | L         | [124]      |
| 227 | Kaempferol                         | T4      | B, L, S, R, F | [23, 66]  |
|     |                                    | T8      | B, L, S, F | [23]       |
|     |                                    | T16, T17 | B, L, S, R, F | [23]       |
|     |                                    | T20, T39 | L, S, R, F | [23]       |
|     |                                    | T24     | F         | [122]      |
| 228 | Kaempferol-3-O-β-D-rutinoside      | T4, T8, T17 | B, L, S, R, F | [23]       |
|     |                                    | T16     | L, S, F   | [23]       |
|     |                                    | T39     | L, R, F   | [23]       |
|     |                                    | T20     | L, S, R   | [23]       |
|     |                                    | T36     | L         | [38]       |
| 229 | Afzelin (kaempferol 3-O-rhamnoside)| T49     | L         | [124]      |
| 230 | Rutin                              | T4, T16 | B, L, S, F | [23]       |
|     |                                    | T8      | L         | [23]       |
|     |                                    | T17, T39 | B, L, S, R, F | [23]       |
|     |                                    | T20     | L, S, F   | [23]       |
|     |                                    | T32     | L         | [135, 136] |
|     |                                    | T36     | L         | [38]       |
| 231 | Narcissin                          | T32     | L         | [135, 136] |
### Table 2 (continued)

| No. | Compounds                                           | Plants | Organs     | References |
|-----|----------------------------------------------------|--------|------------|------------|
| 232 | Quercetin-3,4′-di-O-glucoside                      | T4     | B, L, S, F | [23]       |
|     |                                                   | T8     | B, S, F    | [23]       |
|     |                                                   | T16, T17, T20, T39 | B, L, S, R, F | [23]       |
| 233 | Quercetin-7-O-rhamnoside                           | T4     | F          | [80]       |
| 234 | 2-O-β-glucosyloxy-4,6,2′,4′-tetramethoxychalcone   | T1     | R          | [53]       |
| 235 | Cerasidin                                           | T4     | F          | [80]       |
| 236 | Genistein                                          | T4     | B, L, S, R, F | [23, 80] |
|     |                                                   | T8, T16, T17, T20, T39 | B, L, S, R, F | [23]       |
| 237 | Cyaniding                                           | T4     | B          | [66]       |
| 238 | Pelargonidin                                        | T4     | B          | [66]       |
| 239 | Leucocyanidin                                       | T4     | B          | [80]       |
| 240 | 7-Hydroxy-3′,4-(methylenedioxy)flavan              | T8     | FR         | [12]       |

**Lignan (27)**

| No. | Compounds          | Plants | Organs | References |
|-----|--------------------|--------|--------|------------|
| 241 | Termilignan        | T8     | FR     | [12]       |
|     |                    | T39    |        | [144]      |
| 242 | Anolignan B        | T8     | FR     | [12]       |
|     |                    | T44    | R      | [43, 151]  |
| 243 | Thannilignan       | T8     | FR     | [12]       |
| 244 | Termilignan B      | T44    | R      | [133]      |
| 245 | Ferulic acid dehydrodimer | T24 | F | [125] |
| 246 | (7S,8R,7′R,8′S)-4′-hydroxy-4-methoxy-7,7′-epoxylignan | T48 | SB | [50] |
| 247 | Meso-(rel7S,8R,7′R,8′S)-4′-dimethoxy-7,7′-epoxylignan | T48 | SB | [50] |
| 248 | 4′-O-cinnamoyl cleomiscosin A                      | T50    | R      | [72]       |
| 249 | Diethylstilbestrol monosulphate                    | T24    | F      | [126]      |
| 250 | Terminaloside A   | T19    | L      | [22]       |
| 251 | Terminaloside B   | T19    | L      | [22]       |
| 252 | Terminaloside C   | T19    | L      | [22]       |
| 253 | Terminaloside D   | T19    | L      | [22]       |
| 254 | Terminaloside E   | T19    | L      | [22]       |
| 255 | Terminaloside F   | T19    | L      | [22]       |
| 256 | Terminaloside G   | T19    | L      | [22]       |
| 257 | Terminaloside H   | T19    | L      | [22]       |
| 258 | Terminaloside I   | T19    | L      | [22]       |
| 259 | Terminaloside J   | T19    | L      | [22]       |
| 260 | Terminaloside K   | T19    | L      | [22]       |
| 261 | 2-Epiterminaloside D | T19 | L | [22] |
| 262 | 6-Epiterminaloside K | T19 | L | [22] |
| 263 | Terminaloside L   | T19    | L      | [121]      |
| 264 | Terminaloside M   | T19    | L      | [121]      |
| 265 | Terminaloside N   | T19    | L      | [121]      |
| 266 | Terminaloside O   | T19    | L      | [121]      |
| 267 | Terminaloside P   | T19    | L      | [121]      |
| No. | Compounds                                      | Plants | Organs          | References |
|-----|-----------------------------------------------|--------|-----------------|------------|
| 268 | Phenols and glycosides (52)                   |        |                 |            |
| 269 | Methyl ellagic acid                           | T4     | B               | [90]       |
| 270 | 3-O-methyellagic acid                         | T33    | SB              | [158]      |
| 271 | 3,3'-Di-O-methyellagic acid                   | T28    | SB              | [29]       |
|     |                                               | T39    | H, B            | [8, 9, 143, 144] |
|     |                                               | T48    | SB              | [50]       |
| 272 | 3,3'-Di-O-methyellagic acid 4-mono glucoside  | T39    | H               | [147, 148] |
| 273 | Tetra-O-methyl ellagic acid                    | T39    | H               | [148]      |
| 274 | 3,3'-Di-O-methyellagic acid 4-O-β-n-glucosyl-(1 → 4)-β-n-glucosyl-(1 → 2)-α-l-arabinoside | T1 | R | [52] |
| 275 | 3,4,3'-Tri-O-methylflavellagic acid            | T7, T12, T24, T25, T31, T28, T32, T39, T48 | B, F, L, B, R, RI, H, B, SB, H, B, L, B, R, RI | [126, 100, 126, 26, 70, 127, 128, 127, 29, 128, 128, 138, 143, 148] |
| 276 | 3,3',4-O-trimethyl-4'-O-β-n-glucosylellagic acid | T28 | SB | [29] |
| 277 | 3,3'-Di-O-methyl ellagic acid 4'-O-β-n-xyloside | T48 | SB | [50] |
| 278 | 3,4'-Di-O-methyellagic acid 3'-O-β-n-xyloside  | T48    | SB              | [153]      |
| 279 | 4'-O-galloy-3,3'-di-O-methyellagic acid 4-O-β-n-xyloside | T48 | SB | [153] |
| 280 | Flavogallonic acid                            | T7     | SB              | [92]       |
|     |                                               | T40    | B               | [41]       |
|     |                                               | T31    | W               | [134]      |
|     |                                               | T12    | R               | [101]      |
|     |                                               | T36    | L               | [38]       |
| 281 | Methyl (S)-flavogallonate                      | T36    | L               | [38]       |
| 282 | Vanillic acid 4-O-β-n-(6'-O-galloyl) glucoside | T32    | B               | [138]      |
| 283 | 3-O-methyellagic acid 4'-O-α-l-rhamnoside      | T4     | B               | [76]       |
|     |                                               | T34    | SB              | [35]       |
|     |                                               | T33    | SB              | [158]      |
| 284 | Eschweilenol C (ellagic acid 4-O-α-l-rhamnoside) | T12, T17 | B, F | [100, 164] |
| 285 | 3-O-methyellagic acid 4'-O-xyloside            | T31    | R               | [101]      |
| 286 | Brevifolin carboxylic acid                     | T35    | L               | [139]      |
| No. | Compounds                                      | Plants | Organs | References                  |
|-----|-----------------------------------------------|--------|--------|----------------------------|
| 287 | Terflavin D                                   | T17    | F      | [159]                       |
| 287 | Gallic acid                                   | T17    | L      | [21]                        |
| 287 |                                              | T3     | F      | [154]                       |
| 288 |                                              | T4, T8, T20, T39 | B, L, S, R, F |                        |
| 288 |                                              | T10, TM, TT | SB    | [14]                        |
| 288 |                                              | T17    | SB, F, R, L | [14, 21, 23, 118, 119]     |
| 288 |                                              | T16    | SB, F, R, L | [14, 21, 23, 118, 119]     |
| 288 |                                              | T34    | L      | [14, 21, 23, 41, 108]       |
| 288 |                                              | T12    | B      | [35]                        |
| 288 |                                              | T31    | R, W   | [100]                       |
| 288 |                                              | T40    | B      | [101, 134]                  |
| 288 |                                              | T24    | F      | [41]                        |
| 288 |                                              | T30    | R      | [123, 125]                  |
| 288 |                                              | T35    | L      | [133]                       |
| 288 |                                              | T36    | L      | [139]                       |
| 288 |                                              | T38    | L      | [38]                        |
| 288 |                                              | T42    | R, SB  | [141]                       |
| 288 |                                              | T44    | R      | [133]                       |
| 288 |                                              | T45, T46 | L    | [133]                       |
| 288 |                                              | T48    | SB    | [133]                       |
| 288 |                                              | T49    | L      | [50]                        |
| 289 | Phyllemblin (ethyl gallate isomers1 progallin A) | T4    | B      | [86]                        |
| 289 |                                              | T8     | F      | [96, 113]                   |
| 289 |                                              | T24    | F      | [126]                       |
| 289 |                                              | T28    | SB    | [29]                        |
| 289 |                                              | T36    | L      | [38]                        |
| 290 | Monogalloyl glucose                           | T3     | F      | [154]                       |
| 290 |                                              | T8     | F      | [113]                       |
| 290 |                                              | T17    | F      | [21]                        |
| 290 |                                              | T31    | R      | [101]                       |
| 291 | Methyl gallate                               | T14    | L      | [18]                        |
| 291 |                                              | T8     | F      | [113]                       |
| 291 |                                              | T32    | L      | [135, 136]                  |
| 291 |                                              | T36    | L      | [38]                        |
| 291 |                                              | T48    | SB    | [50]                        |
| 291 |                                              | T49    | L      | [124]                       |
| 292 | Shikimic acid                                 | T32    | L      | [135, 136]                  |
| 293 | 5-O-galloyl-(−)-shikimic acid                 | T3     | F      | [118]                       |
| 293 |                                              | T17    | F      | [154, 159]                  |
| 294 | 4-O-galloyl-(−)-shikimic acid                 | T17    | F      | [159]                       |
| 295 | 3,5-Di-O-galloyl-(−)-shikimic acid            | T3     | F      | [154]                       |
| 296 | Digallic acid                                 | T17    | F      | [159]                       |
| 297 | Ethyl gallate isomers2                       | T24    | F      | [126]                       |
| 298 | Ethyl gallate isomers3                       | T24    | F      | [126]                       |
| 299 | Dimethyl gallic acid                          | T35    | L      | [139]                       |
| 300 | Chebulic acid                                 | T3     | F      | [154]                       |
| 300 |                                              | T17    | F      | [4, 9, 112, 119, 159]       |
| 300 |                                              | T24    | F      | [159]                       |
| 300 |                                              | T35    | L      | [125, 126]                  |
| 301 | 6′-O-methyl chebulate                         | T17    | F      | [159]                       |
| 302 | 7′-O-methyl chebulate                         | T17    | F      | [159]                       |
| 303 | Chebulic acid trimethyl ester                | T32    | L      | [135, 136]                  |
| 304 | Terminalin                                   | T38    | L      | [39]                        |
| 305 | Decarboxyellagic acid                        | T3     | F      | [154]                       |
| 306 | 3-O-galloyl-α-glucose                        | T3     | F      | [154]                       |
| No. | Compounds | Plants | Organs | References |
|-----|-----------|--------|--------|------------|
| 307 | 6-O-galloyl-d-glucose | T3, T17 | F | [154] |
|     |           | T4, T8, T20, T39 | B, L, S, R, F | [23] |
| 308 | Vanillic acid | T17 | B | [23, 117] |
|     |           | T16 | S, R, B, F | [23] |
|     |           | T44 | R | [43] |
| 309 | Benzoic acid | T44 | R | [43] |
|     |           | T24 | F | [122] |
| 310 | Hydrocinnamic acid | T44 | R | [43] |
| 311 | Gentic acid | T16 | L | [108] |
| 312 | Protocatechuic acid | T4, T8, T16, T17, T20, T39 | B, L, S, R, F | [23] |
| 313 | 2,3-Di-hydroxyphenyl β-d-glucosiduronic acid | T24 | F | [125] |
| 314 | Quinic acid | T4, T8, T16, T17, T20, T39 | B, L, S, R, F | [23] |
|     |           | T24 | | [125] |
| 315 | p-Coumaric acid | T17 | WP | [117] |
|     |           | T44 | R | [43] |
| 316 | Caffeic acid | T4, T8 | L, S | [23] |
|     |           | T17 | L, S, R | [23] |
|     |           | T16 | L | [23] |
|     |           | T39 | B, L, S, R, F | [23] |
|     |           | T20 | B | [23] |
|     |           | T44 | R | [43] |
| 317 | Chlorogenic acid | T4 | L, S | [23] |
|     |           | T17 | S, R, F, L | [23] |
|     |           | T16, T39 | L | [23] |
|     |           | T20 | B | [23] |
| 318 | Ferulic acid | T4 | B, L, S, F | [23] |
|     |           | T8, T17, T20, T39 | B, L, S, R, F | [23] |
|     |           | T16 | L, S, R | [23] |
| 319 | Sinapic acid | T4, T16, T20, T39 | B, L, S, R, F | [23] |
|     |           | T8 | S, R, F | [23] |
|     |           | T17 | B, S, R, F | [23] |
|     | Steroids (8), polyols (9) and esters (6) | | | |
| 320 | β-Sitosterol | T1 | B, H | [55, 56] |
|     |           | T4 | S, F | [57, 83] |
|     |           | T8 | F | [96, 113] |
|     |           | T12 | F | [99] |
|     |           | T16 | B, SB | [128] |
|     |           | T48 | H | [128] |
|     |           | T25 | H | [129] |
|     |           | T36 | SB | [140] |
|     |           | T39 | B | [147, 148] |
|     |           | T44 | H, SB, R | [43, 133, 152] |
| 321 | β-Sitosterol-3-acetate | T44 | SB, R | [43] |
| 322 | β-Sitosteryl palmitate | T16 | SB, H | [128] |
|     |           | T25, T31 | L, F | [128] |
| 323 | Stigmasterol 3-O-β-d-glucoside | T4 | F | [80] |
|     |           | T33 | SB | [158] |
| 324 | Stigmasterol | T12 | B | [99] |
|     |           | T25 | SB | [129] |
|     |           | T33 | SB | [158] |
|     |           | T44 | RB | [133, 152] |
| 325 | Stigma-4-ene-3-one | T44 | RB | [43] |
| 326 | 16,17-Dihydrorneridienone 3-O-β-d-galactosyl-(1→6)-O-β-d-galactoside | T4 | R | [59] |
### Table 2 (continued)

| No. | Compounds                                                                 | Plants | Organs | References |
|-----|---------------------------------------------------------------------------|--------|--------|------------|
| 327 | Cannogenol 3-O-β-D-galactosyl-(1→4)-O-α-L-rhamno-side                     | T8     | Se     | [94]       |
| 328 | 2-Hexanol                                                                | T9     | L      | [13]       |
| 329 | Octanol                                                                  | T9     | L      | [13]       |
| 330 | Methoxycarbonyloxymethyl methylcarbonate                                  | T24    | F      | [125]      |
| 331 | Ribonolactone                                                            | T24    | F      | [125]      |
| 332 | Apionic acid                                                              | T24    | F      | [125]      |
| 333 | Ascorbic acid                                                            | T24    | F      | [125]      |
| 334 | Gluconolactone                                                           | T24    | F      | [125]      |
| 335 | Glucohepatic acid-1,4-lactone                                            | T24    | F      | [125]      |
| 336 | Galacturonic acid                                                        | T44    | R      | [43]       |
| 337 | Geranyl formate                                                           | T9     | L      | [13]       |
| 338 | Citronellyl acetate                                                      | T9     | L      | [13]       |
| 339 | Geranyl acetate                                                          | T9     | L      | [13]       |
| 340 | Geranyl tiglate                                                          | T9     | L      | [13]       |
| 341 | Laxiflorin                                                               | T31    | RB     | [127]      |
| 342 | (1S,5R)-4-oxo-6,8-dioxabicyclo[3.2.1]oct-2-ene-2-carboxylic acid          | T24    | F      | [125]      |
|     | Others (26)                                                              |         |        |            |
| 343 | Glucuronic acid                                                          | T24    | F      | [125]      |
| 344 | Coumarin                                                                 | T45    | L      | [133]      |
| 345 | Eujavonic acid                                                           | T24    | F      | [125]      |
| 346 | Purine                                                                   | T24    | F      | [125]      |
| 347 | 5-(4-Hydroxy-2,5-dimethylphenoxo)-2,2-dimethylpentanoic acid (gemfibrozil M1) | T24    | F      | [125]      |
| 348 | p-Hydroxytiaprofenic acid                                                | T24    | F      | [125]      |
| 349 | Cis-polyisoprene                                                         | T32    | L      | [135]      |
| 350 | Arachidic acid                                                           | T17    | F      | [113]      |
| 351 | Behenic acid                                                             | T8, T17| F      | [113]      |
| 352 | Arjunaphthanoloside                                                      | T4     | SB     | [87]       |
| 353 | Resveratrol (3′,4,5′-trihydroxystilbene)                                 | T24    | F      | [126]      |
|     |                                                                         | T44    | R      | [43]       |
| 354 | Resveratrol glucoside (piceid)                                           | T24    | F      | [126]      |
|     |                                                                         | T44    | RB     | [152]      |
| 355 | Resveratrol-β-D-glucoside                                                | T44    | RB     | [152]      |
| 356 | Combretatatin                                                            | T24    | F      | [126]      |
| 357 | Combretastatin A1                                                        | T24    | F      | [126]      |
| 358 | (Z)-Stilbene                                                             | T44    | R      | [133]      |
| 359 | (E)-Stilbene                                                             | T44    | R      | [133]      |
| 360 | 3′,5′-Dihydroxy-4-(2-hydroxyethoxy) resveratrol-3-O-β-rutinoside          | T44    | R, RB  | [43, 152]  |
| 361 | Resveratrol-3-O-β-rutinoside glycoside                                   | T44    | R, RB  | [43, 152]  |
| 362 | 1,4-Cineole                                                              | T9     | L      | [13]       |
| 363 | Terpinen-4-ol                                                            | T9     | L      | [13]       |
| 364 | Terminalanone                                                            | T12    | B      | [98]       |
| 365 | Termicalcicolanone A                                                     | T15    | WP     | [19]       |
| 366 | Termicalcicolanone B                                                     | T15    | WP     | [19]       |
3.2 Tannins

As the main secondary metabolites, 91 tannins (105–195) were reported from the genus *Terminalia* (Fig. 2), including ellagitannins, gallotannins, dimeric, and trimeric tannins. Four cinnamoyl-containing gallotannins (182–185) were discovered firstly from the fruits of *T. chebula*, and 1,2,3,6-tetra-O-galloyl-4-O-cinnamoylβ-D-glucose (183) and 4-O-(2′,4′-di-O-galloyl-α-L-rhamnosyl) ellagic acid (186) showed significant inhibitory activity on α-glucosidase with IC₅₀ values of 2.9 and 6.4 μM, respectively [159].

Tannins possess not only liver and kidney protection properties, but also anti-diarrhea, anticancer, antibacterial and hypoglycemic activities [133]. However, a condensed tannin terminalin (186) from *T. oblongata* was reported to have severe hepatorenal toxicity and even caused renal necrosis [39].

3.3 Flavonoids

The *Terminalia* genus are rich in flavonoids (Fig. 3) comprising of flavanones (196–202), flavones (203–215), flavan-3-ols (216–225), and flavonols (226–233). Among them, cerasidin (235) of chalcone, genistein (236) of isoflavone, and leucocyanidin (239) of flavan-3,4-diol from *T. arjuna* [80] were described as rare structural types in the *Terminalia* genus. Moreover, a new chalcone glycoside 2-O-β-glucosyloxy-4,6,2′,4′-tetramethoxychalcone (234) was reported from the roots of *T. alata* [53]. In addition, anthocyanidin cyanidin (237) and pelargonidin (238), flavanoid 7-hydroxy-3′,4′-(methylenedioxy)flavon (240) and other structure were reported [12, 23, 66]. Compounds 209–213, 215 were C-glycosides at C-6 or C-8 of ring A.

3.4 Lignans

Twenty-seven lignans (241–267) were reported from the genus *Terminalia* (Fig. 4). A new lignan 4′-O-cinnamoyl cleomiscosin A (248) was reported from the ethanol extract of *T. tropophylla* roots [72]. Moreover, 13 new furofuran lignan glucosides, terminalosides A–K (250–260), 2-epiterminaloside D (261), 6-epiterminaloside K (262) and 5 new polyalkoxyated furofuranone lignan glucosides, terminalosides L–P (263–267) were obtained from the leaves of *T. citrina*. All of them were tested for their estrogenic and/or antiestrogenic activities using estrogen responsive breast cancer cell lines T47D and MCF-7, and showed varying degrees of inhibitory activity. Among them, terminalosides B (251), G (256), L (263) and M (264) inhibited cell growth by up to 90% at a minimum concentration of 10 nM [22, 121].

3.5 Phenols and Glycosides

There are 52 phenols and glycosides reported in the *Terminalia* genus (Fig. 5), in which ellagic acid (268) and gallic acid (289) are present in almost all species. Studies have shown that most of the simple phenolic compounds have antioxidant, antibacterial, hypoglycemic, liver and kidney protection [23].

3.6 Sterols and Cardiac Glycosides

Only 6 sterols (320–325) and 2 cardiac glycosides (326–327) were isolated from the genus *Terminalia* before 2001 (Fig. 6).

3.7 Polyols and Esters

Polyols and lipids were reported to be abundant in the genus *Terminalia* and concentrated mainly in fruits and leaves [125]. So far, 9 polyol (328–336) and 6 esters (337–342) have been documented (Fig. 7).

3.8 Other Compounds

Other compounds featured in the *Terminalia* genus are shown in Fig. 8 and are mostly styrenes. Cao et al. isolated two new cytotoxic xanthones - terminalcalcicolanone A (365),
termicalcicolanone B (366) in *T. calcicola*, and found an inhibitory effect on ovarian cancer [19]. Hiroko Negishi et al. obtained a new chromone derivative - terminalianone (364) from the barks of *Terminalia brownii* [98]. Ansari et al. isolated the novel compound, 4′-substituted benzoyl-β-D-glycoside (368), from the fruits of *T. bellirica* and illustrated its potential for anticoagulation [160]. Moreover, chlorophyll and various vitamins were reported from the genus *Terminalia*.

### 4 Pharmacological Activities

The pharmacological activities of the genus *Terminalia*, mainly including antimicrobial, antioxidant, cytotoxicity, anti-inflammatory, hypoglycemic, cardiovascular, mosquito-cidal and antiviral, have been extensively studied.

#### 4.1 Antimicrobial

Extracts of several *Terminalia* species exhibit antimicrobial activity against various microbes. For example, methanol and aqueous extracts of *T. australis* were demonstrated antimicrobial activity against *Ca. albicans* (MIC = 180 and 250 µg/mL, resp.) and *Ca. kruzei* (MIC = 250 and 300 µg/mL, resp.) [8]. Aqueous extracts of the stem barks, woods and whole roots of *T. brownii* showed antibacterial activity against standard strains of *Sta. aureus* (14.0 ± 1.1 µg/mL), *Escherichia coli*, *Ps. aeruginosa* (12.0 ± 1.1 µg/mL), *Klebsiella pneumonia* (6.0 ± 1.0 µg/mL), *Sa. typhi* and *Bacillus anthracis* (13.0 ± 1.0 µg/mL), as well as fungi *Ca. albi-cans* (12.3 ± 1.5 µg/mL) and *Cr. neoformans* (9.7 ± 1.1 µg/mL) [16]. Ethanol extracts of the root barks and leaves of *T. schimperiana* were against *Sta. aureus*, *Ps. aeruginosa* and *Sa. typhi* (MIC = 0.058–2.089 mg/mL), with inhibition...
zone diameters (IZDs) of 17.2 to 10.0 mm, compared to gentamicin (IZD = 21.8–10 mm). The results supported the efficacy of the extracts in the folkloric treatment of burns wounds, bronchitis and dysentery, respectively [42]. Antibacterial tests on *Mycobacterium smegmatis* ATCC 14468 showed that methanol extract of *T. sambesiaca* roots and stem barks had promising effects (MIC = 1.25 mg/mL, both) [133].

Ellagitannin punicalagin (133) obtained from the stem barks of *T. mollis* demonstrated crucial activity against *Ca. parapsilosis* and *Ca. krusei* (MIC = 6.25 μg/mL), as well as *Ca. albicans* (MIC = 12.5 μg/mL) [35].
7-Hydroxy-3',4'-(methylenedioxy) flavan (240), termilignan (241), anolignan B (242) and thannilignan (243) isolated from the fruit rinds of *T. bellirica* displayed significant antifungal activity against *Penicillium expansum* (MIC = 1.0, 2.0, 3.0 and 4.0 µg/mL, resp.), also with 240 and 241 against *Ca. albicans* at 10 and 6 µg/mL, resp. [12]. The antimycobacterial activity of friedelin (79) furnished from the root barks of *T. avicennioides* was 4.9 µg/mL in terms of MIC...
value [93]. β-Arjungenin (16), betulinic acid (74), sitosterol (319) and stigmasterol (323) from *T. brownii* were proved to possess antibacterial activity, with 74 the most active against *A. niger* and *S. ipomoea* (MIC = 50 μg/ml) [99].

### 4.2 Antioxidant

*Terminalia* species have also illustrated some interesting antioxidant properties [161]. By a 2,2-diphenyl-1-picrylhydrazyl (DPPH) radical scavenging assay, relatively high antioxidant activities of the methanol extracts of *T. alata*, *T. belblica* and *T. corticosa* trunk-barks were found (IC₅₀ = 0.24, 1.02 and 0.25 mg/mL, resp.), compared to the positive control, l-ascorbic acid (IC₅₀ = 0.24 mg/mL) [2].

Flavonoid glycosides, apigenin-6-C- (211) and apigenin-8-C- (212) (2″-O-galloyl)-β-D-glucoside, isolated from dried fallen leaves of *T. catappa*, showed significant antioxidative effects (IC₅₀ = 2.1 and 4.5 μM, resp.) on Cu²⁺/O₂⁻-induced low density lipoprotein lipid peroxidation, with probucol (IC₅₀ = 4.0 μM) as positive control [105].

Arjunaphthanoloside (351), isolated from the stem barks of *T. arjuna* showed potent antioxidant activity and inhibited nitric oxide (NO) production in lipopolysaccharide (LPS)-stimulated rat peritoneal macrophages [87], while ivorenosides B (51) and C (52), two triterpenoid saponins from *T. ivorensis*, exhibited scavenging activities against DPPH and ABTS⁺ radicals [131].

The antioxidant potential of *T. paniculata* (TPW) was investigated by DPPH, ABTS⁻, NO, superoxide (O₂⁻), Fe²⁺ chelating and ferric reducing/antioxidant power (FRAP) assays. TPW showed maximum superoxide, ABTS⁻, NO, DPPH inhibition, and Fe²⁺-chelating property at 400 μg/mL, resp. FRAP value was 4.5 ± 0.25 μg Fe(II)/g, which
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demonstrated the efficacy of aqueous barks extract of T. paniculata as a potential antioxidant and analgesic agent [142].

TaB contains various natural antioxidants and has been used to protect animal cells against oxidative stress. The alleviating effect of TaB aqueous extract against Ni toxicity in rice (Oryza sativa L.) suggested that TaB extract considerably alleviated Ni toxicity in rice seedlings by preventing Ni uptake and reducing oxidative stress in the seedlings [162]. Behavioral paradigms and PCR studies of TaB extract against picrotoxin-induced anxiety showed that TaB supplementation increased locomotion towards open arm (EPM), illuminated area (light–dark box test), and increased rearing frequency (open field test) in a dose dependent manner, compared to picrotoxin (P < 0.05). Furthermore, alcoholic extract of TaB showed protective activity against picrotoxin in mice by modulation of genes related to synaptic plasticity, neurotransmitters, and antioxidant enzymes [174].
Fig. 2 (continued)
Fig. 2 (continued)
Fig. 3 The structures of flavonoids 197–240
4.3 Cytotoxicity

70% Acetone extracts of T. calamansanai leaves inhibited the viability of human promyelocytic leukemia HL-60 cells. Sanguin H-4 (115), 1-α-O-galloylpunicalagin (136), punicalagin (135), 2-O-galloylpunicalin (147) and methyl gallate (290) were the main components isolated from T. calamansanai with the IC₅₀ values of 65.2, 74.8, 42.2, 38.0 and > 100 µM, respectively, for HL-60 cells. Apoptosis of HL-60 cells treated with 1-α-O-galloylpunicalagin, 115, 135, and 147 was noted by the appearance of a sub-G₁ peak in flow cytometric analysis and DNA fragmentation by gel electrophoresis. 115 and 147 induced a decrease of the human poly (ADP-ribose) polymerase (PARP) cleavage-related procaspase-3 and elevated activity of caspase-3 in HL-60 cells, but not normal human peripheral blood mononuclear cells, PBMCs [18].

Terminaliaside A (60), an oleanane-type triterpenoid saponin isolated from the roots of T. tropophylla showed antiproliferative activity against the A2780 human ovarian cancer cell line with an IC₅₀ value of 1.2 µM [72]. The 70% methanolic extract of T. chebula fruits was found to decrease cell viability, inhibit cell proliferation, and induce cell death of human (MCF-7) and mouse (S115) breast cancer, human osteosarcoma (HOS-1), human prostate cancer (PC-3) and a non-tumorigenic, immortalized human prostate (PNT1A) cell lines. Flow cytometry and other analyses showed that some apoptosis was induced by the extract at lower concentrations, but at higher concentrations, necrosis was the major mechanism of cell death. Chebulinic acid (143) and ellagic acid (186) were tested by ATP assay on HOS-1 cell line in comparison with three known anti-growth phenolics of Terminalia, gallic acid (287), methyl gallate (290), luteolin (206), and tannic acid (169). Results showed that the most growth inhibitory phenolics in T. chebula fruits were chebulinic acid (IC₅₀ = 53.2 µM ±/0.16) > tannic acid (IC₅₀ = 59.0 mg/mL ±/0.19) > ellagic acid (IC₅₀ = 78.5 µM ±/0.24) [111].

Aqueous and ethanolic extracts of T. citrina fruits were revealed to exhibit significant mutagenicity in tested strains of baby hamster kidney cell line (BHK-21). Ethanolic extract showed higher mutagenicity in TA 100 strain, whereas aqueous extract exhibited higher mutagenicity in TA 102 strain than TA 100. Both extracts showed dose-dependent
mutagenicity. Fifty percent cell viability was exhibited by 260 and 545 μg/mL of ethanolic and aqueous extracts respectively [169]. Moreover, ivorenoside A (50) showed antiproliferative activity against MDA-MB-231 and HCT116 human cancer cell lines with IC₅₀ values of 3.96 and 3.43 μM, respectively [131].
4.4 Anti-inflammatory

Inflammation has been considered as a major risk factor for various kinds of human diseases. Macrophages play substantial roles in host defense against infection. It can be activated by LPS, the major component of the outer membrane of Gram-negative bacteria. An investigation was carried out to determine anti-inflammatory potential of ethyl acetate fraction isolated from *T. bellirica* (EFTB) in LPS stimulated RAW 264.7 macrophage cell lines. EFTB (100 μg/mL) inhibited all inflammatory markers in dose dependent manner. Moreover, EFTB down regulated the mRNA expression of TNF-α, IL-6, COX-2 and NF-κB against LPS stimulation. These results demonstrated that EFTB is able to attenuate...
inflammatory response possibly via suppression of ROS and NO species, inhibiting the production of arachidonic acid metabolites, proinflammatory mediators and cytokines release [165].

Anolignan B (242) isolated from roots of T. sericea was tested for anti-inflammatory activity using the cyclooxygenase enzyme assays (COX-1 and COX-2). It showed activity against both COX-1 (IC$_{50}$ = 1.5 mM) and COX-2 (IC$_{50}$ = 7.5 mM) enzymes [151]. Termiarjunosides I (47) and II (48) isolated from stem barks of T. arjuna inhibited aggregation of platelets and suppressed the release of NO and superoxide from macrophages [156].

The anti-inflammatory activities of a polyphenol-rich fraction (TMEF) obtained from T. muelleri was assessed using carrageenan-induced paw edema model by measuring PGE$_2$, TNF-α, IL-1β, and IL-6 plasma levels as well as the paw thickness. The group treated with 400 mg/kg of TMEF showed a greater inhibition in the number of writhes (by 63%) than the standard treated group (61%). TMEF pretreatment reduced the edema thickness by 48, 53, and 62% at the tested doses, respectively. TMEF administration inhibited the carrageenan-induced elevations in PGE$_2$ (by 34, 43, and 47%), TNF-α (18, 28, and 41%), IL-1β (14, 22, and 29%), and IL-6 (26, 31, and 46%) [166].

4.5 Hypoglycemic

Some species and isolates from Terminalia have indicated possession of α-glucosidase inhibitory capabilities. Gallic acid (287) and methyl gallate (290), from stem barks of T. superba, showed significant activity (IC$_{50}$ = 5.2 ± 0.2 and 11.5 ± 0.1 μM), resp.). Arjunic acid (5) and glucinoic acid (46) from stem barks of T. glaucescens showed significant β-glucuronidase inhibitory activity with IC$_{50}$ value 80.1 and 500 μM, resp., against β-glucuronidase [130].

In a study to investigate α-glucosidase inhibition of extracts and isolated compounds from T. macroptera leaves, chebulagic acid (142) showed an IC$_{50}$ value of 0.05 μM towards α-glucosidase and 24.9 ± 0.4 μM towards 15-lipoxynagenase (15-LO), in contrast to positive controls (acarbose: IC$_{50}$ = 201 ± 28 μM towards α-glucosidase, quercetin: IC$_{50}$ = 93 ± 3 μM towards 15-LO). Corilagin (116) and narcissin (231) were good 15-LO and α-glucosidase inhibitors. Rutin (230) was a good α-glucosidase inhibitor (IC$_{50}$ ca. 3 μM), but less active towards 15-LO [136].

From the fruits of T. chebula, 23-O-galloylarjunonic acid (30) and 23-O-galloylarjunonic acid 28-O-β-d-glucosyl ester (31) were afforded and showed potent inhibitory activities with IC$_{50}$ values of 21.7 (30) and 64.2 (31) μM, resp., against Baker’s yeast α-glucosidase, compared to the positive control, acarbose (IC$_{50}$ = 174.0 μM) [146].

Hydrolyzable tannins, 1,2,3,6-tetra-O-galloyl-4-O-cinnamoyl-β-d-glucose (183) and 4-O-(2″,4″-di-O-galloyl-α-L-rhamnosyl) ellagic acid (186) from the fruits of T. chebula, showed significant α-glucosidase inhibitory activities with IC$_{50}$ values of 2.9 and 6.4 μM, resp. In addition, inhibition kinetic studies showed that both compounds have mixed-type inhibitory activities with the inhibition constants (Ki) of 1.9 and 4.0 μM, respectively [159].

4.6 Cardiovascular

A few species of Terminalia have demonstrated cardiovascular activities. It was reported that the barks of T. arjuna possessed significant inotropic and hypotensive effect, mild diuretic, antithrombotic, prostaglandin E2 enhancing and hypolipidemic activities [66].

Ethanol extract of T. pallida fruits (TpFE) were studied to determine their cardioprotection against isoprostene (ISO)-administered rats. The supplementation of TpFE dose-dependently exerts notable protection on myocardium by virtue of its strong antioxidant activity. It could be used as a medicinal food for the treatment of cardiovascular ailments [163].

4.7 Mosquitocidal

Insect-borne diseases remain to this day a major source of illness and can cause death worldwide. The resistance to chemical insecticides among mosquito species has been a major problem in vector control. The larvicidal and ovicidal activities of crude benzene, hexane, ethyl acetate, chloroform and methanol extracts of T. chebula were tested for their toxicity against three important vector mosquitoes, viz., Anopheles stephensi, Aedes aegypti and Culex quinquefasciatus. All extracts showed moderate larvicidal effects, the highest larval mortality was found in the methanol extract of T. chebula against the larvae of A. stephensi, A. aegypti, and C. quinquefasciatus with the LC$_{50}$ values of 87.13, 93.24 and 111.98 ppm, respectively. Mean percent hatchability of the ovicidal activity was observed 48 h post treatment. All the five solvent extracts showed moderate ovicidal activity. The maximum egg mortality (zero hatchability) was observed in the methanol extract of T. chebula at 200 and 250 ppm against A. stephensi, while A. aegypti and C. quinquefasciatus showed 100% mortality at 300 ppm. No mortality was observed in the control group. The finding of the investigation revealed that the leaf extract of T. chebula possesses remarkable larvicidal and ovicidal activity against medically important vector mosquitoes [167, 168].

4.8 Antiviral

Termilignan (241) and anolignan B (242), obtained from T. bellirica exhibited antimalarial activity against the
In vitro anti-HIV-1 activity of acetone and methanol extracts of *T. paniculata* fruits was studied by Durge A. et al. Cytotoxicity tests were conducted on TZM-bl cells and PBMCs, the CC₅₀ values of both extracts were ≥ 260 μg/mL. By using TZM-bl cells, the extracts were tested for their ability to inhibit replication of two primary isolates HIV-1 (X4, Subtype D) and HIV-1 (R5, Subtype C). The activity against HIV-1 primary isolate (R5, Subtype C) was confirmed by using activated PBMC and quantification of HIV-1 p24 antigen. Both the extracts showed anti-HIV-1 activity in a dose-dependent manner. The EC₅₀ values of the acetone and methanol extracts of *T. paniculata* were ≤ 10.3 μg/mL. Furthermore, the enzymatic assays were performed to determine the mechanism of action which indicated that the anti-HIV-1 activity might be due to inhibition of reverse transcriptase (≥ 77.7% inhibition) and protease (≥ 69.9% inhibition) enzymes [172].

Kesharwani A. et al. investigated anti-HSV-2 activity of *T. chebula* extract and its constituents, chebulagic acid (142) and chebulinic acid (143). Cytotoxicity assay using Vero cells revealed CC₅₀ = 409.71 ± 47.70 μg/mL for the extract whereas 142 and 143 showed more than 95% cell viability up to 200 μg/mL. The extract from *T. chebula* (IC₅₀ = 0.01 ± 0.0002 μg/mL), chebulagic (IC₅₀ = 1.41 ± 0.51 μg/mL) and chebulinic acids (IC₅₀ = 0.06 ± 0.002 μg/mL) showed dose dependent in vitro anti-viral activity against HSV-2, which can also effectively prevent the attachment and penetration of the HSV-2 to Vero cells. In comparison, acyclovir showed poor direct anti-viral activity and failed to significantly (p > 0.05) prevent the attachment as well as penetration of HSV-2 to Vero cells when tested up to 50 μg/mL. Besides, in post-infection plaque reduction assay, *T. chebula* extract, chebulagic and chebulinic acids showed IC₅₀ values of 50.06 ± 6.12, 31.84 ± 2.64, and 8.69 ± 2.09 μg/mL, resp., which were much lower than acyclovir (71.80 ± 19.95 μg/mL) [173].

### 4.9 Others

*Terminalia* species were also reported to be used in the treatment of diarrhea [95], Alzheimer’s disease [112], psoriasis [164], liver disease [170], kidney disease [171], etc. Terminalosides A–K (249–259) from the leaves of the Bangladeshi medicinal plant *T. citrina* possess estrogen-inhibitory properties. Among them, Terminaloside E (253) showed inhibitory activity against the T47D cell line, such terminalosides C (252), F (255), and I (258). Besides, 6-epiterminaloside K (262) displayed antiestrogenic activity against MCF-7 cells [22].

### 5 Conclusion and Future Prospects

The genus *Terminalia* contains not only a large number of tannins, simple phenolics, but also a lot of terpenoids, flavonoids, lignans and other compounds. Most tannins, simple phenolics and flavonoids have antioxidation, antibacterial, antiinflammatory and anticancer activities. The plants of the genus *Terminalia* have exhibited positive effect on immune regulation, cardiovascular disease and diabetes, and can accelerate wound healing [157]. Therefore, the *Terminalia* genus has great medicinal potential. However, most of the chemical composition of species is still unknown, we should use modern advanced technology such as LC–MS to continue to isolate its compounds, and determine their pharmacological activities and mechanism of action, to explore other possible greater medicinal value.

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**Conflict of interest** All authors declare no conflict of interest.

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