



# A review on phytochemical constituents, analytical data, and pharmacological properties of the genus *Plumeria*

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## Abstract

The genus *Plumeria* of the *Apocynaceae* family has a rich history of traditional medicines supported by empirical evidences. This review consolidates diverse biological attributes, phytochemical compositions, physical properties (melting point, shape, optical rotation, etc.), and analytical data (UV, IR, Mass spectroscopic data, elemental analysis) of various species of *Plumeria*. The review covered the chemistry of wide range of natural compounds like iridoids, triterpenoids, alkaloids, flavonoids, steroids, cardiac glycosides, quinones, anthocyanins, cardenolides, fatty acid esters, lignans, coumarins, etc. found in various species of the genus *Plumeria*. Analytical techniques including chromatography, IR, UV, and mass spectroscopy have significantly contributed to elucidating the complex chemical profiles of extracts of various species of *Plumeria* which are systematically presented in a tabular format. The review also defines the historical background, geographical distribution, and traditional uses of various species of the genus *Plumeria*. The review also includes the mechanisms of action and biotransformation of compounds, providing a deeper understanding of their therapeutic potential. The comprehensive review reveals the significance of the natural products isolated from a number of species of genus *Plumeria*. It is also suggestive that there is an extensive scope for further investigation to explore new therapeutic components of the genus *Plumeria*.

**Keywords** Apocynaceae family · *Plumeria* · Triterpenoids · Iridoids · Phytochemicals · Biological activity · Analytical data · Mechanism of action · Biotransformation

## Introduction

The *Apocynaceae* family is extensively spread in tropical and subtropical areas; however, it does not grow well there because of the high temperature [1]. This family's genera, including *Alstonia*, *Adenium*, *Nerium*, *Alyxia*, *Plumeria* (*P.*), and *Vinca*, have a long history of use as traditional remedies supported by empirical research. *Adenium* was typically employed as a skin treatment to cure lice because of its poisonous milk latex. *Alstonia* was traditionally used for respiratory disease [2], whereas *alyxia* was used for postnatal care [3]. *Nerium* tried to treat cancer [4], and for patients with diabetes, *Vinca* was used [5]. According to

scientific research, certain herbs have pharmacological effects, including acting as an antioxidant for adenium.

Conversely, *Alstonia* is an herbal antiviral. While *Nerium* and *Vinca* are poisonous herbals utilized as CNS depressants [6] and antitumors [7], respectively, *Alyxia* is well-known for its antifungal properties [8]. To be more specific, *Plumeria* is one of the *Apocynaceae* plants that merits exploration for its variety and potential medical applications. Numerous studies have been done on frangipani latex, which contains alkaloid and sterol components that are pharmacologically effective as purgatives, hypotensive, and antitumors [9]. Compared to the abundance of sterol compounds like lupeol, taraxerol, and betulin, which have been shown to have anti-inflammatory [10], anticancer, and hypolipidemic properties. Plumerinine, an alkaloid, has been explored as an antianaphylaxis [11] agent.

Most tiny genus *Plumeria* species are deciduous shrubs and lactiferous trees. Although endemic to the Caribbean, South America, Mexico, and warm tropical regions of the Pacific Islands, *Plumeria* (*Apocynaceae*) originated in Central America. Various species may be found extensively spread over the world's warmer areas. *P. rubra*, *P. dichotoma*, and

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*P. bicolor* are ornamental plants in India [12]. *Plumeria* is between thirty and forty feet tall. It has a scent unlike any other plant, and the various colored species have a distinct aroma. Certain *Plumeria* species smell pleasant, while others have lemony, jasmine, or peach scents [11]. Long, meaty, leathery leaves grow in clusters close to the apex of the branches. Since leaves are susceptible to cold, they often fall in early winter. *Plumeria acuminata*, *P. rubra*, *P. cubensis*, *P. alba*, *P. bahamiensis*, *P. acutifolia*, *P. bicolor*, *P. bracteata*, *P. lancifolia*, *P. jamaicensis*, *P. stenopetale*, *P. montana*, *P. obtuse*, *P. obtusifolia*, *P. pudica*, *P. stenophylla*, and *P. tuberculata* are among the genus that includes these species. There are as many *Plumeria* species as stated above, but *P. acuminata*, *P. acutifolia*, *P. alba*, *P. bicolor*, *P. dichotoma*, *P. lancifolia*, *P. obtuse*, *P. obtusifolia*, *P. rubra*, *P. multiflora*, and *P. serifolia* are the primary species covered in this study [11, 13].

A few review articles provide comprehensive information on the phytochemicals of the genus *Plumeria*. With this and the emerging potential applications of *Plumeria* species, this review presents an overview of their distribution, structure, biological activity, and analytical studies. The information is compiled and entered in a tabular format (Table 1). Furthermore, mechanisms of action and biotransformation of compounds and the potential pharmaceutical applications of compounds isolated from *Plumeria* species and their prospects were also discussed.

## Brief description of the *Plumeria* species

Numerous hybrids and varieties of the *Plumeria* species, which vary widely in many traits, have emerged over time. So, while one author can count over sixty species, another might only count seven or eight, claiming the others are just hybrids and varieties [12].

Each kind of *Plumeria* has alternate leaves that vary in size, form, and development patterns. While *P. pudica* has elongated, glossy, dark green leaves, *P. alba* has relatively thin, corrugated leaves. *P. pudica* has evergreen and non-deciduous leaves. In the winter, *P. obtuse* keeps its leaves and blossoms. Flowers on plants can be between two and four inches across and come in white, yellow, pink, or red hues. One of the effective methods for this genus's multiplication is tissue culture, which can be done with aseptically germinated seeds or cuttings of recently extended stems. Pruning is best done on deciduous kinds during the wintertime or when cuttings are needed.

## Geographical distribution

Trees and shrubs in the genus *Plumeria* are native to New Zealand, Mexico, Central America, the Caribbean, and

South America, extending as far south as Brazil. *P. bracteata* originated in the Brazilian state of Bahia. *P. Alba* is a native of the Caribbean and Central America. It is now standard and naturalized across southern and southeast Asia. *P. obtuse* is native to the Greater Antilles, northern Central America, and southern Mexico. It is typically grown in tropical areas like Hawaii, Asia, and eastern Africa. *P. pudica* is indigenous to Colombia, Panama, and Venezuela. *P. alba* is cultivated extensively in tropical and subtropical climates across the globe. It is mainly used as a plant in gardens and parks, and in many parts of India, there are also temples and cemeteries [13].

## Historical background

French botanist Charles Plumier first used the name *Plumeria* in the 17th century. However, Plumier was one of many to call the plant *Plumeria*. The name was first given in 1522 by a Spanish priest, Francisco de Mendoza. The flowers were given the name frangipani when first found because the natural aroma of the *Plumeria* blossoms made people think of perfumed gloves. Since then, species of *Plumeria* have been widely used for both medicinal and decorative purposes all over the world. However, the extraction, isolation, structure elucidation, and establishment of the therapeutic activity of chemical elements of plants of the *Plumeria* species have been the subject of extensive investigation since the early 19th century. When Peckolt reported isolating the primary iridoid glycoside plumieride from the stem bark of *P. lancifolia* and *P. rubra*, phytochemical research on the genus *Plumeria* began [14].

## Traditional uses

Asthma is managed by an extract from the leaves [15]. According to reports, extracts of various *Plumeria* species contain antifungal, antibacterial, and antiviral qualities that are used topically. Decoction of leaves is used as a purgative, anthelmintic, emmenagogue, and in several other applications [16–18]. Infusions of the roots and bark of *Plumeria* are used to calm agitation, ease constipation, induce menstruation, lower fever, and cure asthma [19, 20]. Gonorrhoea is treated with crushed bark applied topically to complex tumors. Scabies are cured in Fiji using a decoction prepared from scraped bark. The leaves have rubefacient, antimicrobial, antipyretic, stimulant, and swelling properties. They treat various skin conditions [21], including ulcers, leprosy, inflammatory conditions, rheumatism, pneumonia, cholera, cough, and cold. Mexicans have used floral infusions as a traditional treatment for diabetes mellitus [22, 23]. Ruiz-Teran et al. [24] state that latex and flowers are used to treat eye hygiene, vaginal bleeding, and toothaches [24]. Fruit pulp, stem bark, and latex have all

**Table 1** Phytoconstituents isolated from various parts of *Plumeria*, class of compounds, biological activities, solvents used for extraction and analytical data

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
1.	<i>P. rubra</i> <i>P. acutifolia</i>	(B.)	Fulvoplumerin	Antibacterial, Anticancer, Cytotoxic	Petroleum ether		[130]
2.	<i>P. rubra</i> <i>P. obtuse</i>	(B. A.P.)	15-demethyl-plumeride		Chloroform/ Methanol	White cubic crystals, mp 230–232 °C, $[\infty]_D^{25}$ – 120.0° (c = 0.1, H <sub>2</sub> O). <b>UV</b> $\lambda_{max}$ nm (log $\epsilon$ ) (CH <sub>3</sub> OH) 219 nm (3.5). <b>IR</b> $\nu_{max}$ (KBr) 3435–3545 (broad), 1769, 1689, 1117, 1708, 1039, 1006 cm <sup>-1</sup> . <b>FAB-MS</b> (glycerol) m/z: [M + H] <sup>+</sup> 457, calcd for C <sub>20</sub> H <sub>25</sub> O <sub>12</sub> , 457.1346.	[130]
3.	<i>P. rubra</i>	(B.)	$\alpha$ - allamcidin		Chloroform	Prism crystal, mp 180 °C, $[\infty]_D^{25}$ + 36° (c = 0.1, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{max}$ max (log $\epsilon$ ) (CH <sub>3</sub> OH) 211(4.25). <b>IR</b> $\nu_{max}$ (KBr) 3400, 1756, 1731, 1231, 1125, 1120, 1023, 877 cm <sup>-1</sup> . <b>FAB-MS</b> (glycerol) m/z: [M] <sup>+</sup> 310(4%), 292(5), 279(8), 246(40), 233 (35), 187 (70), 160(100), 98(18).	[130]
4.	<i>P. rubra</i>	(B.)	$\beta$ - allamcidin		Chloroform	Prism crystal, mp 180 °C, $[\infty]_D^{25}$ + 36° (c = 0.1, CH <sub>3</sub> OH) <b>UV</b> $\lambda_{max}$ max (log $\epsilon$ ) (CH <sub>3</sub> OH) 211 nm (4.25). <b>IR</b> $\nu_{max}$ (KBr) 3400, 1756, 1731, 1231, 1125, 1120, 1023, 877 cm <sup>-1</sup> . <b>FAB-MS</b> (glycerol) m/z: [M] <sup>+</sup> 310(4%), 292(5), 279(8), 246(40), 233 (35), 187 (70), 160(100), 98(18).	[130]
5.	<i>P. rubra</i>	(B.)	Allamcin	Anticancer	Petroleum ether or Chloroform	Needles, mp 198–210 °C, $[\infty]_D^{25}$ + 65.6° (c = 0.50, pyridine). <b>UV</b> $\lambda_{max}$ max (log $\epsilon$ ) (CH <sub>3</sub> OH) 214 (22700). <b>IR</b> $\nu_{max}$ (CHCl <sub>3</sub> ) 3340, 1760, 1730, 1680 cm <sup>-1</sup> . <b>Elemental analysis:</b> Anal. Calcd for C <sub>13</sub> H <sub>14</sub> O <sub>5</sub> : C, 62.39. H, 5.64. M, 250.0837. Found: C, 62.56. H, 5.84. M, 250.0842. <b>FAB-MS</b> m/z: [M] <sup>+</sup> 250, 232, 211, 153, 136, 98.	[130]
6.	<i>P. rubra</i>	(B.)	$\alpha$ -allamcidin diacetate		Chloroform	<b>FAB-MS</b> (glycerol) m/z: [M] <sup>+</sup> 310(4%), 292(5), 279(8), 246(40), 233 (35), 187 (70), 160(100), 98(18).	
7.	<i>P. rubra</i>	(B.)	$\beta$ -allamcidin diacetate		Chloroform		[130]
8.	<i>P. multiflora</i> <i>P. rubra</i> <i>P. acutifolia</i> <i>P. bicolor</i>	(R.B. Le. St.B.)	Plumericin	Algicidal, Antimicrobial, Antiparasitic, Antifungal, Cytotoxic	Methanol	A soild, mp 211.5–212.5 °C, $[\infty]_D^{25}$ + 197.5° (c = 0.982, CHCl <sub>3</sub> ). <b>UV</b> $\lambda_{max}$ nm (log $\epsilon$ ): 214 (4.24). <b>FAB-MS</b> m/z: 290.0790 (Calcd for C <sub>15</sub> H <sub>14</sub> O <sub>6</sub> ). <b>IR</b> $\nu_{max}$ (KBr): 1757, 1751, 1705, 1715, 1655, 1622 cm <sup>-1</sup> .	[39]
9.	<i>P. rubra</i> <i>P. dichotoma</i>	(R.B. St. B.)	Isoplumericin,	Algicidal, Antifungal, Cytotoxic	Methanol	White crystals, mp 196–198 °C $[\infty]_D^{25}$ + 216.4° (c = 1.01, CHCl <sub>3</sub> ). <b>UV</b> $\lambda_{max}$ nm (log $\epsilon$ ): 214–215 (4.24) (199). <b>IR</b> $\nu_{max}$ (KBr): 1761, 1701, 1640, 1664, 1590 cm <sup>-1</sup> . <b>HRMS</b> m/z (rel. int): Anal. Calcd for C <sub>15</sub> H <sub>14</sub> O <sub>6</sub> 290 (M <sup>+</sup> ), 291 (M <sup>+</sup> H).	[39]
10.	<i>P. rubra</i>	(R.B.)	$\beta$ -Dihydroplumericin		Methanol	A soild, mp 191–192 °C, $[\infty]_D^{25}$ + 208.9° (c = 0.892, CHCl <sub>3</sub> ).	[245]
11.	<i>P. acutifolia</i>	(R.)	8-Isoplumeride		Methanol	A soild, mp 168–173 °C, $[\infty]_D^{25}$ – 164.8° (c = 0.75, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{max}$ nm (log $\epsilon$ ): 210 (4.20), 230 (sh). <b>FAB-MS</b> m/z: 493.133 (Calcd for C <sub>21</sub> H <sub>26</sub> O <sub>12</sub> + Na: 493.132).	[136]
12.	<i>P. acutifolia</i>	(R.)	13-O-caffeoylplumeride (deglucosyl protoplumericin B)		Methanol	A soild, $[\infty]_D^{25}$ – 60.0° (c = 1.00, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{max}$ nm (log $\epsilon$ ): 205 (4.50), 220 (4.44), 300 (sh) (3.96), 323 (4.05). <b>FAB-MS</b> m/z: 655.162 (Calcd for C <sub>30</sub> H <sub>32</sub> O <sub>15</sub> + Na: 655.164), 537, 237, 163.	[137]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
13.	<i>P. acutifolia</i>	(R.)	13-deoxyplumeride (allamdin $\beta$ -D-glucoside)		Methanol	A crystalline powder, mp 129–131 °C [ $\infty$ ] <sub>D</sub> <sup>25</sup> – 113.6° (c = 1.50, CH <sub>3</sub> OH). UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 213 (4.27), 238 (sh), (4.06) FAB-MS m/z: 477.138 (Calcd for C <sub>21</sub> H <sub>26</sub> O <sub>11</sub> + Na: 476.137), 293, 275.	[137]
14.	<i>P. acutifolia</i>	(R.)	$\beta$ -dihydro-plumericinic acid glucosyl ester (plumenoside)		Methanol	A solid, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 117.3° (c = 1.54, CH <sub>3</sub> OH). UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 238 (4.10) FAB-MS m/z: 463.122 (Calcd for C <sub>20</sub> H <sub>24</sub> O <sub>11</sub> + Na: 463.122).	[137]
15.	<i>P. acutifolia</i> <i>P. alba</i> <i>P. rubra</i> <i>P. obtusifolia</i> <i>P. obtuse</i> <i>P. dichotoma</i> <i>P. bicolor</i>	(Le., St. B., RB., HW., St., R., Fl.)	1 $\alpha$ -plumeride,	Antimicrobial, anticancer, treatment of hyperproliferative tissue	Methanol	A solid, [ $\infty$ ] <sub>D</sub> <sup>25</sup> – 46.4° (c = 1.30, CH <sub>3</sub> OH). UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 205 (4.26) FAB-MS m/z: 493.136 (Calcd for C <sub>21</sub> H <sub>26</sub> O <sub>12</sub> + Na: 493.132).	[137]
16.	<i>P. acutifolia</i>	(R.)	1 $\alpha$ -Protoplumericin A (13-O- <i>p</i> -O-glucosylCoumaroyl plumeride),	Antialgal	Methanol	A Solid, [ $\infty$ ] <sub>D</sub> <sup>26</sup> – 44.1° (c = 1.00, CH <sub>3</sub> OH) UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 205 (4.53), 220 (4.45), 295 (4.03), 305 (4.03). FAB-MS m/z: 801 (C <sub>36</sub> H <sub>42</sub> O <sub>19</sub> : 794), 585, 273.	[137]
17.	<i>P. acutifolia</i>	(R. Le.)	Protoplumericin B (13-O- <i>p</i> -O-glucosyl-Caffeoyl plumeride)		Methanol	Solid, [ $\infty$ ] <sub>D</sub> <sup>16</sup> – 61.2° (c = 1.41, CH <sub>3</sub> OH). UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 206 (33500), 230 (22000), 288 (13500), 320 (11800). FD-MS m/z: 817 [M <sup>+</sup> ] + Na, C <sub>36</sub> H <sub>42</sub> O <sub>20</sub> : (794).	[137]
18.	<i>P. acutifolia</i>	(Fl.)	1 $\alpha$ -Protoplumericin-B	Anticancer	Methanol	White powder, mp 201–203 °C, [ $\infty$ ] <sub>D</sub> <sup>21</sup> – 46.2° (c = 0.202, CH <sub>3</sub> OH). IR $\nu_{\text{max}}$ (KBr): 3410, 2982, 2917, 1752, 1697, 1638, 1604, 1510, 1409, 1337, 1243, 1162, 1074, 1039, 1015, 949, 893, 860 cm <sup>-1</sup> . HREIMS m/z: 763.2095 [M – H] <sup>-</sup> (calcd for C <sub>35</sub> H <sub>39</sub> O <sub>19</sub> , 763.2094).	[136]
19.	<i>P. acutifolia</i>	(Fl.)	1 $\alpha$ -Protoplumericin-C	Anticancer	Methanol	White powder, mp 205–206 °C, [ $\infty$ ] <sub>D</sub> <sup>21</sup> – 94.1° (c = 0.202, CH <sub>3</sub> OH). IR $\nu_{\text{max}}$ (KBr): 3411, 2983, 2916, 1752, 1697, 1635, 1603, 1581, 1511, 1423, 1399, 1310, 1243, 1203, 1176, 1074, 1038, 1015, 945, 891, 869 cm <sup>-1</sup> . HREIMS m/z: 763.2090 [M – H] <sup>-</sup> (calcd for C <sub>35</sub> H <sub>39</sub> O <sub>19</sub> , 763.2094).	[136]
20.	<i>P. acutifolia</i>	(Fl.)	13-O-caffeoyl-15-demethyl-plumeride	Anticancer	Methanol	White powder, mp 215–216 °C, [ $\infty$ ] <sub>D</sub> <sup>21</sup> – 38.1° (c = 0.013, CHCl <sub>3</sub> ). IR $\nu_{\text{max}}$ (KBr): 3403, 2983, 2916, 1751, 1696, 1636, 1588, 1509, 1441, 1343, 1307, 1267, 1180, 1161, 1072, 1037, 1015, 986, 946, 891, 864 cm <sup>-1</sup> . HREIMS m/z: 779.2031 [M – H] <sup>-</sup> (calcd for C <sub>35</sub> H <sub>39</sub> O <sub>20</sub> , 779.2094).	[136]
21.	<i>P. acutifolia</i>	(Fl.)	15-demethyl-plumeride- <i>p</i> -E-coumarate	Anticancer	Methanol	White powder, mp 196–197 °C, [ $\infty$ ] <sub>D</sub> <sup>21</sup> – 89.7° (c = 0.039, CH <sub>3</sub> OH). IR $\nu_{\text{max}}$ (KBr): 3411, 2984, 2933, 2691, 1750, 1692, 1633, 1604, 1588, 1515, 1444, 1368, 1340, 1307, 1262, 1204, 1169, 1072, 1035, 1015, 984, 944, 890, 868 cm <sup>-1</sup> . HREIMS m/z: 601.1550 [M – H] <sup>-</sup> (calcd for C <sub>29</sub> H <sub>29</sub> O <sub>14</sub> , 601.1636).	[136]
22.	<i>P. acutifolia</i> <i>P. rubra</i> <i>P. obtuse</i> <i>P. bicolor</i> <i>P. alba</i> <i>P. lancifolia</i>	(Le. St. B. Fr. R.)	Agoniadin (Plumeride)	Antimicrobial, anticancer, treatment of hyperproliferative tissue, Antialgal	Methanol	A solid, mp 168–173 °C, [ $\infty$ ] <sub>D</sub> <sup>25</sup> – 164.8° (c = 0.75, CH <sub>3</sub> OH). UV $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 210 (4.20), 230 (sh). FAB-MS m/z: 493.133 (Calcd for C <sub>21</sub> H <sub>26</sub> O <sub>12</sub> + Na: 493.132).	[135]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
23.	<i>P. rubra</i> <i>P. bicolor</i> <i>P. tricolor</i> <i>P. lutea</i> <i>P. alba</i> <i>P. obtuse</i>	(R. St. Le. Fl.B.)	Plumieride <i>p</i> -( <i>E</i> )-coumarate	Algicidal, Antibacterial	Methanol		[171]
24.	<i>P. rubra</i>	(A.P.)	<i>P. rubradoid</i> (Plumieridine-1- <i>O</i> - $\beta$ -D-galactopyranoside)		Methanol	White amorphous powder, $[\infty]_D^{25} - 64.6^\circ$ (c = 0.11, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 218 (4.01). <b>IR</b> $\nu_{\max}$ (KBr): 3440, 3005, 1755, 1603, 1094 cm <sup>-1</sup> . <b>HRFABMS</b> m/z: 471.1515 (M + H) <sup>+</sup> , calcd. for C <sub>21</sub> H <sub>27</sub> O <sub>12</sub> , 471.1502.	[246]
25.	<i>P. obtuse</i>	(Le.)	6''- <i>O</i> -Acetyl-Plumieride- <i>p</i> -( <i>E</i> )-Coumarate	Algicidal, Antibacterial	Methanol	Prismatic rods, mp 202–203 °C, $[\infty]_D^{25} - 56^\circ$ (c = 0.0132, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 193 (4038.8), 207 (7590.2), 284.8 (4932.2). <b>IR</b> $\nu_{\max}$ (KBr): 3500 br. (O.H.), 1750–1670 ( $\alpha$ and $\beta$ unsaturated $\gamma$ -lactone and esters), and 1640–1560 (aromatic ring/olefinic C = C). <b>FAB-MS</b> m/z: 657 [M + H] <sup>+</sup>	[171]
26.	<i>P. obtuse</i>	(Le.)	6''- <i>O</i> -Acetyl-plumieride ( <i>Z</i> )- <i>p</i> -coumarate	Algicidal, Antibacterial	Methanol	Rods, mp 196–197 °C, $[\infty]_D^{25} - 56^\circ$ (c = 0.0132, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 193 (3938), 207 (7390.8), 311 (4668.2). <b>IR</b> $\nu_{\max}$ (CHCl <sub>3</sub> ): 3450 br. (O.H.), 1750–1670 ( $\alpha$ and $\beta$ unsaturated $\gamma$ -lactone and esters), and 1640–1560 (aromatic ring/olefinic C = C). <b>FAB-MS</b> m/z: 657 [M + H] <sup>+</sup>	[171]
27.	<i>P. rubra</i>	(St. B.)	Plumeridoids A	Antifungal, Antialgal	Methanol	White crystals, mp 186 °C $[\infty]_D^{24} + 256^\circ$ (c = 0.027, CH <sub>2</sub> Cl <sub>2</sub> ). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 237 (3.62). <b>IR</b> $\nu_{\max}$ (KBr): 3439, 2983, 2645, 2564, 1775 (acid C = O), 1677, 1645, 1623, 1433, 1313, 1193, 1085, 927, 791 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel. int.): 278 [M-H <sub>2</sub> O] <sup>+</sup> (82), 260 [M-2H <sub>2</sub> O] <sup>+</sup> (64), 249 (76), 232 (90), 203 (48), 179 (78), 172 (65), 164 (100), 147 (59), 119 (44), 91 (59), 87 (51). <b>HRMS</b> (E.I., 70 eV, C <sub>14</sub> H <sub>16</sub> O <sub>7</sub> ): calcd. 296.0896, found 296.0901.	[131]
28.	<i>P. rubra</i>	(St. B.)	Plumeridoids B	Antibacterial, Antifungal, Antialgal	Methanol	Colorless crystals, mp 144–145 °C $[\infty]_D^{24} + 125^\circ$ (c = 0.08, CH <sub>2</sub> Cl <sub>2</sub> ). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 237 (4.01). <b>IR</b> $\nu_{\max}$ (KBr): 3437, 2939, 1775, 1699, 1645, 1444, 1297, 1193, 1090, 1025, 775 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel. int.): 292 [M-H <sub>2</sub> O] <sup>+</sup> (92), 263 (87), 232 (100), 231 (70), 193 (80), 139 (86). <b>HRMS</b> (E.I., 70 eV, C <sub>15</sub> H <sub>18</sub> O <sub>7</sub> ): calcd. 310.1053, found 310.1058.	[131]
29.	<i>P. rubra</i>	(St. B.)	Plumeridoids C		Methanol	A prisMS crystal, mp 189–192 °C $[\infty]_D^{24} + 71.4^\circ$ (c = 0.07, CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 220 (3.85). <b>IR</b> $\nu_{\max}$ (KBr): 3331, 3184, 2890, 1775, 1732, 1645, 1378, 1324, 1090, 998, 786 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel. int.): 310 (100), 267 (33), 255 (58), 205 (82), 149 (96), 91 (49). <b>HRMS</b> (E.I., 70 eV, C <sub>15</sub> H <sub>18</sub> O <sub>7</sub> ): calcd. 310.1053, found 310.1052.	[131]
30.	<i>P. rubra</i>	(St. B.)	Epiplumeridoids C		Methanol	A prisMS crystal, mp 196 °C $[\infty]_D^{24} + 105^\circ$ (c = 0.014, CH <sub>2</sub> Cl <sub>2</sub> /CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 228 (3.90). <b>IR</b> $\nu_{\max}$ (KBr): 3333, 3191, 2897, 1770, 1733, 1655, 1290, 1324, 1190, 990, 790 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel. int.): 310 (100), 267 (33), 255 (58), 205 (82), 149 (96), 91 (49). <b>HRMS</b> (E.I., 70 eV, C <sub>15</sub> H <sub>18</sub> O <sub>7</sub> ): calcd. 310.1053, found 310.1052.	[131]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
31.	<i>P. rubra</i>	(St. B.)	Allamcin (Descarbomethoxy allamandin),	Antibacterial, Antifungal, Antialgal	Methanol	Needles, mp 198–210 °C [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 65.6° (c = 0.50, pyridine). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 214 (22700). IR $\nu_{\max}$ (CHCl <sub>3</sub> ): 3340, 1760, 1730, 1680 cm <sup>-1</sup> . Anal. Calcd for C <sub>13</sub> H <sub>14</sub> O <sub>5</sub> : C, 62.39. H, 5.64. M <sub>r</sub> , 250.0837. Found: C, 62.56. H, 5.84. M <sub>r</sub> , 250.0842. MS m/z (rel. int.): 250 (M <sup>+</sup> ), 232, 211, 153, 136, 98.	[131]
32.	<i>P. rubra</i>	(St. B.)	Allamandin,	Antibacterial, Antileukemic, Cytotoxic	Methanol	Thin plates, mp 217–223 °C [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 15° (c = 0.06, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 220 (3.85). IR $\nu_{\max}$ (CHCl <sub>3</sub> ): 3360, 1735, 1680 cm <sup>-1</sup> . Elemental analysis: Anal. Calcd for C <sub>15</sub> H <sub>16</sub> O <sub>7</sub> : C, 58.44. H, 5.23. Found: C, 58.17. H, 5.11. MS. (m/e): 308 (M <sup>+</sup> ), 290, 277, 262, 258, 230, 211, 179, 161, and 151. HRMS m/z (rel. int): Anal. Calcd for C <sub>15</sub> H <sub>16</sub> O <sub>7</sub> : 308.0891, found 308.0892.	[131]
33.	<i>P. obtuse</i>	(A.P.)	<i>P. obtusedoid</i> A		Methanol	White amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 31.7° (c = 0.01, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 211 IR $\nu_{\max}$ (KBr): 3321, 3231 – 2624, 1755, 1719, 1605, 1110 cm <sup>-1</sup> . EI-MS m/z: 280 (8), 262 (12), 262 (12), 214 (34), 185 (45), 115 (15), 91 (19), 44 (100). HR-EI-MS (m/z): 280.0938 [M] <sup>+</sup> (calcd for C <sub>14</sub> H <sub>16</sub> O <sub>6</sub> , 280.0946).	[247]
34.	<i>P. obtuse</i>	(A.P.)	<i>P. obtusedoid</i> B		Methanol	White amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 62.3° (c = 0.012, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 211 IR $\nu_{\max}$ (KBr): 3440, 3005, 1755, 1603, 1094 cm <sup>-1</sup> . EI-MS m/z: 264 (4), 235 (65), 217 (21), 188 (29), 160 (100), 137 (55), 119 (65), 109 (75), 91 (90). HR-EI-MS (m/z): 264.0990 [M] <sup>+</sup> (calcd for C <sub>14</sub> H <sub>16</sub> O <sub>5</sub> , 264.0997).	[247]
35.	<i>P. obtuse</i> , <i>P. acutifolia</i>	(A.P. Fl.)	Plumieridin A		Methanol / Ethanol	Amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>23</sup> + 46° (c = 0.12, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 211 IR $\nu_{\max}$ (KBr): 3384, 1756, 1640, 1153, 1045 cm <sup>-1</sup> . ESI-MS m/z: 274.6 ([M+Na] <sup>+</sup> ). HR-ESI-MS (m/z): 275.0890 ([M+Na] <sup>+</sup> ), C <sub>13</sub> H <sub>16</sub> O <sub>5</sub> Na <sup>+</sup> , calcd 275.0895).	[248]
36.	<i>P. obtuse</i> , <i>P. acutifolia</i>	(A.P. Fl.)	Plumieridin B		Methanol / Ethanol	Amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>23</sup> + 44° (c = 0.12, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 211 IR $\nu_{\max}$ (KBr): 3380, 1755, 1640, 1154, 1044 cm <sup>-1</sup> . ESI-MS m/z: 274.6 ([M+Na] <sup>+</sup> ). HR-ESI-MS (m/z): 275.0891 ([M+Na] <sup>+</sup> ), C <sub>13</sub> H <sub>16</sub> O <sub>5</sub> Na <sup>+</sup> , calcd 275.0895).	[248]
37.	<i>P. obtuse</i>	(A.P.)	Plumieridine		Methanol	Crystals, mp 161–163 °C, [ $\infty$ ] <sub>D</sub> <sup>29</sup> – 57.4° (c = 0.406, C <sub>2</sub> H <sub>5</sub> OAc). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 245 (2.36, sh). IR $\nu_{\max}$ (KBr): 3490, 3300, 3096, 3082, 1745, 1703, 1625, 1152, 1109, 1098, 1040, 895, 805, 760 cm <sup>-1</sup> .	[249]
38.	<i>P. acutifolia</i>	(St. B.)	Gaertneroside		Methanol	Pale yellow solid, mp 150 ± 1 °C, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 43.1° (c = 0.75, CH <sub>3</sub> OH). IR $\nu_{\max}$ (KBr): 3510, 3120, 2960, 2872, 1735, 1695 cm <sup>-1</sup> . FAB-MS (m/z): 549 [M <sup>+</sup> + H], 369, 351, 307, 289, 154, 136, 128, 107.	[250]
39.	<i>P. rubra</i>	(RB.)	$\beta$ -dihydro plumericinic acid		Methanol	C <sub>14</sub> H <sub>14</sub> O <sub>6</sub> (278.25), mp 189–190 °C Elemental analysis: found, % (C) 60.74. (H) 5.07. CH <sub>3</sub> (C) 5.40%. Calculated, %: (C) 60.50. (H) 4.90. CH <sub>3</sub> (C) 5.50%. IR $\nu_{\max}$ (KBr): 1780, 1680, 1648, 1630 (199) cm <sup>-1</sup> .	[39]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
<b>Iridoids</b>							
40.	<i>P. acutifolia</i>	(St. B.)	Sweroside		Methanol	Amorphous powder, mp 168 ± 1 °C, $[\infty]_D^{20}$ -237° (c = 0.020, CH <sub>3</sub> OH). UV $\lambda_{max}$ nm (log $\epsilon$ ): 244. IR $\nu_{max}$ (KBr): 3386 (OH), 1698 (C=O).cm <sup>-1</sup> . CI-MS m/z: 448, 301, 285, 251, 235, 146 ESI-MS (m/z): 449.1 [M + H] <sup>+</sup>	[251]
41.	<i>P. bicolor</i>	(St. B.)	Plumieride-4'-O-glucoside				
42.	<i>P. dichotoma</i>	(St. B.)	3'-O-methyl-plumieride				
43.	<i>P. rubra</i> <i>P. bicolor</i> <i>P. tricolor</i> <i>P. lutea</i> <i>P. alba</i> <i>P. obtuse</i>	(R., St., Le., Fl. B.)	Plumieride <i>p</i> -(Z)-coumarate,	Algicidal, Antibacterial	Methanol		[171]
44.	<i>P. acutifolia</i> <i>P. obtuse</i>	(R., Le.)	13-O-coumaroyl Plumieride	Antialgal	Methanol		[137]
45.	<i>P. rubra</i>	(St. B.)	<i>p</i> -E-coumaric acid	Antibacterial, Antialgal	Methanol		[131]
<b>Triterpenoid</b>							
46.	<i>P. obtuse</i>	(St. B.)	(20Z)-Dammara-12, 20(22)-dien-3-one (Champalin A)		Methanol,	Amorphous powder, $[\infty]_D^{23} + 43.1^\circ$ (c = 0.58, CHCl <sub>3</sub> ). UV $\lambda_{max}$ nm (log $\epsilon$ ): 204.2 IR $\nu_{max}$ (CHCl <sub>3</sub> ): 3100 (C-H), 1710 (cyclic ketone), 1610 (c = c), 1384, 1359 cm <sup>-1</sup> . FAB-MS m/z: 424.3692 [M] <sup>+</sup> (required for C <sub>30</sub> H <sub>48</sub> O, 424.3705) (6), 409.3477 [M]CH <sub>3</sub> , C <sub>29</sub> H <sub>45</sub> O] <sup>+</sup> (22), 220.1835 [C <sub>15</sub> H <sub>24</sub> O] <sup>+</sup> (24), 218.1990 [C <sub>16</sub> H <sub>26</sub> ] <sup>+</sup> (100), 205.1594 [C <sub>14</sub> H <sub>21</sub> O] <sup>+</sup> (25), 109.1019 [C <sub>8</sub> H <sub>13</sub> ] <sup>+</sup> (37).	[169]
47.	<i>P. obtuse</i>	(Le. St. B.)	(3 $\beta$ ,20Z)-Dammara-12,20 (22)-dien-3-ol(Champalin B)		Methanol	Colorless oil, $[\infty]_D^{25} + 44.2^\circ$ (c = 0.04, CHCl <sub>3</sub> ). UV $\lambda_{max}$ nm (log $\epsilon$ ): 204. IR $\nu_{max}$ (CHCl <sub>3</sub> ): 3650 br s (O.H.), 1710 vs (C = O), 1600 s (C = C) cm <sup>-1</sup> .	[169]
48.	<i>P. obtuse</i>	(St. B.)	3 $\beta$ ,27-dihydroxy-olea-12-ene or (3 $\beta$ )-Olean-12-ene-3,27-diol (Champalinol)		Methanol	Amorphous powder, $[\infty]_D^{25} + 42.1^\circ$ (c = 0.80, CHCl <sub>3</sub> ). UV $\lambda_{max}$ nm (log $\epsilon$ ): 202.2. IR $\nu_{max}$ (CHCl <sub>3</sub> ): 3250 (O.H.), 2950 (C-H aliphatic), 1625 (C = C), 1130 (C-O), 960-940 (C = C-H) cm <sup>-1</sup> . FAB-MS m/z: 442.3802 [M] <sup>+</sup> (required for C <sub>30</sub> H <sub>50</sub> O <sub>2</sub> 442.3810) (31), 411.3632 [C <sub>29</sub> H <sub>47</sub> O] <sup>+</sup> (12), 234.1973 [C <sub>16</sub> H <sub>26</sub> O] <sup>+</sup> (20), 207.1750 [C <sub>14</sub> H <sub>23</sub> O] <sup>+</sup> (14), 203.1791 [C <sub>15</sub> H <sub>23</sub> ] <sup>+</sup> (100), 189.1652 [C <sub>14</sub> H <sub>21</sub> ] <sup>+</sup> (11), 133.1019 [C <sub>10</sub> H <sub>13</sub> ] <sup>+</sup> (35).	[169]
49.	<i>P. obtuse</i>	(Le. St. B.)	27-hydroxyolean-12-en-3-one(Champalinone)		Methanol	Colorless amorphous powder, UV $\lambda_{max}$ nm (log $\epsilon$ ): 203.5. IR $\nu_{max}$ (CHCl <sub>3</sub> ): 3250 br s(O.H.), 3000 (C-H aliphatic), 1710 vs (C = O), 1150 s (C-O) cm <sup>-1</sup> . FAB-MS m/z: 440.3652 [M] <sup>+</sup> , (required for C <sub>30</sub> H <sub>48</sub> O <sub>2</sub> 440.3654) (43), 409.3480 (M) CH <sub>2</sub> OH, C <sub>29</sub> H <sub>45</sub> O] <sup>+</sup> (5), 234.1990 [C <sub>16</sub> H <sub>26</sub> O] <sup>+</sup> 219.1756 [C <sub>15</sub> H <sub>23</sub> O] <sup>+</sup> (14), 205.1598 [C <sub>14</sub> H <sub>21</sub> O] <sup>+</sup> (20), 203.1805 [C <sub>15</sub> H <sub>23</sub> ] <sup>+</sup> (100), 133.1021 [C <sub>10</sub> H <sub>13</sub> ] <sup>+</sup> (39).	[169]
50.	<i>P. obtuse</i>	(St. B.)	(3 $\beta$ )-3,27-Dihydroxyl up-29-ene or 3 $\beta$ ,28-dihydroxy-20 (29)-lupen or lup-20(29)-en-3 $\beta$ ,28-diol (Betulin)	Anti-inflammatory	Methanol	<b>Elemental analysis:</b> found, % (C) 81.9. (H) 11.5. (O) 7.9. Calculated, %: (C) 81.4. (H) 11.3. (O) 7.2. IR $\nu_{max}$ (KBr): 3374.32, 2916.65, 2850.02, 2887.13, 1644.49, 1470.82, 1374.99, 1028.83, 879.79 cm <sup>-1</sup> . EIMS m/z: 29, 31, 45, 46.	[169]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
51.	<i>P. obtuse</i>	(Le. St. B.)	3 $\beta$ -hydroxylupan-29-en-28-oic acid (Betulinic acid)		Methanol	Greenish solid, mp 275–278 °C [ $\infty$ ] <sub>D</sub> <sup>23</sup> + 7.9° (c = 0.057, pyridine). <b>Elemental analysis:</b> Found: C, 78.46. H, 10.49. Calc. for C <sub>30</sub> H <sub>48</sub> O <sub>3</sub> : C, 78.90. H, 10.39. <b>IR</b> $\nu$ <sub>max</sub> (KBr): 3480, 3000–2500, 1688, 1685, 1640, 1733, 1043, 880 cm <sup>-1</sup> . <b>EIMS</b> m/e: 207 ( $\Sigma$ <sub>40</sub> = 1.9%), 189 ( $\Sigma$ <sub>40</sub> = 3.0%), 248 ( $\Sigma$ <sub>40</sub> = 1.4%), 219 ( $\Sigma$ <sub>40</sub> = 0.75%), 220 ( $\Sigma$ <sub>40</sub> = 1.0%).	[169]
52.	<i>P. obtuse</i>	(Le. St. B.)	Urs-12-en-3-one or $\alpha$ - amyrenone		Methanol	mp 124 °C, <b>IR</b> $\nu$ <sub>max</sub> (KBr): 2930, 1740 (carbonyl), 1470, 1460 cm <sup>-1</sup> . <b>Elemental analysis:</b> C <sub>30</sub> H <sub>48</sub> O C, 84.90. H, 11.32 found C, 84.76. H, 11.40.	[169]
53.	<i>P. rubra</i>		6 $\alpha$ -hydroxy-3-epi- Oleanolic acid		Methanol	mp 235–237 °C, [ $\infty$ ] <sub>D</sub> <sup>20</sup> + 7° (c = 0.07, CHCl <sub>3</sub> ). <b>IR</b> $\nu$ <sub>max</sub> (CHCl <sub>3</sub> ): 3600, 3460, 2650–3400, 1700. 1660, 820 cm <sup>-1</sup> .	[155]
54.	<i>P. obtuse</i>	(St. B.)	3 $\beta$ -Hydroxy-27- <i>p</i> - ( <i>E</i> )-coumaroyloxy- olean-12-en-28-oic acid (uncarinic acid E)		Methanol	White amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>27.5</sup> –2.56° (c = 0.5, <sup>i</sup> PrOH). <b>UV</b> $\lambda$ <sub>max</sub> ( <sup>i</sup> PrOH) nm (log $\epsilon$ ): 206 (4.17), 229 (4.05), 315 (4.37) <b>IR</b> $\nu$ <sub>max</sub> (KBr): 3447, 1685, 1640, 1509, 1168 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel int) 454.3451 (M <sup>+</sup> - C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> , 100), 393 (15), 246 (9), 201 (8), 189 (8), 164 0.0475 (M <sup>+</sup> - C <sub>30</sub> H <sub>46</sub> O <sub>3</sub> , 85), 147 (30), 119 (15). <b>HRFABMS</b> (positive) m/z 641.3799 (calcd for C <sub>39</sub> H <sub>54</sub> O <sub>6</sub> Na: 641.3818).	[252]
55.	<i>P. obtuse</i>	(St. B.)	3 $\beta$ -Hydroxy-27-( <i>E</i> )-feruloyloxyurs-12-en-28-oic acid (uncarinic acid C)		Methanol	White amorphous powder, mp 263–266 °C [ $\infty$ ] <sub>D</sub> <sup>27.5</sup> + 5.06° (c = 0.5, <sup>i</sup> PrOH). <b>UV</b> $\lambda$ <sub>max</sub> ( <sup>i</sup> PrOH) nm (log $\epsilon$ ): 204 (4.21), 236 (3.94), 327 (4.18). <b>IR</b> $\nu$ <sub>max</sub> (KBr): 3422, 1700, 1630, 1509 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel int) 454 (M <sup>+</sup> - C <sub>10</sub> H <sub>10</sub> O <sub>4</sub> , 15), 421 (8), 246 (8), 207 (8), 201 (18), 194 (M <sup>+</sup> - C <sub>30</sub> H <sub>46</sub> O <sub>3</sub> , 100), 189 (12), 179 (38), 177 (33), 77 (60). <b>HRFABMS</b> (positive) m/z 671.3950 (calcd for C <sub>40</sub> H <sub>56</sub> O <sub>7</sub> Na: 671.3924).	[169]
56.	<i>P. obtuse</i>	(St. B.)	Urs-12-en-3 $\beta$ -hydroxy-27( <i>Z</i> )-feruloyloxy-28-oic acid (3 $\beta$ -hydroxy-27 <i>Z</i> -feruloyloxy-urs-12-en-28-oic acid) (uncarinic acid D)		Methanol	White amorphous powder, mp 195–197 °C [ $\infty$ ] <sub>D</sub> <sup>27.5</sup> + 2.16° (c = 0.5, <sup>i</sup> PrOH). <b>UV</b> $\lambda$ <sub>max</sub> ( <sup>i</sup> PrOH) nm (log $\epsilon$ ): 204 (4.37), 236 (shoulder), 327 (4.14). <b>IR</b> $\nu$ <sub>max</sub> (KBr): 3436, 1693, 1660, 1640, 1044 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel int) 454 (M <sup>+</sup> - C <sub>10</sub> H <sub>10</sub> O <sub>4</sub> , 20), 441 (5), 375 (3), 285 (15), 239 (12), 201 (18), 194 (M <sup>+</sup> - C <sub>30</sub> H <sub>46</sub> O <sub>3</sub> , 100), 177 (45), 133 (62). <b>HRFABMS</b> (positive) m/z 671.3951 (calcd for C <sub>40</sub> H <sub>56</sub> O <sub>7</sub> Na: 671.3924).	[169]
57.	<i>P. obtuse</i>	(Le.)	3 $\beta$ -hydroxyolean-12-en-28-oic acid (Oleanolic acid)		Methanol	White amorphous powder, mp 271–273 °C. <b>IR</b> $\nu$ <sub>max</sub> (KBr): 2960, 2880, 1735 (acetyl carbonyl) 1465, 1380, 1250 cm <sup>-1</sup> . <b>MS</b> . m/z: 470 (M) <sup>+</sup> , 260 (a) base peak, 203 (b). <b>Elemental analysis:</b> C <sub>30</sub> H <sub>48</sub> O <sub>3</sub> C, 78.94. H, 10.52, found C, 78.52. H, 10.39.	[253]
58.	<i>P. obtuse</i> (Le.)	(Le.)	Zamanic acid (3 $\beta$ -hydroxy-urs-30- <i>p</i> - <i>E</i> -hydroxy-cinnamoyl-12-en-28-oic-acid)		Methanol	[ $\infty$ ] <sub>D</sub> <sup>27</sup> + 26° (c = 0.15, CHCl <sub>3</sub> ). <b>UV</b> $\lambda$ <sub>max</sub> nm (log $\epsilon$ ): 311.4 and 201.8 <b>IR</b> $\nu$ <sub>max</sub> (KBr): 3500–2600 (O.H., COOH), 2900 (C-H), 1735–1690 (C = O), 1625 (C = C), 1600–1350 (aromatic ring), 1375 (Geminal dimethyl) and 1140 (C-O str.) cm <sup>-1</sup>	[254]



Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
59.	<i>P. acuminata</i> , <i>P. acutifolia</i> , <i>P. obtuse</i> , <i>P. rubra</i> , <i>P. alba</i>	(Le., Fr.St. B.)	3 $\beta$ -hydroxylursan-12-en-28-oic acid (Ursolic acid)	Antimutagenic, Antimicrobial	Methanol	mp 284–288 °C, $[\infty]_D + 65.3^\circ$ (c = 1.00, C <sub>2</sub> H <sub>5</sub> OH). <b>Elemental analysis:</b> Found: C, 78.75. H, 10.34. Calc. for C <sub>30</sub> H <sub>48</sub> O <sub>3</sub> : C, 78.89. H, 10.59%.	[140]
60.	<i>P. obtuse</i> (Le.)		Coumarobtusenoic acid ((2 $\alpha$ ,3 $\beta$ )-27-[( <i>E</i> )- <i>p</i> -coumaroyloxy]-2,3-dihydroxyursan-28-oic acid)		Methanol	Amorphous powder, UV $\lambda_{max}$ ( <sup>1</sup> PrOH) nm (log $\epsilon$ ): 282.5 <b>IR</b> $\nu_{max}$ (KBr): 3400-2650 br (O.H., COOH), 1725-1690 br (ester and acid), 1600- 1335 cm <sup>-1</sup> (aromatic C = C) cm <sup>-1</sup> . <b>EIMS</b> m/z (%) [M- 164- 18] <sup>+</sup> 454.3448 (C <sub>30</sub> H <sub>26</sub> O <sub>3</sub> calcd 454.3446)(9), 248 (100), 205 (14), 204 (4), 187 (24), 164.0467 (C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> ), calcd (164.0473) (14), 147.0446 (C <sub>9</sub> H <sub>7</sub> O <sub>2</sub> , calcd 147.0445) (38).	[154]
61.	<i>P. obtuse</i> (Le.)		Coumarobtusene ((2 $\alpha$ ,3 $\beta$ )-27-[( <i>E</i> )- <i>p</i> - coumaroyloxy]-2,3-dihydroxyursane)		Methanol	Amorphous powder, UV $\lambda_{max}$ ( <sup>1</sup> PrOH) nm (log $\epsilon$ ): 282 <b>IR</b> $\nu_{max}$ (KBr): 3450-3200 br (O.H.),1725 (ester), 1600-1350 (aromatic C = C) cm <sup>-1</sup> . <b>EIMS</b> m/z (%) [M- 164- 18] <sup>+</sup> 424.3715 (C <sub>30</sub> H <sub>48</sub> O calcd 424.3705) (10), 218 (12), 206 (18), 205 (22), 187 (32), 164.0467 (C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> ), calcd (164.0473) (38), 147.0446 (C <sub>9</sub> H <sub>7</sub> O <sub>2</sub> , calcd 147.0445) (100), 119 (44), 81 (44).	[154]
62.	<i>P. alba</i> , <i>P. rubra</i> , <i>P. obtuse</i> , <i>P. bicolor</i>	(R. B. Le. Fr.)	$\alpha$ -amyrin cinnamate	Anti-inflammatory, Fungicide, Antimicrobial, Treatment of hyperproliferative tissue	Methanol	Crystals, mp 97–100 °C, $[\infty]_D^{34} + 68^\circ$ . <b>IR</b> $\nu_{max}$ (KBr): 1710,1630,1570,1478, 1450,1380,1362,1180,765 and 706 cm <sup>-1</sup> . <b>HR-MS</b> m/z: 555.4271 (M <sup>+</sup> ), 541, 408, 337, 218, 205, 204, 203, 192.191.190 and 189 <b>MS</b> . (m/z): (Found: C, 83.56. H, 10.72. C <sub>39</sub> H <sub>56</sub> O <sub>2</sub> . Required: C, 84.16. H, 10.08%).	[154]
63.	<i>P. obtuse</i> (Le.)		Obstusin (3 $\beta$ -Hydroxy-24- <i>p</i> - <i>E</i> -coumaroyloxyurs- 12-en-28- oic acid)		Methanol	Irregular plates, mp 198-199 °C. UV $\lambda_{max}$ nm (log $\epsilon$ ): 203, 296 <b>IR</b> $\nu_{max}$ (CHCl <sub>3</sub> ): 3500-2600, 1738-1680 and 1600–1380 cm <sup>-1</sup> .	[155]
64.	<i>P. obtuse</i> (Le.)		Obstusilic acid (3 $\beta$ -Hydroxy-27- <i>p</i> -Z- coumaroyloxyurs-12- en-30- oic acid)		Methanol	Needles, mp 290-291 °C, UV $\lambda_{max}$ nm (log $\epsilon$ ): 226, 313.6. <b>IR</b> $\nu_{max}$ (CHCl <sub>3</sub> ): 3630-2600 br (O.H. and CO <sub>2</sub> H), 1750-1660 (ester and acid carbonyls) and 1660-1560 (aliphatic and aromatic C = C) cm <sup>-1</sup> .	[155]
65.	<i>P. rubra</i> (St., B., H.W., Le., R., Fl.)		Rubrinol ((3 $\beta$ )-urs-12-ene-3,20-diol)	Antibacterial			[150]
66.	<i>P. dichotoma</i> (St. B)		3 $\beta$ -Acetoxy-28-hydroxy-urs-12-ene				[255]
67.	<i>P. bicolor</i> (St. B)		3 $\beta$ -acetoxy plumerian- 12-ene				[255]
68.	<i>P. bicolor</i> (St. B)		3 $\beta$ -Hydroxy-Plumerian-12-ene				[255]
69.	<i>P. bicolor</i> (St. B)		3 $\beta$ -acetoxyurs 5,12-diene				
70.	<i>P. bicolor</i> (St. B)		29-Devinyllup-5-enol				
71.	<i>P. acutifolia</i> (Le.St. B.)		Plumeriate				
72.	<i>P. obtuse</i> (St. B)		(3 $\beta$ ,20S)-Dammarane-3, 20, 25-triol		Methanol		[169]
73.	<i>P. rubra</i> (St. B)		$\beta$ -amyrin acetate		Methanol	<b>MS</b> m/z: C <sub>32</sub> H <sub>52</sub> O <sub>2</sub> : 468 (M <sup>+</sup> 5), 218 (100), 203 (44), 189 (17).	[131]
74.	<i>P. alba</i> , <i>P. bicolor</i> (St. B. Le.)		$\alpha$ -Amyrin acetate	Treatment of hyperproliferative tissue	Methanol	m.p 222 °C <b>IR</b> $\nu_{max}$ (KBr): 2960, 2880, 1735 (acetyl carbonyl) 1465, 1380, 1250 cm <sup>-1</sup> . <b>MS</b> . m/z: 468 (M <sup>+</sup> ), 453 (M-CH <sub>3</sub> ), 408 (M-acetate), 218 (a) base peak, 203 (b). <b>Elemental analysis:</b> C <sub>32</sub> H <sub>52</sub> O <sub>2</sub> C, 82.05. H, 11.11 found C, 81.71. H, 11.41.	[243]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
75.	<i>P. alba</i> , <i>P. rubra</i>	(R. B. Fr.)	$\beta$ -amyrin		Methanol	White needle crystals, mp 195–197 °C, $\text{IR}\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3400, 3242, 1690 cm <sup>-1</sup> . $\text{GCMS}$ m/z (%): 426.1 [M] <sup>+</sup> (10), 218 (100), 203 (79), 189 (60).	[256]
76.	<i>P. rubra</i>	(St. B.)	Cycloart-25-en-3 $\beta$ ,24-diol		Methanol	White crystals, mp 180–184 °C, $\text{IR}\nu_{\text{max}}$ (KBr): hydroxyl group (3373), double bond (1650 and 756), C-O (1219, 1095 and 1026), cyclopropane C-H (3018), and C-H stretch bonds (2916 and 2848) cm <sup>-1</sup> .	[131]
77.	<i>P. rubra</i>	(W.P.)	Cycloart-22-ene-3 $\alpha$ , 25-diol		Methanol		[150]
78.	<i>P. rubra</i>	(St. B.)	Arjunolic acid (2 $\alpha$ ,3 $\beta$ ,23-trihydroxy olean-12-en-28-oic acid)	Antibacterial	Methanol	Needles, mp 251–253 °C [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 64° (c = 0.23, CH <sub>3</sub> OH). $\text{IR}\nu_{\text{max}}$ (KBr): 3400, 1700, 1640 $\text{EIMS}$ m/z (rel. int.): 488 [M] <sup>+</sup> (C <sub>30</sub> H <sub>48</sub> O <sub>5</sub> ), 470, 452, 248, 240, 230, 215, 203 and 147.	[131]
79.	<i>P. acuminata</i> <i>P. rubra</i> <i>P. bicolor</i> <i>P. dichotoma</i> <i>P. obtusifolia</i>	(Le. Fr.)	Lupeol Acetate	Antimutagenic, Antimicrobial, Anti-inflammatory, Analgesic, Fungicide		White microcrystalline powder, mp 222–224 °C. $\text{IR}\nu_{\text{max}}$ (KBr): 3400, 3240, 1725, 1689 cm <sup>-1</sup> . $\text{MS}$ m/z (%): 468.2 [M] <sup>+</sup> (7.9), 408 [M-CH <sub>3</sub> COO] <sup>+</sup> (40), 218 (56), 203 (77), 189 (100).	[140]
80.			Lupeol Cinnamate	Fungicide		Amorphous solid, mp 238–241 °C,	[14]
81.	<i>P. obtuse</i>	(Le.)	Neriucoumaric acid (3 $\beta$ -Hydroxy-2 $\alpha$ -cis- <i>p</i> -coumaryl-oxy-urs-12-en-28-oic acid)		Methanol	Colorless needles, mp 120–121 °C, [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 16.66° (c = 1.00, CHCl <sub>3</sub> ). $\text{UV}$ $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 208, 280. $\text{IR}\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3450 (O.H.), 1720, 1700 (ester and acid carbonyls), 1600–1380 (Four peaks aromatic ring) cm <sup>-1</sup> .	[155]
82.	<i>P. obtuse</i>	(Le.)	Isoneriucoumaric acid (3 $\beta$ -Hydroxy-2 $\alpha$ -trans- <i>p</i> -coumaryloxy- urs-12-en-28-oic acid)		Methanol	Colorless needles, mp 208–209 °C, [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 50.0° (c = 1.00, CHCl <sub>3</sub> ). $\text{UV}$ $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 208, 280. $\text{IR}$ $\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3450 (OH), 1720, 1700(ester and acid carbonyls), 1600–1380 (Four peaks, aromatic ring) cm <sup>-1</sup> .	[155]
83.	<i>P. obtuse</i>	(Le.)	Alphitolic acid		Methanol	Colorless needles, mp 275–278 °C, [ $\infty$ ] <sub>D</sub> <sup>19</sup> –4.0° (c = 1.00, pyridine). $\text{IR}\nu_{\text{max}}$ (KBr): 3400, 1690, 1640, 1050, 890 cm <sup>-1</sup> . $\text{HRMS}$ m/z: 472.3598 (M <sup>+</sup> , Calcd. for C <sub>30</sub> H <sub>48</sub> O <sub>4</sub> , 472.3553), 454 (M <sup>+</sup> -H <sub>2</sub> O), 426 (M <sup>+</sup> -COOH, -H).	[155]
84.	<i>P. obtuse</i>	(Le.)	Oleanonic acid (3-oxo-olean-12-en-28-oic acid)		Methanol	Needle, mp 159–161 °C, $\text{LRMS}$ m/z (%): 454 [M] <sup>+</sup>	[155]
85.	<i>P. rubra</i>		(3 $\alpha$ )-3,27-Dihydroxy-olean-12-ene		Methanol	mp 183–184 °C, [ $\infty$ ] <sub>D</sub> <sup>20</sup> + 32° (c = 0.094, CHCl <sub>3</sub> ). $\text{IR}$ $\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3650, 3400, 1640, 822 cm <sup>-1</sup> .	[14]
86.	<i>P. alba</i> <i>P. rubra</i> <i>P. obtuse</i> , <i>P. bicolor</i>	(B. Le. Fr.)	$\alpha$ -amyrin	Antimicrobial, treatment of hyper-proliferative tissue	Methanol	White needle crystals, mp 185–186 °C. $\text{IR}\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3400, 3242, 1690 cm <sup>-1</sup> . $\text{GCMS}$ m/z (%): 426 [M] <sup>+</sup> (12.3), 218 (100), 203 (38.46), 189 (34.61). $\text{Elemental analysis}$ : C <sub>30</sub> H <sub>50</sub> O C, 84.50. H, 11.73 found C, 84.62. H, 11.68.	[155]
87.	<i>P. obtuse</i>	(Le.)	Obtusol (3 $\beta$ ,27-dihydroxy-urs-12-ene)		Methanol	[ $\infty$ ] <sub>D</sub> <sup>27</sup> + 4° (c = 0.2, CHCl <sub>3</sub> ). $\text{UV}$ $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 192.4 $\text{IR}$ $\nu_{\text{max}}$ (KBr): 3250 (OH), 3050 (C-H), 1130 (C-O) and 960–940 (C = C-H) cm <sup>-1</sup> .	[254]
88.	<i>P. acutifolia</i>	(Le.)	Uvaol (3 $\beta$ )-3,28-dihydroxy-urs-12-ene)		Methanol	Colorless plates, mp 222–224 °C [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 70° (c = 0.09, CHCl <sub>3</sub> ). $\text{UV}$ $\lambda_{\text{max}}$ nm (log $\epsilon$ ): 205 $\text{Elemental analysis}$ : Found: C, 78.46. H, 10.49. Calc. for C <sub>30</sub> H <sub>48</sub> O <sub>3</sub> : C, 78.90. H, 10.39.) $\text{IR}\nu_{\text{max}}$ (CHCl <sub>3</sub> ): 3400 (-O.H.), 2900–2840 (C-H), 1640 (C = C), 1000–1150 (C-O) cm <sup>-1</sup> . $\text{EIMS}$ m/z: 442.2807 (M <sup>+</sup> , C <sub>30</sub> H <sub>50</sub> O <sub>2</sub> requires 442.3810).	[257]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
89.	<i>P. obtuse</i>	(Le.)	3 $\beta$ , 27-dihydroxylup-12-ene (obtuselin)		Methanol	Needles, mp 194–196 °C [ $\infty$ ] <sub>D</sub> <sup>24</sup> + 67.9° (c = 0.412, CHCl <sub>3</sub> ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 210 <b>IR</b> $\nu_{\max}$ (KBr): 3300–3250, 1600, 1370, 1343, 1330, 1125, 1000 cm <sup>-1</sup> . <b>EIMS</b> m/z: 442.3807 [M] <sup>+</sup> (C <sub>30</sub> H <sub>50</sub> O <sub>2</sub> requires: 442.3810, 4), 412.3668 [C <sub>29</sub> H <sub>48</sub> O] <sup>+</sup> (4), 234 (20), 207(18), 203 (100), 189 (10), 175 (6), 133 (44), 95 (20), 69 (18).	[253]
90.	<i>P. obtuse</i>	(Le.)	3,27-dioxolup-12-ene		Methanol	Needles, mp 159–160 °C. <b>EIMS</b> m/z: 438.3508 [M] <sup>+</sup> (C <sub>30</sub> H <sub>46</sub> O <sub>2</sub> requires: 438.3497 (4), 299 (2), 273 (6), 232(4), 218 (12), 205 (4), 203 (10), 189 (8), 149(42), 135(22), 133 (10), 97(18), 95 (24), 85 (72), 83 (100), 71 (50), and 57 (64).	[253]
91.	<i>P. obtuse</i> (Le.)		3,11,27-tri-oxolup-12-ene		Methanol	Amorphous, mp 159–160 °C. <b>EIMS</b> m/z: 452.3301 [M] <sup>+</sup> (C <sub>30</sub> H <sub>46</sub> O <sub>2</sub> requires: 452.3290, 12), 437 (10), 425 (14), 424 (12), 408 (24), 238 (4), 287 (38), 269 (20), 257 (18), 246 (60), 217 (38), 205 (40), 203 (38), 191 (40), 175 (44), 161 (70), 135 (80), and 119 (100).	[253]
92.	<i>P. obtuse</i>	(Le.)	27-hydroxy-3-oxolup-12-ene		Methanol	Rods (CHCl <sub>3</sub> -MeOH, 1: 1), mp 122–124 °C. <b>EIMS</b> m/z: 440.3599 [M] <sup>+</sup> (C <sub>30</sub> H <sub>48</sub> O <sub>2</sub> requires: 440.3654, 5), 422 (10), 407 (7), 275 (8), 257 (8), 234(18), 216(18), 205(10), 203(19), 149(38), 133(22), 121(30), 109 (28), 97(32), 95 (54), 83 (64), 69 (70), 57(88) and 55 (100).	[253]
93.	<i>P. obtuse</i>	(Le.)	3-oxo-14-hydroxy-27-norlup-12-ene		Methanol	Amorphous, <b>EIMS</b> m/z: 426.3522 [M] <sup>+</sup> (C <sub>29</sub> H <sub>46</sub> O <sub>2</sub> requires: 426.3497, 10), 408 (30), 393 (5), 338 (4), 220(14), 203 (100), 189 (14), 133 (30), 132 (98), 107 (32), 95 (42), 83 (82), 69 (24) and 55 (65).	[253]
94.	<i>P. acutifolia</i> <i>P. obtusifolia</i>	(Le. B.)	Lupeol (3 $\beta$ -Hydroxylup-20(29)-ene)		Chloroform/ Methanol	White powder, mp 212–216 °C, [ $\infty$ ] <sub>D</sub> -2° (c = 0.1, pyridine). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 350. <b>IR</b> $\nu_{\max}$ (KBr): 3311, 2946, 2870, 1638, 1464, 1189, 1035, 996, 680 cm <sup>-1</sup> . <b>GCMS</b> m/z: 426 (M <sup>+</sup> , C <sub>30</sub> H <sub>50</sub> O), 43 (100), 382 (6), 367 (4), 261 (14), 213 (15), 161 (16), 55 (100), 408 (9), 393 (9), 365 (14), 297 (8), 218 (68), 203 (37), 189 (50), 175 (37), 161 (41), 147 (48), 135 (64), 121 (71), 95 (78), 81 (36), 69 (68), 41 (64).	[131]
95.	<i>P. obtuse</i>	(Le.)	(3 $\beta$ -Hydroxy-27-[(Z)-p-coumaroyloxy]-urs-12-en-28-oic acid)		Methanol	Amorphous, mp 158–161 °C. UV $\lambda_{\max}$ nm (log $\epsilon$ ): 206 and 311. <b>IR</b> $\nu_{\max}$ (CHCl <sub>3</sub> ): 3600–2600 (br., O.H. and COOH), 1730 (br., acid and ester carbonyls), 1645 (C = C) and 1612–1370 (four peaks, aromatic ring) cm <sup>-1</sup> . <b>EIMS</b> m/z (rel. int.): 454.3448 (C <sub>30</sub> H <sub>46</sub> O <sub>3</sub> : 454.3446, M-p-coumaric acid, 42), 246.2076 (C <sub>16</sub> H <sub>22</sub> O <sub>2</sub> , 20), 207.1809 (C <sub>14</sub> H <sub>23</sub> O, 38), 201.1552 (C <sub>15</sub> H <sub>21</sub> , 45), 189.1556 (C <sub>14</sub> H <sub>21</sub> , 100), 164.0452 (C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> , 10), 147.0501 (C <sub>9</sub> H <sub>7</sub> O <sub>2</sub> , 30).	[258]
96.	<i>P. obtuse</i>	(Le. St. B.)	Obtusilinin (3 $\beta$ -Hydroxy-27-(Z)-p-coumaroyloxyolea-12-en-28-oic acid)		Methanol	White Amorphous powder, mp 240–242 °C. <b>EIMS</b> m/z (rel. int.): 454.3441 (C <sub>30</sub> H <sub>46</sub> O <sub>3</sub> : 454.3446, M-p-coumaric acid, 28), 246.2076 (C <sub>16</sub> H <sub>22</sub> O <sub>2</sub> , 58), 207.1771 (C <sub>14</sub> H <sub>23</sub> O, 22), 201.1551 (C <sub>15</sub> H <sub>21</sub> , 60), 189.1656 (C <sub>14</sub> H <sub>21</sub> , 47), 164.0453 (C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> , 26), 147.0450 (C <sub>9</sub> H <sub>7</sub> O <sub>2</sub> , 8), 57.0343 (C <sub>3</sub> H <sub>5</sub> O, 100).	[259]
97.	<i>P. obtuse</i>	(Le.)	Obtusinin (2 $\alpha$ ,3 $\beta$ -dihydroxy-24-p-E-coumaroyloxyurs-12-en-28-oic acid)		Methanol	Amorphous. UV $\lambda_{\max}$ nm (log $\epsilon$ ): 207 and 286 <b>IR</b> $\nu_{\max}$ (KBr): 3500–2600, 1735–1690 and 1580–1370 cm <sup>-1</sup> . <b>HRMS</b> m/z (%): 470.3443 [M-p-hydroxycinnamic acid] <sup>+</sup> (C <sub>30</sub> H <sub>46</sub> O <sub>4</sub> , 21), 452.3344 (C <sub>30</sub> H <sub>44</sub> O <sub>3</sub> , 9), 424.3328 (C <sub>29</sub> H <sub>44</sub> O <sub>2</sub> , 10), 248.1782 (C <sub>16</sub> H <sub>24</sub> O <sub>2</sub> , 70), 203.1790 (C <sub>15</sub> H <sub>23</sub> , 62), 185.1295 (C <sub>14</sub> H <sub>17</sub> , 16), 164.0526 (C <sub>9</sub> H <sub>8</sub> O <sub>3</sub> , 45), 147.0484 (C <sub>9</sub> H <sub>7</sub> O <sub>2</sub> , 16) and 133.1012 (C <sub>10</sub> H <sub>13</sub> , 6).	[259]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
<b>Iridoids</b>							
98.	<i>P. obtuse</i>	(Le.)	Obtusilin (3 $\beta$ -hydroxy-11-oxours-12-en-28-oic acid)		Methanol	UV $\lambda_{\max}$ nm (log $\epsilon$ ): 250 IR $\nu_{\max}$ (KBr): 1740-1700 and 1610 $\text{cm}^{-1}$ . HRMS m/z (rel. int.): 526.3660 [M] <sup>+</sup> (C <sub>33</sub> H <sub>50</sub> O <sub>5</sub> , 4), 467.3522 (C <sub>31</sub> H <sub>47</sub> O <sub>3</sub> , 12), 317.2158 (C <sub>20</sub> H <sub>29</sub> O <sub>3</sub> , 5), 276.1724 (C <sub>17</sub> H <sub>24</sub> O <sub>3</sub> , 34), 249.1853 (C <sub>16</sub> H <sub>25</sub> O <sub>2</sub> , 100), 216.1515 (C <sub>15</sub> H <sub>20</sub> O, 16) and 189.1641 (C <sub>14</sub> H <sub>21</sub> , 74).	[259]
99.	<i>P. obtuse</i>	(Le.)	3,23-dihydroxyurs-12-en-28-oic acid		Methanol	UV $\lambda_{\max}$ nm (log $\epsilon$ ): 250 IR $\nu_{\max}$ (KBr): 1740-1720 and 1610 $\text{cm}^{-1}$ .	[259]
100.	<i>P. obtuse</i>	(Le.)	Obtusidin (3 $\beta$ -hydroxy-28-phydroxyphenoxyurs-12-en-27-oic acid)		Methanol	UV $\lambda_{\max}$ nm (log $\epsilon$ ): 223 and 281 IR $\nu_{\max}$ (KBr): 1720 and 1600-1400 $\text{cm}^{-1}$ .	[259]
101.	<i>P. obtuse</i>	(Le.)	Obtusininid (3 $\beta$ -hydroxy-27- <i>p</i> -hydroxyphenoxyurs-12-en-28-oic acid)		Methanol	UV $\lambda_{\max}$ nm (log $\epsilon$ ): 222 and 281 IR $\nu_{\max}$ (KBr): 1725 and 1600-1400 $\text{cm}^{-1}$ .	[259]
102.	<i>P. obtuse</i>	(Le.)	27-[ <i>p</i> -( <i>E</i> )-Coumaroyl- oxy] ursolic acid		Methanol	White amorphous powder, mp 200–203 °C IR $\nu_{\max}$ (KBr): 1690 $\text{cm}^{-1}$ .	[259]
103.	<i>P. acuminata</i>	(Le.)	Lupeol carboxylic Acid	Antimutagenic	Ethanol		[11]
104.	<i>P. acutifolia</i> <i>P. rubra</i>	(Le. St. B.)	Plumeric acid	Antitumor, Anesthetic, Cardiotonic and bacteriostatic activities			[11]
105.	<i>P. acutifolia</i> <i>P. rubra</i>	(Le. St. B.)	Methyl plumerate	Antitumor, anesthetic, cardiotonic and bacteriostatic activities			[11]
106.	<i>P. obtuse</i>	(Le.)	Obtusic acid				
107.	<i>P. rubra</i>	(W.P.)	Taraxasteryl acetate [(20(30) Taraxasten- 3 $\beta$ -yl acetate)]				[255]
<b>Sterol</b>							
108.	<i>P. obtusifolia</i>	(B.)	Stigmasterol		Chloroform	White powder, mp 174–176 °C, MS m/z: 412 [M] <sup>+</sup> , 394, 351, 314, 300, 271, 229, 213, 55.	[167]
109.	<i>P. acutifolia</i> <i>P. alba</i> <i>P. rubra</i>	(Le. St. B. Fr.)	$\beta$ -Sitosterol 3-O-glucoside	Antimicrobial	Chloroform	White microcrystalline powder, mp 288–290 °C. IR $\nu_{\max}$ (CHCl <sub>3</sub> ): 3400, 3242, 1690, 1212, 1051, 1022, 953 $\text{cm}^{-1}$ . GCMS m/z: 577 (M + H <sup>+</sup> , C <sub>35</sub> H <sub>61</sub> O <sub>6</sub> ).	[156]
110.	<i>P. obtusifolia</i>	(B.)	Campesterol		Chloroform	White powder, mp 161–164 °C. UV $\lambda_{\max}$ nm (log $\epsilon$ ): 251 IR $\nu_{\max}$ (CHCl <sub>3</sub> ): 3320, 2946, 1464, 1189, 1096, 1042, 680 $\text{cm}^{-1}$ . GCMS m/z with % abundance: 400 (M <sup>+</sup> , C <sub>28</sub> H <sub>48</sub> O), 367, 316, 289, 255, 213, 173, 145, 109, 81, and 43.	[167]
111.	<i>P. acutifolia</i> <i>P. obtusifolia</i> <i>P. rubra</i> <i>P. alba</i> <i>P. obtuse</i>	(Le. St. B. Fr.)	3 $\beta$ -hydroxy- $\Delta^5$ -stigmasterane ( $\beta$ -Sitosterol)	Antimicrobial	Methanol	Clear crystal, mp 145–147 °C, [ $\infty$ ] <sub>D</sub> –36.5° (c = 1.00, CHCl <sub>3</sub> ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 257 Elemental analysis: Found: C, 83.75. H, 12.30. Calc. for C <sub>29</sub> H <sub>50</sub> O: C, 83.99. H, 12.15%. IR $\nu_{\max}$ (CHCl <sub>3</sub> ): 3320, 2946, 2854, 1480, 1388, 1189, 1096, 1035, 668 $\text{cm}^{-1}$ . GCMS m/z with % abundance: 414 (M <sup>+</sup> , C <sub>29</sub> H <sub>50</sub> O), 397, 381, 342, 303, 255, 213, 173, 145, 109, 81, and 43	[167].
112.	<i>P. acuminata</i>	(Le.)	Stigmast-7-en-3-ol	Antimutagenic	Ethanol		[140]
<b>Flavonoid</b>							
113.	<i>P. acutifolia</i>	(St. B.)	Narcissin		Methanol	yellow needles, mp 179 ± 1 °C. UV $\lambda_{\max}$ nm (log $\epsilon$ ): 254, 356. FAB-MS (m/z): C <sub>28</sub> H <sub>32</sub> O <sub>16</sub> , 625 [M + H] <sup>+</sup>	[142, 260]
114.	<i>P. acutifolia</i>	(Fl.)	Kaempferol-3-Rutinoside		Ethanol	UV $\lambda_{\max}$ nm (log $\epsilon$ ): 265, 350 ESI-MS (m/z): 593.46 [M - H] <sup>-</sup> , C <sub>27</sub> H <sub>19</sub> O <sub>15</sub>	[261]
115.	<i>P. acutifolia</i>	(Fl.)	Ayanin (5,3'-Dihydroxy-3,7,4'-trimethoxyflavone)		Ethanol	mp 172–174 °C. EI-MS m/z: 344 (M <sup>+</sup> , 100). HR-ESI-MS (m/z): Calcd for C <sub>18</sub> H <sub>16</sub> O <sub>7</sub> (M <sup>+</sup> ): 344.0896. Found: 344.0891.	[262]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
116.	<i>P. acutifolia</i>	(Fl.)	Kaempferol		Ethanol	mp 271–272 °C, UV $\lambda_{\max}$ nm (log $\epsilon$ ): 258, 325 sh, 370. <b>FAB-MS</b> (m/z): 287 [M+H] <sup>+</sup> , C <sub>15</sub> H <sub>10</sub> O <sub>6</sub> .	[263]
117.	<i>P. acutifolia</i>	(Fl.)	Pillion		Ethanol		
118.	<i>P. acutifolia</i>	(St. B.)	Quercitrin		Methanol	White amorphous powder, mp 183 ± 1 °C, [ $\infty$ ] <sub>D</sub> <sup>25</sup> –178° (c = 0.1, CH <sub>3</sub> OH). <b>CI-MS</b> m/z: 448, 301, 285, 251, 235, 146 <b>ESI-MS</b> (m/z): 449.1 [M + H] <sup>+</sup>	[264]
119.	<i>P. rubra</i>	(Le. Fl. St.)	Quercetin		Flavonoid	mp >300 °C, <sup>1</sup> H NMR ( $\delta$ , ppm) (DMSO-d <sub>6</sub> ): 6.18 (1H, s, H-6), 6.41 (1H, s, H-8), 6.87 (1H, d, J = 8.5, H-5'), 7.54 (1H, d, J = 8.5, H-6'), 7.70 (1H, s, H-2'), 12.47 (1H, s, 5-OH), 10.76 (1H, s, 7-OH), 9.57 (1H, s, 3-OH), 9.35 (1H, s, 3'-OH), 9.29 (1H, s, 4'-OH).	[265]
120.	<i>P. rubra</i>	(Le. St. B.)	Plumerubroside ((2R,3S)-3,4'-dihydroxy-7,3',5'-trimethoxyflavan-5-O- $\beta$ -D-glucopyranoside).		Methanol	White powder, mp 210–211 °C, [ $\infty$ ] <sub>D</sub> –2° (c = 0.1, pyridine). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 278 (3.6) 315 (3.0). <b>IR</b> $\nu_{\max}$ (KBr): 3400, 1624, 1469, 1173, 1153, 1051 cm <sup>-1</sup> . <b>EIMS</b> m/z (rel int. %): 510 [M] <sup>+</sup> (1), 348 (8), 330 (2), 254 (1), 196 (11), 168 (100). <b>FABMS</b> m/z: 511 [M + 1] <sup>+</sup> <b>HR-FABMS</b> m/z: found 511.1817, calcd for C <sub>20</sub> H <sub>30</sub> O <sub>12</sub> , 511.1816.	[253]
121.	<i>P. rubra</i>	(AP.)	Rubranonoside (7-O- $\alpha$ -L-rhamnopyranosyl-4-O- $\beta$ -D-Glucopyranosyl-naringenin)		Methanol	White amorphous powder, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 24.7° (c = 0.01, MeOH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 286 (3.15), 315 (3.89). <b>IR</b> $\nu_{\max}$ (KBr): 3420, 2929, 1729, 1641–1485, 1261, 1173 and 849 cm <sup>-1</sup> . <b>HRFABMS</b> m/z: 579.1725 (M-H) <sup>-</sup> , calcd. for C <sub>27</sub> H <sub>31</sub> O <sub>14</sub> , 579.1713.	[246]
122.	<i>P. obtuse</i>	(AP.)	Glochiflavanoside B ((2R,3S)-3,7,4'-trihydroxy-5,3',5'-trimethoxyflavan 7-O- $\beta$ -D-glucopyranoside)		Methanol	Colorless needles, mp 222–224 °C, [ $\infty$ ] <sub>D</sub> <sup>22</sup> –61.4° (c = 0.57, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 226sh (4.24), 271 (3.28). <b>IR</b> $\nu_{\max}$ (KBr): 3326, 2944, 1619, 1598, 1525, 1498, 1455, 1217, 1166, 1121, 1073, 837 cm <sup>-1</sup> . <b>HR-FAB-MS</b> (m/z): 509.1671 [M-H] <sup>-</sup> (Calcd for C <sub>24</sub> H <sub>29</sub> O <sub>12</sub> : 509.1659).	[266]
123.	<i>P. obtuse</i>	(Le.)	methyl <i>p</i> -E-coumarate		Methanol	Light yellow needles, mp 138–139 °C, <b>IR</b> $\nu_{\max}$ (CHCl <sub>3</sub> ): 3452.2 (O-H), 2972.2, 2930.4 (C-H), 1725.4 ( $\alpha$ , $\beta$ unsaturated C = O), 1630.2 (C = C), 1606.8, 1574.8, 1450.8 (Aromatic C = C) and 1142.4 (C-O) cm <sup>-1</sup> . <b>HREIMS</b> m/z: 178.0634 [M] <sup>+</sup> , (calcd. for C <sub>10</sub> H <sub>10</sub> O <sub>3</sub> , 178.0629).	[155]
Alkaloid							
124.	<i>P. acutifolia</i>		Laurelliptine			mp 190–192 °C, [ $\infty$ ] <sub>D</sub> <sup>25</sup> + 34° (c = 0.5, CH <sub>3</sub> OH). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 304, 284 and 220. <b>Elemental analysis:</b> (Found: C, 69.1. H, 6.1. N, 4.5. O, 20.0. N-CH <sub>3</sub> , 0.2. OCH <sub>3</sub> , 19.2. C <sub>18</sub> H <sub>19</sub> NO <sub>4</sub> requ <sup>r</sup> IRes C, 69.0. H, 6.1. N, 4.5. O, 20.4. 2 × CH <sub>3</sub> O, 19.8%). <b>MS</b> m/z: 313 (M <sup>+</sup> ) (80), 312 (100), 298 (17), 284 (15), 269 (7), 254 (7), 253 (11).	[153]
125.	<i>P. acutifolia</i>		Phoebegrandine B	Antibacterial		Amorphous gum, UV $\lambda_{\max}$ nm (log $\epsilon$ ): 225 (4.55), 278 (3.97), 308 sh (3.51). <b>EI-MS</b> m/z: 473 [M] <sup>+</sup> (42), 230 (42), 227 (40), 214 (100). <b>FAB-MS</b> (m/z): 549 [M <sup>+</sup> + H], 369, 351, 307, 289, 154, 136, 128, 107.	[152]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
126.	<i>P. lancifolia</i>	(B.)	Uleine			mp 74–79 °C, UV $\lambda_{\max}$ nm (log $\epsilon$ ): 209, 305, 316. IR $\nu_{\max}$ (KBr): 3394, 2921, 1733, 1555, 1459, 725 $\text{cm}^{-1}$ . MS m/z: 267 ( $M^+ + 1$ , 8), 266 ( $M^+$ , 25), 237 (12), 233 (9), 209 (18), 194 (18), 180 (22), 91 (100), 44 (50) [calcd. for $C_{18}H_{22}N_2$ : 266.1783. found: 266.1781].	[267]
127.	<i>P. lancifolia</i>	(B.)	Demethoxyaspido-Spermine			$[\infty]_D + 10^\circ$ (c = 0.009, $\text{CHCl}_3$ ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 253, 280, 289. IR $\nu_{\max}$ (KBr): 3364 $\text{cm}^{-1}$ . MS m/z: 325 ( $M^+ + 1$ , 8), 324 ( $M^+$ , 12, $C_{21}H_{28}N_2O$ ), 296 (29), 281 (5), 156 (21), 152 (30), 144 (27), 124 (20), 84 (26), 51 (32), 49 (100), 47 (24).	[267]
128.	<i>P. acutifolia</i>	(Le.)	Plumerianine ((R)-4'-(S)-1-hydroxyethyl)-5,6-dihydro-5'H-Spiro [cyclopenta[c]pyridine-7,2'-furan]-5'-one		Methanol	Amorphous yellow powder, $[\infty]_D^{25} + 18^\circ$ (c = 0.18, $\text{CHCl}_3$ ). ESI-MS m/z: 254 ( $[M + Na]^+$ ), 232 ( $[M + H]^+$ ).	[257]
129.	<i>P. rubra</i>	(St. Le.)	Plumerinine			Light brown viscous oil, $[\infty]_D^{20} 14.4^\circ$ (c = 0.31, $\text{CH}_3\text{OH}$ ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 202, 215 IR ( $\nu_{\max}$ ) (KBr): 3650, 3350 (OH), 1150 (C-N stretch.), 1370 (isopropyl), 2820 and 2720 (Bohlman bands) $\text{cm}^{-1}$	[268]
130.	<i>P. rubra</i> <i>P. acutifolia</i>	(Fl.)	Plumericidine, (= ((7S)-5,6-Dihydro-4'-[(1R)-1-hydroxyethyl]-5'H-spiro [cyclopenta[c]pyridine-7,2'-furan]-5'-one)	Anticancer, Antiviral		Cubic crystalline compound, mp 214–216 °C, $[\infty]_D^{23} + 17^\circ$ (c = 0.12, $\text{CH}_3\text{OH}$ ). IR $\nu_{\max}$ (KBr): 2989, 1761, 1604, 1425, 1356, 790 $\text{cm}^{-1}$ . EI-HRMS m/z: 231.0890 ( $M^+$ , $C_{13}H_{13}NO_3^+$ : calc. 231.0895).	[138]
131.	<i>P. sericifolia</i>	(St.)	Vincubine	Anticancer			
132.	<i>P. acutifolia</i>		Grandine A	Antibacterial	(oxoproaporphine)	Brown amorphous solid, $[\infty]_D^{23} + 55.0^\circ$ (c = 1.0, $\text{CHCl}_3$ ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 250, 320 IR $\nu_{\max}$ (KBr): 3376, 1927, 2922 $\text{cm}^{-1}$ . HREI-MS m/z: 318.0768 $[M+Na]$ , (calc. 318.0742 for $C_{17}H_{13}NO_4Na$ ). FAB-MS (m/z): 549 $[M^+ + H]$ , 369, 351, 307, 289, 154, 136, 128, 107.	[151]
133.	<i>P. acutifolia</i>		Grandine B	Antibacterial			[151]
134.	<i>P. acutifolia</i>		Grandine C	Antibacterial			[151]
Cardiac glycoside							
135.	<i>P. obtuse</i>	(Le.)	Oleandrine		Methanol		[155]
136.	<i>P. obtuse</i>	(Le.)	Kaneroside (3 $\beta$ -O-(D-diginosyl)-2 $\alpha$ -hydroxy-8,14 $\beta$ -epoxy-5 $\beta$ -carda-16:17,20:22-dienolide)		Methanol	Needles, mp 110–111 °C, $[\infty]_D^{24} + 26.66^\circ$ (c = 1.00, $\text{CHCl}_3$ ). UV $\lambda_{\max}$ nm (log $\epsilon$ ): 218, 267. IR $\nu_{\max}$ ( $\text{CHCl}_3$ ): 3450, 1780, 1750, 1625 $\text{cm}^{-1}$ . FAB-MS m/z (%): 531.2952 $[M - H]^+$ (Calc. for $C_{30}H_{43}O_8$ : 531.2957). EIMS m/z: 368.1994 ( $C_{23}H_{28}O_4^+$ , frag. a), 355.1926 ( $C_{22}H_{27}O_4^+$ , frag. b), 145.0882 ( $C_7H_{13}O_3^+$ , frag. c) $^+$ .	[155]
Quinone							
137.	<i>P. rubra</i>	(B.)	2,5-dimethoxy- <i>p</i> -Benzoquinone	Anticancer	Chloroform	Yellow needle crystal ( $C_2H_5OAc$ ), mp 278–280 °C. IR $\nu_{\max}$ (KBr): 3443, 3127, 1627, 1567, 1479, 1368, 1320, 1269, 1221, 1161, 996, 777 $\text{cm}^{-1}$ . EI-MS m/z: 168, 138, 125, 112, 97, 80, 69.	[131]
138.	<i>P. rubra</i>	(St. B.)	2,6-dimethoxy- <i>p</i> -Benzoquinone	Antibacterial, Antifungal	Chloroform	Yellow crystals, mp 240 °C. UV $\lambda_{\max}$ nm (log $\epsilon$ ): 288 IR $\nu_{\max}$ (KBr): 1696, 1594 $\text{cm}^{-1}$ . EIMS m/z: 169.0202 ( $M + H$ , $C_8H_6O_4$ : calc. 169.0498).	[131]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
<b>Iridoids</b>							
<b>nor-terpenoid</b>							
139.	<i>P. rubra</i>	(AP.)	<i>P. rubra</i> jaleelol		Methanol	White amorphous powder, $[\alpha]_D^{25} + 54.3^\circ$ (c = 0.012, CHCl <sub>3</sub> ). <b>IR</b> $\nu_{\max}$ (KBr): 3470, 2950, 1667, 1070 cm <sup>-1</sup> . <b>HREIMS</b> m/z: 444.3610 (M) <sup>+</sup> , calcd. for C <sub>29</sub> H <sub>48</sub> O <sub>3</sub> , 444.3603.	[246]
140.	<i>P. rubra</i>	(AP.)	<i>P. rubra</i> jaleelic acid		Methanol	Colorless amorphous solid, $[\alpha]_D^{25} + 68.7^\circ$ (c = 0.011, CHCl <sub>3</sub> ). <b>IR</b> $\nu_{\max}$ (KBr): 3430, 3285-2560, 1710, 1655, 1065 cm <sup>-1</sup> . <b>HREIMS</b> m/z: 458.3408 (M) <sup>+</sup> , calcd. for C <sub>29</sub> H <sub>46</sub> O <sub>4</sub> , 458.3396.	[246]
<b>Anthocyanin</b>							
141.	<i>P. rubra</i>	(Fl.)	cyanidin 3-O- $\beta$ - (2''-glucopyranosyl-O- $\beta$ -galactopyranoside)				[265]
142.	<i>P. rubra</i>	(Fl.)	cyanidin-3- O- $\beta$ -galactopyranoside				[265]
<b>Cardenolide</b>							
143.	<i>P. obtuse</i>	(Le. St. B.)	(3 $\alpha$ ,14 $\beta$ ,17 $\beta$ )-3,14-dihydroxy-17-card-20(22)-enolide (3-epidigitoxigenin)		Methanol		[169]
<b>Fatty acid ester</b>							
144.	<i>P. bicolor</i>	(St. B.)	34-hydroxy tetratri-acontanyl ferulate		Chloroform	Colorless powder, C <sub>44</sub> H <sub>78</sub> O <sub>5</sub> , mp 95-96°, <b>IR</b> $\nu_{\max}$ (KBr) 3440, 2910, 2831, 1712, 1687, 1619, 1590, 1500, 1253, 1050, 1000, 960, cm <sup>-1</sup> . <b>FAB-MS</b> m/z: [M] <sup>+</sup> 686 (8.7), 685 (14.8), 671 (18.7), 219 (16.8), 194 (49.2), 178 (15.6), 177 (100), 150 (26.1), 137 (36.4), 135 (26.3), 131 (15.6).	[269]
145.	<i>P. bicolor</i>	(St. B.)	34-O-Acetyl tetra triacontanyl ferulate		Chloroform	Colorless powder, C <sub>46</sub> H <sub>80</sub> O <sub>6</sub> , mp 68-69 °C, <b>IR</b> $\nu_{\max}$ (KBr) 3440, 2910, 2831, 1712, 1687, 1619, 1590, 1500, 1253, 1050, 1000, 960, cm <sup>-1</sup> . <b>FAB-MS</b> m/z: [M] <sup>+</sup> 728 (2.8), 685 (7.4), 657 (17.1), 644 (2.8), 219 (16.8), 195 (49.2), 177 (100).	[269]
146.	<i>P. obtuse</i>	(Le. St. B.)	Methyl <i>n</i> -octadecano-ate (Methyl stearate)		Methanol		[169]
147.	<i>P. obtusifolia</i>	(B.)	Lupeol fatty esters I				
<b>Lignan</b>							
148.	<i>P. rubra</i>	(B.)	Liriodendrin	Cytotoxic	Water soluble	Colorless crystals, mp 262-265°, Anal. Calcd. for C <sub>34</sub> H <sub>16</sub> O <sub>18</sub> : C, 54.98. H, 6.24. CH <sub>3</sub> O, 16.71. Found: C, 54.54. H, 6.35. CH <sub>3</sub> O, 16.2.	[132]
<b>Coumarin</b>							
149.	<i>P. obtuse</i> <i>P. rubra</i>	(Le. St. B.)	Scopoletin	Antibacterial	Chloroform	Yellow needles, mp 208-210 °C, <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 345, 298, 252, 229 <b>IR</b> $\nu_{\max}$ (CHCl <sub>3</sub> ): Hydroxyl group (3387), carbonyl $\delta$ -lactone (1711), double bond (1613), aromatic ring (1595, 1567 and 1510) cm <sup>-1</sup> . <b>HR ESI-MS</b> m/z (%): C <sub>10</sub> H <sub>6</sub> O <sub>4</sub> requires 193.0495, found .m/z 193.0489 [M + H] <sup>+</sup> , C <sub>10</sub> H <sub>8</sub> O <sub>4</sub> Na requires 215.0315, found 215.0309 [M + Na] <sup>+</sup> .	[155]
150.	<i>P. obtuse</i>	(AP.)	rel-(3 R,3' S,4 R,4' S)- 3,3',4,4'-tetrahydro- 6,6' -dimethoxy [3,3'-bi-2 <i>H</i> -benzopyran]- 4,4' -diol		Methanol, bi-2 <i>H</i> -benzo-pyran	Colorless oil, <b>IR</b> $\nu_{\max}$ (KBr): 3365, 1605, 1514, 1464, 1124, 854, 819, 752 cm <sup>-1</sup> . <b>EI-MS</b> m/z: 358 (53, M <sup>+</sup> ), 327 (12), 205 (21), 151 (100), 180 (11), 137 (43). <b>HR-ESI-MS</b> (m/z): 358.1412 (C <sub>20</sub> H <sub>22</sub> O <sub>6</sub> <sup>+</sup> , calc. 358.141).	[270]

Table 1 (continued)

S.N.	Plant Source	Part (s) used	Compound isolated	Biological activity	Solvents	Analytical data	Ref.
Iridoids							
<b>Others</b>							
151.	<i>P. rubra</i>	(AP.)	P. rubranin ((2S,3S,4 R)-2- {[(2 R,16E)-2-hydroxyhexae-ico- 16-en] amino} octadecane-1,3,4- triol-1-O-β-D-gluco- pyranoside)		Methanol, sphingolipid	White gummy solid, $[\infty]_D^{25} + 24.7^\circ$ ( $c = 0.013$ , CH <sub>3</sub> OH). <b>IR</b> $\nu_{\max}$ (KBr): 3500-3200, 2945, 1660 cm <sup>-1</sup> . <b>HRFABMS</b> m/z: 870.7120 (M-H) <sup>+</sup> , calcd. for C <sub>50</sub> H <sub>96</sub> NO <sub>10</sub> , 870.7112	[193]
152.	<i>P. acutifolia</i>	(Fl.)	Cerberic acid B		Phenyl- Propanoid	$[\infty]_D^{20} + 10^\circ$ ( $c = 0.2$ , CH <sub>3</sub> OH). <b>UV</b> $\lambda_{\max}$ nm (log $\epsilon$ ): 206, 234, 280 <b>ESI-MS</b> (m/z): (209.22 [M - H] <sup>-</sup> , C <sub>10</sub> H <sub>9</sub> O <sub>5</sub> ,	[122]
153.	<i>P. rubra</i>	(St. B.)	1-(p-hydroxyphenyl) propan-1-one (2'-methyl-p-hydroxy- acetophenone)	Antibacterial, Antifungal, Antialgal			[43]
154.	<i>P. rubra</i>	(St. B.)	2,3-dihydroxypropyl octacosanoate		Mono- Glyceride	Mass fragment: 73/147/203/539/627a 642a	[132]
155.	<i>P. acutifolia</i>	(Le.)	L- (+)-bornesitol				[126]
156.	<i>P. rubra</i>	(St. B.)	2,4,6-trimethoxy-aniline			A colorless oil, b.p. 131–133 °C	[133]

AP. aerial parts, B. Bark, Fl. Flower, Fr. Fruits, Le. Leaves, St. Stem, St. B. Stembark, R. Root, RB. Root bark, WP. Wholeplants, HW. Heartwood, P. Plumeria, GC gas chromatography, GC-MS gas chromatography-massspectrometry, FAB-MS Fast Atom Bombardment Mass Spectrometry, HRMS High Resolution Mass Spectrometry, EIMS electronionization mass spectrometry, ESI-MS electrospray ionization, mass spectrometry, HREIMS High Resolution electron ionization Mass Spectrometry, HRFABMS High Resolution Fast Atom Bombardment Mass Spectrometry, ppm part per million, FTIR Fourier-Transform Infrared Spectroscopy, IR infraredspectroscopy, UV ultravioletspectrophotometry, molecular ion, parention Mass spectrometry: m/z [M]<sup>+</sup>, uncorrected melting points: uncorr., ppt precipitate, temp temperature, mp melting point, b.p. boiling point, UV ultraviolet spectrophotometry, A (absorbance, not OD - opticaldensity),  $\nu$  wave number, Ac Acetyl,  $\lambda$  wavelength of light, Me Methyl, glc glucose, c concertation, Anal. Calcd Analysis Calculated,  $\nu_{\max}$  Maximum frequency,  $\epsilon$  molar absorptivity, Hz the unit of frequency

been utilized as abortifacients and purgatives in eastern Asia [25–28]. Flower tops and betel leaves (Piper betel) are eaten with ague [29]. In India, intestinal parasites, diarrhea, rheumatism, loose motions, and dysentery are all treated with the bark of the *Plumeria* [30]. It cleans the tongue by rubbing it on it [31]. The fruit is also used as an abortifacient [32] in southern Vietnam to treat malaria [33] and in Latin America for subcutaneous mycosis [34]. Latex is effective as a lubricant in rheumatoid arthritis and is used to heal blisters and wounds directly [35, 36]. Bark paste, when applied externally, aids in the healing of wounds [37]. Women are permanently sterilized with a specific amount of plant flowers, as Kalita et al. described in 2011 [38]. *P. rubra* is used to treat skin abscesses, herpes rash, dysentery, syphilis, and cough and as a laxative in Guinea and Northern Namibia.

## Phytochemistry

Iridoids, triterpenes, alkaloids, flavonoids, isoflavonoids, quinolizidine, and other chemical components have all been detected in the *Plumeria* genus. Of these, alkaloids, iridoids, and triterpenoids appear in practically every species and serve as chemotaxonomic markers for the genus. Table 1 thoroughly lists the substances discovered in *Plumeria* species [11].

## Iridoids

### Classification

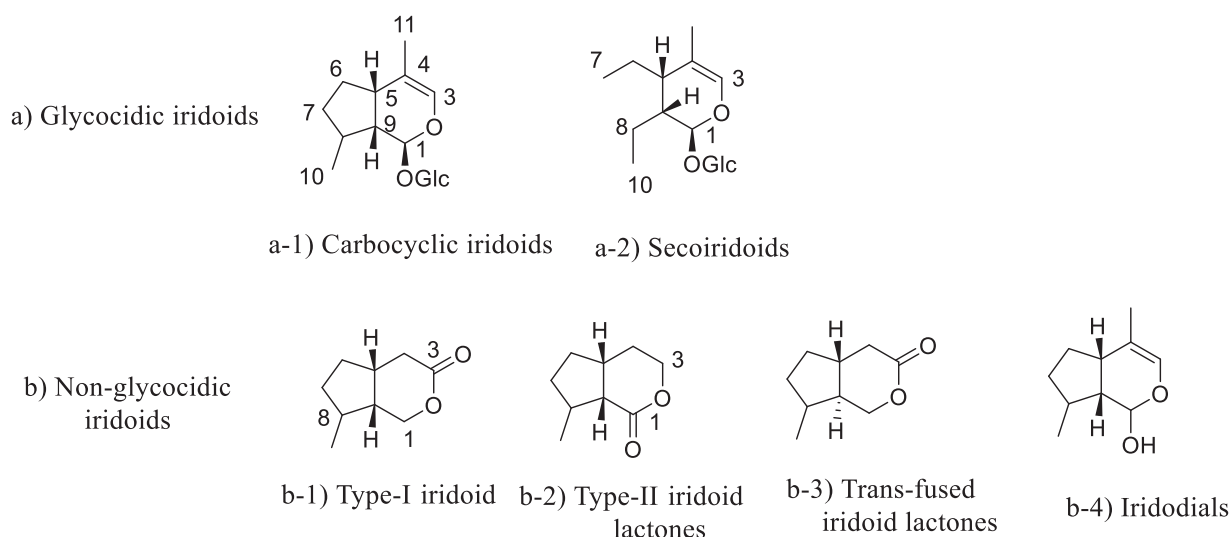
As secondary metabolites, iridoids are a family of cyclic monoterpenoids found in plants and animals [39, 40]. The structural classification of iridoids is based on a glycosidic link inside the molecule [41].

### Types of iridoids and their structural variations

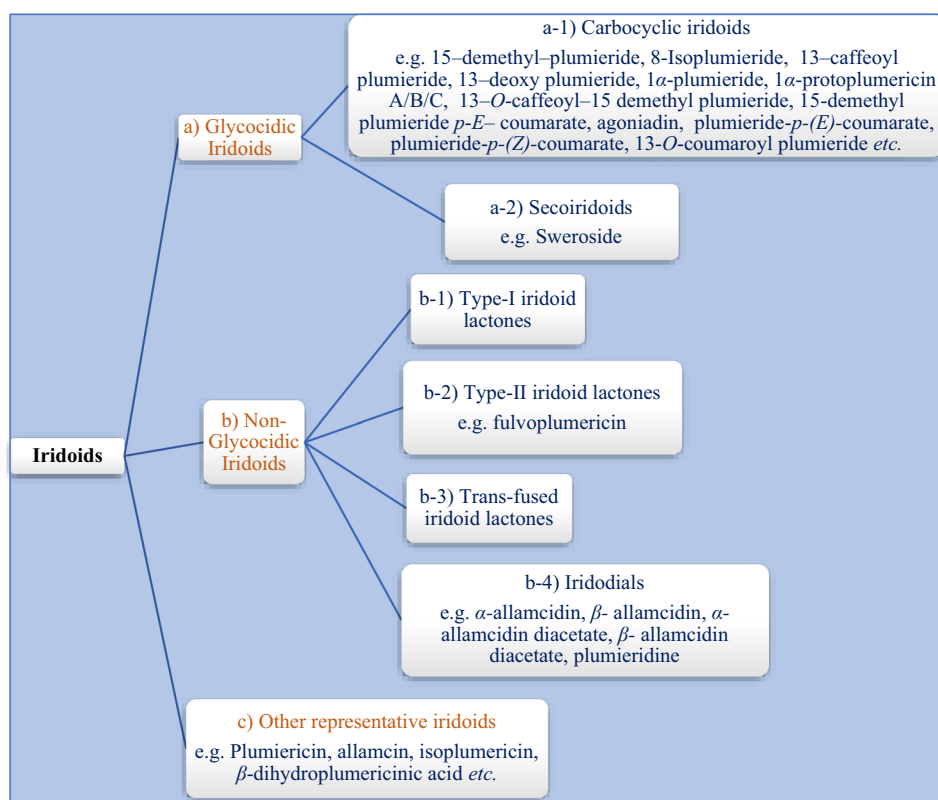
A class of iridoid glycosides with a β-D-glucopyranosyl moiety at the C1 position is shown in Fig. 1. There are two more subtypes of iridoid glycosides: secoiridoids and carbocyclic iridoids (Figs. 1, 2) [42, 43].

The ring structure of cyclopenta[c]pyran is substituted and cis-fused in carbocyclic iridoids (Fig. 1). Substitutes of the cyclopentane moiety, such as epoxy, olefin, and hydroxy groups aid in structural variety [42]. Natural products, such as hydrogen, methyl, aldehyde, esters, and carboxylic acids, exhibit a range of modifications at the C11 position [42, 43]. Representative carbocyclic iridoids are shown to be the structure of different phytochemicals in the genus *Plumeria* (Figs. 3, 4). The cleaved cyclopentane ring in secoiridoids lacks a C–C link between C7 and C8 (Fig. 1). The primary precursor of iridoid alkaloids is C7 aldehyde type Iridoid, sweroside (40). Furthermore, the aldehyde moiety of 3 groups of terpenes or





**Fig. 1** General structures of glycosidic and non-glycosidic iridoids based on structural classification of iridoids

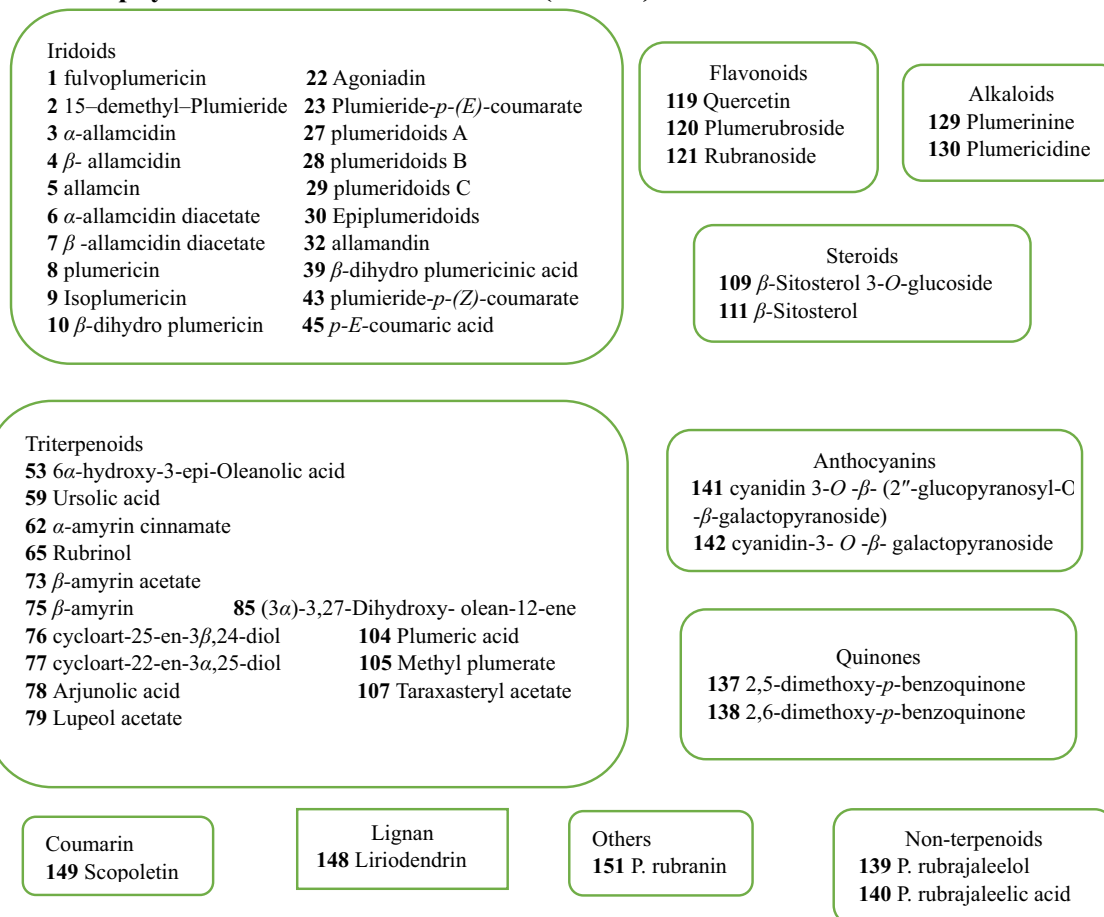
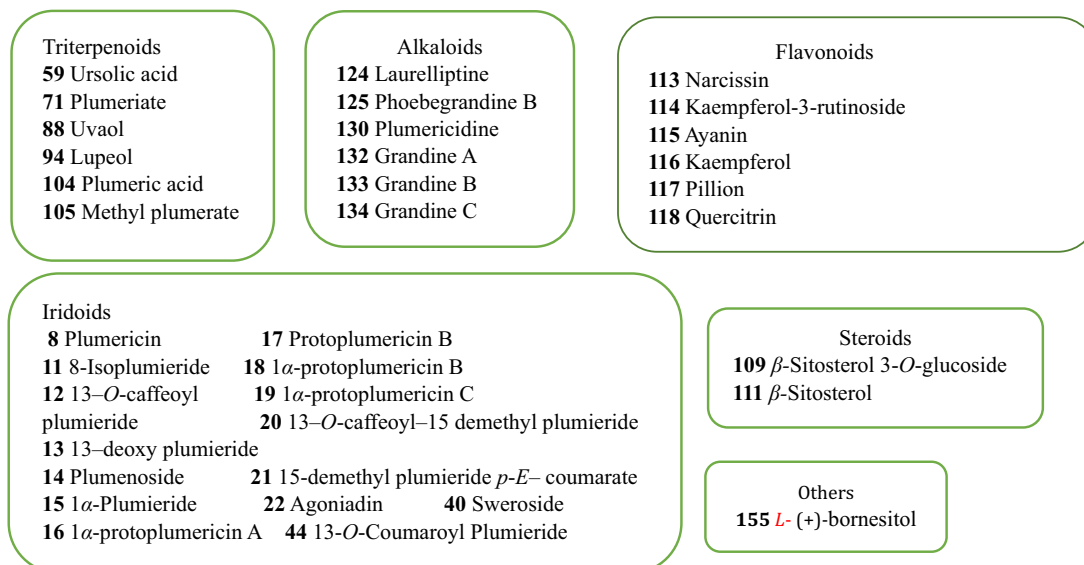


**Fig. 2** Structural classification of iridoids and classification of compounds isolated from the genus *Plumeria*, based on their structural moieties

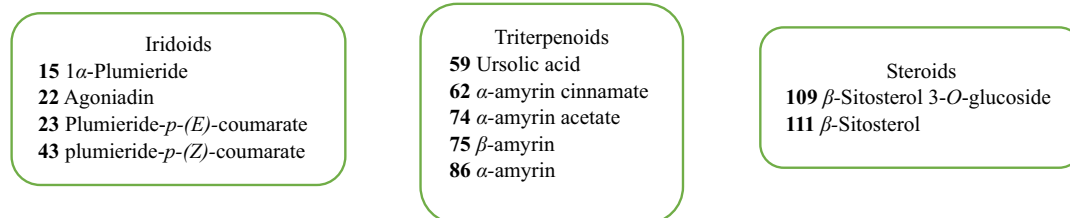
phenolics may be conjugated to extend this series's structural complexity further.

Figure 1 illustrates non-glycosidic iridoids, including lactones and iridodial iridoids. This compound exhibits regioisomeric variations involving the lactonyl carbon moiety, classified into type I and II iridoid lactones [41]. A carbonyl group is located at C3 in type I iridoid lactones,

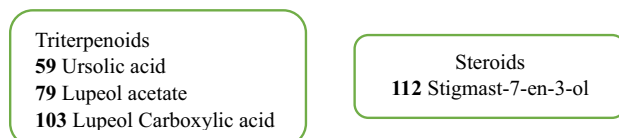
whereas in type II lactones, it is located at C1. The stereochemical difference arises from the methyl substituents at C8. Fulvolumericin is depicted as iridoid lactone type II (Fig. 2) [2, 14]. Although cis-fused ring structures have been well documented, trans-fused iridoid lactones are relatively rare [44]. Iridodials represent the aglycone of iridoid glycosides, which exist in equilibrium between the

**Isolated phytochemicals from the *P. rubra* (Table 1):****Isolated phytochemicals from the *P. acutofolia* (Table 1):****Fig. 3** List of compounds isolated from various classes of phytochemicals of different species of the genus *Plumeria*

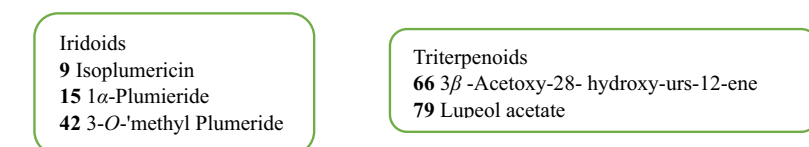
**Isolated phytochemicals from the *P. alba* (Table 1):**



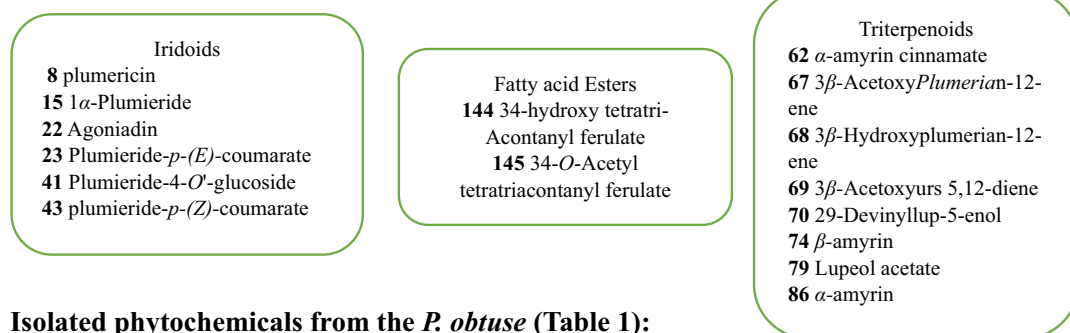
**Isolated phytochemicals from the *P. acuminata* (Table 1):**



**Isolated phytochemicals from the *P. dichotoma* (Table 1):**



**Isolated phytochemicals from the *P. bicolor* (Table 1):**



**Isolated phytochemicals from the *P. obtuse* (Table 1):**

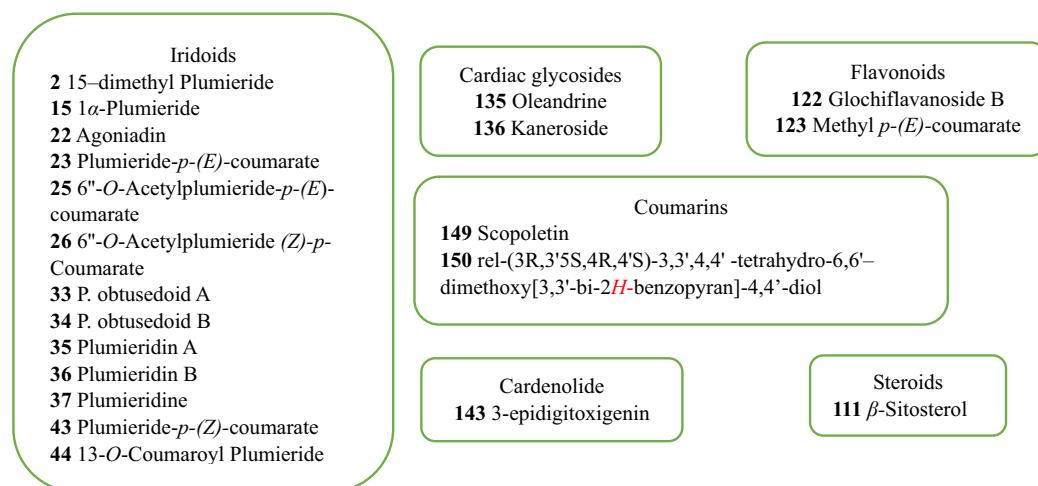


Fig. 3 (Continued)

Fig. 3 (Continued)

Triterpenoids	
46 Champalin A	90 3,27-dioxolup-12-ene
47 Champalin B	91 3,11,27-tri-oxolup-12-ene
48 Champalinol	92 27-hydroxy-3-oxolup-12-ene
49 Champalinone	93 3-oxo-14-hydroxy-27-up-12-ene
50 Betulin	95 (3 $\beta$ -Hydroxy-27-[(Z)-p-coumaroyl oxy]- urs-12-en-28-oic acid)
51 Betulinic acid	96 Obtusilin
52 $\alpha$ - amyrenone	97 Obtusin
54 uncarinic acid E	98 Obtusilin
59 Ursolic acid	
64 Obstusilic acid	
72 (3 $\beta$ ,20S)-Dammarane-3, 20, 25-triol	
81 Neriucoumaric acid	
82 Isoneriucoumaric acid	
83 Alplitolic acid	99 3,23-dihydroxyurs-12-en-28-oic acid
84 Oleanonic acid	100 Obtusidin
86 $\alpha$ -amyrin	101 Obtusinidin
102 27-[p-(E)-Coumaroyl- oxy] ursolic acid	
89 P. obtusalin	106 Obtusic acid

### Isolated phytochemicals from the *P. obtusifolia* (Table 1):

Iridoids 15 1 $\alpha$ -Plumieride	Triterpenoids 79 Lupeol acetate 94 Lupeol	Steroids 108 Stigmasterol 109 $\beta$ -Sitosterol 3-O-glucoside 111 $\beta$ -Sitosterol
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### Isolated phytochemicals from the *P. Seriflia* (Table 1):

Alkaloid 131 Vincubin
--------------------------

### Isolated phytochemicals from the *P. multiflora* (Table 1):

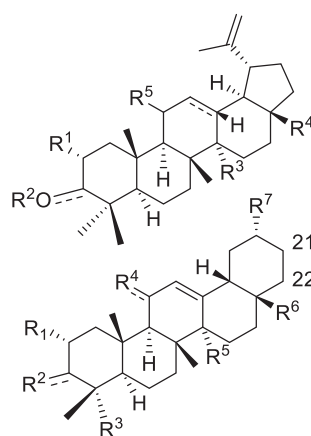
Iridoids 8 plumericin
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### Isolated phytochemicals from the *P. lancifolia* (Table 1):

Alkaloids 126 Uleine 127 Demethoxy-aspidospermine
---

lactol and dialdehyde forms [45] (Figs. 1, 2). Therefore, the stability of the iridodial structure depends on the non-glycosidic entity.

The structures of plumieridine,  $\alpha$ -allamcidin,  $\beta$ -allamcidin, and their diacetates are shown in Fig. 4. As for other iridoids, plumericin (8) (minor iridoids) [46] has appeared



	R <sup>1</sup>	R <sup>2</sup>	R <sup>3</sup>	R <sup>4</sup>	R <sup>5</sup>	
<b>79</b>	H	Ac	Me	Me	H	C(12)-C(13)
<b>80</b>	H	Cinn	Me	Me	H	C(12)-C(13)
<b>50</b>	H	H	Me	HO-CH <sub>2</sub>	H	C(12)-C(13)
<b>94</b>	H	H	Me	Me	H	C(12)-C(13)
<b>83</b>	OH	H	Me	COOH	H	C(12)-C(13)
<b>51</b>	H	H	Me	COOH	H	C(12)-C(13)
<b>91</b>	H	=O	=O	Me	=O	C(12)=C(13)
<b>92</b>	H	=O	HO-CH <sub>2</sub>	Me	H	C(12)=C(13)
<b>93</b>	H	=O	OH	Me	H	C(12)=C(13)
<b>103</b>	H	OH	Me	HO-CH <sub>2</sub>	H	C(12)-C(13)
<b>147</b>	H	Me (CH <sub>2</sub> ) <sub>n</sub> CO (n = 14, 16, 18-26)	Me	Me	H	C(12)-C(13)

	R <sup>1</sup>	R <sup>2</sup>	R <sup>3</sup>	R <sup>4</sup>	R <sup>5</sup>	R <sup>6</sup>	R <sup>7</sup>	
<b>59</b>	H	β-OH	Me	H	Me	COOH	Me	C(21)-C(22)
<b>86</b>	H	β-OH	Me	H	Me	Me	Me	C(21)-C(22)
<b>74</b>	H	β-AcO	Me	H	Me	Me	Me	C(21)-C(22)
<b>63</b>	H	β-OH	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	H	Me	COOH	Me	C(21)-C(22)
<b>64</b>	H	β-OH	Me	H	( <i>Z</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	Me	COOH	C(21)-C(22)
<b>95</b>	H	β-OH	Me	H	( <i>Z</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	COOH	Me	C(21)-C(22)
<b>97</b>	OH	β-OH	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	H	Me	COOH	Me	C(21)-C(22)
<b>98</b>	H	β-OH	Me	=O	Me	COOH	Me	C(21)-C(22)
<b>99</b>	H	β-OH	HO-CH <sub>2</sub>	H	Me	COOH	Me	C(21)-C(22)
<b>101</b>	H	β-OH	Me	H	HO-C <sub>6</sub> H <sub>4</sub> -OCH <sub>2</sub>	COOH	Me	C(21)-C(22)
<b>100</b>	H	β-OH	Me	H	COOH	HO-C <sub>6</sub> H <sub>4</sub> -OCH <sub>2</sub>	Me	C(21)-C(22)
<b>102</b>	H	β-OH	Me	H	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	COOH	Me	C(21)-C(22)
<b>106</b>	H	β-OH	Me	H	Me	COOH	Me	C(21)=C(22)
<b>60</b>	OH	β-OH	Me	H	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	COOH	Me	C(21)-C(22)
<b>61</b>	OH	β-OH	Me	H	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	Me	Me	C(21)-C(22)
<b>65</b>	H	β-OH	Me	H	Me	Me	HO-OCH <sub>2</sub>	C(21)-C(22)
<b>81</b>	( <i>Z</i> )- <i>p</i> -Coum-O	β-OH	Me	H	Me	COOH	Me	C(21)-C(22)
<b>82</b>	( <i>E</i> )- <i>p</i> -Coum-O	β-OH	Me	H	Me	COOH	Me	C(21)-C(22)
<b>87</b>	H	β-OH	Me	H	HO-OCH <sub>2</sub>	Me	Me	C(21)-C(22)
<b>88</b>	H	β-OH	Me	H	Me	HO-CH <sub>2</sub>	Me	C(21)-C(22)
<b>52</b>	H	O	Me	H	Me	Me	Me	C(21)-C(22)
<b>55</b>	H	β-OH	Me	H	Feruloylo-OCH <sub>2</sub>	COOH	Me	C(21)-C(22)
<b>58</b>	H	β-OH	Me	H	Me	COOH	( <i>E</i> )- <i>p</i> -Coum-OCH <sub>2</sub>	C(21)-C(22)
<b>62</b>	H	Cinn	Me	H	Me	Me	Me	C(21)-C(22)
<b>66</b>	H	OAc	Me	H	Me	CH <sub>2</sub> -OH	Me	C(21)=C(22)
<b>69</b>	H	OAc	Me	H	Me	Me	Me	C(21)-C(22), C(5)=C(6)
<b>56</b>	H	OH	Me	H	Feruloyl	COOH	Me	C(21)-C(22)
<b>139</b>	OH	OH	Me	H	Me	Me	H	C(21)-C(22)
<b>140</b>	OH	OH	HO-CH <sub>2</sub>	H	Me	COOH	H	C(21)-C(22)

 Fig. 4 Chemical structures of phytochemicals isolated from various species of the genus *Plumeria*

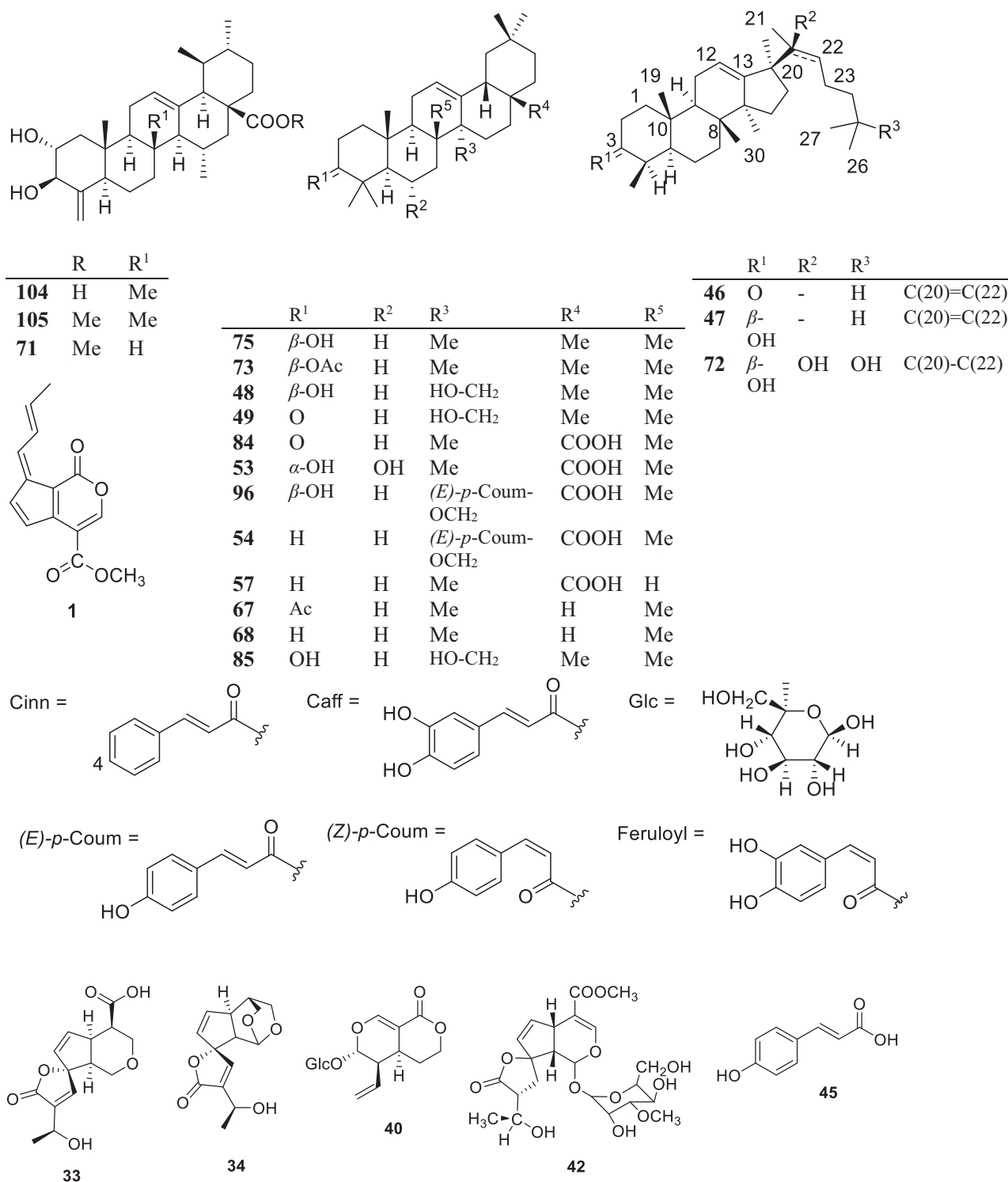


Fig. 4 (Continued)

in Fig. 4 [47], which comprises an unusual framework based on the cis-fused ring framework. Nitrogen-containing iridoids can, moreover, be classified as iridoid-related alkaloids [45].

#### Iridoids in *Plumeria* species

List of iridoids isolated from various species of the genus *Plumeria* is provided in Fig. 3. From the different parts of

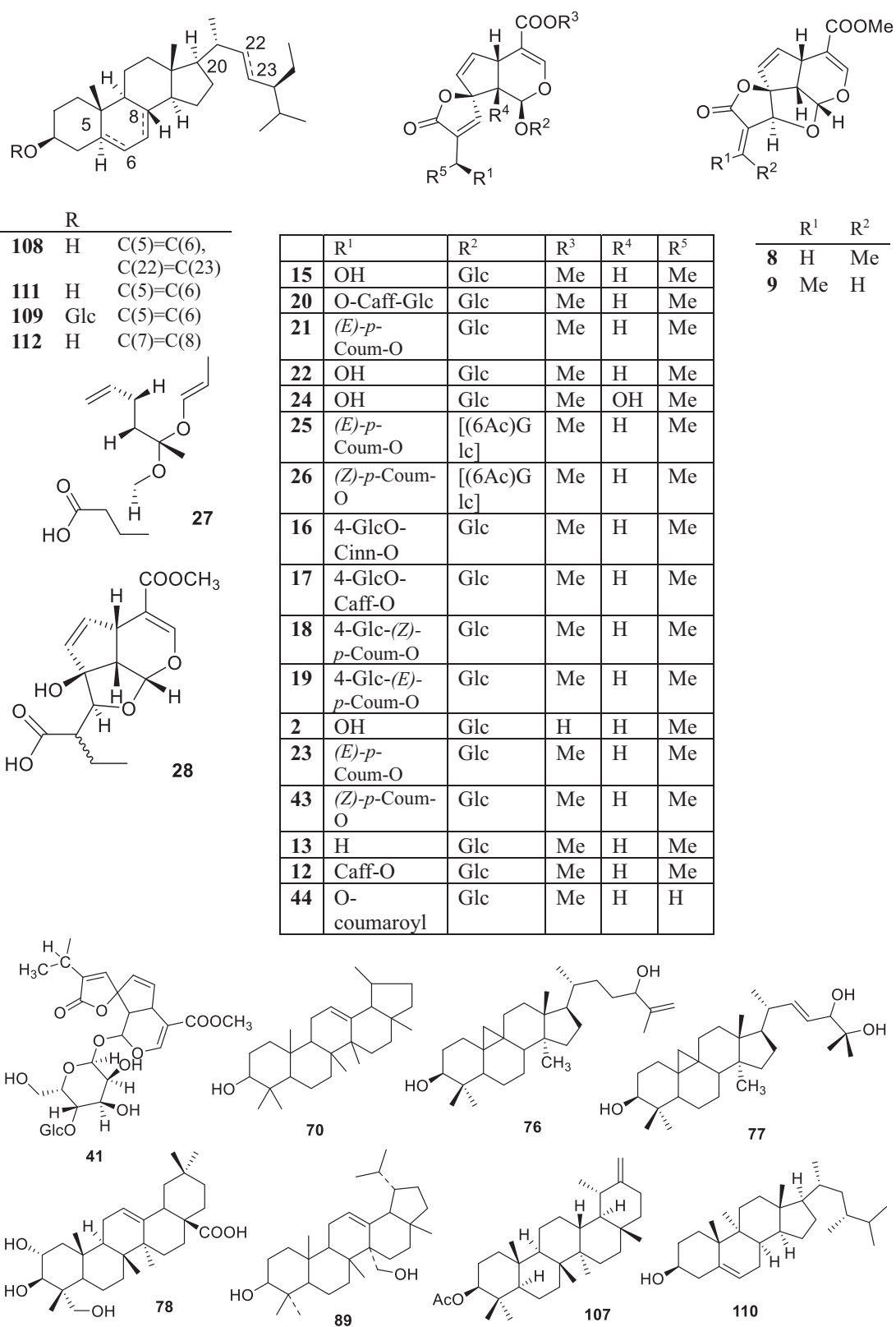
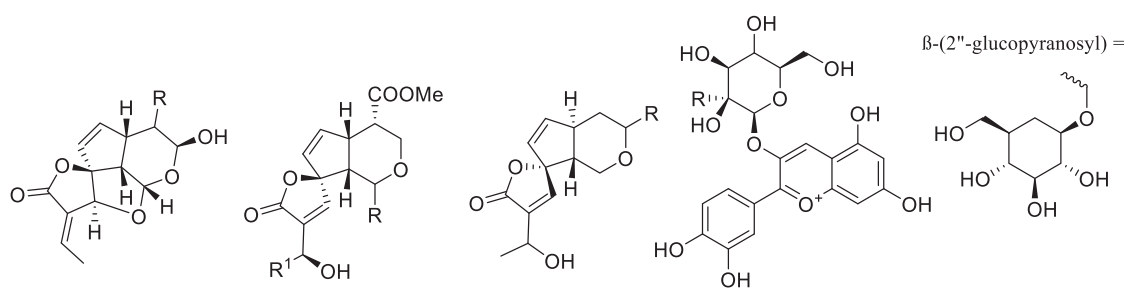


Fig. 4 (Continued)

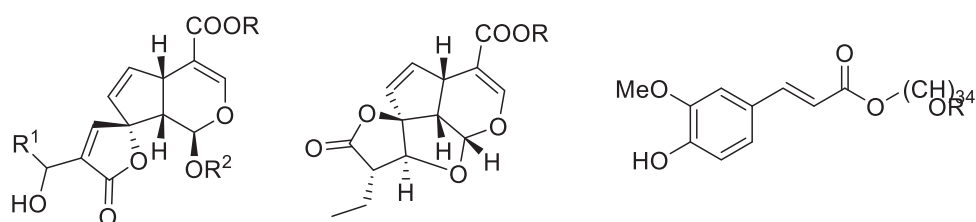


**5** R=H  
**32** R=COOMe  
**31** R=H

	R	R <sup>1</sup>
<b>3</b>	$\alpha$ -OH	-
<b>4</b>	$\beta$ -OH	-
<b>6</b>	$\alpha$ -OH	$\alpha$ -OAc
<b>7</b>	$\beta$ -OH	$\beta$ -OAc

**35** R=  $\alpha$ -OH  
**36** R=  $\beta$ -OH

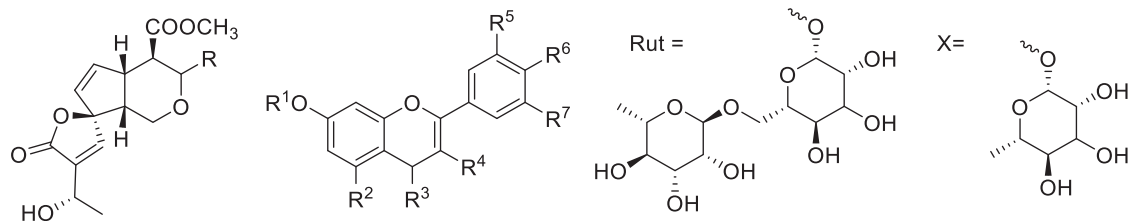
**141** R=  $\beta$ -(2''-glucopyranosyl)  
**142** R=H



	R	R <sup>1</sup>	R <sup>2</sup>
<b>11</b>	Me	Me	Glc
<b>38</b>	Me	$\Phi$ -OH	Glc
<b>37</b>	Me	Me	H

**10** R= Me  
**39** R= H  
**14** R= Glc

**144** R= H  
**145** R= Ac



**29** R=  $\alpha$ -OAc  
**30** R=  $\beta$ -OAc

	R <sup>1</sup>	R <sup>2</sup>	R <sup>3</sup>	R <sup>4</sup>	R <sup>5</sup>	R <sup>6</sup>	R <sup>7</sup>	
<b>113</b>	H	OH	C=O	Rut	OCH <sub>3</sub>	OH	H	C(2)=C(3)
<b>114</b>	H	OH	C=O	Rut	H	OH	H	C(2)=C(3)
<b>115</b>	Me	OH	C=O	OCH <sub>3</sub>	H	OCH <sub>3</sub>	OH	C(2)=C(3)
<b>116</b>	H	OH	C=O	OH	H	OH	H	C(2)=C(3)
<b>117</b>	Me	OH	C=O	OH	H	OCH <sub>3</sub>	OH	C(2)=C(3)
<b>118</b>	H	OH	C=O	X	OH	OH	H	C(2)=C(3)
<b>119</b>	H	OH	C=O	OH	H	OH	OH	C(2)=C(3)
<b>120</b>	Me	CH <sub>2</sub> -OGlc	CH <sub>3</sub>	OH	OCH <sub>3</sub>	OH	OCH <sub>3</sub>	C(2)-C(3)
<b>121</b>	X	OH	C=O	H	H	OGlc	H	C(2)-C(3)
<b>122</b>	Glc	OCH <sub>3</sub>	H	OH	OCH <sub>3</sub>	OH	OCH <sub>3</sub>	C(2)-C(3)

Fig. 4 (Continued)



*P. rubra*, fulvoplumericin (1), 15-demethyl-plumieride (2),  $\alpha$ -allamcidin (3),  $\beta$ -allamcidin (4), allamcin (5),  $\alpha$ -allamcidin diacetate (6),  $\beta$ -allamcidin diacetate (7), plumericin (8), isoplumericin (9),  $\beta$ -dihydro-plumericin (10), agoniadin (22), plumieride-*p*-(*E*)-coumarate (23), plumeridoids A (27), plumeridoids B (28), plumeridoids C (29), epiplumeridoids (30), allamandin (32),  $\beta$ -dihydro plumiericinic acid (39), plumieride-*p*-(*Z*)-coumarate (43), *p*-*E*-coumaric acid (45) have been isolated. Plumericin (8), 8-isoplumieride (11), 13-*O*-caffeoyl plumieride (12), 13-deoxy plumieride (13), plumenoside (14), 1 $\alpha$ -plumieride (15), 1 $\alpha$ -protoplumericin A (16), protoplumericin B (17), 1 $\alpha$ -protoplumericin B (18), 1 $\alpha$ -protoplumericin C (19), 13-*O*-caffeoyl-15 demethyl plumieride (20), 15-demethyl plumieride *p*-*E*-coumarate (21), agoniadin (22), sweroside (40), 13-*O*-coumaroyl plumieride (44) have been reported in different parts of *P. acutifolia*. Isolated reported phytochemicals from *P. alba* are 1 $\alpha$ -plumieride (15), agoniadin (22), plumieride-*p*-(*E*)-coumarate (23), plumieride-*p*-(*Z*)-coumarate (43). Iridoids isoplumericin (9), 1 $\alpha$ -plumieride (15), and 3-*O*'-methyl plumeride (42) have been isolated from the species *P. dichotoma*.

## Triterpenoids

### Classification

Triterpenoid saponins, natural sugar conjugates of triterpenes, are common in many dicotyledonous plants, whereas they are rarely found in monocots. These compounds contain linear or branched oligosaccharides attached to hydroxyl or carboxyl groups, forming the glycone fraction. Attachment sites can be one (monodesmosides), two (bisdesmosides), or three (tridesmosides). As components of cell membranes, these plant metabolites play a central role in defense mechanisms, biological efficacy, and cell fluidity.

### Types of triterpenoids and their structural variations

Classification of saponins based on aglycone skeleton structure produces six main types: Oleanane-like, Hederin-like, Lupane-like, Ursane-like, Fernane-1-like, and Fernane-2-like, determined by the chemical composition of the sapogenin arrangement (Fig. 5).

Among the triterpenoid saponins, Hederin, Oleanane, and Ursane share the same pentacyclic saponin backbone 6/6/6/6/6, which exhibits notable similarities beyond the variation in the C-23 substituent and position methyl group. In contrast, the Lupane-type saponins, Fernane-1 and Fernane-2, use a 6/6/6/6/5 pentacyclic saponin backbone, with differences mainly centered on the position of the isopropyl and carbonyl groups.

Rastogi and colleagues' excellent comprehensive reviews of triterpenoid saponins [48, 49] covered the literature until 1978. A thorough review of Saponins' chemical and

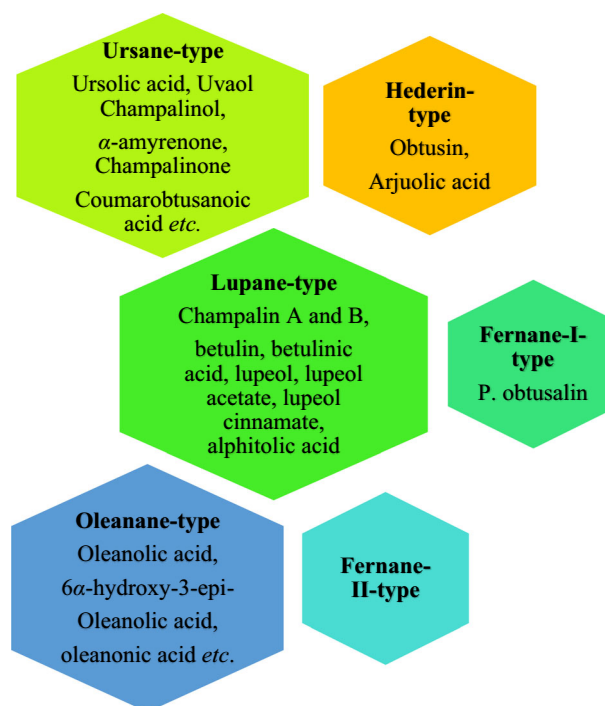


Fig. 5 Skeleton types of triterpenoids from *Plumeria* Linn

biological importance in food and animal feed has recently been presented [50]. A new review briefly discusses advances in the structural elucidation of triterpenoid saponins [51]. Adler and Hiller have also reviewed the bisdesmosidic triterpene saponins [52], with new findings on these substances appearing in addition to those reported above [53].

### Triterpenoids in *Plumeria* species

The triterpenoids found in various species of *Plumeria* and their biological and pharmacological activities are also reviewed, and their plant sources are listed in Table 1. Phytochemicals isolated from *P. rubra* are 6 $\alpha$ -hydroxy-3-epi-oleanolic acid (53), ursolic acid (59),  $\alpha$ -amyrin cinnamate (62), rubrinol (65),  $\beta$ -amyrin acetate (73),  $\beta$ -amyrin (75), cycloart-25-en-3 $\beta$ ,24-diol (76), cycloart-22-en-3 $\alpha$ ,25-diol (77), arjunolic acid (78), lupeol acetate (79), (3 $\alpha$ )-3,27-Dihydroxy-olean-12-ene (85), plumeric acid (104), methyl plumerate (105), taraxasteryl acetate (107). Phytochemicals extracted from *P. acutifolia* are ursolic acid (59), plumeriate (71), uvaol (88), lupeol (94), plumeric acid (104), methyl plumerate (105). From the species *P. bicolor*, phytochemicals isolated are  $\alpha$ -amyrin cinnamate (62), 3 $\beta$ -acetoxy plumerian-12-ene (67), 3 $\beta$ -Hydroxy plumerian-12-ene (68), 3 $\beta$ -acetoxyurs 5,12-diene (69), 29-devinylup-5-enol (70),  $\beta$ -amyrin (75), lupeol acetate (79),  $\alpha$ -amyrin (86). From the different parts of *P. obtuse*, various constituents are isolated, viz. champalin A (46), champalin B (47), champalinol (48), champalinone (49), betulin (50), betulinic acid (51),  $\alpha$ - amyrenone (52), uncarinic acid E (54), ursolic acid (59), obtusilic acid (64), (3 $\beta$ ,20S)-

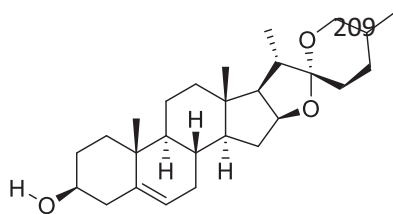


Fig. 6 Steroid glycosides

dammarane-3, 20, 25-triol (**72**), neriucoumaric acid (**81**), isoneriucoumaric acid (**82**), alphitolic acid (**83**), oleanonic acid (**84**),  $\alpha$ -amyrin (**86**), 3,27-dioxolup-12-ene (**90**), 3,11,27-trioxolup-12-ene (**91**), 27-hydroxy-3-oxolup-12-ene (**92**), 3-oxo-14-hydroxy-27-up-12-ene (**93**), 3 $\beta$ -Hydroxy-27-[(*Z*)-*p*-coumaroyl oxy]- urs-12-en-28-oic acid (**95**), obtusiniln (**96**), obtusin (**97**), obtusilin (**98**), 3,23-dihydroxyurs-12-en-28-oic acid (**99**), obtusidin (**100**), obtusinidin (**101**).

## Steroids

### Classification

Steroid glycosides are synthetic triterpenes with a structure consisting of a six-membered tetracyclic ring and a five-membered bicyclic ring containing 27 carbon atoms.

### Types of steroids and their structural variations

Steroid glycosides have two heterocyclic rings, one of which is a furan ring, and the other is a pyran ring—a common spirocarbon atom between two heterocycles (furanose and pyranose rings). Figure 6 shows an example of steroid glycosides [54]. Sterols include several major steroid groups characterized by a hydroxyl group at C3, usually in the  $\beta$  configuration, and a branched side chain of 8 to 10 carbon atoms at C17. They are common in all animals, especially those belonging to plant kingdoms [55].

### Steroids in *Plumeria* species

The sterols commonly isolated from higher plants are  $\beta$ -stigmasterol,  $\beta$ -sitosterol, campesterol, and lanosterol, which are also quite common. Five sterols from the various *Plumeria* species have been isolated: stigmasterol (**108**),  $\beta$ -sitosterol 3-*O*-glucoside (**109**),  $\beta$ -sitosterol (**111**), campesterol (**110**), and stigmast-7-en-3-ol (**112**) (Figs. 3, 4).

## Flavonoids

### Classification

Flavonoids, bioactive polyphenols of relatively low molecular weight [56, 57], are pivotal in cellular

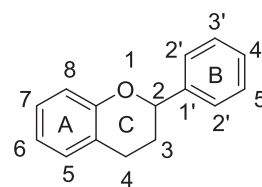


Fig. 7 Basic structure of flavonoids

photosynthesis [58, 59]. The exploration of flavonoids commenced in 1936, credited to Hungarian scientist Albert Szent-Gyorgi. He uncovered a synergistic interaction between pure vitamin C and unidentified cofactors extracted from lemon peels, initially calling them “flavonoids” before later referring to them as “vitamins P.” [60].

### Types of flavonoids and their structural variations

Flavonoids, characterized by a hydroxylated phenolic nature and a benzo- $\gamma$ -pyrone structure, are synthesized by plants in response to bacterial contamination [61]. These compounds exist as aglycones, glycosides, and methylated derivatives [62]. Numerous primary forms of flavonoid aglycones, flavonoids without sugars, are connected in plants. The fundamental chemical structure of flavonoids may be a diphenylpropane skeleton containing 15 carbon particles in its primary center [63]. Two benzene rings (rings A and B) are primarily connected by a third heterocyclic pyrene ring containing oxygen [64]. So, this structure is additionally called C6-C3-C6, labeled A, B, and C (Fig. 7) [65, 66].

Flavonoids can be categorized into different groups based on the carbon atom of the C ring to which the B ring is attached, as well as the level of unsaturation and oxidation of the C ring. The compounds are termed isoflavones when the B ring is linked to position 3 of the C ring [67]. If the B ring connects to position 4 of the C ring, they are called neoflavonoids. Substances where the B ring attaches to position 2 of the C ring can be further subdivided into various groups according to the fundamental characteristics of the C ring. This subgroup comprises flavones, flavonols, flavanones, flavanonols, flavanols (catechins), and anthocyanins [68–70] (Fig. 8).

### Flavonoids in *Plumeria* species

Eleven flavonoids (**113–123**) have been extracted from the *Plumeria* species. From *P. rubra*, quercetin (**119**), plumerubroside (**120**), rubranoside (**121**), from *P. obtuse* glochiflavanoside B (**122**), methyl *p*-(*E*)-coumarate (**123**), and *P. acutofolia* narcissin (**113**), kaempferol-3-rutinoside (**114**), ayanin (**115**), kaempferol (**116**), pillion (**117**), quercitrin (**118**).

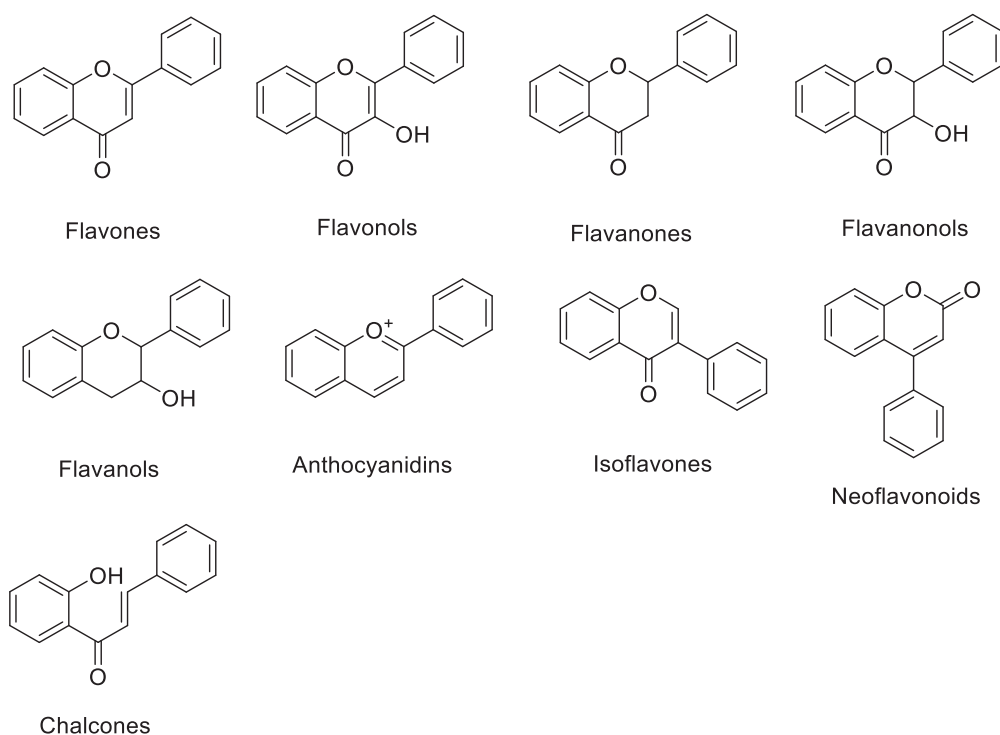


Fig. 8 Different types of flavonoids and their chemical structures

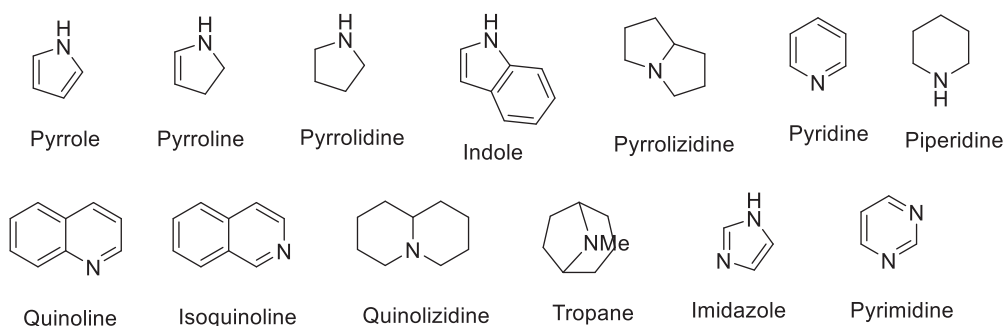


Fig. 9 Heterocyclic structures of the skeleton constituting the group of alkaloids

## Alkaloids

### Classification

Alkaloids are heterocyclic nitrogen compounds [71]. Nitrogen is the only distinguishing feature of all alkaloids. Amino acids like tryptophan, tyrosine, and lysine are the primary metabolites from which they are derived.

### Types of alkaloids and their structural variations

The primary alkaloid isolation happened in the 19th century after several alkaloid-containing drugs were presented in pharmaceuticals. The dissemination of alkaloids concurring with the essential structure of the C-N skeleton is the foremost exact and common way of classifying alkaloids

(Fig. 9). The alkaloids are partitioned into the taking after fundamental bunches: pyrrolidine, pyridine, quinoline, indole, quinazoline, steroids, and diterpenoids. Depending on the structure of its representatives, each group is divided into different subgroups [72].

### Alkaloids in *Plumeria* species

Eleven alkaloids, **124–134**, have been isolated from the *Plumeria* species so far (Fig. 4). From the species *P. rubra*, plumerinine (**129**) and plumeridine (**130**) have been isolated. Six alkaloids have been identified in the species *P. acutofolia* viz. laurelliptine (**124**), phoebegrandine B (**125**), plumeridine (**130**), grandine A (**132**), grandine B (**133**), grandine C (**134**), vincubin (**131**) in *P. Seriflia* and two phytochemicals named uleine (**126**) and demethoxyaspido-

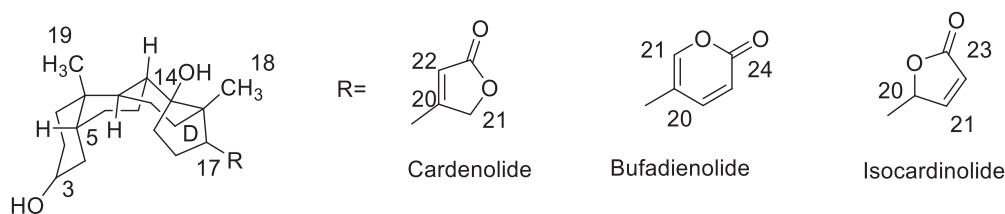


Fig. 10 Structures of cardiac glycosides

spermine (**127**) in species *P. lancifolia* have been isolated [73].

## Cardiac glycosides

### Classification

The most significant number of druglike molecules that have been investigated in multiple studies and were found to be beneficial for the development of potential drugs has been cardioglycaemic glycosides, a type of glycosylation molecule [74–78]. These are chemical compounds that poison pets and treat congestive heart failure.

### Types of cardiac glycosides and their structural variations

Cardiac glycosides represent a class comprising two significant groups of compounds, each with distinct aglycone structures, illustrated in Fig. 10. These glycosides are C23 or C24 steroids wherein the standard cyclopentanoperhydrophenanthrene core at C17 is replaced. Cardenolides feature a five-membered lactone group at C17, having an unsaturated  $\gamma$ -lactone ring (butenolide), whereas the other group, bufadienolide, was initially identified as a toxin in toad skin. The C17 substituent bears a doubly unsaturated six-membered lactone ring ( $\alpha$ -pyrone). Plants can synthesize both cardenolides and bufadienolides. An additional subgroup, isocardenolide, exhibits the double bond of the butenolide ring positioned at either 21 or 22 instead of the conventional 20, as depicted in Fig. 10.

### Cardiac glycosides in *Plumeria* species

*P. obtuse* produced the cardiac glycosides oleandrine (**135**) and kaneroside (**136**), which were isolated (Fig. 4) [79–81].

## Quinones

### Classification

The quinones are a class of organic compounds that are formally “derived from aromatic compounds [such as benzene or naphthalene] by conversion of an even number of

–CH= groups into –C(=O)– groups with any necessary rearrangement of double bonds,” resulting in “a fully conjugated cyclic dione structure” [82–84].

### Types of quinones and their structural variations

The prototype member of this class is 1,4-benzoquinone, also known simply as “quinone” or cyclohexadienedione. Given that this compound is one of the products of quinic acid oxidation, its name is derived from quinic acid with the suffix “one,” indicating a ketone [85]. Other notable examples include 1,2-benzoquinone (*o*-quinone), 1,4-naphthoquinone, and 9,10-anthraquinone [86].

### Quinones in *Plumeria* species

From *P. rubra*, the quinones 2,5-dimethoxy-*p*-benzoquinone (**137**) and 2,6-dimethoxy-*p*-benzoquinone (**138**) were isolated (Fig. 4).

## Nor-Terpenoids

### Classification

By removing one or more carbon atoms from their carbon skeletons, nor terpenoids are a class of organic compounds that derive from terpenoids.

### Types of nor-Terpenoids and their structural variations

Terpenoids derived from five-carbon isoprene units are a comprehensive and diversified class of natural chemical substances. The prefix “nor” means something has been reduced in size compared to its parent compound. This reduction usually involves the removal of methyl groups or other carbon-containing moieties from the terpenoid structure in the case of nor-terpenoids.

### Nor-terpenoids in *Plumeria* species

From *P. rubra*, the nor-terpenoids *P. rubra*jaleelol (**139**) and *P. rubra*jaleelic acid (**140**) were separated (Fig. 4).

## Anthocyanins

### Classification

One of the most exciting groups of polyphenols is anthocyanins. These compounds, identified from their glycosylation form [86], are generally considered one of the largest groups of naturally occurring water-soluble phenolic compounds. Anthocyanins, which can produce colors ranging from red to blue, are present in many plants and natural products.

### Types of anthocyanins and their structural variations

Anthocyanins derive their structure from the central framework of flavonoids [87]. Chemically, they are 2-phenylbenzopyrylium compounds composed of an aromatic ring (A) linked to a heterocyclic pyran (C), which connects to an aromatic core. A carbon-carbon bond strengthens the B aromatic ring. This ring can exhibit various hydroxylation and methoxylation patterns, with hydroxyl groups typically present at C3, C5, and C7. Additionally, the carbon atoms within the core structure can undergo glycosylation with other sugars [88] (Fig. 11).

Only the glycosylated structure is called anthocyanin, while the non-glycosylated structure is anthocyanidin and is considered an anthocyanin precursor. Anthocyanins have many structural features, from simple mongolcosides to complex structures involving multiple types of glycosylation and acylation, and to date, more than 700 have been described [88–93].

### Anthocyanins in *Plumeria* species

Two anthocyanins, cyanidin 3-*O*- $\beta$ -(2''-glucopyranosyl-*O*- $\beta$ -galactopyranoside) (**141**) and cyanidin-3-*O*- $\beta$ -galactopyranoside (**142**) were isolated from the flowers of *P. rubra*.

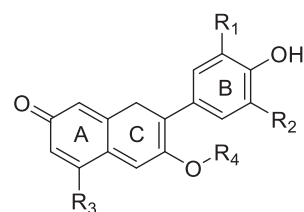
## Cardenolides

### Classification

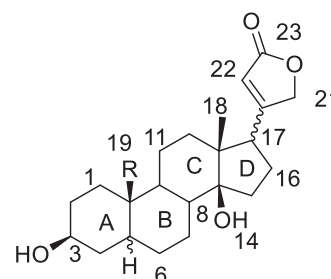
Cardenolides, a group of steroid-derived compounds found naturally in plants, exist as glycosides or free genins (lactones plus steroids) [77].

### Types of cardenolides and their structural variations

These compounds display diverse chemical structures but share standard features, including a 23-carbon steroid core with A/B and C/D rings in *cis* form (unlike sex hormones and corticosteroids) [94], an unsaturated  $\gamma$ -lactone (furanone) at C17, a  $\beta$ -hydroxyl group at C14,  $\beta$ -methyl groups



**Fig. 11**  $R_1 = \text{H, OH or OCH}_3$ ;  $R_2 = \text{H, OH or OCH}_3$ ;  $R_3 = \text{OH or sugar moiety}$ ;  $R_4 = \text{sugar moiety}$



**Fig. 12** Basic structure of cardenolides

at C10 and C13, and a glycosidic moiety at C3 [95]. Some may also bear substituents like hydroxyl, formyl, or acetyl groups at C16 (Fig. 12) [96, 97].

Recent findings indicate that the genin or aglycone segment is the pharmacologically active site or pharmacophore [77]. However, cardenolide manifests its activity when it contains at least one hydroxyl group or a sugar comprising one to five C3 monosaccharides [94]. Various sugars have been identified, including pentoses, hexoses, deoxy sugars, and others [96, 97]. While the glycoside component lacks pharmacological activity, it influences this compound family's pharmacodynamic and pharmacokinetic properties, as discussed in [77, 96, 98]. Furthermore, the type of sugar attached impacts the potency of the compound, with monosaccharides and substances with a  $3\beta$ -hydroxyl group demonstrating higher activity than disaccharides, trisaccharides, or aglycones [96, 97, 99–102].

### Cardenolides in *Plumeria* species

*P. obtuse* yielded a single cardenolide named 3-epidigitoxigenin (**143**), which was isolated [103–105].

## Fatty Acid Esters

From the *Plumeria* species, four fatty acid esters, 34-hydroxy tetratri-acontanyl ferulate, 34-*O*-acetyl-tetratri-acontanyl ferulate, methyl *n*-octadecanoate, and lupeol fatty acid esters I numbered **144–147**, respectively have been isolated.

## Lignans

### Classification

Lignans, a class of secondary metabolites resulting from the oxidative dimerization of two phenylpropanoid units, are widely distributed throughout the plant kingdom. These compounds have been discovered in the roots, rhizomes, stems, bark, leaves, seeds, and fruits of over 70 plant families [106].

### Types of lignans and their structural variations

Although lignans are composed only of two phenylpropane C6–C3 units, their molecular backbone contains a sizeable structural diversity due to the various patterns of linkage for these phenylpropane units on which classification is based. The benzene ring is most lignans' C6 partial structure of the phenylpropane unit [106].

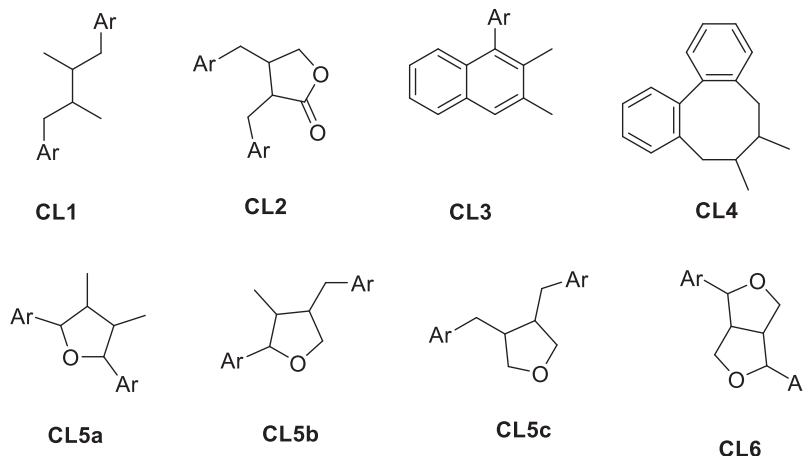
Traditionally, there are two types of lignan: regular lignan and neolignan. Classical lignans consist of phenylpropane dimers connected through a  $\beta$ - $\beta'$  (8-8') linkage, while neolignans encompass similar dimers featuring this  $\beta$ - $\beta'$  bond. Classical lignans include six subgroups: dibenzyl butanes (CL1), dibenzylbutyrolactones (CL2), aryl naphthalenes (CL3), dibenzocyclooctadienes (CL4), substituted tetrahydrofurans (CL5a-c) and 2,6-diarylfurofurans (CL6) (Fig. 13), and neolignans are made up of fifteen subtypes (NL1 to NL15) (Fig. 14).

Other sorts of lignans [107–115], such as oligomeric lignans, hybrid lignans, and norlignans, have also been detailed, other than conventional lignans and neolignans.

### Lignans in *Plumeria* species

From *P. rubra*, the lignan liriodendrin (148) was isolated.

**Fig. 13** Subtypes of classical lignans (Ar = aryl): **CL1** (dibenzylbutanes); **CL2** (dibenzylbutyrolactones); **CL3** (arylnaphthalenes); **CL4** (dibenzocyclooctadienes); **CL5a** (2,5-diaryltetrahydrofurans); **CL5b** (2-aryl-4-benzyltetrahydrofurans); **CL5c** (3,4-dibenzyltetrahydrofurans); **CL6** (2,6-diarylfurofurans)



## Coumarins

### Classification

Coumarins are classified into various types: simple coumarins, furanocoumarins, pyranocoumarins, pyrone-substituted coumarins.

### Types of coumarins and their structural variations

Simple coumarins [116–123], which feature a hydroxylated, alkoxyated, or alkylated radical on the benzene ring; furanocoumarins, characterized by a furan ring attached to the benzene ring; pyranocoumarins, distinguished by a pyran ring connected to the benzene ring; and pyrone-substituted coumarins, wherein substitution typically occurs on the pyrone ring, often at the 3-C or 4-C position.

### Coumarins in *Plumeria* species

Two coumarins, identified as scopoletin (149) and rel-(3R,3'S,4R,4'S)-3,3',4,4'-tetrahydro-6,6'-dimethoxy[3,3'-bi-2*H*-benzopyran]-4,4'-diol (150), have been isolated from *P. rubra* and have been reported [124–126].

### Other

*P. rubra* and *P. acutifolia* have been reported to contain six more compounds: *P. rubra*nin, cerberic acid B, 1-(*p*-hydroxyphenyl) propan-1-one, 2,3 dihydroxypropyl octacosanoate, *L*-(+)-bornesitol and 2,4,6-trimethoxy aniline numbered (151–156).

## Pharmacological activities

Because of their vast range of pharmacological properties, plants in the genus *Plumeria* are frequently employed in

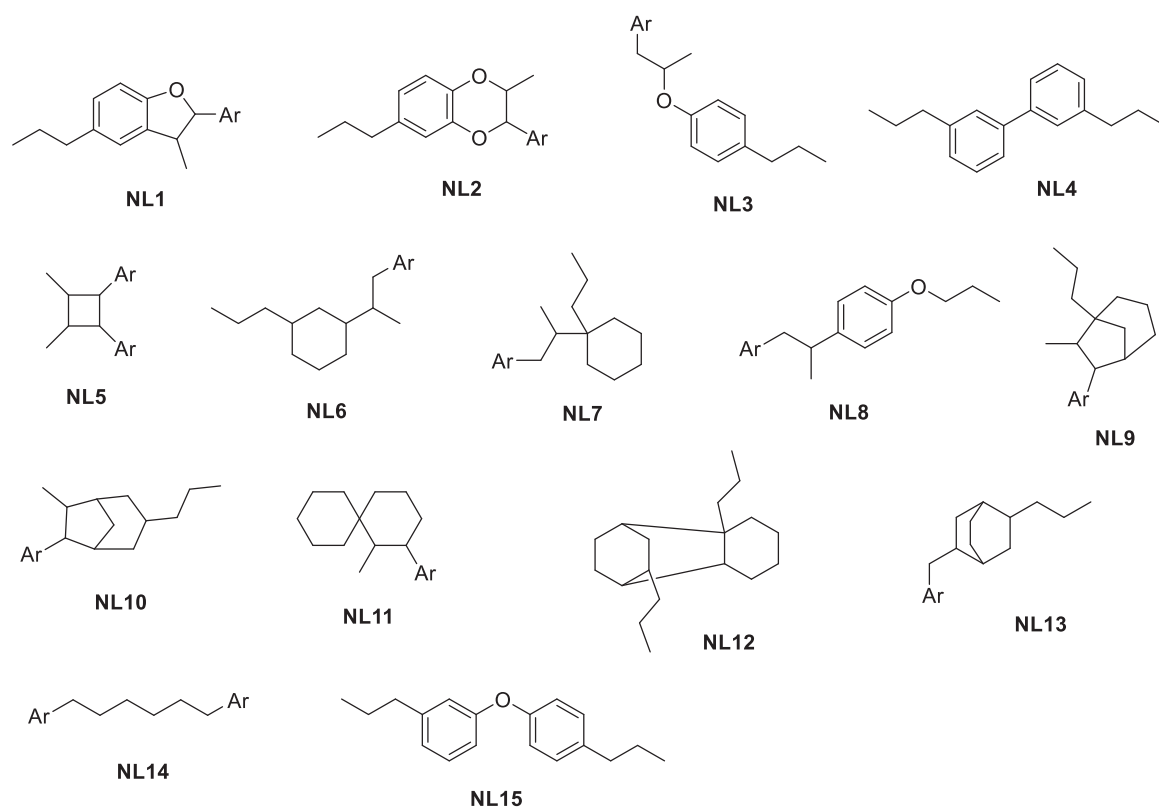


Fig. 14 Subtypes of neolignans (Ar = aryl)

traditional medicine [11]. The extracts and substances from this genus have been shown to have substantial antioxidant, analgesic, anti-inflammatory, antidiabetic, anticancer, estrogenic/antiestrogenic, antibacterial, and anti-hyperglycemic activity in accumulating pharmacological research (Table 1).

### Antitumor effects

By effectively stopping tumor growth, the ethanolic leaf extract of *P. rubra* could prolong the lives of EAC albino male Swiss mice administered at 200 and 400 mg per kg body weight over their lifetimes [127]. Likewise, methanolic leaf extract showed recovery of hemoglobin and red blood cell counts, a significant decrease in tumor volume and lipid peroxidation, and an increase in GSH, SOD, and CAT levels in mice bearing EAC tumors [128]. The ethanolic extract of the flowers showed cytotoxicity against the HepG2 cell line, inducing apoptosis at this concentration, and showing anticancer activity [129]. Compounds **1** [130], **5** [130, 131], **8** and **9** have been isolated from the bark of *P. rubra*. Lignan **148** [132] and quinone **137** [131] showed moderate activity against various human cancer and murine lymphocytic leukemia cell lines [130]. The six compounds isolated from plant heartwood, **8**, **9** and 4-hydroxyacetophenone showed varying antibacterial and

cytotoxic activity [133]. Moreover, the fraction of petroleum hydrocarbons showed high cytotoxic activity against HepG2, HCT116, and MCF-7 cell lines and moderate or lower activity levels in other fractions. Ethanolic stem bark extract has been toxic to T47D cells but not to lymphocytes with an LC<sub>50</sub> of 273.744 gm [134]. The triterpenes **104** and **105** [11], the iridoids **22** [135], **20** [136], **2** [130], **18** and **19** [137] were found to have antitumor action. Alkaloids **130** [138] and **131** also showed antileukemic activity.

The methanol extract from *leaves of P. alba* has a potent antitumor activity against Dalton's lymphoma in mice. The results indicate that a methanolic extract from *P. alba* has been shown to significantly extend the lives of host mice, reduce tumor size, and improve hematological parameters [139].

### Antimutagenic effects

Antibacterial substances were extracted from the organic hexane and carbon tetrachloride fractions, followed by a micronucleus test to assess their antimicrobial activity. According to this hypothesis, a vital role of the antimutagenic activity detected in these isolates is that all three isolated antibacterial substances have been found to contain a hydroxyl group, particularly in the 3rd position [140]. From ethanol extract of the green leaves of *P. acuminata*,

59, 79, 112 [140], and 103 [11], these four isolates exhibited antimutagenic activity.

## Antimicrobial effects

### Antibacterial and antifungal activity

The MIC value of 125 µg/mL and the MBC/MFC value of 250 µg/mL indicated antibacterial solid activity in ethanolic stem bark extract compared to different bacteria and fungi. The various pieces of stem bark from *P. rubra* were characterized by multiple antibacterial activities. When the MICs of 7.81 g/mL and 3.9 g/mL were compared against some strains, a fraction of ethyl acetate showed comparable efficacy to amphotericin B and gentamicin [141]. Nevertheless, resistance to all fractions selected was found in *Pseudomonas aeruginosa* [142]. In comparison to ciprofloxacin and against fungal strains with MIC values of 50 g per mL compared to fluconazole, methanolic bark extract has significant activity against certain bacterial strains with MIC values of 25 g per mL [143]. The essential oils extracted from *Plumeria* flowers showed varying antibacterial action against the bacteria tested, indicating that gram-positive strains are more susceptible. Inhibition zone diameter ranges from 6.8 to 221.3 mm and MICs of 2.8 to 46.5 mg/mL, respectively [144]. Previous studies have investigated the antibacterial activity using a disk diffusion method. It is recommended that these results be complemented with more relevant MIC tests, as disk diffusion methods are inherently limited [145–147].

The agar disc diffusion method investigated methanolic extract's in vitro antibacterial properties from *P. acuminata*. The crude methanol extracts MEPA inhibited the growth of both gram-positive bacteria (*Micrococcus luteus*, *Bacillus subtilis*, *Staphylococcus aureus*) and gram-negative bacteria (*P. aeruginosa*, *Escherichia coli*, *Salmonella typhimurium*). The tested gram-positive bacteria were more susceptible to the extract than the gram-negative bacteria [148].

The essential oil of the *P. alba* flower was evaluated against various microorganisms. The results show that gram-negative bacteria are the least susceptible to the effects of many other plant essential oils. The flower parts of *P. alba* were more effective in *S. aureus* and *B. subtilis* but also significantly inhibited growth at lower concentrations [149].

Rubrinol's antimicrobial tests [150] showed its effectiveness against *P. aeruginosa*, *P. pseudomallei*, *B. anthracis*, and *Corynebacterium pseudodiphthericum*. *P. acutifolia* was also the source of three novel alkaloids, 132–134 [151], as well as 125 and 124 [152] and [153], respectively. From the bark and leaves, three main iridoids were isolated: plumieride [137], 16 [137], and 2 [130]. Among the phytochemicals found in *P. rubra* are lignan

148 from its bark [132], 137 [131] from its stem bark, 123 [11] from its leaves, 8 [39], 15 [137], 22 [135], 59 [140], 62 [154], 79 [140], 86 [155], 109 [156], 111 [157] against various pathogenic fungus and bacteria.

Iridoids such as 8, 9 [39], 27, and 28 [131], alongside 5 [130, 131], 62 [154], triterpenoid 79 [140], 80 [14], quinone 138 [131], and other compounds like 153 [131] have demonstrated fungicidal activity.

### Anthelmintic activity

The methanolic stem bark extract of *P. rubra* showed dose-dependent anthelmintic activity, especially at 50 mg/mL, and was more effective than piperazine citrate (15 mg/mL) against *Pheretima posthuma* worms [158]. Similarly, against laboratory nematodes, methanol leaf extract at 25 and 50 mg/mL was as effective or more effective than piperazine citrate at 15 and 50 mg/mL [159].

### Antimalarial activity

A dose-dependent antimalarial effect was observed in aqueous and chloroform extracts of *Plumeria* bark. The aqueous extract inhibited the growth of parasites by 74.1, 76, and 80.3% in inhibition, treatment, and prevention tests, respectively, at 200 mg/kg per day. An inhibition of 60, 62.7, and 64.1% was observed with the chloroform extracts. A comparison was made with chloroquine (5 mg/kg/day) [160]. On the other hand, the hydroalcoholic extract of dried *P. rubra* shoot is a potent protozoan against chloroquine-susceptible 3D7 strain and chloroquine-resistant RKL9 strain of *P. falciparum* with IC<sub>50</sub> values of 2.678 µg/mL and 2.389 µg/mL, respectively [161].

### Antiviral activity

Petroleum ether extract of *Plumeria* bark showed 35% inhibition against HIV-1 RT at 200 µg/mL, and further chromatography yielded an active fraction showing 70% inhibition at the same concentration. The IC<sub>50</sub> value for 1, an iridoid isolated from the extract, was 45 g/mL compared to HIV-1 RT. However, there was no evident inhibitory effect from water or CHCl<sub>3</sub> extracts. Tannins, known as RT inhibitors, have been removed from plant extracts before testing based on their activity, and they were not set out with any unique thresholds [162].

### Larvicidal activity

Compared to the aqueous crude latex extract (1000, 500, 250, 125, 62.50, 31.25 ppm), silver nanoparticles (AgNPs) prepared from the latex of *Plumeria* were found to be highly toxic to larvae *Anopheles stephensi* and *Aedes aegypti* at



different concentrations (10, 5, 2.5, 0.625, 0.3125 ppm), It has a robust larvicidal effect. Toxicity studies have not shown toxicity at LC<sub>50</sub> or LC<sub>90</sub> AgNP doses in the nontarget fish species *Poecilia reticulata* [163].

### Anti-inflammatory and analgesic effects

The extract (500 mg kg<sup>-1</sup> body weight) showed the most excellent anti-inflammatory effect. E.g., carrageenan, dextran, histamine, and serotonin were 30.51, 47.06, 34.48, and 32.50% ( $p < 0.001$ ), respectively, at the end of 3 h. Administration of MEPA (500 mg kg<sup>-1</sup> body weight) and indomethacin (10 mg kg<sup>-1</sup> body weight) significantly reduced the granulomatous tissue formation induced by the cotton pellet method by 45.06 and 51.57%, respectively [164]. **128** (10, 25, and 50 mg/kg body weight) from a methanolic root bark extract caused a dose-dependent decrease and a similar effect to indomethacin (10 mg/kg body weight). A significant inhibitory effect on edema and granuloma tissue formation was shown by Vijayalakshmi et al. [165]. A latex-derived protease, Plumerin-R, showed a reduction in carrageenan-induced paw edema comparable to indomethacin (10 mg/kg) at various doses [166]. Furthermore, it also showed anti-irritant and anti-inflammatory effects compared to betamethasone (1 mg/kg) [167]. *P. rubra* methanolic leaf extract (100 and 200 mg/kg body weight) showed inhibition of carrageenan-induced paw edema in rats, with the highest inhibition at 200 mg/kg body weight and indomethacin Comparable (10 mg/kg) [159]. In different pain and inflammation models, ethanol bark extract (250 mg or 500 mg per kg) bodyweight in *P. rubra* is very active compared with diclofenac sodium 10 mg/kg body weight [168]. At 200 mg/kg, the triterpenoids **50** [169], **79** [140], and **62** [154] reduced the production of edema by 35.9%. However, at 100 mg/kg, no effect was seen. Methanol extract of *P. acuminata* leaves exhibits significant anti-inflammatory effects against dextran-, histamine-, carrageenan-, and serotonin-induced inflammation in a rat hind paw edema model. These results show that methanol extract has a substantial inhibitory effect against inflammation in the experimental animal models studied.

### Antiarthritic activity

The hydroalcoholic stem bark extract of *P. rubra* at oral doses of 250 and 500 mg/kg body weight significantly increased body weight and spleen index over 14 days in complete Freund's adjuvant (CFA)-induced arthritis in male albino Wistar rats, compared to a standard oral dose of piroxicam 10 mg/kg. In addition, this extract also significantly reduced the biochemical, behavioral, radiological, and hematological changes caused by CFA that showed significant antiarrhythmic activity [170].

### Antialgal effects

In iridoids **22** [135], **9** [39], **16** [137], **8** [39], plumierides **23**, **25**, **26** [171], **27**, **28** [131], **43** [171], **5** [130, 131], **44** [137], **45** [131], triterpenoid **79** [140] with other substances **153** [131], algicidal properties are demonstrated.

### Anesthetic effects

Anesthetic activity was detected in the triterpenes **104** and **105** [11, 172].

### Antipyretic and antinociceptive activity

In Wistar albino rats, a methanolic extract of 100, 250, and 500 mg/kg of plant leaves effectively treats brewer's yeast hyperthermia compared with paracetamol at 500 mg/kg body weight for 23 h. Later, the rectal temperature was lowered to 37.3 °C (100 mg/kg) at 37.2 °C. It also showed a significant antinociceptive effect in Swiss albino mice, reducing acetic acid-induced orthographic and tail motor responses comparable to aspirin [173, 174]. In addition, in albino rabbits, ethanolic extract from *P. rubra* leaves (200 mg/kg body weight, compared to aspirin 10 mg/kg body weight, significantly reduced the incidence of boil fever [175]. Similarly, methanol bark extract reduced the rise in body temperature in a yeast-induced fever model and showed significant dose-dependent activity compared to aspirin [176].

Furthermore, methanol bark extract effectively suppressed fever induced by rabbit typhoid vaccine and prostaglandin E (PGE1) at 100 mg/kg body weight and 200 mg/kg body weight, respectively, as well as paracetamol and aspirin, respectively [177]. In rats, a significant reduction of brewer's yeast hyperthermia was observed with only one orally administered methanol extract at various doses between 250 and 500 mg/kg. In mouse antinociception experiments, methanolic extract of *P. acuminata* has also been found to have significant inhibitory effects on acetic acid-induced writhing response, hot plate responses, tail movements, and tail dipping [174].

### Antioxidant activity

The methanol leaf extract of the plant increased the peroxidation inhibition of linoleic acid emulsion by 46.01, 52.83, 57.43, 61.38, and 73.14% it showed that it was at 50, 100, 200, 300, 400, and 500 µg/mL concentrations, respectively. The reduced power and scavenging capacity of DPPH, nitric oxide radicals, superoxide, and hydroxyl radicals increased dose-dependently. The IC<sub>50</sub> values for catechin and superoxide removal were 5.27 and 72.39 µg/mL, respectively [173, 174]. Furthermore, protein

fractions from *P. rubra* latex effectively inhibited total superoxide dismutase (SOD) and peroxidase activities at a concentration of 10 mg/mL [178]. In comparison, methanolic extracts of *P. rubra* flowers showed strong antioxidant activity. DPPH, iron-reducing antioxidant activity, metal chelates, hydrogen peroxide, nitric oxide, and superoxide scavenging among the tested extracts showed the highest inhibition in the test. It also exhibited significant xanthine oxidase (XO) inhibitory activity with 84.39% inhibition at 200  $\mu\text{g/mL}$  [179].

A significant antioxidant and free radical scavenging activity is demonstrated in the methanol extract of *P. acuminata*. The results showed that at different concentrations of 50, 100, 200, 300, 400, and 500  $\mu\text{g mL}^{-1}$ , methanol extract had dose-dependent antioxidant activity and 46.01, 52.83, 57.43, 61.38, 68.27, and 73.14% inhibition, respectively on peroxidation of linoleic acid.  $\alpha$ -tocopherol showed 81.21% inhibition at a concentration of 500  $\mu\text{g mL}^{-1}$  simultaneously [173].

### Antidiabetic and hypoglycaemic activity

Equivalent to the effects of glibenclamide 10 mg/kg orally, aqueous extract of *P. rubra* flowers significantly reduced blood glucose levels in STZ-induced diabetic mice at doses of 100, 200, and 400 mg/kg of body weight. After 28 days, the level decreased significantly from 380.3 mg per dL to 113.3 mg per dL at the 200 mg per kg dose. It is equivalent to reducing glibenclamide from 381.7 mg per deciliter to 100.2 mg per deciliter. An improvement in STZ-induced tubular necrosis and pancreatic injury was observed in a histopathological examination by Yadav and Undale [180]. In diabetic mice in which alloxan was induced [181], aqueous extract showed decreases in fasting glucose and glycosylated hemoglobin levels. The hydrous ethanolic stem bark extract of *P. rubra* (3:7) significantly lowered blood glucose levels and promoted pancreatic  $\beta$ -cell recovery in STZ-induced diabetic rats at doses of 250 and 500 mg/kg body weight, improving markers of pancreatic  $\beta$  cells. Oxidative stress compared to metformin hydrochloride (5 mg/kg body weight) [182]. Furthermore, 200 and 400 mg/kg body weight of the aqueous ethanolic extract of leaves reduced liver and kidney enzyme levels and restored antioxidant levels. It reversed histopathological damage [183] in diabetic rats, comparable to glibenclamide (120 mg/kg body weight).

### Hypolipidemic activity

Flavone glycosides (250 mg/kg body weight) from the methanol fresh flower extract of *P. rubra* significantly lowered serum triglycerides, blood urea, and creatinine levels in rats. There was no change in serum cholesterol or

glucose levels, but like glibenclamide (10 mg/kg body weight), it significantly affected AST and ALT activity [184].

### Hepatoprotective activity

Methanol extract of *P. rubra* leaves at 400 mg/kg body weight effectively inhibited the increase in enzyme levels caused by  $\text{CCl}_4$ , PCM, and antituberculosis drug intoxication in rats and mice, compared with the 200 mg/kg dose showed better results. Histopathological examination revealed reduced liver damage [185]. Similarly, administration of ethanolic extract of *P. rubra* pods at 200 mg/kg body weight for four days showed liver protection against  $\text{CCl}_4$ -induced damage, with a decrease in the marker enzymes AST, ALT, and ALP. This dose showed similar efficacy to the standard drug silymarin (10 mg/kg body weight) [186].

### Antifertility activity

Several studies have evaluated the effects of different extracts from *P. rubra* pods and barks on pregnancy and fertility in rats. *P. rubra* pods alcoholic extract administered at 200 mg/kg body weight from day 11 to 15 of gestation caused complete abortion in rats, which increased post-implantation losses and absorption index. Similarly, the ethanolic extract of *P. rubra* sheaths resulted in abortion rates of 13.46 to 100% in female albino rats, affected viable fetuses, and increased resorption index and post-implantation losses. In another study, methanol bark extract administered at various doses (50, 100, and 200 mg/kg body weight) over 60 days significantly reduced fertility in male rats. In comparison, a 200 mg/kg body weight dose ultimately reduces fertility. At low doses, entirely negative birth rates resulted in 58 to 64% negative birth rates [187–189].

### Antiulcer activity

Ethanol and chloroform extracts of *Plumeria* leaves at 250 mg/kg p.o. in rats, ulcer index, and gastric fluid volume decreased. At the same time, SOD, CAT, and GSH levels increased, indicating potential for free radical damage. Omeprazole at 20 mg per kg showed a 91.39% protective effect against pylorus ligation compared to ulcer control. The protection was 75.05 and 63.13%, respectively, for ethanol and chloroform extracts of 250 mg per kg. Both extracts alleviated gastric glandular lesions, decreased acid secretion, and increased mucus secretion, and the ethanolic extract showed superior antiulcer activity. Soluble latex protein from *P. rubra* prevented ethanol-induced gastric lesions through prostaglandin involvement and antioxidant

balance mediated by capsaicin-sensitive afferents and NO/cGMP/KATP pathways [190, 191].

## Mechanism of action of compounds extracted from species of *Plumeria*

The pharmaceutical, food industry, and cosmetic sectors have made substantial use of marker components like plumeride from *P. alba*. [192, 193] White frangipani has been shown to have antiarthritic properties in a 2014 study. A persistent inflammatory condition that destroys cartilage and erodes bone is rheumatoid arthritis [194].

Hyperlipidemia, a risk factor for cardiovascular diseases, can potentially be mitigated by white frangipani flowers, as demonstrated by Rahman et al. [195]. Although its hypolipidemic activity was not as high as simvastatin (92%), the results were promising [195]. Additionally, white frangipani has shown hypoglycemic activities, as evaluated by an oral glucose tolerance test in mice [196].

Despite the continuous demand for novel vaccinations and anti-infectious drugs, the current scenario indicates a slowdown in identifying new active chemical entities. Natural products were the source of almost 61% of newly developed medications between 1981 and 2002; these drugs were especially effective in treating infectious disorders and cancer [197]. Thus, new natural compounds originating from plants, such as those belonging to the *Plumeria* genus, continue to present a prospective source of various anti-bacterial agents that may have novel modes of action.

### Iridoids

Numerous iridoids display critical anti-inflammatory impacts by restraining basic pathways included within the inflammatory reaction. Compounds such as **8** and **9** hinder the activation of nuclear factor-kappa B (NF- $\kappa$ B), pivotal for the expression of pro-inflammatory cytokines and proteins like IL-1 $\beta$ , TNF- $\alpha$ , and cyclooxygenase-2 (COX-2). This inhibition decreases irritation and its related indications [198].

Iridoids like **22** [135] and plumeridoids (A, B, and C) [131] have strong antioxidant properties. They neutralize free radicals and improve the body's antioxidant defense framework by upregulating chemicals such as catalase (CAT) and SOD. Compounds such as **1** and **5** appear to have antimicrobial action by disrupting the cell films of pathogens, leading to cell lysis and death. They interfere with microbial protein frameworks and nucleic acid synthesis, repressing the development and replication of bacteria, fungi, and viruses.

Iridoids like **32** and **39** exhibit cytotoxic effects against cancer cells. They induce apoptosis through the

mitochondrial pathway, increase reactive oxygen species (ROS) production, and disrupt cell cycle progression. These actions inhibit cancer cell proliferation and tumor growth [39, 130, 136, 137]. Certain iridoids, such as **4** and its derivatives, have neuroprotective effects. They modulate neurotransmitter systems, reduce neuroinflammation, and protect neuronal cells from excitotoxicity and oxidative damage, critical factors in neurodegenerative diseases like Alzheimer's and Parkinson's.

Iridoids such as **23** and its derivatives manage diabetes by improving insulin sensitivity, enhancing insulin secretion, and inhibiting enzymes involved in glucose production. Some iridoids exhibit analgesic properties by interacting with opioid receptors and inhibiting pain pathways. Compounds like **6** and **7** reduce pain perception and relieve chronic pain conditions.

### Triterpenoids

Many triterpenoids exhibit significant anti-inflammatory effects, including **53**, **59**, **75**, **94**, and **51**. They inhibit the expression of pro-inflammatory mediators such as COX-2, nitric oxide (NO), and various cytokines (e.g., IL-1 $\beta$ , TNF- $\alpha$ ), achieved by suppressing the NF- $\kappa$ B signaling pathway, a key regulator of the inflammatory response.

**59**, **86**, **94**, and **51** possess potent antioxidant properties. They scavenge free radicals and upregulate the expression of endogenous antioxidant enzymes like CAT, SOD, and glutathione peroxidase (GPx). This action helps reduce oxidative stress. **51**, **59**, and **94** induce apoptosis in cancer cells by modulating multiple pathways, including the extrinsic (death receptor) and intrinsic (mitochondrial) apoptotic pathways. They also inhibit cancer cell proliferation by arresting the cell cycle at various phases (e.g., G1, G2/M).

**50**, **57**, and **59** exhibit hepatoprotective effects. They protect hepatocytes from damage induced by toxins, drugs, or oxidative stress. This protection is mediated through activating antioxidant defense mechanisms, inhibiting lipid peroxidation, and modulating signaling pathways involved in liver regeneration and repair. **78** and **79** have shown cardioprotective properties. They improve cardiac function and reduce myocardial damage by exerting antioxidant, anti-inflammatory, and anti-apoptotic effects. Additionally, they can improve lipid profiles and prevent the oxidation of low-density lipoprotein (LDL) and the risk of atherosclerosis by lowering cholesterol levels.

Compounds **94** and **59** exhibit broad-spectrum antimicrobial activity by disrupting microbial cell membranes, inhibiting the synthesis of vital cellular components, and interfering with microbial metabolism. **86** and **51** enhance insulin sensitivity, promote glucose uptake, and inhibit the enzymes involved in gluconeogenesis and breakdown

(glycolysis), thus helping maintain blood glucose levels within normal ranges [198]. **78** also inhibit  $\alpha$ -amylase and  $\alpha$ -glucosidase inhibitors [199] and reduce mRNA expression levels of lipogenic genes and, as a result, inhibit lipid accumulation in HepG2 cells of obese diabetic rats [200].

## Sterols

Phytosterols [55] modify prostaglandin pathways by blocking inflammatory enzymes, thus protecting platelets [201]. Compounds **108–112** reduce inflammation by inhibiting the production of COX-2 and lipoxygenase (LOX)—specifically, **109** and **111** exhibits anti-neoplastic, anti-inflammatory, and antipyretic activity in animals. A mixture of **109** and **111** improved T-lymphocyte and natural killer cell activity by testing in vitro, in animals, and in human clinical trials, targeting specific T-helper lymphocytes (Th1 and Th2 cells). Compound **108** reduces the production of NO and prostaglandins, thereby alleviating inflammation. These compounds also protect cells from oxidative damage by scavenging ROS and enhancing the activity of enzymes like CAT and SOD.

In the body, phytosterols such as **109–112** compete with cholesterol for absorption in the intestines and promote cholesterol excretion as bile acids. Saturated phytosterols are more effective than unsaturated ones in decreasing cholesterol concentrations [202, 203]. Compounds **108** and **111** inhibit the enzyme  $\beta$ -Hydroxy  $\beta$ -methylglutaryl-CoA (HMG-CoA) reductase involved in cholesterol synthesis [204]. Compounds **109** and **110** exhibit anticancer effects by inducing apoptosis, inhibiting cancer cell proliferation, and affecting signal transduction pathways, including phosphatidylinositol 3-kinase/protein kinase B (PI3K/Akt) and mitogen-activated protein kinase (MAPK).

Compound **111** is also known for its beneficial effects on prostate health, particularly in reducing benign prostatic hyperplasia (BPH) symptoms by inhibiting 5- $\alpha$ -reductase and reducing inflammation.

## Flavonoids

Flavonoids provide health benefits through modulatory effects on various metabolic and signaling enzymes beyond being direct chemical protectants [205]. They block the angiotensin-converting enzyme, which raises blood pressure, inhibit cyclooxygenase, which forms prostaglandins, and block enzymes that produce estrogen. These actions suggest that flavonoids could prevent platelet aggregation, reduce heart disease and thrombosis, and inhibit estrogen synthase, potentially decreasing the risk of estrogen-related cancers.

Hertog et al. discovered a substantial inverse relationship between consuming flavonoids and the death rate from coronary heart disease [201]. Of these, flavonol **116** is

directly mutagenic and has antibacterial and anti-inflammatory properties [206]. For instance, Silva et al. [207] discovered a time-dependent biotransformation of kaempferol to quercetin by CYP in V79 cells in short-term tests such as the production of chromosomal abnormalities in eukaryotic cells. In higher plants, compound **119** is a common flavonoid that increases the mutagenicity of **116** when microsomal metabolizing systems are present. Compound **116** also suppresses the growth of rat lymphocytes, the contraction of smooth muscle, and a number of other enzymes [206].

Flavonoids act as potent antioxidants by neutralizing free radicals and ROS. They chelate metal ions like iron and copper, which catalyze the production of ROS. Flavonoids can induce the expression of endogenous antioxidant enzymes such as SOD, CAT, and GPx.

Flavonoids, such as those found in *Plumeria* species, i.e., **113–114**, **116–123**, exhibit antioxidant activity [208, 209]. **120–123** exhibit anti-inflammatory properties by modulating various inflammation-related signaling pathways and cytokines. **115–119** inhibit COX-1, COX-2, and LOX enzymes, reducing the production of pro-inflammatory mediators like prostaglandins and leukotrienes. **116–119** inhibit the activation of the NF- $\kappa$ B, which regulates the expression of inflammatory cytokines (e.g., TNF- $\alpha$ , IL-1 $\beta$ , IL-6). Flavonoids modulate the MAPK pathway, influencing the production of inflammatory cytokines and enzymes.

Through activating caspases and regulating pro-apoptotic (like Bax) and anti-apoptotic (like Bcl-2) proteins, **115**, **116**, and **119** encourage apoptosis in cancer cells. **119** [210, 211] suppresses the growth of cancer cells by inducing cell cycle arrest at several phases (G0/G1, S, G2/M) [212]. **119** and **117** inhibit the formation of new blood vessels required for tumor growth by downregulating angiogenic factors like vascular endothelial growth factor (VEGF). Compound **116** [213, 214] prevents cancer cell migration and invasion by modulating matrix metalloproteinases (MMPs) and adhesion molecules [206].

**113** and **114** protect the cardiovascular system through vasodilation by increasing the bioavailability of NO and modulating endothelial function. They inhibit platelet aggregation, reducing the risk of thrombosis. Flavonoids modulate lipid metabolism, reducing LDL cholesterol levels and preventing atherosclerosis.

Compound **115** exerts neuroprotective effects by scavenging free radicals and upregulating antioxidant [215, 216] defenses; flavonoids protect neurons from oxidative damage. It reduces neuroinflammation by inhibiting microglial activation and the release of pro-inflammatory cytokines. Flavonoids influence neurotransmitter systems (e.g., dopamine, serotonin), potentially improving cognitive function and mood.

Glycoside-rich fraction **116** [217] is associated with reducing glycosylated hemoglobin. In the experiment, hepatic fatty acid synthase decreased after receiving **116**.

## Alkaloids

Alkaloids like **125** and **129** may modulate neurotransmitter systems, affecting receptors such as acetylcholine, serotonin, dopamine, and norepinephrine, leading to changes in neural activity and potentially resulting in neuroprotective or psychoactive effects. Compounds **130**, **132–134** may exert their effects by disrupting bacterial and fungal cell membranes or interfering with essential enzymatic processes, leading to cell death [151, 152].

Compounds **124**, **127**, and **131–134** may exhibit cytotoxicity against cancer cells by inducing apoptosis (programmed cell death) through mitochondrial pathways or disrupting cell division. It might inhibit specific enzymes in cancer cell proliferation or survival, contributing to its anticancer effects [138].

Compounds **125** and **127** may interfere with the life cycle of malaria parasites, possibly by inhibiting essential enzymes or disrupting cellular structures. Compound **131** might act on cardiovascular systems, potentially affecting heart rate and blood pressure through interactions with cardiac ion channels or neurotransmitter receptors.

Compounds **126** and **130** may act on neurons' pain receptors or sodium channels, providing pain relief or local anesthesia. It might inhibit inflammatory pathways, reducing pain and swelling. An alkaloid was shown by Sharma et al. to have antidiabetic effects in diabetic mice by enhancing GLUT-4, glucokinase activity, and peroxisome PRAY $\gamma$  [217].

## Cardiac glycosides

Cardiac glycosides, such as **135** and **136** found in *Plumeria* species, primarily affect the heart. Cardiac glycosides cause sodium ions to build up inside heart muscle cells (myocytes) by blocking the Na<sup>+</sup>/K<sup>+</sup>-ATPase pump, which is found in the cell membrane. Usually, this pump causes a secondary inhibition of the Na<sup>+</sup>/Ca<sup>2+</sup> exchanger by pumping potassium and calcium ions into the cell against their concentration gradients and sodium ions out of the cell. As a result, there is an increase in intracellular calcium levels (Ca<sup>2+</sup>). Elevated intracellular calcium levels increase cardiac muscle fibers' contractility (positive inotropic effect) so the heart can contract more forcefully with each beat.

Cardiac glycosides also affect the autonomic nervous system, particularly by increasing parasympathetic (vagal) tone, which can slow heart rate (negative chronotropic effect). They may also enhance cardiac output and improve symptoms in certain heart conditions [79–81].

Cardiac glycoside isolated from Iranian folk medicine also mediates its hypoglycaemic activity by increasing secretion [218]. While cardiac glycosides can be beneficial in medical use for conditions like heart failure, they have a narrow therapeutic window, and overdose can lead to toxicity, characterized by arrhythmias, nausea, vomiting, and potentially fatal cardiac effects.

## Quinones

Quinones are highly reactive due to their ability to accept and donate electrons. They can undergo reversible redox reactions, cycling between quinone (oxidized) and hydroquinone (reduced) forms. Quinones can undergo one-electron reduction to form semiquinone radicals and then further reduction to hydroquinones. During these processes, ROS, such as hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>), superoxide anion radicals (O<sub>2</sub><sup>-</sup>), and hydroxyl radicals (OH<sup>\*</sup>), can be generated as byproducts.

Notably, the compound 2,5-dimethoxy-p-benzoquinone was the inaugural benzoquinone extracted from the *Plumeria* genus. Its cytotoxic effects appear to be previously unreported [86].

Some quinones can inhibit enzymes by covalently modifying their active sites or essential cysteine residues, which affect various cellular processes dependent on those enzymes. Despite their potential to generate ROS, quinones can also act as antioxidants under certain conditions. Quinones can induce cytotoxicity [131] and exhibit anti-inflammatory properties and antimicrobial activity against various pathogens.

## Nor-terpenoids

Nor-terpenoids such as **139** and **140** can interact with cellular signaling pathways, influencing gene expression, protein synthesis, and cell function. Depending on the specific pathways affected, this modulation can lead to diverse physiological responses.

They inhibit specific enzymes involved in biochemical pathways. For example, they may interfere with enzymes related to lipid metabolism, cell signaling, or neurotransmission, impacting cellular functions and physiological processes. Nor-terpenoids also exhibit anti-inflammatory, antioxidant, neuroprotective, antimicrobial, antifungal, antiproliferative, and anticancer properties.

## Anthocyanins

Anthocyanins are potent antioxidants [88, 93, 219, 220], and some anthocyanins can chelate transition metals (e.g., iron and copper) that catalyze the production of ROS, thereby reducing their harmful effects. Anthocyanins may

improve endothelial function by enhancing NO production, which helps dilate blood vessels, regulate blood pressure, and promote cardiovascular health. Anthocyanins exhibit antidiabetic activity by inhibiting  $\alpha$ -glucosidase and pancreatic  $\alpha$ -amylase [221]. Anthocyanins can have anticancer [219] and neuroprotective properties [88–91]. Additionally, they have been recognized as antibacterial modulators [92].

### Cardenolides

Since the 1980s, cardenolide has been used to treat heart failure and blood vessel arrhythmias [77, 100]. Due to their ability to regulate the life and death of cancer cells at the molecular and cellular levels through numerous signaling pathways, research on these compounds within cancer prevention and treatment has attracted significant consideration [101, 102].

Several cardenolides in *N. oleander*'s leaves make up the most significant amount of oleandrin [103, 104]. It is reported in *Nerium oleander*, *Nerium odorum*, *Beaumontia grandiflora*, *Thevetia peruviana*, and *P. obtuse* for its high anticancer activity. Therefore, the search for biological sources where these substances could be extracted in significant quantities has increased because of several targets that may be affected by oleandrin or Cardenolides [101]. Several investigations have been carried out to clarify the mechanism of action of oleandrin on cancer cells [105].

### Fatty acid esters

Fatty acid esters, particularly those with phenolic groups like ferulates (144 and 145), may exhibit antioxidant properties [211]. Some fatty acid esters, such as those containing 147, may have anti-inflammatory and anticancer properties.

146 [169] may influence lipid metabolism by affecting lipid synthesis, storage, or cell breakdown, causing metabolic disorders like obesity and dyslipidemia.

Some fatty acid esters can exhibit antimicrobial and antifungal effects. Fatty acid esters, particularly those with moisturizing or emollient properties, like 147, may benefit skin health. They can help maintain skin barrier function, improve hydration, and have wound-healing effects.

### Lignans

Lignans possess antioxidant properties. Some lignans, including 148, have been found to modulate inflammatory pathways. Depending on the context, lignans can interact with estrogen receptors in the body, exerting estrogenic or anti-estrogenic effects. They may act as weak agonists or antagonists of estrogen receptors, influencing hormone balance and offering benefits in conditions influenced by estrogen levels.

Specific lignans have demonstrated antimicrobial and anticancer [132] activities. Lignans may contribute to cardiovascular health. Furthermore, bioassays of lignans have revealed critical pharmacological activities, including anticancer, anti-inflammatory, immunosuppressive, cardiovascular, antioxidant, and antiviral activities [108–115].

### Coumarins

Coumarin is a phytochemical with several biological and therapeutic properties such as antibacterial, antiviral [116], antidiabetic [117], anticoagulant, [118, 119] estrogenic, skin sensitizing, vasodilators, molluscicidal, sedatives and hypnotic, analgesic, antipyretic [120, 121] and anticancer properties [122, 123]. In addition, the antioxidant, anti-parasitic, antihelminthic, antiproliferative, anticonvulsant, anti-inflammatory [124], and antihypertensive [120, 121, 125, 126] activities of some coumarins also have been studied by several researchers.

Some coumarins, including scopoletin, exhibit anti-inflammatory properties by inhibiting pro-inflammatory enzymes (e.g., LOX, COX-2) and cytokines (e.g., TNF- $\alpha$ , IL-6). Coumarins can interact with various enzymes involved in metabolic pathways, such as those related to drug metabolism, detoxification, and cellular signaling.

### Biotransformation of compounds extracted from various species of *Plumeria*

The bioactive compounds undergo various biotransformation processes in the body, categorized into two phases. Phase I reactions usually include hydrolysis, reduction, and oxidation. Functional groups, such as hydroxyl groups, are introduced or exposed by these events, increasing the polarity and frequently the reactivity of the molecules for phase II reactions that follow. Enzymes like cytochrome P450 oxidases (CYPs), which are essential for the oxidation of substances, aid in the oxidation process. CYPs are linked enzyme systems comprising the NADPH-containing cytochrome P450 reductase (CPR) and the heme-containing CYP [222, 223]. (Fig. 15) Hydroxylation involves the introduction of hydroxyl groups to form hydroxy derivatives. Epoxidation leads to the formation of epoxides, which can further react to form diols. Dehydrogenation converts hydroxyl groups to ketones, forming keto derivatives. Reduction reactions, in which certain iridoids undergo reduction, convert ketone or aldehyde groups to hydroxyl groups. Reduction of double bonds transforms double bonds to single bonds, and carbonyl reduction converts ketones or aldehydes to alcohols. Hydrolysis, mediated by esterases and other hydrolytic enzymes, cleaves ester bonds, forming corresponding alcohol and acid derivatives. Table 2

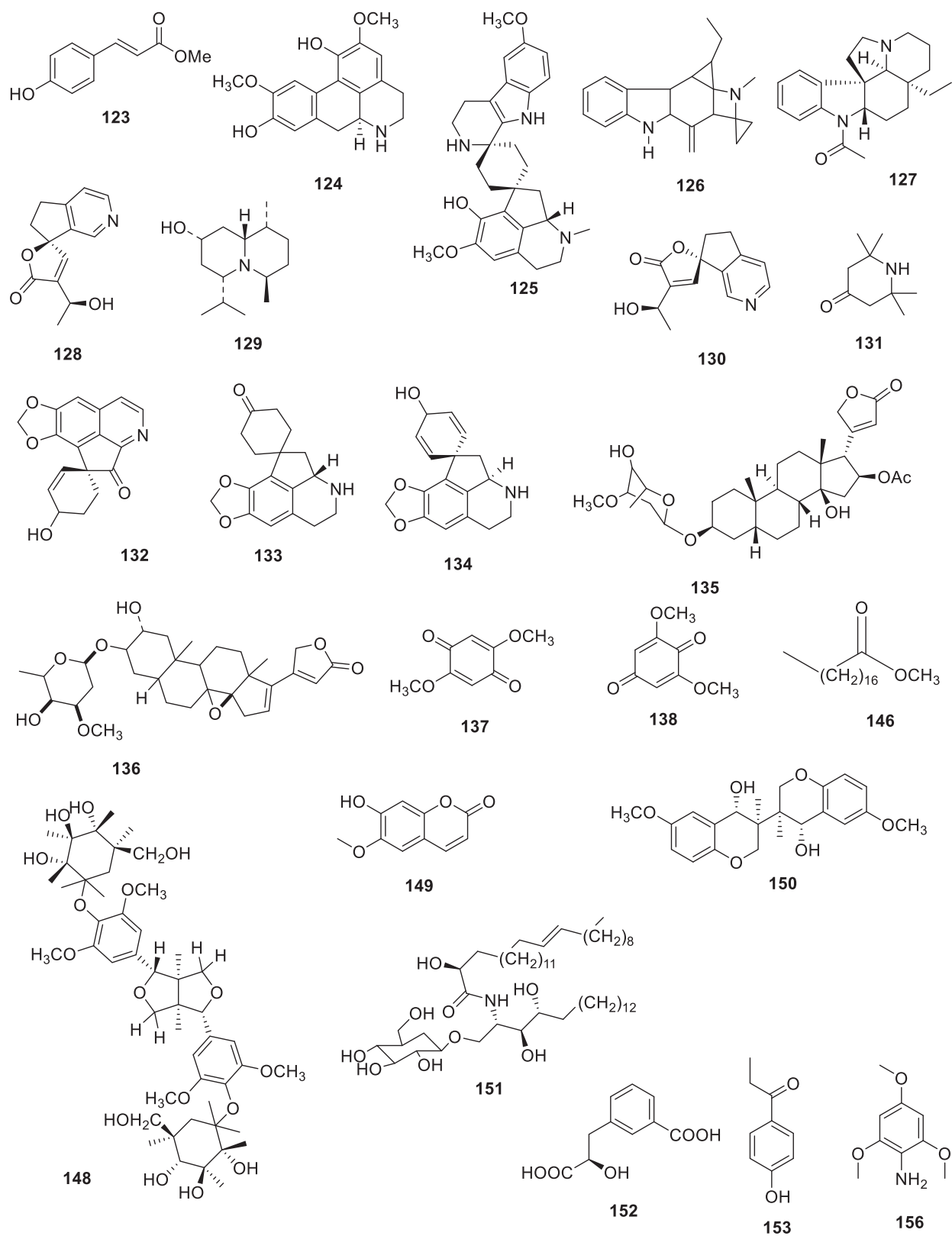


Fig. 15 General mechanism of cytochrome P450 catalyzed reactions

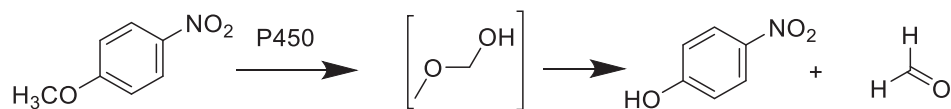
**Table 2** Examples of oxidative and reductive biotransformation catalyzed by cytochrome P450 enzymes

## Oxidative biotransformation

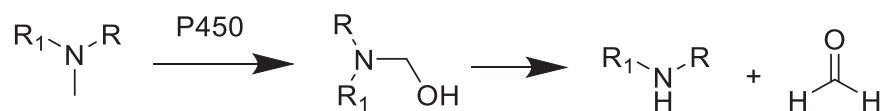
## Aliphatic hydroxylation



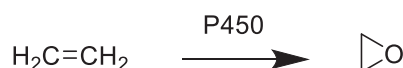
## O-dealkylation



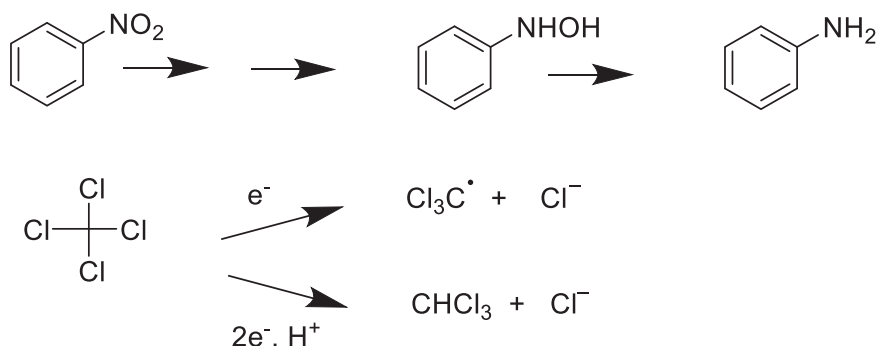
## N-dealkylation



## epoxidation



## Reductive biotransformation



shows examples of oxidation reactions catalyzed by CYP [224–227].

Phase II reactions involve conjugating compounds or their phase I metabolites with endogenous substrates, increasing their water solubility and promoting excretion through urine or bile. Glucuronidation, mediated by UDP-glucuronosyltransferases (UGTs), is a significant phase II pathway for compounds. Some typical examples are shown in Table 3 [228]. Sulfation involves sulfotransferases (SULTs) catalyzing the conjugation of sulfate groups to hydroxyl or amine groups, increasing solubility. The resulting products are sulfate esters or sulfamates (Table 3). Methylation involves transferring a methyl group to hydroxyl or amino groups, mediated by methyltransferases. Acetylation is catalyzed by acetyltransferases, which transfer acetyl groups to amine or hydroxyl groups of

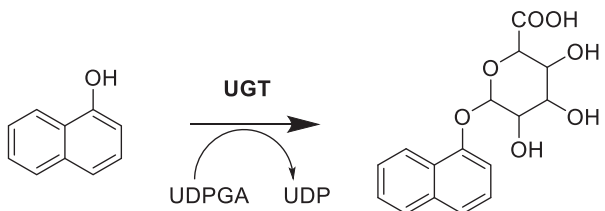
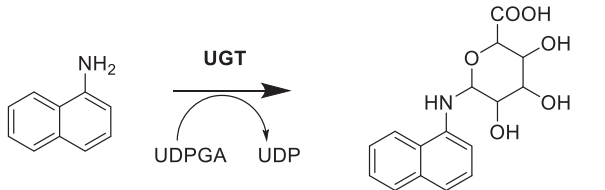
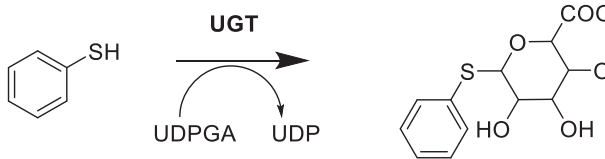
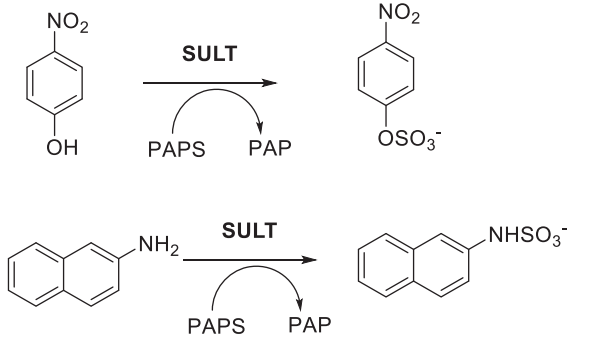
compounds. Glycosylation involves the conjugation with glucose or other sugars, often forming glycosides. Glutathione conjugation involves the conjugation with glutathione, usually catalyzed by glutathione S-transferases (GSTs). The conjugated moieties are often identified by specific active transport mechanisms, facilitating their movement across plasma membranes and increasing their excretion rate [229]. Table 4 includes specific examples of the biotransformation of compounds in the genus *Plumeria*.

Glucuronides and sulfates are typically excreted via the kidneys, whereas some metabolites may undergo enterohepatic circulation and be excreted through bile. This metabolic processing is crucial for the pharmacokinetics and overall bioavailability of compounds in the body.

The liver is the primary site of biotransformation enzyme localization. The liver receives a substantial



**Table 3** Typical conjugation reactions catalyzed by UDP-glucuronosyltransferases (UGT) and mammalian sulfotransferases (SULT)

Type of reaction	Examples
<i>O</i> -glucuronide formation	
<i>N</i> -glucuronide formation	
<i>S</i> -glucuronide formation	
Sulfate formation	

portion of blood from the splanchnic area, which contains xenobiotics that have been absorbed from the gut. As a result, most of these compounds can now be modified enzymatically by the liver. Nevertheless, biotransformation reactions can also be catalyzed by other tissues. The chemical structure, dosage, and mode of delivery are some variables that affect how much an extrahepatic organ contributes to biotransformation. Critical toxicological ramifications can result from biotransformation within extrahepatic tissues, which can have toxic effects unique to those tissues.

Phase I enzymes are primarily located in the lipoprotein membranes that connect the nucleus and mitochondria to the plasma membrane and the endoplasmic reticulum within cells. Phase I enzyme localization in membranes is important because lipophilic compounds tend to collect in

lipid membranes, which can result in high concentrations of lipophilic xenobiotics at the biotransformation sites. Biotransformation processes primarily serve the function of detoxification by converting xenobiotics into more readily excreted compounds. However, metabolites more dangerous than the original substance can arise, depending on the chemical structure and the implicated enzymes. Numerous xenobiotics with minimal chemical reactivity are hazardous and carcinogenic due to a process called bioactivation. Cell death, cancer, organ failure, and other toxic symptoms can result from the interaction of hazardous metabolites. Phase II reactions and mixtures of both phases can also contribute to intoxication, even though phase I reactions are more frequently linked to the production of reactive and more hazardous metabolites [230–232].

**Table 4** Specific examples of biotransformation [271]

Phase I			Phase II		
Metabolic process	Enzymes	Conversion of compounds	Metabolic process	Enzymes	Conversion of compounds
<b>Oxidation</b>	Cytochrome P450 oxidases	quinones → hydroquinones	<b>Glucuronidation</b> Conjugation with glucuronic acid	UDP-glucuronosyl transferases	Plumericin, Ursolic acid, lupeol, betulinic acid, Stigmasterol, $\beta$ -Sitosterol → their glucuronide quercetin → quercetin-3- <i>O</i> -glucuronide
<b>Hydroxylation</b> Introduction of hydroxyl groups to form hydroxy derivatives	CYP1A1, CYP1A2, and CYP3A4	ursolic acid → 3 $\beta$ ,23-dihydroxy ursolic acid, $\beta$ -amyrin → 3 $\beta$ ,27-dihydroxy-olean-12-ene, lupeol → 3 $\beta$ ,20-dihydroxy-lupeol, Stigmasterol → Hydroxy-stigmasterol quercetin → quercetin-3'- <i>O</i> -glucuronide	<b>Sulfation</b> catalyze the conjugation of sulfate groups to hydroxyl or amine groups	Sulfotransferases	$\beta$ -amyrin, Stigmasterol, $\beta$ -Sitosterol → Their sulfate Quercetin → quercetin-3- <i>O</i> -sulfate
<b>Epoxidation</b> Formation of epoxides, which can further react to form diols			<b>Methylation</b> involves the transfer of a methyl group to hydroxyl or amino groups	Methyltransferases Catechol- <i>O</i> -methyl-transferases	Plumeride → 3- <i>O</i> -methyl plumeride Quercetin → isorhamnetin (3'-methylquercetin)
<b>Dehydrogenation</b> converting hydroxyl groups to ketones		Stigmasterol → Keto-stigmasterol	<b>Acetylation</b> Transfer of acetyl groups to amine or hydroxyl groups	Acetyl-transferases	$\alpha$ -allamcidin and $\beta$ -allamcidin → their diacetates
<b>Reduction</b> ketone or aldehyde groups are converted to hydroxyl groups	<b>Reduction of double bonds</b>	Lupeol → dihydrolupeol	<b>Glycosylation</b> Conjugation with glucose or other sugars, often forming glycosides		lupeol → lupeol glucoside
	<b>Carbonyl reduction</b> Conversion of ketones or aldehydes to alcohols	betulinic acid → betulin	<b>Glutathione Conjugation</b>	glutathione <i>S</i> -transferases	
<b>Hydrolysis</b> Cleavage of ester bonds and formation of alcohol and acid derivatives	Esterases $\beta$ -glucosidase amidases	lupeol acetate → lupeol quercitrin → quercetin $\beta$ -Sitosterol 3- <i>O</i> -glucoside → $\beta$ -Sitosterol			

## Iridoids

Compounds **1–4**, **21–22**, **13**, **15**, **27–29**, **32**, **39**, and **44** can be hydrolyzed to corresponding alcohols and then subjected to glucuronidation or sulfation. **5** undergoes oxidation to form more polar metabolites. **8–9**, **11**, **16–19**, **30**, and **40** Oxidize and then conjugate through glucuronidation or sulfation. Compound **10** can be formed through reduction

of **8**, further conjugated *via* glucuronidation. **12**, **14**, **20**, **23**, and **43** undergo conjugation *via* glucuronidation or sulfation. **42** undergoes further methylation, hydroxylation, and conjugation. Esterases and other hydrolytic enzymes cleave ester bonds in iridoids such as **6** and **7**, forming corresponding alcohol and acid derivatives. For instance, compound **8** can undergo glucuronidation to form plumericin glucuronide, which is more water-soluble and readily

excreted. Compounds like **6** and **7** can be further modified by acetylation, affecting their pharmacokinetic properties.

### Triterpenoids

Functionalization through polyhydroxylation of native pentacyclic triterpenoids is one of the most promising ways to improve their pharmacological potential. These hydroxylated derivatives are widely distributed in nature, but they are usually found in trace amounts or as components of complicated mixtures. They are formed by plant P450-dependent monooxygenases [233]. Microorganisms' ability to convert pentacyclic triterpenoids enzymatically produces hydroxylated derivatives with a high yield and regioselectivity. Not only can microbial hydroxylation happen in the A ring, but it can also happen at difficult locations on the B, D, and E rings. Moreover, though they are less common, processes including carboxylation, glycosylation, lactone production, and others might contribute to the microbial functionalization of pentacyclic triterpenoids.

**59** can be hydroxylated to form **99**. For instance, **75** may undergo epoxidation at the double bond. Reduction of double bonds to single bonds, such as reducing lupeol to dihydrolupeol. The reduction of betulinic acid's carbonyl group to form **50**.

Compound **59** can be conjugated to form ursolic acid glucuronide. Triterpenoids like **75** can form sulfated metabolites. For example, **94** can be glycosylated to form lupeol glucoside. GSTs usually catalyze conjugation with glutathione.

De Carvalho et al. (2006) discussed the opportunities and challenges in the industrial-scale biotransformation of monoterpenes [234]. Research on using directed biotransformation to produce novel glycyrrhetic acid (GA), oleanolic acid (OA), and ursolic acid (UA) derivatives has demonstrated potential. More than 20 instances of these chemicals' biotransformation utilizing bacterial and fungal cultures—mainly hydroxylation—have been reported since 2013. Less often described processes include deeper oxidation, glycosylation, esterification, acetylation, or carboxylation of triterpenoids. Only a few instances of the biocatalytic synthesis of triterpenic lactones or their derivatives with broken C–C bonds utilizing UA have been documented [235, 236].

Triterpenic acid conversion rates in fungal biotransformation processes normally vary from 2.6 to 77.5%, starting at concentrations of 0.02 g/L–1.0 g/L. The conversion rates of bacteria range from 27.5 to 70.0%, and their starting concentrations range from 0.04 g/L to 0.3 g/L. Derivatives with antioxidant, anti-inflammatory, antiviral, anticancer, antiparasitic, antibacterial, neuroprotective, and hepatoprotective qualities have been produced through the biotransformation of the pentacyclic triterpenoids oleanane and ursane.

Additional research into this multidisciplinary approach may yield powerful antibacterial medications to combat microorganisms resistant to antibiotics and novel therapeutic medicines for cancer and neurological disorders. Through the process of converting native pentacyclic triterpenoids into bioavailable chemicals and back again, industrial microbiology has the potential to establish a beneficial cycle of production for biologically active substances.

However, significant drawbacks exist with the microbial catalysts used. Fungi typically exhibit mycelial growth and produce spores and mycotoxins, while the few bacterial catalysts described are often pathogenic strains. Therefore, further studies are needed to explore the biological transformation processes of pentacyclic triterpenoids and to find new non-pathogenic bacterial strains capable of effectively synthesizing triterpene derivatives with notable biological activities.

### Sterols

Compounds **108** and **110–112** undergo oxidation primarily in the liver, where CYP introduces hydroxyl groups at specific positions on the sterol nucleus or side chain. They may undergo dehydrogenation, converting hydroxyl groups to ketones, forming keto derivatives. **109** undergoes enzymatic hydrolysis to remove the glucose moiety, yielding free **111**. Enzymes such as  $\beta$ -glucosidase hydrolyze the glucoside bond, releasing **111**. The hydroxylated or ketone metabolites of **108** and **110–112** undergo conjugation reactions to increase their solubility.

### Flavonoids

The biotransformation of flavonoids from *Plumeria* species involves metabolic reactions in phases I (oxidation, reduction, hydrolysis) and II (glucuronidation, sulfation, methylation).

CYP enzymes, such as CYP1A1, CYP1A2, and CYP3A4, oxidize flavonoids, i.e., **119**, **115–116**, **123**, to form hydroxylated metabolites. For example, **119** can be oxidized to quercetin-3'-O-glucuronide. Some flavonoids undergo reduction reactions, which are less common compared to oxidation. Esterases can hydrolyze flavonoid glycosides into their aglycone forms and sugar moieties. For instance, **118** can be hydrolyzed to **119**. In **114** and **118**, esterases hydrolyze it to release **116**, rutinose, and **119** and rhamnose, respectively. Both phytochemicals then undergo phase I and II metabolism, as described above.

By UGTs catalysis, **119** can be conjugated to form quercetin-3-O-glucuronide. **119** is commonly glucuronidated at the 3, 4', or 7 positions. **116** is glucuronidated, primarily at the 3 and 7 positions. **115** and **123** Likely

conjugated with glucuronic acid and sulfate. With the help of SULTs, **119** can be sulfated to quercetin-3-*O*-sulfate—catechol-*O*-methyltransferases (COMTs) methylate hydroxyl groups on flavonoids. Compound **119** can be methylated to isorhamnetin (3'-*O*-methyl quercetin).

The gut microbiota also plays a significant role in flavonoid metabolism. Microbial enzymes can do de-glycosylation, ring cleavage, and reduction. These processes occur mainly in the liver and gastrointestinal tract, with significant contributions from the gut microbiota.

### Alkaloids

**124**, **132–134**, **127**, and **129** may undergo oxidation by CYP enzymes, introducing hydroxyl groups to increase their polarity. The resulting metabolites can be conjugated with glucuronic acid or sulfate to enhance solubility for excretion.

Compound **130** may undergo dealkylation, hydroxylation, or demethylation by CYP enzymes, producing more polar metabolites. Metabolites from phase I are often conjugated with glucuronic acid, sulfate, or glutathione, facilitating renal or biliary excretion. Compound **125** might be reduced or hydrolyzed to form simpler metabolites. The metabolites can be further conjugated with polar molecules like glucuronic acid.

Compound **131** may be metabolized by hydroxylation or dealkylation. Compound **126** can undergo oxidation or reduction to form more polar metabolites. Resulting metabolites are often conjugated with glucuronic acid or sulfate, enhancing excretion through urine or bile.

### Cardiac glycosides

The biotransformation of cardiac glycosides typically involves several steps within the body, often in the liver. After ingestion, cardiac glycosides are absorbed from the gastrointestinal tract into the bloodstream. They are transported via the bloodstream to various tissues, including the liver, where much of the biotransformation occurs.

The biotransformation of cardiac glycosides involves Phase I and II metabolic processes, primarily mediated by liver enzymes. The specific pathways and enzymes involved may vary depending on the chemical structure, but the general mechanisms include oxidation, reduction, hydrolysis, and conjugation.

### Quinones

The biotransformation of quinones, such as **137** and **138** found in *Plumeria* species, involves several enzymatic processes, primarily in the liver.

CYP enzymes in the liver catalyze oxidation reactions, converting quinones into hydroquinones or other oxidized

forms. This process can involve introducing hydroxyl (-OH) or different functional groups. Quinones can undergo either enzymatically or non-enzymatically reduction reactions to form hydroquinones. Some quinones may undergo hydrolysis reactions, resulting in the cleavage of chemical bonds and the formation of smaller molecules. The metabolites produced in phase I reactions are conjugated with endogenous molecules such as glucuronic acid, sulfate, or amino acids (e.g., glycine).

### Biotransformation of other classes of compounds

The biotransformation of nor-terpenoids, anthocyanins, cardenolides, fatty acid esters, lignans, and coumarins found in *Plumeria* species involves enzymatic processes primarily in the liver. The general process of their biotransformation is same as followed by quinones (Table 4).

## Result and discussion

The study delved into the *Apocynaceae* family, specifically focusing on the genus *Plumeria*, renowned for its traditional medicinal use and empirical research support [1–8]. *Plumeria* species have multifaceted applications addressing conditions from skin treatments to respiratory ailments and postnatal care [15–25]. Their pharmacological effects span antioxidants [57, 65], antiviral actions [17], CNS depression, and antitumor potential [128]. *Plumeria* encompasses diverse deciduous shrubs and lactiferous trees, primarily found in tropical regions.

Out of 274 research articles cited, a total of 129 articles containing 156 phytochemicals, including 45 iridoids, 62 triterpenes, 11 flavonoids, 11 alkaloids, steroids, cardiac glycosides, quinones, nor-terpenoids, anthocyanins, cardenolides, fatty acid esters, lignans, coumarins, and others have been displayed in the search results (Table 1).

These compounds exhibit diverse pharmacological activities, including anti-inflammatory, anticancer, hypolipidemic, and antianaphylaxis effects [39, 120–214, 237–242]. Their structures (Fig. 4) and properties have been meticulously analyzed and organized in a tabular format (Table 1). Aerial parts, bark [130, 143], flowers [32, 129, 136, 144, 145], fruits [69], leaves [169], stem, stem bark [132, 142, 159, 160], root [165], whole plants, and heartwood were among the *Plumeria* species parts that were extracted, according to the literature. However, the extraction of phytochemicals with biological activity was regularly carried out using the stem bark [132, 142], root bark [165], and leaves [127, 139]. The genus *Plumeria* has several species with potential medical uses. This study explains the main bioactive phytoconstituents that have been separated from this genus *Plumeria*

and how they are used in various traditional medical systems to treat different illnesses such as diarrhea, venereal disease, blennorrhoea, rheumatism, and leprosy [30]. The phytoconstituents of genus *Plumeria* are excellent analgesics [2], antioxidants [128, 173, 179, 184], anticancer, antibacterial [150, 239, 240], and anti-hyperproliferative agents [135, 243], among other properties. Numerous phytochemical components of the terpenoid, iridoid, alkaloid, and other classes are present in the plants [9, 12]. The pharmacological activities of extracts obtained from various parts of plants, varied chemical constituents, their distribution, structure, the solvents used for extraction (primarily petroleum ether, chloroform, and methanol), physical properties, and the analytical data (mass, IR, and UV spectroscopical data) of phytoconstituents of the genus *Plumeria* are all summarised in this review.

In addition to these findings, the review also explores the general mechanisms of action and biotransformation [244] of the phytoconstituents found in *Plumeria* species. The bioactive compounds interact with various biological targets, leading to their diverse pharmacological effects. [244] For instance, triterpenoids [198] and iridoids [200] have been identified as key agents in anticancer and anti-inflammatory activities through their ability to modulate signaling pathways and inhibit specific enzymes. The biotransformation processes, including metabolic pathways and enzymatic modifications, contribute significantly to the bioavailability and therapeutic efficacy of these compounds [244]. Understanding these mechanisms provides deeper insights into the therapeutic potential and optimization of *Plumeria*-derived compounds in pharmaceutical applications.

While several comprehensive review articles discuss the phytochemicals of the genus *Plumeria*, this review aims to provide an overview of their distribution, structure, pharmacological properties, and analytical studies. Additionally, it delves into the potential pharmaceutical applications of compounds isolated from *Plumeria* species, shedding light on their prospects in medicine.

## Conclusion

The therapeutic potential of various species of the genus *Plumeria* is quite broad. The essential bioactive phytoconstituents that were extracted from this genus and their functions in various traditional medical fields to treat various ailments are discussed in this review. Phytoconstituents of the genus *Plumeria* work as very effective analgesic, anticancer, antibacterial, anti-hyperproliferative, and antioxidant. The plants include several terpenoids, iridoids, steroids, fatty acid esters, coumarins, anthocyanins, cardenolides, lignans and alkaloids etc. as phytochemical

components. The following review summarizes the phytochemical constituents, obtained from the extracts of various species of genus *Plumeria*, analytical data and their pharmacological properties.

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## Compliance with ethical standards

**Conflict of interest** The authors declare no competing interests.

## Abbreviations

AgNPs	Silver nanoparticles
ALP	Alkaline phosphatase
ALT	Alanine transaminase
AST	Aspartate transaminase
BPH	Benign prostatic hyperplasia
CAT	Catalase
CCl <sub>4</sub>	Carbon tetrachloride
CHCl <sub>3</sub>	Chloroform
CNS	Central Nervous System
COX-2	Cyclooxygenase-2
CPR	Cytochrome P450 reductase
CYP	Cytochrome P450
CYPs	Cytochrome P450 oxidases
DPPH	2,2-diphenyl-1-picrylhydrazyl
EAC	Ehrlich ascites carcinoma
GA	Glycyrrhetic acid
GPx	Glutathione peroxidase
GSH	Glutathione
GSTs	Glutathione S-transferases
HCT	Human Colorectal Carcinoma
HepG	Hepatoblastoma
HIV-1 RT	human immunodeficiency virus type I- reverse transcriptase
HMG-CoA	$\beta$ -Hydroxy $\beta$ -methylglutaryl-CoA
IC <sub>50</sub>	Half maximal inhibitory concentration
IR	Infrared spectroscopy
LC <sub>50</sub>	Lethal concentration
LD <sub>50</sub>	Median lethal dose
LD <sub>90</sub>	90% lethal dose
LDL	Low-density lipoprotein
LOX	Lipoxygenase
MAPK	Mitogen-activated protein kinase
MCF	Michigan Cancer Foundation
MEPA	Methanolic extract of <i>P. acuminata</i>
MIC	Minimal inhibitory concentration
MBC/MFC	Minimal bactericidal or fungicidal concentration
MMPs	Metalloproteinases
NF- $\kappa$ B	Nuclear factor-kappa B
NK	Natural killer
NO	Nitric oxide
OA	Oleanolic acid
P.	<i>Plumeria</i>
PCM	Paracetamol
PI3K/Akt	Phosphatidylinositol 3-kinase/protein kinase B

ROS	Reactive oxygen species
SOD	Superoxide dismutase
STZ	Streptozotocin
SULTs	Sulfotransferases
UA	Ursolic acid
UGTs	UDP-glucuronosyltransferases
UV	Ultraviolet spectrophotometry
VEGF	Vascular endothelial growth factor
XO	Xanthine oxidase

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