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The genus *Rumex* (Polygonaceae): an ethnobotanical, phytochemical and pharmacological review

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Abstract

Rumex L., a genus in Polygonaceae family with about 200 species, is growing widely around the world. Some *Rumex* species, called "sorrel" or "dock", have been used as food application and treatment of skin diseases and hemostasis after trauma by the local people of its growing areas for centuries. To date, 29 *Rumex* species have been studied to contain about 268 substances, including anthraquinones, flavonoids, naphthalenes, stilbenes, diterpene alkaloids, terpenes, lignans, and tannins. Crude extract of *Rumex* spp. and the pure isolates displayed various bioactivities, such as antibacterial, anti-inflammatory, antitumor, antioxidant, cardiovascular protection and antiaging activities. *Rumex* species have important potential to become a clinical medicinal source in future. This review covers research articles from 1900 to 2022, fetched from SciFinder, Web of Science, ResearchGate, CNKI and Google Scholar, using "*Rumex*" as a search term ("all fields") with no specific time frame set for the search. Thirty-five *Rumex* species were selected and summarized on their geographical distribution, edible parts, traditional uses, chemical research and pharmacological properties.

Keywords: Polygonaceae, *Rumex* L., Anthraquinones, Phenolics, Pharmacological properties

1 Introduction

Rumex L., the second largest genus in the family Polygonaceae, with more than 200 species, is mainly distributed in the northern temperate zone [1]. It is mostly perennial herbs with sturdy roots, paniculate inflorescences, and triangular fruits that are enveloped in the enlarged inner perianth. The name "*Rumex*" originated from the Greek word–"dart" or "spear", alluding to the shape of leaves [2]. The other explanation from Rome–"rums" alludes to the function that the leaves could be sucked to alleviate thirst [3]. *R. acetosa*, a typical vegetable and medicinal plant, whose name 'acetosa' originated from the Latin word "acetum", described the taste of the plant as vinegar. Currently, many oxalic acids have been reported from *Rumex*, verifying its sour tastes [4].

Rumex species have had a valued place as global folk medicine, e.g., in Southern Africa, America, India, China, and Turkey. The earliest medicinal record of *Rumex* spp. in China was in "Shennong's Herbal Classic", in which *Rumex* was recorded for the treatment of headed, scabies, fever, and gynecological diseases. Roots of *Rumex*, also called dock root, have been reported for its therapeutic capacity of bacterial infections, inflammatory, tumor and cardiovascular diseases [5, 6]. Recently, pharmacological study showed that *Rumex* species displayed apparent antibacterial and antifungal effects [7], and were employed in the management of skin scabies and inflammation [8, 9]. The processed *Rumex* exhibited different chemical profiles and bioactivities [10, 11]. Leaves, flowers and seeds of some *Rumex* plants are edible as vegetables, while in some regions, the *Rumex* plants are

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regarded as noxious weeds because oxalic acid makes them difficult to be digested [12].

To date, 268 components from 29 *Rumex* species have been reported. Anthraquinones, flavonoids, tannins, stilbenes, naphthalenes, diterpene alkaloids, terpenes, and lignans were as the main chemical components, with a broad spectrum of pharmacological activities, such as anti-inflammatory, antioxidant, antibacteria, antitumor, and antidiabetic activities [13–17]. In addition to important role of *Rumex* in the traditional applications, researchers also regard *Rumex* as a potential effective medicine of many diseases. This article has reviewed a comprehensive knowledge on the distribution, traditional uses, chemistry and bioactivity progress of *Rumex*, and their therapeutic applications and utilizations were provided.

2 Geographical distributions, local names, parts used and traditional uses

The genus *Rumex* with more than 200 species, is distributed widely in the world and has been used traditionally in many regions, e.g., Asia, America, Europe and other continents. Many of them known as "sorrel" or "dock" have a long history of food application and medicinal uses for the treatment of skin diseases, and hemostasis after trauma by the local people of its growing areas. For example, *R. acetosa* is commonly used medicinally for diuretics around the world [4]. *R. maritimus* and *R. nepalensis*, used as laxatives, have long-term medicinal applications in India as substitutes for *Rheum palmatum* (Polygonaceae), which is usually used to regulate the whole digestive system. Moreover, Indians have also recorded nine *Rumex* plants as astringent agents, including *R. acetosa*, *R. acetosella*, *R. crispus*, *R. dentatus*, *R. hastatus*, *R. maritimus*, *R. nepalensis*, *R. scutatus*, and *R. vesicarius* [18]. All seven species included *R. acetosa*, *R. trisetifer*, *R. patientia*, *R. crispus*, *R. japonicus*, *R. dentatus* and *R. nepalensis*, called "jinbuhuan", have been used for hemostasis remediation in China [19]. *R. thyrsiflorus*, rich in nutrition, has been used as food by Europeans in history and as folk medicine due to its obvious anti-inflammatory activity [20]. *R. lunaria* has been used to treat diabetes by Canarian medicine [16]. The leaves of more than 14 *Rumex* spp., such as *R. acetosa*, *R. hastatus*, *R. thyrsiflorus*, *R. aquaticus*, *R. crispus*, *R. gmelini*, *R. patientia*, *R. vesicarius*, *R. ecklonianus*, *R. abyssinicus*, *R. confertus*, *R. hymenosepalus*, *R. alpinus* and *R. sanguineus* (Table 1) could be eaten freshly or cooked as vegetables in the folk of many places [5, 6]. In Table 1, the geographical distributions, local names, parts used and traditional uses of 35 *Rumex* species are summarized.

3 Chemical constituents

To date, 268 compounds including 56 quinones (**1**–**56**), 57 flavonoids (**57**–**113**), 25 tannins (**114**–**138**), 6 stilbenes (**139**–**144**), 22 naphthalenes (**145**–**166**), 6 terpenes (**167**–**172**), 3 diterpene alkaloids (**173**–**175**), 14 lignans (**176**–**189**) and 79 other types of components (**190**–**268**) were isolated and reported from 29 *Rumex* species (Table 2).

3.1 Quinones

Quinones are widely found in *Rumex*, particularly accumulated in the roots. 56 quinones (Fig. 1) including anthraquinones, anthranones, and *seco*-anthraquinones and their glycosides and dimers were isolated and identified from more than 17 *Rumex* species (Table 2). Among them, anthraquinone *O*- and *C*- glycosides with glucose, galactose, rhamnose, and 6-hydroxyacetylated glucose as commonly existing sugar moieties, were normally found in *Rumex*. Three anthraquinones, chrysophanol (**1**), emodin (**8**) and physcion (**18**) are commonly used indicators to evaluate the quality of *Rumex* plants [22]. Some new molecules were also reported. For example, xanthorin-5-methylether (**30**) was isolated from *R. patientia* for the first time [23, 24], and two new antioxidant anthraquinones, obtusifolate A (**45**) and B (**46**) were isolated from *R. obtusifolius* [25].

The anthranones often existed in pairs of enantiomers, whose *meso*-position is commonly connected with a *C*-glycosyl moiety. The enantiomers, rumejaposides A (**21**) and B (**22**), E (**25**) and F (**26**), G (**27**) and H (**28**) were reported from *R. dentatus*, *R. japonicus*, *R. nepalensis* and *R. patientia* [26–28]. Three hydroxyanthrones, chrysophanol anthrone (**7**), emodin anthrone (**17**), physcion anthrone (**20**), whose C-10 were reduced as an alphatic methylene, were isolated from the roots of *R. acetosa* for the first time [29], while a new anthrone, rumexone (**31**) was reported from the roots of *R. crispus* [30]. Two anthranones, 10-hydroxyaloins A (**39**) and B (**40**) were reported from *Rumex* for the first time [31]. A new 8-ionized hydroxylated 9,10-anthraquinone namely, rumpictusoide A (**56**) was isolated from the whole plant of *R. pictus* [183]. Moreover, two new oxanthrone *C*-glucosides 6-methoxyl-10-hydroxyaloins A (**41**) and B (**42**) were isolated from the roots of *R. gmelini* [32].

Seco-anthraquinones are oxidized anthraquinones with a loop opened at C-10, resulting in the fixed planar structure of anthraquinone destroyed and causing of a steric hindrance between the two left benzene rings. So far, only two *seco*-anthraquinone glucosides, nepalensides A (**49**) and B (**50**) were reported from the roots of *R. nepalensis* [33].

Table 1 Traditional uses of *Rumex* plants

No	Species	Local names	Country	Parts used	Traditional uses	Ref
R1	*Rumex acetosa* L	Sorrel, garden sorrel, common dock, broad-leaved sorrel, English sorrel, sheep's sorrel, red sorrel, sour weed, field sorrel	South Africa, North America, Europe, Yemen, Czech Republic, Korea, Britain, Ireland, China, Hungary, Romania and Bulgaria	Leaf, flower, whole plant, fruit, root and seed	Gastrointestinal disorders (constipation, cramping, diarrhea, tenesmus), antiscorbutic, hemostasis, dermatological, tumors, cramping, sore throats, warts, dysentery, gonorrhea, ulcer, scabies, kidney diseases (diuretic), fever, worm, abscesses. Seed: astringent	[4, 18, 19, 57, 135, 192, 198]
R2	*R. hastatus* D. Don	Heartwing sorrel, hastate-leaved dock, sour dock, khatimal	China, India, Nepal, Bhutan, Pakistan and Afghanistan	Leaf, flower, seed, root, whole plant, anile part and contemporary tuber	Astringent, sexually transmitted diseases (AIDs), constipation, tonic agent, diuretic, rheumatism, dermatological, piles, bleeding of the lungs, cough, headache, fever, blood pressure, abdominal pain, sore throat, tonsillitis diseases, worm, wounds	[18, 58, 191, 195]
R3	*R. thyrsiflorus* Fingerh	Compact dock, thyrse sorrel	China, Kazakhstan and Russia, and Europe	Leaf	For food	[59, 198]
R4	*R. aquaticus* L	Red dock, western dock	China, Japan, Kazakhstan, Russia and Europe	Leaf	Disinfection, constipation, fever, diarrhea, stomach problems, edema, jaundice	[60, 201]
R5	*R. Chalepensis* Mill		Asia, Middle East, Morocco and Africa	–	–	[40, 61, 202]
R6	*R. crispus* L	Curled dock, curly dock, yellow dock, narrow-leaf dock	Asia, Europe, North America, Northern Africa, Colombia and India	Leaf, root, stem, seed	Antidysentery, hemostasis, ulcers, cough. Root: laxative, astringent, skin eruptions, skin diseases, scrofula, scurvy, intermittent fevers, congested liver and jaundice. Seed: astringent	[18, 19, 62, 195, 197]
R7	*R. dentatus* L	Toothed dock	Asia, Middle East and Southeast Europe and Pakistan	Whole plant	Cutaneous disorders, stomach problems. Plant: astringent, hemostasis	[18, 19, 28, 63, 195]
R8	*R. gmelini* Turcz. ex Ledeb		China, Japan, North Korea, Russia, Mongolia and Siberia	Leaf	Tumor, bacterial infection	[31, 64]
R9	*R. japonicus* Houtt		China, Japan, North Korea and Russia	Whole plant	Hemostasis, fever, constipation	[19, 65, 199]
R10	*R. maritimus* L	Golden dock	Bangladesh, India, North Africa and America	Leaf, root and seed	Leaf and root: laxative; externally applied to burns. Seed: aphrodisiac	[18, 66]

Table 1 (continued)

No	Species	Local names	Country	Parts used	Traditional uses	Ref
R11	*R. nepalensis* Spreng		Asia, Europe and Africa, Ethiopia, Nepal, Pakistan and India	Leaf, root and whole plant	Hemostasis, stomach problems, itch, astringent, paralysis, tonsillitis, ascariasis, uterine bleeding, as an abortifacient, joint pain. Leaf: colic; externally applied to syphilitic ulcers. Root: constipation	[18, 19, 33, 67, 195, 196]
R12	*R. obtusifolius* L	Broad-leaf dock, bitter dock, blunt-leaf dock	China, Japan, Europe, Africa and Ireland	Whole plant	Nettle, depurative, astringent, constipation, tonic agent, sores, blisters, hyperglycemic, burns, tumors	[62, 193, 194]
R13	*R. patientia* L	Herb patience, garden patience, patience dock, spinach dock	Asia, Europe, North India, Bulgaria and Ukraine	Leaf	Hemostasis, diarrhoea, diarrhoea in cows	[4, 19, 68, 192, 198]
R14	*R. cristatus* DC	Greek dock	France, Turkey and Spain	–	–	[69–71]
R15	*R. vesicarius* L	Bladder dock, country sorrel	South Asia, Egypt and North Africa	Leaf, seed and whole plant	Plant: astringent, antiscorbutic, stomach problems, diuretic. Seed: antidysentery	[18, 72, 73, 203]
R16	*R. luminiastrum* Jaub & Spach		Europe	–	–	[42]
R17	*R. pictus* Forssk	Veined dock	Egypt, Gulf States, Kuwait, Lebanon-Syria, Libya, Palestine, Saudi Arabia, Sinai and Israel	Whole plant	For food	[41, 74, 75] [76, 203]
R18	*R. bucephalophorus* L		North America and Libya	Whole plant	Laxative	[77, 204]
R19	*R. tingitanus* L	Koressa	Europe, Asia and Africa	Whole plant	Hepatoprotective, antidepression, blood purifcation, constipation, tonic	[78, 186]
R20	*R. ecklonianus* Meissner	South African dock	South Africa	Young leaf	Anemia, chlorosis	[79]
R21	*R. abyssinicus* Jacq	Spinach rhubarb, mekmeko	Europe, Africa and Spinach	Young shoot, leaf, fresh or dried plant	Brest cancer, stomach problems, gonorrhea, liver diseases, wounds, diabetes, cough, hypertension, sores, rheumatism, hemorrhoids, scabies, diarrhoea	[80, 123]
R22	*R. confertus* Willd	Russian dock, Asiatic dock, mossy sorrel	Russia, Kazakhstan, China, Hungary, Slovakia, Romania, Italy, Europe, Finland, Norway, Sweden, Lithuania, Britain,Canada, north Dakota,Bulgaria and Ukraine	Leaf, root and rhubarb	Diarrhoea, diarrhoea in cows	[81–91, 198]

Table 1 (continued)

No	Species	Local names	Country	Parts used	Traditional uses	Ref
R23	*R. hymenosepalus* Torr	Canaigre, canaigre dock, desert rhubarb, wild rhubarb, sand dock	Australia, American California, Sonoran and Mexico	Leaf, tuber and rhubarb	Throat infections	[92, 93, 205, 206]
R24	*R. alpinus* L	Alpine dock, monk's rhubarb	Europe and Asia	Leaf and rhubarb	For food	[94]
R25	*R. rugosus* Campd		North America, Europe	Leaf	For food	[95, 96, 200]
R26	*R. nervosus* Vahl	Ithrib	Himalayas, Nilgiri, Nainital, East Africa and Arab	Leaf	Microbial infections, anticoccidial	[97, 98, 207]
R27	*R. maderensis* Lowe	Azedas, madeira sorrel	Portugal	Leaf	Blood depurative, dermatosis, diuretic, simulated gastrointestinal digestion, antidiabetic	[99, 100]
R28	*R. chinensis* Campd. (Syn. = *R. trisetifer*)		Vietnam, China	–	Microbial infections	[101]
R29	*R. algeriensis* Barratte & Murb. (Syn. = *R. elongatus*)		Algeria	–	–	[102]
R30	*R. tunetanus*		Tunisia	–	–	[103, 104]
R31	*R. rechingerianus* Losinsk. (Syn. = *R. pamiricus*)		Trans-Ili Ala-Tau	–	–	[61]
R32	*R. lunaria* L		Canarian	–	Diabetes	[16]
R33	*R. rothschildianus* Aarons		Palestine	Whole plant	Constipation, diarrhea, wound, diuretic, eczema and for food	[105]
R34	*R. sanguineus* L	Bloody dock, red veined dock, red-veined dock, red veined sorrel, red-veined sorrel	America, Canada, Chile and Italy	Young leaf	Wound, bacterial infections and abscesses	[61, 106]
R35	*R. acetosella* Linn	Sheep sorrel	Asia and Colombia	Root, the aerial part and leaf	Diuretic, constipation, diaphoretic, antiscorbutic. Fresh plant: urinary and kidney diseases	[18, 195]

– unknown

Table 2 The summary of compounds in *Rumex*

No	Compounds	Formula	Species	Plant parts	Ref
Quinones					
1	Chrysophanol	$C_{15}H_{10}O_4$	R2, R5, R7, R8, R9, R11, R13, R21, R22, R23, R28, R31	Rh, R, WP, T, A, S, F	[23, 35, 45, 46, 50, 51, 63, 80, 93, 101, 113, 125, 128, 129]
2	Chrysophanol-1-*O*-*β*-D-glucoside	$C_{21}H_{20}O_9$	R8, R31	R, S	[64, 128]
3	Chrysophanol-8-*O*-*β*-D-glucoside (chrysophanein)	$C_{21}H_{20}O_9$	R8, R9, R13, R21, R28	A, S, R, WP	[32, 46, 54, 101, 123, 129, 130]
4	Chrysophanol-8-*O*-*β*-D-galactoside	$C_{21}H_{20}O_9$	R8, R14	R	[52, 112]
5	Chrysophanol-1-*O*-(4-*O*-*β*-D-galactosyl)-*α*-L-rhamnoside	$C_{27}H_{30}O_{13}$	R2	WP	[184]
6	6′-Acetyl-chrysophanol-8-*O*-*β*-D-glucoside	$C_{23}H_{22}O_{10}$	R8	R	[32, 112, 113]
7	Chrysophanol anthrone	$C_{15}H_{12}O_3$	R1	R	[29]
8	Emodin (1,6,8-trihydroxy-3-methylanthraquinone)	$C_{15}H_{10}O_5$	R2, R5, R6, R8, R9, R11, R13, R21, R28, R31	Rh, R, WP, A, S, F, L	[23, 32, 34, 35, 40, 45–47, 51, 54, 80, 101, 112, 113, 128, 129]
9	Emodin-1-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{10}$	R7, R8	R, A	[14, 64]
10	Emodin-1-*O*-*β*-D-glucosyl-*α*-L-rhamnoside	$C_{27}H_{30}O_{14}$	R5, R31	R, S, L	[128, 131]
11	Emodin-6-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{10}$	R13	R	[54, 130]
12	Emodin-8-*O*-*β*-D-glucoside (PMEG)	$C_{21}H_{20}O_{10}$	R4, R6, R8, R9, R13, R28	WP, A, R, S	[23, 32, 34, 38, 46, 47, 101, 112, 129, 130]
13	Aloe-emodin	$C_{15}H_{10}O_6$	R2, R8, R13	R, WP, L	[23, 27, 35, 112]
14	6-Hydroxy-emodin (citreorosein)	$C_{15}H_{10}O_6$	R9, R21	WP	[50, 123]
15	6-Acetoxy-aloe-emodin	$C_{17}H_{12}O_6$	R1	R	[29]
16	Emodin dimethylether	$C_{17}H_{14}O_5$	R13	WP	[23]
17	Emodin anthrone	$C_{15}H_{12}O_4$	R1	R	[29]
18	Physcion (rheochrysin, emodin 3-methyl ether)	$C_{16}H_{12}O_5$	R2, R8, R9, R11, R13, R21, R23, R28	Rh, R, WP, T, A	[23, 35, 46, 50, 51, 54, 80, 93, 101, 113, 129]
19	Physcion-8-*O*-*β*-D-glucoside (physcionin)	$C_{22}H_{22}O_{10}$	R8, R9, R13, R21, R28	A, F, R, WP	[45, 101, 123, 129, 130]
20	Physcion anthrone	$C_{16}H_{14}O_4$	R1	R	[29]
21	Rumejaposide A	$C_{22}H_{22}O_{11}$	R9	R	[26]
22	Rumejaposide B	$C_{22}H_{22}O_{11}$	R9	R	[26]
23	Rumejaposide C	$C_{22}H_{22}O_{12}$	R9	R	[26]
24	Rumejaposide D	$C_{22}H_{22}O_{13}$	R9	R	[26]
25	Rumejaposide E	$C_{21}H_{22}O_{10}$	R7, R9	R	[26, 28]
26	Rumejaposide F	$C_{21}H_{22}O_{10}$	R7, R13	L, R	[27, 28]
27	Rumejaposide G	$C_{21}H_{22}O_9$	R7	R	[28]
28	Rumejaposide H	$C_{21}H_{22}O_9$	R7	R	[28]
29	Rumejaposide I	$C_{21}H_{22}O_{10}$	R7, R13	L, R	[27, 28]
30	Xanthorin-5-methylether	$C_{17}H_{14}O_6$	R13	WP	[23, 24]
31	Rumexone	$C_{17}H_{16}O_4$	R6	R	[30]
32	Rhein	$C_{15}H_8O_6$	R2	R	[35]
33	Rhein-8-*O*-*β*-D-glucoside	$C_{21}H_{18}O_{11}$	R9	WP	[50]
34	Cassialoin	$C_{21}H_{22}O_9$	R7, R13	L, R	[27, 28]
35	Phallacinol (telochistin)	$C_{16}H_{12}O_6$	R11	R	[51]
36	1,8-Dihydroxyanthraquinone	$C_{14}H_8O_4$	R1	R	[29]
37	Martianine	$C_{42}H_{42}O_{17}$	R11	R	[132]
38	Rumoside A	$C_{42}H_{42}O_{16}$	R8, R13	R	[32, 112]
39	10-Hydroxyaloin A	$C_{21}H_{22}O_{10}$	R8	R	[31]
40	10-Hydroxyaloin B	$C_{21}H_{22}O_{10}$	R8	R	[31]
41	6-Methoxyl-10-hydroxyaloin A	$C_{22}H_{24}O_{11}$	R8	R	[32]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
42	6-Methoxyl-10-hydroxyaloin B	$C_{22}H_{24}O_{11}$	R8	R	[32]
43	10-Hydroxycascaroside C	$C_{27}H_{32}O_{14}$	R11	R	[132]
44	10-Hydroxycascaroside D	$C_{27}H_{32}O_{14}$	R11	R	[132]
45	Obtusifolate A	$C_{39}H_{42}O_{8}$	R12	R	[25]
46	Obtusifolate B	$C_{34}H_{34}O_{7}$	R12	R	[25]
47	Rumexpatientoside A	$C_{22}H_{24}O_{10}$	R11	R	[133]
48	Rumexpatientoside B	$C_{22}H_{24}O_{10}$	R11	R	[133]
49	Nepalenside A	$C_{21}H_{22}O_{11}$	R11	R	[33]
50	Nepalenside B	$C_{21}H_{22}O_{11}$	R11	R	[33]
51	Helminthosporin	$C_{15}H_{12}O_{5}$	R21	Rh	[80]
52	1,3,5-Trihydroxy-7-methylanthraquinone	$C_{15}H_{10}O_{5}$	R13	R	[130]
53	1,5-Dihydroxyanthraquinone	$C_{14}H_{8}O_{4}$	R6	R	[30]
54	1,3,7-Trihydroxy-6-methylanthraquinone	$C_{15}H_{10}O_{5}$	R2	WP	[134]
55	Przewalskinone B	$C_{16}H_{12}O_{5}$	R2	WP	[134]
56	Rumpictusoide A	$C_{21}H_{19}O_{10}$	R17	WP	[183]
Flavonoids					
57	Vitexin	$C_{21}H_{20}O_{10}$	R1	A	[57]
58	Isovitexin	$C_{21}H_{20}O_{10}$	R15	A	[185]
59	Orientin	$C_{21}H_{20}O_{11}$	R1, R16	A, WP	[42, 57]
60	Acetyl-orientine	$C_{23}H_{22}O_{12}$	R16	WP	[42]
61	Iso-orientine	$C_{21}H_{20}O_{11}$	R1	A	[57]
62	Quercetin-3-*O*-*β*-D-galactoside (hyperoside)	$C_{21}H_{20}O_{11}$	R1, R7, R13, R31	S, R, WP	[36, 44, 47, 49]
63	Kaempferol	$C_{15}H_{10}O_{6}$	R2, R6, R7, R13	WP, R, A	[14, 23, 34, 35]
64	Kaempferol-3-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{11}$	R4, R7, R13	WP, A	[14, 23, 36–38]
65	Kaempferol-3-*O*-*α*-L-rhamnoside	$C_{21}H_{20}O_{10}$	R1, R6	L, WP	[34, 39]
66	Kaempferol-3-*O*-*α*-L-rhamnosyl-(1 → 6)-*β*-D-galactoside	$C_{27}H_{30}O_{15}$	R5, R7	L, WP	[36, 40]
67	Kaempferol-3-*O*-*α*-L-arabinosyl-(1 → 6)-*β*-D-galactoside	$C_{26}H_{28}O_{15}$	R17	A	[41]
68	Kaempferol-3-*O*-[2″-O-acetyl-*α*-L-arabinosyl]-(1 → 6)-*β*-D-galactoside	$C_{28}H_{30}O_{16}$	R17	A	[41]
69	Kaempferol-7-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{11}$	R16	WP	[42]
70	Kaempferol-7-*O*-*α*-L-rhamnoside	$C_{21}H_{20}O_{10}$	R16	WP	[42]
71	Quercetin	$C_{15}H_{10}O_{7}$	R2, R5, R7, R8, R13	F, S, R, A	[14, 35, 45, 47, 48]
72	Quercetin-3-*O*-*β*-D-glucoside (isoquercetin, ECQ, QGC)	$C_{21}H_{20}O_{12}$	R4, R5, R7, R13	A, WP, L, S	[14, 23, 27, 37, 38, 46, 47]
73	Quercetin-3-*O*-*β*-D-glucuronide	$C_{21}H_{18}O_{13}$	R7, R13	A	[14, 46]
74	Quercetin-3-*β*-D-glucosyl-(1 → 4)-*β*-D-galactoside	$C_{27}H_{30}O_{17}$	R5	L	[40]
75	Quercetin-3-*O*-*α*-L-rhamnoside (quercitrin)	$C_{21}H_{20}O_{11}$	R4, R5, R9, R13, R31	L, WP, R, A	[27, 38, 40, 49, 50]
76	Isorhamnetol	$C_{16}H_{12}O_{7}$	R13	WP,	[23, 37]
77	Isorhamnetol-3-*O*-rutinoside	$C_{28}H_{32}O_{16}$	R7	WP	[36]
78	Isorhamnetol-3-*O*-*β*-D-galactoside	$C_{22}H_{22}O_{12}$	R7	WP	[36]
79	Isorhamnetol-3-*O*-*β*-D-glucoside	$C_{22}H_{22}O_{12}$	R7	WP	[36]
80	Quercetin-3-*O*-*α*-L-arabinoside	$C_{20}H_{18}O_{11}$	R4, R16	WP, A	[38, 42, 43]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
81	Quercetin-3-*O*-*α*-L-arabinosyl-(1 → 6)-*β*-D-galactoside	$C_{26}H_{28}O_{16}$	R17	A	[41]
82	Quercetin-3-*O*-[2″-*O*-acetyl-*α*-L-arabinosyl]-(1 → 6)-*β*-D-galactoside	$C_{28}H_{30}O_{17}$	R17	A	[41]
83	Quercetin-7-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{12}$	R13, R16	S, WP	[42, 44, 47]
84	Quercetin-7-*O*-*α*-L-rhamnoside	$C_{21}H_{20}O_{11}$	R16	WP	[42]
85	Rutin	$C_{21}H_{30}O_{16}$	R5, R8, R31	R, L	[32, 40, 49, 112]
86	5-Hydroxy-4′-methoxyflavone-7-*O*-*β*-D-rutinoside	$C_{28}H_{32}O_{14}$	R13	WP	[23, 37]
87	Apigenin	$C_{15}H_{10}O_5$	R1	R	[53]
88	Luteolin (cyanidenon)	$C_{15}H_{10}O_6$	R1, R19, R35	L, WP, A	[136, 186–188]
89	Luteolin-7-*O*-*β*-D-glucoside	$C_{21}H_{20}O_{11}$	R16	WP	[42]
90	7-Hydroxy-2,3-dimethyl-chromone	$C_{11}H_{10}O_3$	R14	R	[52]
91	5-Methoxy-7-hydroxy-1(3*H*)-chromone	$C_{10}H_8O_4$	R13	R	[53]
92	5,7-Dihydroxy-1(3*H*)-chromone	$C_9H_6O_4$	R13	R	[53]
93	Mikanin (3,5-dihydroxy-4′,6,7-trimethoxyflavone)	$C_{18}H_{16}O_7$	R13	L	[27]
94	3,5-Dihydroxy-6,7,3′,4′-tetramethoxyflavone	$C_{19}H_{18}O_8$	R13	L	[27]
95	2,5-Dimethyl-7-hydroxychromone-7-*O*-*β*-D-glucoside	$C_{17}H_{20}O_8$	R8	R	[31]
96	2,5-Dimethyl-7-hydroxychromone	$C_{11}H_{10}O_3$	R11	R	[51]
97	3-*O*-Methyl quercetin	$C_{16}H_{12}O_7$	R8	F	[45]
98	Tricin-7-*O*-*β*-D-glucoside	$C_{23}H_{24}O_{12}$	R22	R	[137]
99	2-(2′-Hydroxypropyl)-5-methyl-7-hydroxychromone	$C_{13}H_{14}O_4$	R13	R	[138]
100	2-(2′-Hydroxypropyl)-5-methyl-7-hydroxychromone-7-*O*-*β*-D-glucoside	$C_{19}H_{24}O_9$	R13	R	[138]
101	Maackiain	$C_{16}H_{12}O_5$	R13	A	[46]
102	Maackiain-3-*O*-*β*-D-glucoside	$C_{22}H_{22}O_{10}$	R13	A	[46]
103	Aloesin	$C_{19}H_{22}O_9$	R11	R	[33]
104	4′-*p*-Acetylcoumaroyl luteolin	$C_{26}H_{18}O_9$	R19	L	[78]
105	Catechin	$C_{15}H_{14}O_6$	R1, R6, R13, R19, R31	R, WP	[34, 49, 53, 54]
106	6-Cl-catechin	$C_{15}H_{13}ClO_5$	R13, R19	R	[54]
107	Epicatechin	$C_{15}H_{14}O_6$	R1, R6, R14, R31	R, WP	[34, 49]
108	(+)-Epigallocatechin	$C_{15}H_{14}O_7$	R1	R	[135]
109	(−)-Epigallocatechin	$C_{15}H_{14}O_7$	R1	R	[135]
110	Epicatechin-3-*O*-gallate	$C_{22}H_{18}O_{10}$	R1, R31	A, R	[49, 56]
111	Epigallocatechin-3-*O*-gallate	$C_{22}H_{18}O_{11}$	R1	A	[56]
112	Isokaempferide	$C_{16}H_{12}O_6$	R4	A, R	[148]
113	Quercetin-3,3′-dimethylether	$C_{17}H_{14}O_7$	R4	A, R	[148]
Tannins					
114	Epiafzelechin-(4*β* → 8)-epicatechin-(4*β* → 8)-epicatechin	$C_{45}H_{38}O_{17}$	R1	A	[56]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
115	Epicatechin-(4β → 8)-epicatechin-(4β → 8)-catechin	$C_{45}H_{38}O_{18}$	R1	A	[56]
116	Epicatechin-(4β → 8)-epicatechin-(4β → 8)-epicatechin (Procyanidin C1)	$C_{45}H_{38}O_{18}$	R1	A	[56]
117	Epicatechin-3-*O*-gallate-(4β → 8)-epicatechin-3-*O*-gallate-(4β → 8)-epicatechin-3-*O*-gallate	$C_{66}H_{50}O_{30}$	R1	A	[56]
118	Epicatechin-(4β → 8)-epicatechin-(4β → 8)-epicatechin-(4β → 8)-epicatechin	$C_{60}H_{50}O_{24}$	R1	A	[56]
119	Epicatechin-3-*O*-gallate-(4β → 8)-epicatechin-3-*O*-gallate	$C_{44}H_{34}O_{20}$	R1	A	[139]
120	Epicatechin-(4β → 6)-epicatechin (procyanidin B5)	$C_{30}H_{26}O_{12}$	R1	A	[56]
121	Epicatechin-(4β → 6)-catechin	$C_{30}H_{26}O_{12}$	R1	A	[56]
122	Epicatechin-(4β → 8)-catechin (procyanidin B1)	$C_{30}H_{26}O_{12}$	R1	A	[56, 107]
123	Catechin-(4α → 8)-catechin (procyanidin B3)	$C_{30}H_{26}O_{12}$	R1	A	[56, 107]
124	Catechin-(4α → 8)-epicatechin (procyanidin B4)	$C_{30}H_{26}O_{12}$	R1	A	[56, 107]
125	Epiafzelechin-(4β → 8)-epicatechin (procyanidin B2)	$C_{30}H_{26}O_{11}$	R1	A	[56, 107]
126	Epicatechin-(4β → 8)-epicatechin-3-*O*-gallate	$C_{37}H_{30}O_{16}$	R1	A	[56]
127	Epiafzelechin-(4β → 8)-epicatechin-3-*O*-gallate	$C_{37}H_{30}O_{15}$	R1	A	[56]
128	Epicatechin-(4β → 6)-epicatechin-3-*O*-gallate	$C_{37}H_{30}O_{16}$	R1	A	[56]
129	Epicatechin-3-*O*-gallate-(4β → 6)-epicatechin-3-*O*-gallate	$C_{44}H_{34}O_{20}$	R1	A	[56]
130	Epiafzelechin-3-*O*-gallate-(4β → 8)-epicatechin-3-*O*-gallate	$C_{44}H_{34}O_{19}$	R1	A	[56]
131	Epicatechin-(2β → 7, 4β → 8)-epicatechin-(4β → 8)-epicatechin (cinnamtannin B1)	$C_{45}H_{36}O_{18}$	R1	A	[56]
132	Epicatechin-(2β- > 7, 4β → 8)-epiafzelechin-(4α → 8)-epicatechin	$C_{45}H_{36}O_{17}$	R1	A	[56]
133	Epicatechin-3-*O*-gallate-(2β → 7,4β → 8)-epicatechin-(4β → 8)-epicatechin (cinnamtannin B1-3-*O*-gallate)	$C_{52}H_{40}O_{22}$	R1	A	[56]
134	Epicatechin-(2β → 7, 4β → 8)-epicatechin-(4β → 8)-phloroglucinol	$C_{36}H_{28}O_{14}$	R1	A	[56]
135	Epiafzelechin-(4β → 6)-epicatechin-3-*O*-gallate	$C_{37}H_{30}O_{15}$	R1	A	[56]
136	Parameritannin A1	$C_{60}H_{48}O_{24}$	R1	A	[56]
137	Epicatechin-3-*O*-gallate-(4β → 8)-epicatechin-3-*O*-gallate-phloroglucinol	$C_{50}H_{38}O_{25}$	R1	A	[56]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
138	Epicatechin-(2$\beta \rightarrow 7$, 4$\beta \rightarrow 8$)-epicatechin	$C_{30}H_{26}O_{12}$	R1	A	[56]
Stilbenoids					
139	Resveratrol	$C_{14}H_{12}O_3$	R2, R8	R, F	[32, 35, 45, 112]
140	(*Z*)-Resveratrol	$C_{14}H_{12}O_3$	R1	R	[124]
141	Polydatin (resveratrol-3-*O*-β-D-glucoside, piceid)	$C_{20}H_{22}O_8$	R7, R8	R, A	[14, 32, 112]
142	5,4′-Dihydroxy-3-methoxystilbene	$C_{15}H_{14}O_3$	R18	R	[77]
143	3,5-Dihydroxy-4′-methoxystilbene	$C_{15}H_{14}O_3$	R18	R	[77]
144	5,4′-Dihydroxystilbene-3-*O*-α-arabinoside	$C_{19}H_{20}O_7$	R18	R	[77]
Naphthalenes					
145	Nepodin (musizin)	$C_{13}H_{12}O_3$	R2, R8, R9, R13	R	[32, 35, 112, 113, 130]
146	Nepodin-8-*O*-β-D-glucoside	$C_{19}H_{22}O_8$	R1, R2, R4, R7, R8, R13, R17	R, L, A	[27, 31, 38, 46, 63, 74, 110, 130]
147	Nepodin-8-*O*-β-D-(6′-*O*-acetyl)-glucoside	$C_{21}H_{24}O_9$	R2	R	
148	Neposide	$C_{19}H_{22}O_8$	R2, R22, R24	R, WP	[140, 141]
149	2-Acetyl-3-methyl-6-methoxyl-8-hydroxy-1,4-naphthoquinone	$C_{14}H_{12}O_5$	R9	WP	[141]
150	Torachrysone (TRA, 2-acetyl-1,8-dihydroxy-3-methyl-6-methoxyl-naphthalene)	$C_{14}H_{14}O_4$	R13	WP	[141]
151	Torachrysone-8-*O*-β-D-glucoside	$C_{20}H_{24}O_9$	R2, R7, R9, R13	L, R, A	[27, 46, 53, 63]
152	2-Methoxystypandrone (MSD, 6-acetyl-7-methyl-2-methoxyl-5-hydroxy-1,4-naphthoquinone)	$C_{14}H_{12}O_5$	R9, R10	L, S, R	[115, 116]
153	3-Acetyl-2-methyl-1,5-dihydroxyl-2,3-epoxynaphthoquinol	$C_{13}H_{12}O_5$	R9, R11	R,	[51, 65]
154	Rumexoside	$C_{20}H_{22}O_{10}$	R2	R	[110]
155	2-Acetyl-4-chloro-1,8-dihydroxy-3-methylnaphthalene-8-*O*-β-D-glucoside (patientoside A)	$C_{19}H_{21}O_8Cl$	R13	R	[117]
156	Patientoside B	$C_{17}H_{18}O_7Cl_2$	R13	R	[117]
157	4,4″-Binaphthalene-8,8″-*O*,*O*-di-β-D-glucoside	$C_{36}H_{42}O_{16}$	R13	R	[120]
158	6-Hydroxymusizin-8-*O*-β-D-glucopyranoside	$C_{15}H_{14}O_6$	R2	R	[110]
159	3-Acetyl-2-methyl-1,4,5-trihydroxyl-2,3-epoxynaphthoquinol	$C_{13}H_{14}O_5$	R13	R	[118]
160	3-Acetyl-2-methyl-1,5-dihydroxyl-7-methoxyl-2,3-epoxynaphthoquinol	$C_{14}H_{14}O_6$	R13	WP	[119]
161	Rumexone A	$C_{14}H_{18}O_4$	R11	R	[142]
162	Rumexneposide A	$C_{23}H_{26}O_9$	R11	R	[143]
163	Rumexneposide B	$C_{22}H_{26}O_{10}$	R11	R	[143]
164	Hastatuside B	$C_{21}H_{24}O_9$	R2, R13	L, R	[114] [27]
165	Epi-isoshinanolone	$C_{11}H_{12}O_3$	R13	R	[138]
166	Isoshinanolone	$C_{11}H_{12}O_3$	R9, R13	R, WP	[50, 138]
Terpenes					
167	Tormentic acid	$C_{30}H_{48}O_5$	R9	ST	[121]
168	Myrianthic acid	$C_{30}H_{48}O_6$	R9	ST	[121]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
169	2*α*,3*α*,19*α*-Trihydroxy-24-norurs-4(23),12-dien-28-oic acid	$C_{29}H_{44}O_5$	R9	ST	[121]
170	4(*R*),23-Epoxy-2*α*,3*α*,19*α*-trihydroxy-24-norurs-12-en-28-oic acid	$C_{29}H_{44}O_6$	R9	ST	[121]
171	Taraxasterol acetate	$C_{32}H_{52}O_2$	R2	R	[35]
172	Lupeol	$C_{30}H_{50}O$	R11	A	[189]
Diterpene alkaloids					
173	7,11,14-Trihydroxy-2,13-dioxohetisane (orientinine)	$C_{20}H_{23}NO_5$	R17	A	[75]
174	6,13,15-Trihydroxyhetisane (acorientine)	$C_{20}H_{27}NO_3$	R17	A	[75]
175	6-Hydroxy-11-deoxy-13-dehydrohetisane (panicudine)	$C_{20}H_{25}NO_3$	R17	A	[75]
Lignans					
176	Arctiin	$C_{27}H_{34}O_{11}$	R13	WP	[23]
177	3-Hydroxyarctiin	$C_{27}H_{34}O_{10}$	R13	WP	[23]
178	3-Methoxyarctiin-4″-*O*-*β*-D-xyloside	$C_{27}H_{34}O_{11}$	R13	WP	[23]
179	4-Ketopinoresinol	$C_{20}H_{20}O_7$	R13	L	[27]
180	Syringaresinol	$C_{22}H_{26}O_8$	R9, R13	L, WP	[27, 50]
181	Manassantin A	$C_{42}H_{52}O_{11}$	R13	L	[27]
182	Balanophonin	$C_{22}H_{22}O_7$	R13	L	[27]
183	Schizandriside	$C_{28}H_{32}O_6$	R2	WP	[111]
184	(−)-Isolariciresinol-9-*O*-*β*-D-xylopyranoside	$C_{25}H_{34}O_{10}$	R2	WP	[111]
185	(−)-5-Methoxyisolariciresinol-9-*O*-*β*-D-xylopyranoside	$C_{26}H_{36}O_{11}$	R2	WP	[111]
186	(+)-5-Methoxyisolariciresinol-9-*O*-*β*-D-xylopyranoside	$C_{26}H_{36}O_{11}$	R2	WP	[111]
187	(+)-Lyoniside	$C_{27}H_{38}O_{12}$	R2	WP	[111]
188	Nudiposide	$C_{27}H_{38}O_{12}$	R2	WP	[111]
189	(+)-Lyoniresinol-3α-*O*-*β*-D-glucoside	$C_{28}H_{38}O_{13}$	R11	R	[33]
Others					
190	Phenylethyl-*O*-*α*-L-arabinopyransy-(1 → 6)-*O*-*β*-D-glucoside	$C_{19}H_{28}O_{10}$	R8	R	[31]
191	Methylorsellinate	$C_{11}H_{14}O_4$	R11	R	[51]
192	Ferulic acid	$C_{10}H_{10}O_4$	R11	R	[51]
193	Methyl 2-acetyl-3,5-dihydroxy-phenylacetate	$C_{11}H_{12}O_5$	R11	R	[51]
194	1-(2-Hydroxy-5-methyl-phenyl)-ethanon	$C_9H_{10}O_2$	R11	R	[51]
195	Methyl syringate	$C_{10}H_{12}O_5$	R11	R	[51]
196	1-(2,4-Dihydroxy-6-methylphenyl)-ethanon	$C_9H_{10}O_3$	R11	R	[51]
197	4-Hydroxybenzene ethanol	$C_8H_{10}O_2$	R11	R	[51]
198	Isovanillin	$C_8H_8O_3$	R11	R	[51]
199	*p*-Coumaricacid-*n*-eicosanyl ester	$C_{31}H_{52}O_3$	R13	S	[47]
200	*Z*-Octadecyl caffeate	$C_{27}H_{44}O_4$	R13	S	[47]
201	Dibutylphthalate	$C_{16}H_{22}O_4$	R11	R	[132]
202	2-Methoxyhydroquinone	$C_7H_8O_3$	R11	R	[132]
203	Batiansuanmol	$C_{14}H_{18}O_5$	R13	R	[138]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
204	Orcinol	$C_7H_8O_2$	R13	R	[54]
205	*p*-Hydroxybenzoic acid	$C_7H_6O_3$	R1, R9	L,	[26, 39]
206	*p*-Coumaric acid	$C_9H_8O_3$	R1, R2, R7	L, R, WP, A	[39, 48, 134, 144]
207	Methyl 3,4-dihydroxyphenylpropionate	$C_{10}H_{12}O_4$	R1	L	[39]
208	Vanillic acid	$C_8H_8O_4$	R1	L	[39]
209	Isovanillic acid	$C_8H_8O_4$	R1, R7	L, R	[39, 48]
210	Gallic acid	$C_7H_6O_5$	R2, R7, R13	R,	[35, 48, 53]
211	Methyl gallate	$C_8H_8O_5$	R2	R	[35]
212	2,6-Dimethoxy-4-hydroxyl benzoic acid	$C_9H_{10}O_5$	R9	A	[26]
213	Pyrocatechin	$C_6H_6O_2$	R9	A	[145]
214	Syringic acid	$C_9H_{10}O_5$	R9	A	[145]
215	3,4-Dihydroxybenzaldehyde	$C_7H_6O_3$	R9	A	[145]
216	Ethyl 3,4-dihydroxybenzoate	$C_9H_{10}O_4$	R9	A	[145]
217	Ethyl gallate	$C_9H_{11}O_4$	R9	A	[145]
218	Rumexin	$C_{15}H_{20}O_8$	R4	A	[38]
219	Caffeic acid	$C_9H_8O_4$	R4	A	[38]
220	1-*O*-caffeoylglucose	$C_{15}H_{18}O_9$	R4	A	[38]
221	1-Methyl caffeic acid	$C_{10}H_{10}O_4$	R4	A	[38]
222	Neochlorogenic acid	$C_{16}H_{18}O_9$	R27	L	[146]
223	(*S*)-4′-Methylnonyl benzoate	$C_{17}H_{26}O_2$	R7	A	[14]
224	5-Methoxy-7-hydroxy-1(3*H*)-benzofuranone	$C_9H_8O_4$	R11	R	[51]
225	5,7-Dihydroxy-1(3*H*)-benzofuranone	$C_9H_6O_4$	R13	R	[53]
226	5-Methoxyl-1(3*H*)-benzofuranone-7-glucoside	$C_{15}H_{18}O_9$	R8	R	[31]
227	Sinapic acid	$C_{11}H_{12}O_5$	R1	FL	[147]
228	Protocatechuic acid	$C_7H_6O_4$	R1	L	[55]
229	*p*-Hydroxycinnamic acid	$C_9H_8O_3$	R8	R	[190]
230	Streptokordin	$C_8H_9NO_2$	R11	R	[132]
231	Hastatuside A	$C_{16}H_{18}O_9$	R2	R	[114]
232	*β*-Sitosterol	$C_{29}H_{50}O$	R1, R6, R7, R11, R13, R28	A, R, S, L, WP	[34, 39, 47, 48, 53, 101, 189]
233	Daucosterol	$C_{35}H_{60}O_6$	R1, R7, R8, R13, R28	A, R, F, L	[39, 45, 48, 53, 101, 138, 190]
234	Ergosta-6,22-diene-3,5,8-triol	$C_{28}H_{46}O_3$	R21	WP	[123]
235	Nonadecanoic acid-2,3-dihydroxypropyl ester	$C_{22}H_{44}O_4$	R13	R	[53]
236	Hexadecanoic acid 2,3-dihydroxypropyl ester	$C_{19}H_{38}O_4$	R7	R	[48]
237	1-Stearoylglycerol	$C_{21}H_{42}O_4$	R4	A, R	[148]
238	Triacontanol	$C_{30}H_{62}O$	R13	S	[47]
239	Dotriacontanol	$C_{32}H_{66}O$	R13	S	[47]
240	Hexacosanoic acid	$C_{26}H_{52}O_2$	R6, R13	S, WP	[34, 47]
241	Dotriacontane	$C_{32}H_{66}$	R13	S	[47]
242	Glyceryl 1,3-dipalmitate	$C_{35}H_{68}O_5$	R13	S	[47]
243	(2*E*)-8-Hydroxy-2,6-dimethyl-2-octenoic acid	$C_{10}H_{18}O_3$	R11	R,	[132]
244	Tetratriacontane	$C_{34}H_{70}$	R13	S	[149]
245	Ceryl alcohol	$C_{26}H_{54}O$	R20	A	[125]

Table 2 (continued)

No	Compounds	Formula	Species	Plant parts	Ref
246	Oxalic acid	$C_2H_2O_4$	R1	A	[56]
247	Cardozin	$C_{10}H_{20}O_6$	R7	R	[48]
248	Succinic acid	$C_4H_6O_4$	R7	R	[48]
249	Sucrose	$C_{12}H_{22}O_{11}$	R8	R	[190]
250	Rebeccamycin	$C_{27}H_{21}Cl_2N_3O_7$	R1	L	[9]
251	Vitamin C	$C_6H_8O_6$	R1	L	[9]
252	Calcium oxalate	$C_2H_2O_4$ Ca	R1	L	[9]
253	Tartaric acid	$C_4H_6O_6$	R1	L	[9]
254	*β*-carotene	$C_{40}H_{56}$	R13, R15	R, L	[126, 129]
255	Lutein	$C_{40}H_{56}O_2$	R15, R25	L	[95, 126]
256	Anhydrolutein I	$C_{40}H_{54}O$	R25	L	[95]
257	Anhydrolutein II	$C_{40}H_{54}O$	R25	L	[95]
258	Riboflavin	$C_{17}H_{20}N_4O_6$	R13	R	[129]
259	2-*O*-methyl inositol	$C_7H_{14}O_6$	R13	A	[46]
260	Stigmasterol	$C_{29}H_{48}O$	R13	WP	[23]
261	*α*-Asarone	$C_{12}H_{16}O_3$	R13	WP	[23]
262	7-Hydroxy-5-methoxyphthalide	$C_9H_8O_4$	R11	R	[51]
263	4-Ethyl heptyl benzoate	$C_{16}H_{24}O_2$	R26	R	[150]
264	Glucosylceramide	$C_{40}H_{77}NO_8$	R12	L	[151]
265	Helonioside A	$C_{32}H_{38}O_{17}$	R7	R	[48]
266	1-*O*-*β*-D-(2,4-dihydroxy-6-methoxyphenyl)-6-*O*-(4-hydroxy-3,5-dimethoxybenzoyl)-glucoside	$C_{22}H_{26}O_{13}$	R1	A	[56]
267	1-*O*-*β*-D-(3,5-Dimethoxy-4-hydroxyphenol)-(6-*O*-galloyl)-glucoside	$C_{21}H_{24}O_{13}$	R11	R	[33]
268	RA-P (Polysaccharide (D-glucose-—-D-arabinose)		R1	R	[127]

Rh rhizomes, *R* roots, *WP* whole plants, *T* tubers, *A* the aerial part, *S* seeds, *L* leaves, *F* fruits, *S* stems, *FL* flowers

3.2 Flavonoids

Flavonoids are one of the most important bioactive components existing widely in plant kingdom. To date, 57 flavonoids (**57**–**113**) including flavones, flavanols, chromones and their

glycosides were reported from *Rumex* (Fig. 2, Table 2). They are mostly derived from kaempferol (**63**) and quercetin (**71**) connecting with glucosyl, rhamnosyl, galactosyl and arabinosyl moieties at different positions. For example, kaempferol (**63**) together with seven glycosides, -3-*O*-*β*-D-glucoside (**64**), -3-*O*-*α*-L-rhamnoside (**65**), -3-*O*-*α*-L-rhamnosyl-(1 → 6)-*β*-D-galactoside(**66**), -3-*O*-*α*-L-arabinosyl-(1 → 6)-*β*-D-galactoside (**67**), -3-*O*-(2”-*O*-acetyl-*α*-L-arabinosyl)-(1 → 6)-*β*-D-galactoside (**68**), -7-*O*-*β*-D-glucoside (**69**) and -7-*O*-*α*-L-rhamnoside (**70**) [14, 23, 34–42], and quercetin (**71**) together with 11 derivatives, -3-*O*-*β*-D-glucoside (**72**), -3-*O*-*β*-D-glucuronide (**73**), -3-*O*-*β*-D-glucosyl(1 → 4)-*β*-D-galactoside (**74**), -3-*O*-*α*-L-rhamnoside (**75**), -3-*O*-*α*-L-arabinoside (**80**), -3-*O*-*α*-L-arabinosyl-(1 → 6)-*β*-D-galactoside (**81**), -3-*O*-[2”-*O*-acetyl-*α*-L-arabinosyl]-(1 → 6)-*β*-D-galactoside (**82**), -7-*O*-*β*-D-glucoside (**83**), -7-*O*-*α*-L-rhamnoside (**84**), 3-*O*-methyl quercetin (**97**) and -3,3’-dimethylether (**113**) [14, 23, 27, 35, 37, 38, 40–50, 148], were reported from several *Rumex* plants.

Moreover, a new chromone glucoside, 2,5-dimethyl-7-hydroxychromone-7-*O*-*β*-D-glucoside (**95**) was isolated from the root of *R. gmelini* [31], and five chromones, 7-hydroxy-2,3-dimethyl-chromone (**90**), 5-methoxy-7-hydroxy-1(3*H*)-chromone (**91**), 5,7-dihydroxy-1(3*H*)-chromone (**92**), 2,5-dimethyl-7-hydroxychromone-7-*O*-*β*-D-glucoside (**95**) and 2,5-dimethyl-7-hydroxychromone (**96**) were reported from *R. gmelini*, *R. nepalensis*, *R. patientia* and *R. cristatus* [31, 51–53].

Catechin (**105**) and epicatechin (**107**) are commonly distributed in *R. patientia*, the roots of *R. rechingerianus*, the whole plant of *R. crispus*, and the leaves of *R. acetosa* [34, 37, 39, 49, 54, 55]. Moreover, a variety of flavan-3-ols, **105**, **107**, epicatechin-3-*O*-gallate (**110**), epigallocatechin-3-*O*-gallate (**111**) were isolated from *R. acetosa* [49, 56].

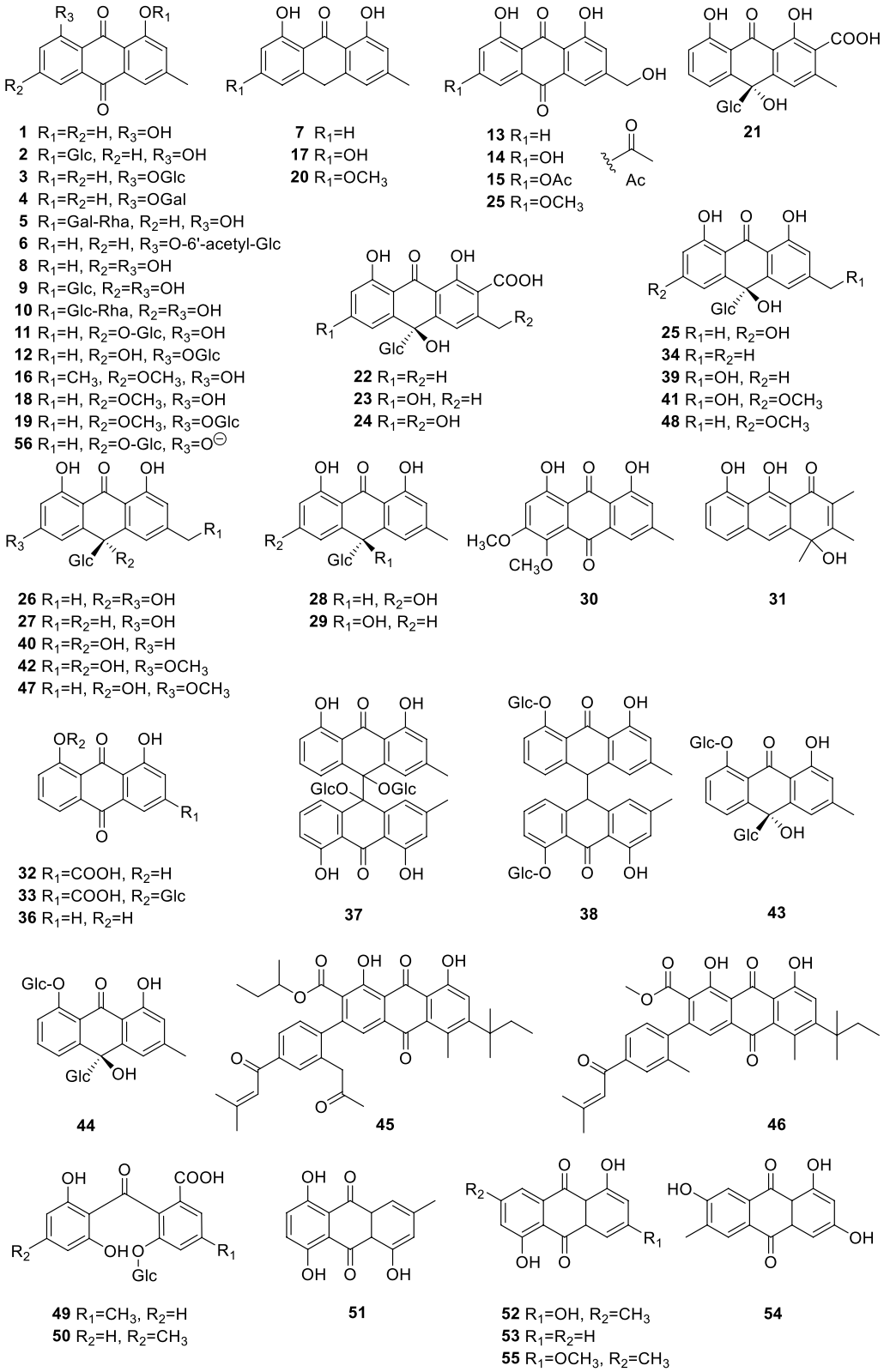
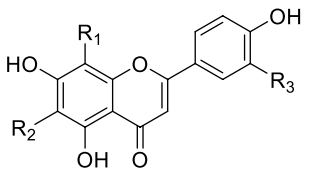
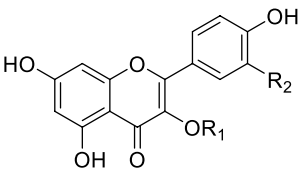


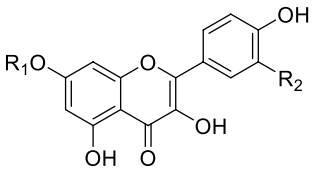
Fig. 1 Structures of quinones (**1**–**56**)



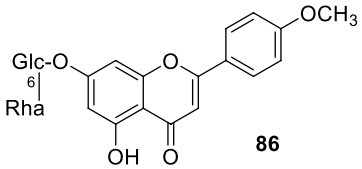
57 R_1=Glc, R_2=R_3=H
58 R_1=R_3=H, R_2=Glc
59 R_1=Glc, R_2=H, R_3=OH
60 R_1=(2'-Ac)-Glc, R_2=H, R_3=OH
61 R_1=H, R_2=Glc, R_3=OH
87 R_1=R_2=R_3=H
88 R_1=R_2=H, R_3=OH



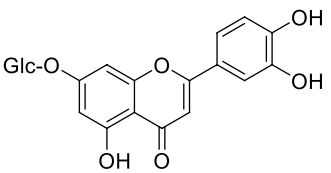
62 R_1=Gal, R_2=OH
63 R_1=H, R_2=H
64 R_1=Glc, R_2=H
65 R_1=Rha, R_2=H
66 R_1=Rha(1-6)Gal, R_2=H
67 R_1=Ara(1-6)Gal, R_2=H
68 R_1=(2''-Ac)-Ara(1-6)Gal, R_2=H
71 R_1=H, R_2=OH
72 R_1=Glc, R_2=OH
73 R_1=glucuronosyl, R_2=OH
74 R_1=Glc(1-4)Gal, R_2=OH
75 R_1=Rha, R_2=OH
76 R_1=H, R_2=OCH_3
77 R_1=Rha(1-6)Glc, R_2=OCH_3
78 R_1=Gal, R_2=OCH_3
79 R_1=Glc, R_2=OCH_3
80 R_1=Ara, R_2=OH
81 R_1=Ara(1-6)Gal, R_2=OH
82 R_1=(2''-Ac)-Ara-(1-6)Gal, R_2=OH
85 R_1=Rha(1-6)Glc, R_2=OH
97 R_1=CH_3, R_2=OH
112 R_1=CH_3, R_2=H
113 R_1=CH_3, R_2=OCH_3



69 R_1=Glc, R_2=H
70 R_1=Rha, R_2=H
83 R_1=Glc, R_2=OH
84 R_1=Rha, R_2=OH



86



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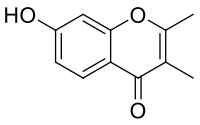

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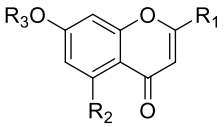
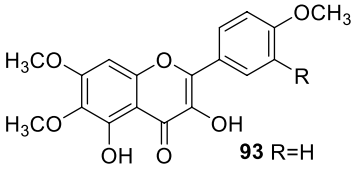
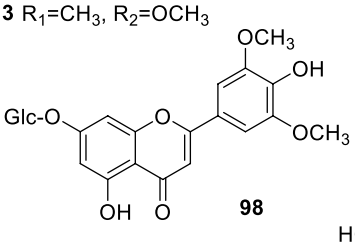


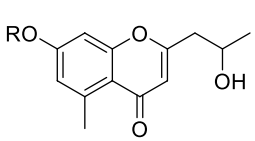
91 R_1=R_3=H, R_2=OCH_3
92 R_1=R_3=H, R_2=OH
95 R_1=R_2=CH_3, R_3=Glc
96 R_1=R_2=CH_3, R_3=H



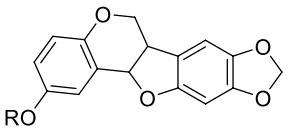
93 R=H
94 R=OCH_3



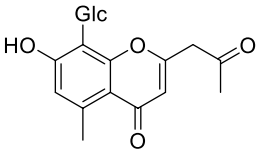
98



99 R=H
100 R=Glc



101 R=H
102 R=Glc



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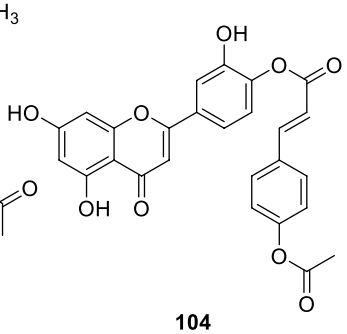

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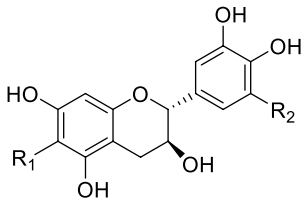
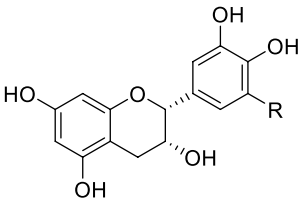
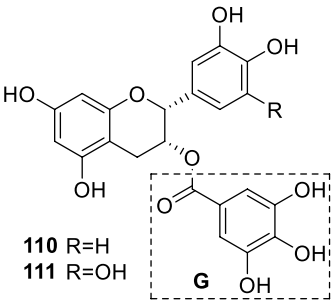


105 R_1=R_2=H
106 R_1=Cl, R_2=H
108 R_1=H, R_2=OH



107 R=H
109 R=OH



110 R=H
111 R=OH

Fig. 2 Structures of flavonoids (**57–113**)

3.3 Tannins

Tannins, which may be involved with the hemostasis activity, are abundant in *Rumex* plants. So far, 25 condensed tannins (**114**–**138**) (Fig. 3, Table 2) were reported from the genus *Rumex*.

Chemical investigations on the EtOAc fraction of acetone–water extract of the aerial parts of *R. acetosa* showed that *R. acetosa* was rich in tannins. Five new condensed tannin dimers, epiafzelechin-(4$\beta \rightarrow$ 8)-epicatechin-3-*O*-gallate (**127**), cinnamtannin B1-3-*O*-gallate (**132**) and epiafzelechin-(4$\beta \rightarrow$ 6)-epicatechin-3-*O*-gallate (**135**), and trimers, epiafzelechin-(4$\beta \rightarrow$ 8)-epicatechin-(4$\beta \rightarrow$ 8)-epicatechin (**114**), and epicatechin-(2$\beta \rightarrow$ 7, 4$\beta \rightarrow$ 8)-epiafzelechin-(4$\alpha \rightarrow$ 8)-epicatechin (**132**), were reported. In addition, some procyanidins and propelargonidins, epiafzelechin-(4$\beta \rightarrow$ 8)-epicatechin-(4$\beta \rightarrow$ 8)-epicatechin (**114**), epicatechin-(4$\beta \rightarrow$ 8)-epicatechin-(4$\beta \rightarrow$ 8)-catechin (**115**), procyanidin C1 (**116**), epicatechin-(4$\beta \rightarrow$ 6)-catechin (**121**), procyanidin B1-B5 (**120**, **122**–**125**), and epicatechin-(4$\beta \rightarrow$ 8)-epicatechin-3-*O*-gallate (**126**), were also isolated [56, 107].

3.4 Stilbenes

So far, 6 stilbenes have been separated from *Rumex* (**139**–**144**) (Fig. 4, Table 2). Resveratrol (**139**) isolated from *R. japonica* Houtt was found for the first time from the Polygonaceae family [108]. It has been widely applied in cardiovascular protection and as antioxidation agent [109]. Resveratrol (**139**), (*Z*)-resveratrol (**140**) and polydatin (**141**) were obtained from *Rumex* spp. [14, 32, 35, 45, 110, 111]. 5,4'-Dihydroxy-3-methoxystilbene (**142**), 3,5-dihydroxy-4'-methoxystilbene (**143**) and 5,4'-dihydroxy-stilbene-3-*O*-α-arabinoside (**144**) were separated from the roots of *R. bucephalophorus* [77].

3.5 Naphthalenes

Naphthalenes are also widely distributed in *Rumex*. At present, 22 naphthalenes including naphthol, α-naphthoquinones and their derivatives have been identified from *Rumex* (**145**–**166**) (Fig. 4, Table 2). Nepodin (**145**) and nepodin-8-*O*-β-D-glucoside (**146**) are widespread in *Rumex* [31, 45, 112, 113]. In addition, **145**, nepodin-8-*O*-β-D-(6'-*O*-acetyl)-glucoside (**147**), rumexoside (**154**), 6-hydroxymusizin-8-*O*-β-D-glucopyranoside (**158**) and hastatuside B (**164**) were isolated from *R. hastatus* [35, 110, 114]. 2-Methoxystypandrone (**152**) was isolated from *R. japonicus* and *R. maritimus* [115, 116]. Notably, some naphthalenes containing Cl, 2-acetyl-4-chloro-1,8-dihydroxy-3-methylnaphthalene-8-*O*-β-D-glucoside (**155**) and patientoside B (**156**) were isolated from *R. patientia* [117]. Moreover, 3-acetyl-2-methyl-1,5-dihydroxyl-2,3- epoxynaphthoquinol (**153**), 3-acetyl-2-methyl-1,4,5-trihydroxyl-2,3-epoxy-naphtho-quinol (**159**) and 3-acetyl-2-methyl-1,5-dihydroxyl-7-methoxyl-2,3-epoxynaphthoquinol (**160**), which contain the ethylene oxide part of the structure, were rarely found in *Rumex*, and they were reported from *R. patientia*, *R. japonicus* and *R. nepalensis* [51, 65, 118, 119]. 4,4"-Binaphthalene-8,8"-*O*,*O*-di-β-D-glucoside (**157**) was isolated from *R. patientia* [120].

3.6 Terpenes

Until now, only six terpenes have been reported from *Rumex* (Fig. 5, Table 2). Four pentacyclic triterpenes, i.e., tormentic acid (**167**), myrianthic acid (**168**) and 2α,3α,19α-trihydroxy-24-norurs-4(23), 12-dien-28-oic acid (**169**) and (4*R*)-23-epoxy-2α,3α,19α-trihydroxy-24-norurs-12-en-28-oic acid (**170**) were obtained from the EtOAc fraction of the stems of *R. japonicus*. Of them, **169** and **170** were two new 24-norursane type triterpenoids, whose C-12 and C-13 were existed as double bonds [121]. A ursane (α-amyrane) type triterpene, taraxasterol acetate (**171**) was isolated from *R. hastatus*. [63]. And lupeol (**172**) was isolated from the roots of *R. nepalensis* for the first time [122].

3.7 Diterpene alkaloids

So far, only three hetisane-type (C-20) diterpene alkaloids, orientinine (7,11,14-trihydroxy-2,13-dioxohetisane, **173**), acorientine (6,13,15-trihydroxyhetisane, **174**) and panicudine (6-hydroxy-11-deoxy-13-dehydrohetisane, **175**) were reported from the aerial part of *R. pictus*. They might be biosynthesized from tetra- or penta-cyclic diterpenes [75] (Fig. 6, Table 2).

3.8 Lignans

Fourteen lignans (**176**–**189**) were summarized from *Rumex* (Fig. 7, Table 2). A new lignan, 3-methoxyarctiin-4"-*O*-β-D-xyloside (**178**), and two known ones, arctiin (**176**) and 3-hydroxy-arctiin (**177**), were obtained from *R. patientia* [23]. Six lignan glycosides, schizandriside (**183**), (-)-isolariciresinol-9-*O*-β-D-xylopyranoside (**184**), (-)-5-methoxyisolariciresinol-9-*O*-β-D-xylopyranoside (**185**), (+)-5-methoxyisolariciresinol-9-*O*-β-D-xylopyran oside (**186**), (+)-lyoniside (**187**) and nudiposide (**188**) were reported from *R. hastatus* for the first time [111].

3.9 Other compounds

Up to now, 79 coumarins, sterides, alkaloids, glycosides and polysaccharide were found in *Rumex* (**190**–**268**) (Fig. 8, Table 2). Phenylethyl-*O*-α-L-arabinopyransy-(1$\rightarrow$6)-*O*-β-D-glucoside (**190**) and 5-methoxyl-1(3*H*)-benzofuranone-7-glucoside (**226**) were isolated from *R. gmelini* for the first time [31]. *p*-Hydroxybenzoic acid (**205**), *p*-coumaric acid (**206**), methyl 3,4-dihydrophenylpropionate (**207**), vanillic

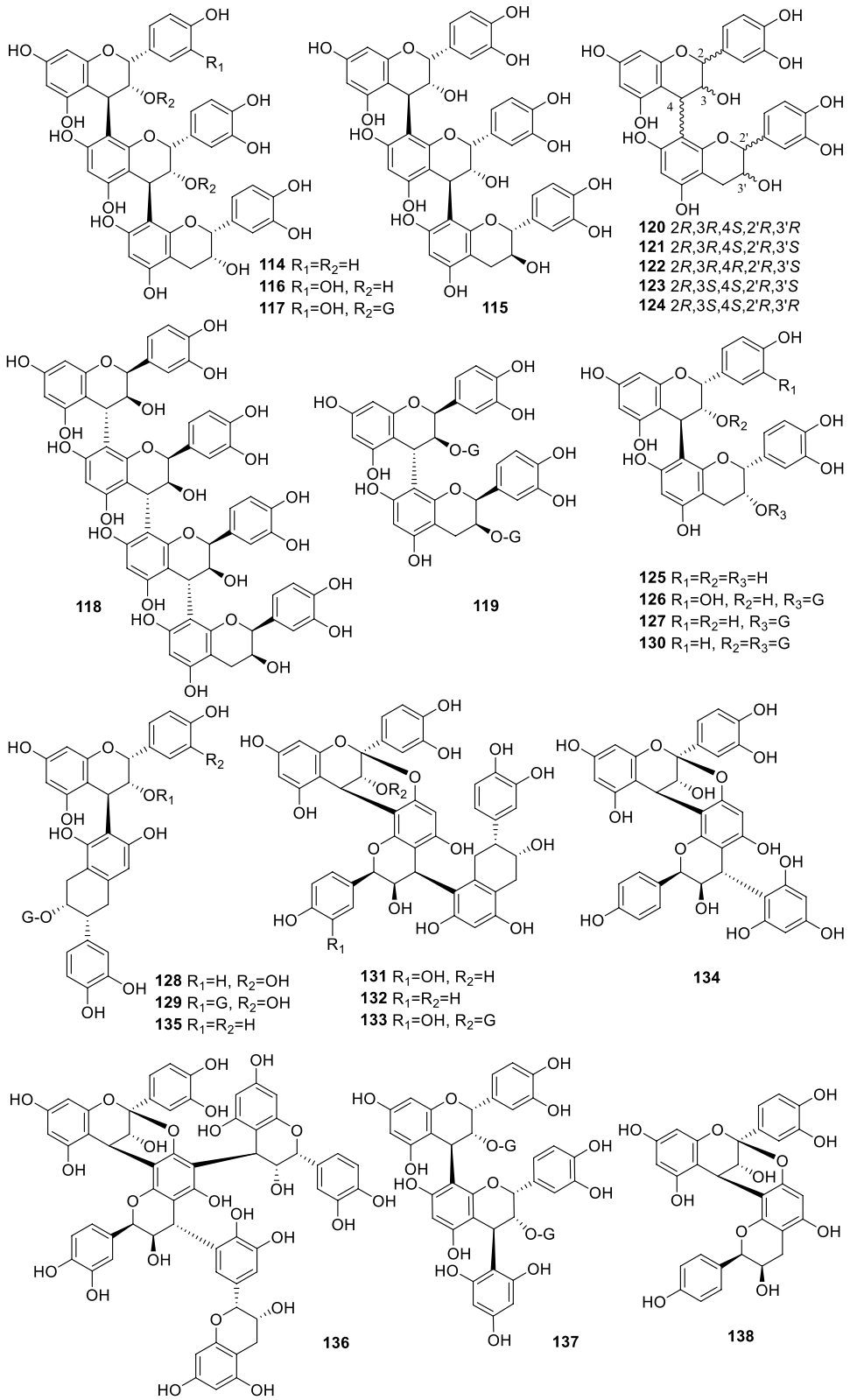


Fig. 3 Structures of tannins (**114–138**)

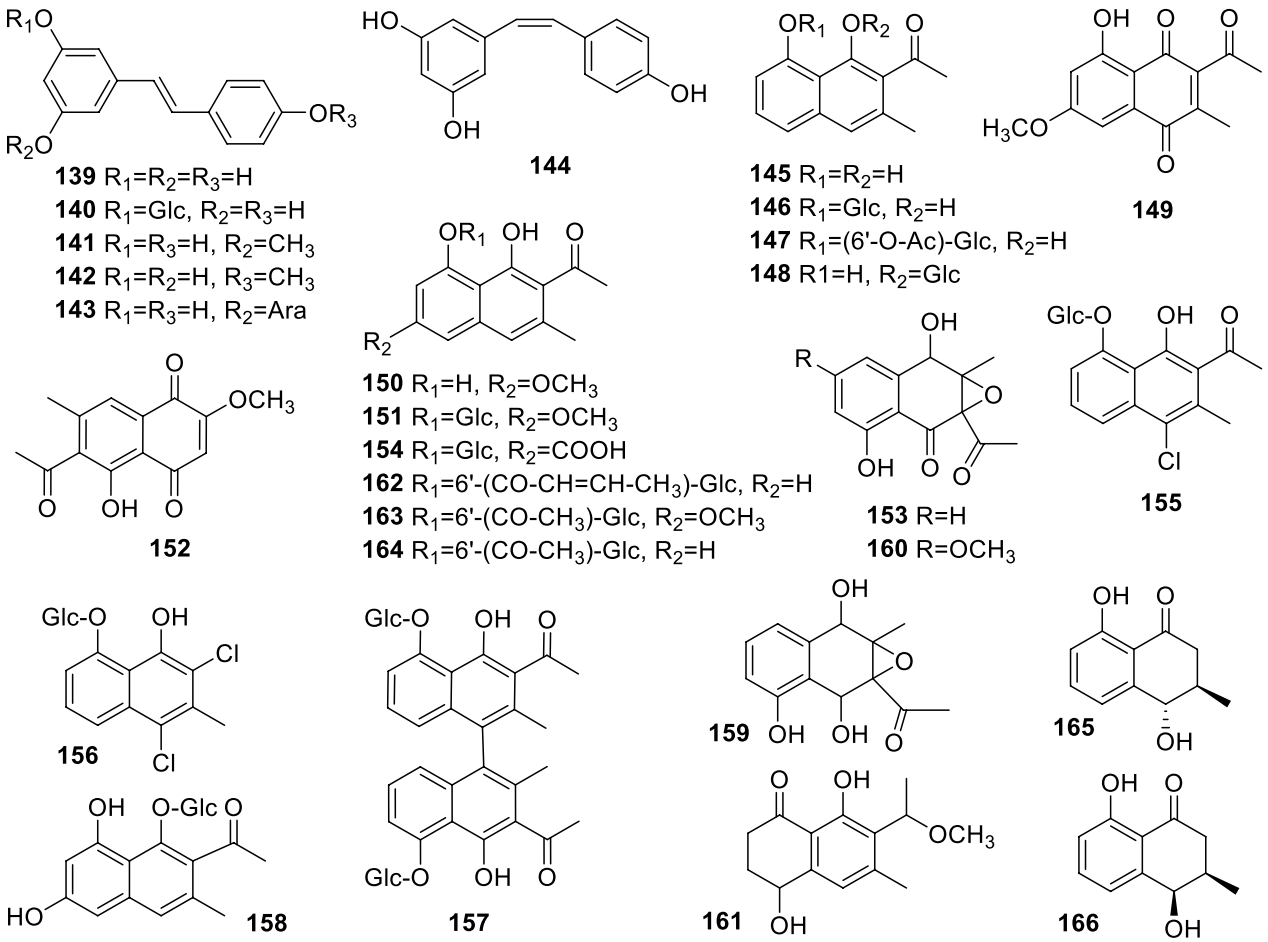


Fig. 4 Structures of stilbenes (**139–144**) and naphthalenes (**145–166**)

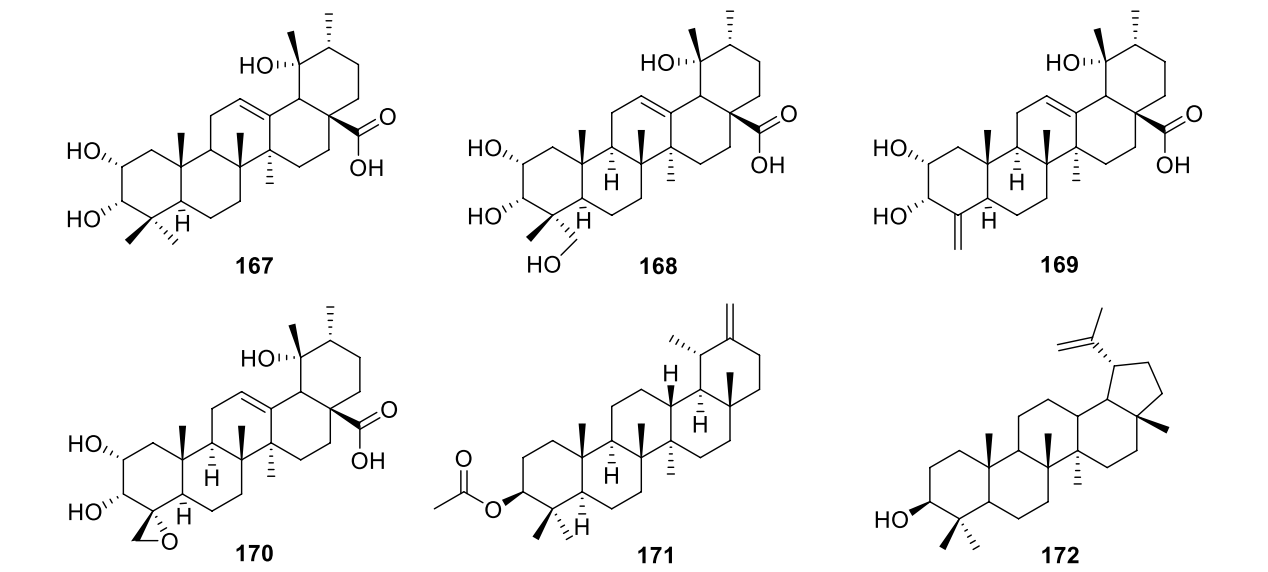


Fig. 5 Structures of terpenes (**167–172**)

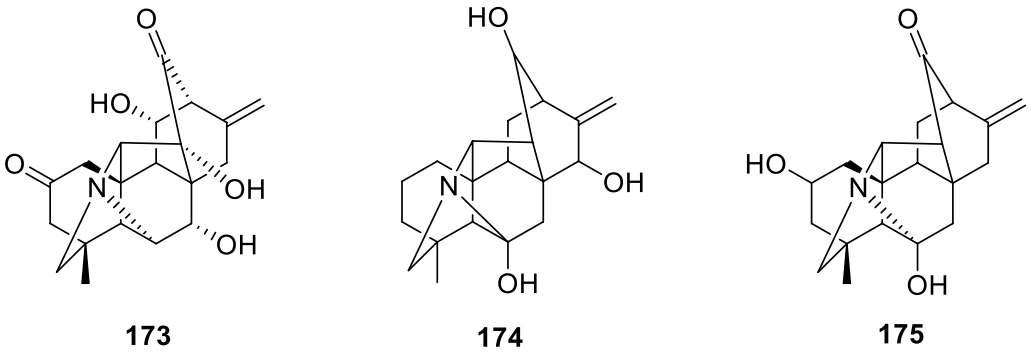


Fig. 6 Structures of diterpene alkaloids (**173–175**)

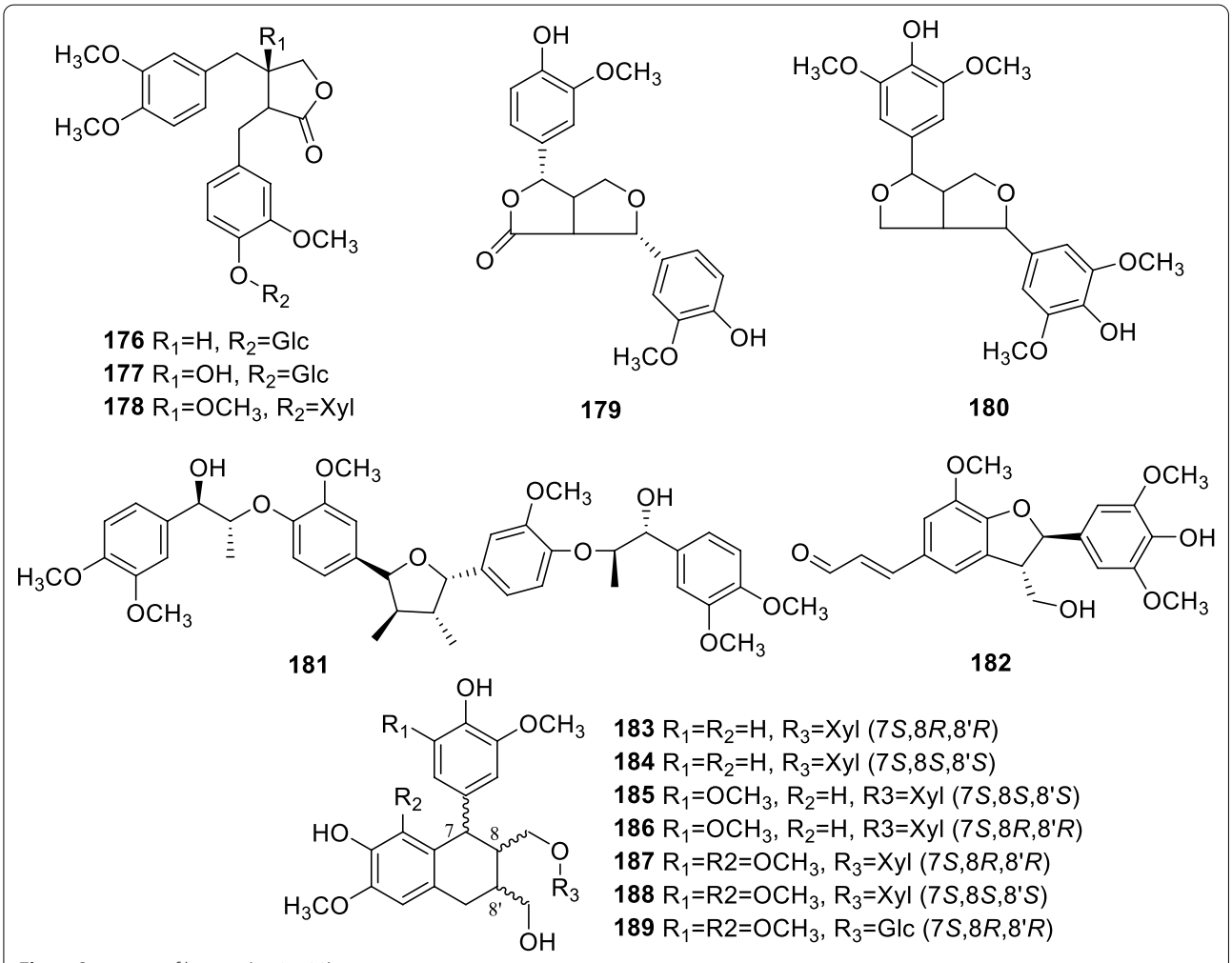


Fig. 7 Structures of lignans (**176–189**)

acid (**208**) and isovanillic acid (**209**) were isolated from the leaves of *R. acetosa* [39]. *β*-Sitosterol (**232**) and daucosterol (**233**) are commonly distributed in *R. acetosa*, *R. chinensis*, *R. crispus* and *R. gmelini* [31, 34, 39, 101]. 2,6-Dimethoxy-4-hydroxyl benzoic acid (**212**) was isolated from *R. japonicus* [26]. Moreover, rumexin (**218**), caffeic acid (**219**), 1-*O*-caffeoylglucose (**220**) and 1-methyl caffeic acid (**221**) were isolated from the aerial

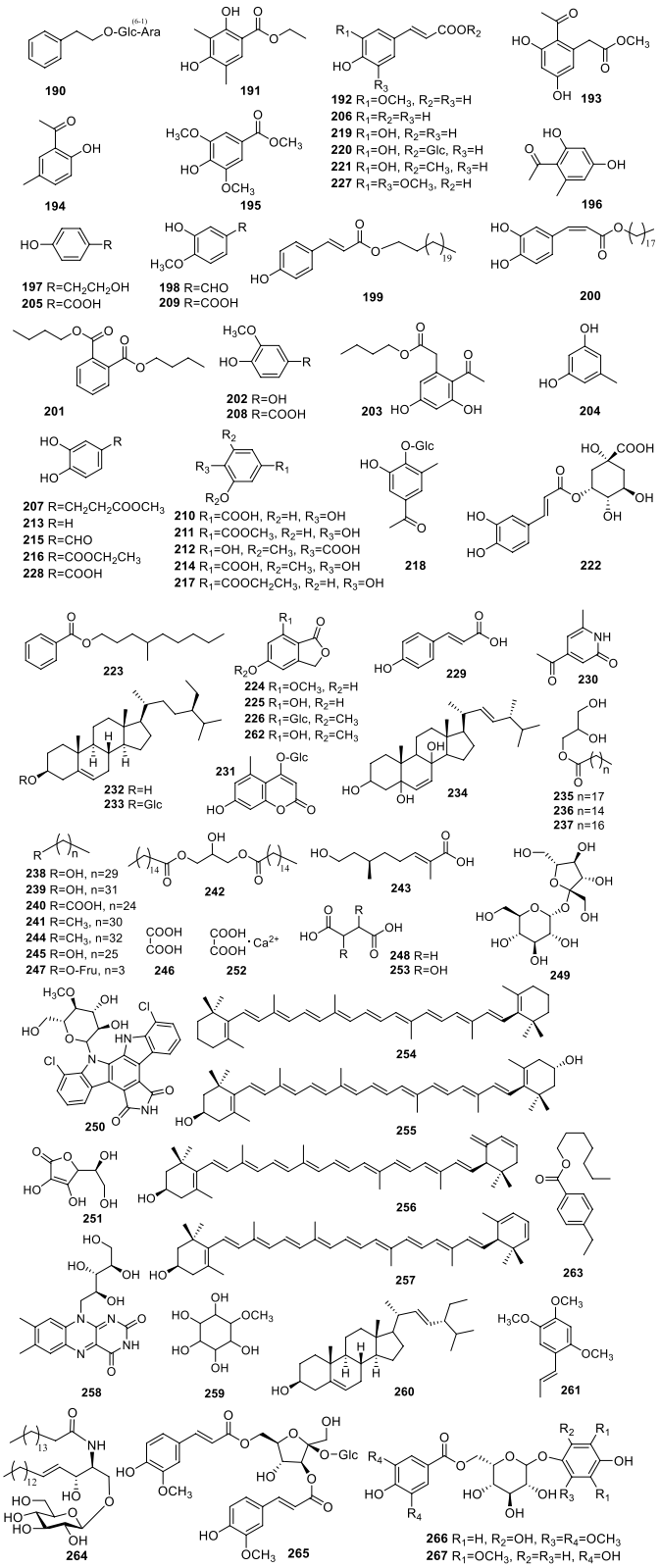


Fig. 8 Structures of other compounds (**190–268**) (Note:**268** not given)

parts of *R. aquatica* [38]. Recently, one new compound (*S*)-4′-methylnonyl benzoate (**223**) was reported from *R. dentatus* [14]. Ergosta-6,22-diene-3,5,8-triol (**234**) was isolated from the EtOAc fraction of *R. abyssinicus* for the first time [123]. Conventional techniques and supercritical fluid extraction (SFE) were compared and the latter yielded great efficiency of phenolics from the roots of *R. acetosa* [124].

Ceryl alcohol (**245**) from *R. ecklonianus* [125], and *β*-carotene (**254**) and lutein (**255**) from *R. vesicarius* [126] were reported. Moreover, anhydroluteins I (**256**) and II (**257**) were separated from *R. rugosus* together with **255** [95]. From the roots of *R. dentatus*, helonioside A (**265**) was isolated for the first time [48]. One new phloroglucinol glycoside 1-*O*-*β*-D-(2,4-dihydroxy-6-methoxyphenyl)-6-*O*-(4-hydroxy-3,5-dimethoxybenzoyl)-glucoside (**266**) was isolated from *R. acetosa* [56]. It was the first time that 1-*O*-β-D-(3,5-dimethoxy-4-hydroxyphenol)-(6-*O*-galloyl)-glucoside (**267**) was isolated from *R. nepalensis* [33].

Rumex polysaccharides have rarely been studied, and only one polysaccharide, RA-P (**268**), which has a 30 kDa molecular weight and consists of D-glucose and D-arabinose, was reported from *R. acetosa* [127].

4 LC–MS analysis

The chemical compositions of *Rumex* spp. were also analyzed by LC–MS techniques. Untargeted metabolomic profiling via UHPLC-Q-TOF–MS analysis on the flowers and stems of *R. tunetanus* resulted in the identification of 60 compounds, 18 of which were reported from the Polygonaceae family for the first time. Quercetin-3-*O*-*β*-D-glucuronide (**73**) was found to be the most abundant phenolic compound in flowers and epicatechin-3-*O*-gallate (**110**) in stems [103]. Moreover, 44 bioactive components classified as sugars, flavanols, tannins and phenolics were clarified from the flowers and stems of *R. algeriensis* based on RP-HPLC–DAD-QTOF-MS and MS–MS [102]. The analysis of sex-related differences in phenolics of *R. thyrsiflorus* has shown female plants of *R. thyrsiflorus* contain more bioactive components than males, such as phenolic acids and flavonoids, especially catechin (**105**) [20].

5 Bioactivity

Rumex has been used as food and medicine in the folk. In addition to important role of *Rumex* in the traditional application, during the past few decades, it was subjected to scientific investigations of the structure of isolated chemical components and their clinical applications by several research groups. Pharmacological studies on *Rumex* extracts and its pure components revealed a wide range of bioactivities, involving antimicrobial, anti-inflammatory, antiviral, renal and gastrointestinal protective effects, antioxidant, antitumor and anti-diabetes effects.

5.1 Antimicrobial

Bioassay-guided isolation on the whole plants of *R. abyssinicus* yielded six antimicrobial quinones, chrysophanol (**1**) and its 8-*O*-*β*-D-glucoside (**3**), emodin (**8**), 6-hydroxy-emodin (**14**), physcion (**18**) and its 8-*O*-*β*-D-glucoside (**19**), with MIC values of 8—256 μg/mL [123].

Proanthocyanidin-enriched extract from the aqueous fraction of the acetone–water (7: 3) extract of the aerial parts of *R. acetosa* (5 μg/mL—15 μg/mL) could interfered with the adhesion of *Porphyromonas gingivalis* (ATCC 33,277) to KB cells (ATCC CCL-17) both in vitro and in situ. In silico docking assay, a main active constituent from *R. acetosa*, epiafzelechin-3-*O*-gallate-(4*β* → 8)-epicatechin-3-*O*-gallate (**130**) exhibited the ability to interact with the active side of Arg-gingipain and the hemagglutinin from *P. gingivalis* [139].

A bacteriostasis experiment of two naphthalenes, torachrysone (**150**) and 2-methoxy-stypandrone (**152**) isolated from *R. japonicus* roots, showed inhibitory effect on both gram-negative and gram-positive bacteria [152]. The antibacterial (*Bacillus subtilis*, *Escherichia coli*, *Moraxella catarrhalis*, etc.) potential of the *n*-hexane, chloroform, aqueous fractions of 14 *Rumex* from Carpathian Basin (*R. acetosella*, *R. acetosa*, *R. alpinus*, *R. aquaticus*, *R. crispus*, *R. patientia*, *R. pulcher*, *R. conglomeratus*, *R. thyrsiflorus*, etc.) were investigated by the disc diffusion method. It showed that the *n*-hexane and chloroform fractions of roots of *R. acetosa*, *R. alpinus*, *R. aquaticus*, *R. conglomeratus* and *R. patientia* exhibited stronger activity against bacteria (inhibition zones > 15 mm). Naphthalenes (**145**, **146**, **151**, **152**) exhibited antibacterial capacity against several bacterial strains (MIC = 48—57.8 μM, in case of *M. catarrhalis*; MIC = 96—529.1 μM, in case of *B. subtilis*) than anthraquinones (**1**, **3**, **8**, **12**, **14**, **18**), flavonoids (**62**, **71**, **80**, **105, 112, 113**), stilbenes (**139**, **141**) and 1-stearoyl-glycerol (**237**), etc., which were isolated from *R. aquaticus* [148].

Antimicrobial study demonstrated that *R. crispus* and *R. sanguineus* have the potential for wound healing due to their anti-*Acinetobacter baumannii* activities (MIC = 1.0—2.0 mg/mL, *R. crispus*; 1.0—2.8 mg/mL, aerial parts of *R. sanguineus*; 1.4—4.0 mg/mL, roots of *R. sanguineus*) [106].

5.2 Anti-inflammatory

The potential effects of anti-inflammatory of AST2017-01 composing of processed *R. crispus* and *Cordyceps militaris* which was widely used in folk medicines in Korea, as well as chrysophanol (**1**) on the treatment of ovalbumin-induced allergic rhinitis (AR) rats were investigated. The serum and tissue nasal mucosa levels of IgE, histamine, TSLP, TNF-α, IL-1, IL-4, IL-5 and IL-13 were both decreased by treatment with AST2017-01 and **1** (positive control: dexamethasone), indicating that *R. crispus* and **1** has the ability to prevent and treat AR [153]. The aqueous extract of roots of *R. patientia* has anti-inflammatory action in vivo. The higher dose of extract (150 mg/kg) showed inhibition (41.7%) of edema in rats compared with the positive control, indomethacin (10 mg/kg, 36.6%) [21]. Methanolic extracts of the roots and stems of *R. roseus* exhibited anti-inflammatory functions in intestinal epithelial cells, reducing TNF-α-induced gene expression of IL-6 and IL-8 [154].

The ethanol extract of the roots of *R. japonicus* could be a therapeutic agent for atopic dermatitis. Skin inflammation in Balb/c mice was alleviated with the extract in vivo. Moreover, an in vitro experiment showed that the extract of *R. japonicus* decreased the phosphorylation of MAPK and stimulated NF-κB in TNF-α in HaCaT cells [155]. The methanolic extract of *R. japonicus* inhibited dextran sulfate sodium (DSS)-induced colitis in C57BL/6 N mice by protecting tight junction connections in the colonic tissue. It was observed that *R. japonicus* has the potential to treat colitis [156]. Ethyl acetate extract of the roots of *R. crispus* showed anti-inflammatory activity in inhibiting NO production and decreasing the secretion of proinflammatory cytokines [157].

5.3 Antivirus

1,4-Naphthoquinone and naphthalenes from *R. aquaticus* presented antiviral activity against *herpes simplex* virus type 2 (HSV-2) replication infected Vero cells. In which, musizin (**145**) showed dose dependent inhibitory property, causing a 2.00 $\log_{10}$ reduction in HSV-2 at 6.25 μM, on a traditional virus yield reduction test and *q*PCR assay. It suggested that *R. aquaticus* had the potential to treat HSV-2 infected patients [158].

Acetone–water extract (R2, which contains oligomeric, polymeric proanthocyanidins and flavonoids) from the aerial parts of *R. acetosa* showed obvious antiviral activities via plaque reduction test and MTT assay on Vero cells. R2 was 100% against herpes simplex virus type-1 at concentrations > 1 μg/mL ($IC_{50} = 0.8 \pm 0.04$ μg/mL). At concentrations > 25 μg/mL ($CC_{50} = 78.6 \pm 12.7$ μg/mL), cell vitality was more than 100% reduced by R2 [107].

5.4 The function in kidney and gastrointestinal tract

It is noted that quercetin-3-*O*-β-D-glucoside (**72**, QGC) from *R. aquaticus* could alleviate the modle that indomethacin (nonsteroidal anti-inflammatory drugs) induced gastric damage of rats and ethanol extract of *R. aquaticus* had a protective effect on the inflammation of gastric epithelial cells caused by *Helicobacter pylori*. In vivo research suggested that QGC pretreatment could decrease gastric damage by increasing mucus secretion, downregulating the expression of intercellular adhesion molecule-1 and decreasing the activity of myeloperoxidase. The in vitro test found that flavonoids including QGC could inhibit proinflammatory cytokine expression and inhibit the proliferation of an adenocarcinoma gastric cell line (AGS) [159, 160]. The cytoprotective effect of QGC against hydrogen peroxide-induced oxidative stress was noticed in AGS [161]. Moreover, QGC also showed protective efficiency in a rat reflux esophagitis model in a dose-dependent manner (1—30 mg/kg) [162].

Ten anthraquinones chrysophanol (**1**), chrysophanol-8-*O*-β-D-glucoside (**3**), 6′-acetyl-chrysophanol-8-*O*-β-D-glucoside (**6**), emodin (**8**), emodin-8-*O*-β-D-glucoside (**12**), physcion (**18**), aloe-emodin (**13**), rumexpatientosides A (**47**) and B (**48**) and nepalenside A (**49**) from *R. patientia*, *R. nepalensis*, *R. hastatus* not only inhibited the secretion of IL-6, but also decreased collagen IV and fibronectin production at a concentration of 10 μM in vitro. On which concentration, they were nontoxic to cells [133]. It suggested that anthraquinones have great potential to treat kidney disease.

5.5 Antioxidant properties

An extraction technology to obtain the total phenolics of *R. acetosa* was optimized and the antioxidant activity of different plant parts of *R. acetosa* was well investigated. It was found that the 80% methanol extract of the roots ($IC_{50} = 118.8$ μM) showed higher scavenging activity to DPPH free radicals than the other parts (leaves: $IC_{50} = 201.6$ μM, flowers and fruits: $IC_{50} = 230.1$ μM, stems: $IC_{50} = 411.2$ μM) [163]. The roots of *R. thyrsiflorus* [164], ethanol extracts of *R. obtusifolius* and *R. crispus* showed antioxidant ability on DPPH, $ABTS^+$ and FRAP assays [165]. Moreover, *R. tingitanus* leaves, *R. dentatus*, *R. rothschildianus* leaves, *R. roseus* and *R. vesicarius* also showed antioxidant activity on DPPH assay [13, 78, 105, 154, 166, 167]. Phenolics isolated from *R. tunetanus* flowers and stems displayed antioxidant properties on DPPH and FRAP assays [103]. DPPH, $ABTS^+$, NO_2^- radical scavenging and phosphomolybdate antioxidant assays verified that *R. acetosella* has antioxidant properties [168]. Phenolic constitutions from *R. maderensis* dispalyed antioxidant activity after the gastrointestinal digestion process. These components are known as dietary

polyphenols and have the potential to be developed as functional products [99].

Moreover, the total antioxidant capacities of *R. crispus* were found to be 49.4%—86.4% on DPPH, $ABTS^+$, NO, phosphomolybdate and SPF assays, which provided the basis to develop *R. crispus* as antioxidant, antiaging and skin care products [169]. Later on, the ripe fruits of *R. crispus* were studied and the aqueous extract showed antioxidant activity in vitro [170]. Dichloromethane and ethyl acetate extracts of *R. crispus* exhibited stronger antioxidant activity, which were associated with the concentration of polyphenols and flavonoids [157]. The antioxidant activities of chrysophanol (**1**), 1,3,7-trihydroxy-6-methylanthraquinone (**54**), przewalskinone B (**55**) and *p*-coumaric acid (**206**) isolated from *R. hastatus* were investigated on a nitric oxide radical scavenging assay, whose IC_{50} values were 0.39, 0.47, 0.45, and 0.45 mM, respectively [134].

5.6 Antitumor properties

MTT assays on HeLa (human cervical carcinoma), A431 (skin epidermoid carcinoma) and MCF7 (human breast adenocarcinoma) cell lines showed that *R. acetosa* and *R. thyrsiflorus* could inhibit the tumor cell proliferation [171]. The fruit of *R. crispus* showed cytotoxicity on HeLa, MCF7 and HT-29 (colon adenocarcinoma) cells in vitro [170]. The methanolic extract of *R. vesicarius* was assessed for hepatoprotective effects in vitro. CCl_4-induced hepatotoxicity was observed at 100 mg/kg bw and 200 mg/kg bw. The plant also has cytotoxicity in HepG2 (human hepatoma cancer) cell lines [172]. Dichloromethane extract of *R. crispus* roots inhibited the growth and induced cellular apoptosis of HepG2 cells [157]. The hexane fraction of *R. rothschildianus* leaves showed 98.9% and 97.4% inhibition of HeLa cells and MCF7 cells at a concentration of 4 mg/mL [105].

Different plant parts (stems, roots, flowers and leaves) of *R. vesicarius* were screened for their cytotoxicity by the MTS method on MCF7, Lovo and Caco-2 (human colon cancer), and HepG2 cell lines. The stems displayed stronger cytotoxicity in vitro and with non-toxicity on zebrafish development, with IC_{50} values of 33.45—62.56 μM. At a concentration of 30 μg/mL, the chloroform extract of the stems inhibited the formation of $\geq$70% of intersegmental blood vessels and 100% of subintestinal vein blood vessels when treated zebrafish embryos, indicating the chloroform extract of *R. vesicarius* stems has apparent antitumor potential [15].

2-Methoxystypandrone (**152**) from *R. japonicus* exhibited antiproliferative effect on Jurkat cells and the potential to treat leukemia, by reducing the mitochondrial membrane potential and increasing the accumulation of mitochondrial reactive oxygen, as shown by flow cytometry [116]. The phenolic extract from the flower parts of *R. acetosa* exhibited in vitro antiproliferative effects on HaCaT cells. When increasing of the extract concentration from 25 μg/mL to 100 μg/mL, the proliferation ability on HaCaT cells gradually decreased [147].

5.7 Antidiabetes activities

Chrysophanol (**1**) and physcion (**18**) from the roots of *R. crispus* showed inhibition on α-glucosidase, with IC_{50} values of 20.1 and 18.9 μM, respectively [180]. The alcohol extract of *R. acetosella* displayed stronger inhibitory activity on α-glucosidase (roots, $IC_{50} = 12.3$ μM; aerial parts, $IC_{50} < 10$ μM), compared to the positive control, acarbose ($IC_{50} = 605$ μM, $p < 0.05$), revealing *R. acetosella* could be developed as an antidiabetic agent [168]. Moreover, the methanolic extract of *R. lunaria* leaves displayed remarkable kinetic of -α-glucosidase activity from the concentration of 3 μM by comparison with blank control [16], and the acetone fraction of *R. rothschildianus* leaves showed inhibitory activity against α-amylase and α-glucosidase ($IC_{50} = 19.1 \pm 0.7$ μM and 54.9 ± 0.3 μM, respectively) compared to acarbose ($IC_{50} = 28.8$, 37.1 ± 0.3 μM, respectively) [105].

The hypoglycemic effects of oral administration of ethanol extract of *R. obtusifolius* seeds (treatment group) were compared to the control group (rabbits with hyperglycemia). The treatment group could decrease fasting glucose levels (57.3%, $p < 0.05$), improve glucose tolerance and increase the content of liver glycogen (1.5-fold, $p < 0.01$). It also not only reduced the total cholesterol, low-density lipoprotein cholesterol levels and liver enzyme levels, but increased the high-density lipoprotein cholesterol levels. The results showed that *R. obtusifolius* has great potential to treat diabetes [173]. In addition, phenolic components of *R. dentatus* showed the ability to ameliorate hyperglycemia by modulating carbohydrate metabolism in the liver and oxidative stress levels and upregulating PPARγ in diabetic rats [14].

5.8 Other biological activities

The vasorelaxant antihypertensive mechanism of *R. acetosa* was investigated in vivo and in vitro. Intravenous injection (50 mg/kg) of the methanol extract of *R. acetosa* (Ra.Cr) leaves caused a mean arterial pressure (MAP) (40 mmHg) in normotensive rats with a decrease of $27.88 \pm 4.55\%$ and a MAP (70 mmHg) in hypertensive rats with a decrease of $48.40 \pm 4.93\%$. In endothelium intact rat aortic rings precontracted with phenylephrine (1 μM), Ra.Cr induced endothelium-dependent vasorelaxation with $EC_{50} = 0.32$ mg/mL (0.21—0.42), while in denuded endothelial rat aortic rings, $EC_{50} = 4.22$ mg/mL (3.2—5.42), which was partially blocked with L-NAME (10 μM), indomethacin (1 μM) and atropine (1 μM). In

isolated rabbit aortic rings precontracted with phenylephrine (1 μM) and K^+ (80 mM), Ra.Cr induces vasorelaxation and the movement of Ca^{2+} [174].

The acetone extract of *R. japonicus* showed protective activity against myocardial apoptosis, through the regulation of oxidative stress levels in cardiomyocytes (LDH, MDA, CK, SOD) and the suppression of the expression of apoptosis proteins (caspase-3, Bax, Bcl-2) on in vitro H_2O_2-induced myocardial H9c2 cell apoptosis [175].

The antiplatelet activity of *R. acetosa* and the protective mechanism on cardiovascular system were investigated yet. The extract of *R. acetosa* showed inhibition of the collagen-induced platelet aggregation by modulating the phosphorylation of MAPK, PI3K/Akt, and Src family kinases and inhibited the ATP release in a dose dependent manner (25—200 μg/mL) [176]. The absorption of fexofenadine was inhibited by the ethanol extract of *R. acetosa* to decrease the aqueous solubility of fexofenadine [177]. The hepatoprotective effect of *R. tingitanus* was investigated by an in vivo experiment, in which the ethanol extract protected effectively the CCl_4-damaged rats by enhancing the activity of liver antioxidant enzymes. Moreover, the extract could reduce the immobility time of mice, comparable of the positive drug, clomipramine. The results indicated that *R. tingitanus* has antidepressant-like effects [78].

Stimulating the ERK/Runx2 signaling pathway and related transcription factors could induce the differentiation of osteoblasts. Fortunately, chrysophanol (**1**), emodin (**8**) and physcion (**18**) from the aqueous extract of *R. crispus* could suppress the RANKL-induced osteoclast differentiation by suppressing the MAPK/NF-κB/NFATc1 signaling axis and increas the inhibitory factors of NFATc1 [178].

Moreover, the ethanol extract of *R. crispus* could reduce the degradation of collagen by inhibiting matrix metalloproteinase (MMP-1, MMP-8, MMP-13), indicating that *R. crispus* exhibited the antiaging function [169].

The anti-Alzheimer effect of helminthosporin (**51**) from *R. abyssinicus* was investigated in PAMPA-BBB permeability research, showing that **51** inhibited obviously AChE and BChE with IC_{50} values < 3 μM. Compound **51** could not only cross the BBB with high BBB permeability, but also bind with the peripheral anion part of the cholinesterase activity site by molecular docking [80].

It is noted, *R. crispus,* a traditional medicinal herb in the folk with rich retinol, ascorbic acid and *α*-tocopherol in the leaves, could be used as a complementary diet [179]. Moreover, chrysophanol (**1**) and physcion (**18**) from *R. crispus* roots showed obvious inhibitory activity on xanthine oxidase (IC_{50} = 36.4, 45.0 μg/mL, respectively) [180].

Inhibition of human pancreatic lipase could reduce the hydrolysis of triacylglycerol into monoacylglycerol and free fatty acids [181]. Chrysophanol (**1**) and physcion (**18**) from *R. nepalensis* with good inhibitory activity on pancreatic lipase (Pearson's r = 0.801 and 0.755, respectively) showed the obvious potential to treat obesity [182].

6 Conclusion

The genus *Rumex* distributing widely in the world with more than 200 species has a long history of food and medicinal application in the folk. These plants with rich secondary metabolites, e.g., quinones, flavonoids, tannins, stilbenes, naphthalenes, terpenes, diterpene alkaloids, lignans and other type of components, showed various pharmacological activities, such as antimicrobial, anti-inflammatory, antiviral, renal and gastrointestinal protective effects, antioxidant, antitumor and anti-diabetes effects. Particularly, quinones as the major components in *Rumex* showed stronger antibacterial activities and exerted the potential to treat kidney disease. However, detailed phytochemical studies are needed for many *Rumex* species, in order to clarify their bioactive components. Further studies and application may focus on the antitumor, anti-diabetes, anti-microbial, hepatoprotective, cardiovascular and gastrointestinal protective effects. Moreover, the toxicity or side effects for *Rumex* plants and their chemical constituents should be evaluated, in order to make the uses of *Rumex* more safety.

Abbreviations

AChE: Acetylcholinesterase; AGS: Adenocarcinoma gastric cell line; AR: Allergic rhinitis; BBB: Blood-brain barrier; BChE: Butyrylcholinesterase; EtOAc: Ethyl acetate; HPLC: High performance liquid chromatograph; IL: Interleukin; UHPLC-Q-TOF-MS: Ultra-high performance liquid chromatography-quadrupole time-of-flight mass spectrometry; MAPK: Mitogen-activated protein kinase; MIC: Minimum inhibitory concentration; MS: Mass Spectrometry; MTT: 3-(4,5-Dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide; NF-κB: Nuclear factor-kappa B; QGC: Quercetin-3-*O*-*β*-D-glucoside; TNF-*α*: Tumor necrosis factor-*α*.

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Author contributions

J-J L, Y-X L, H-T Z, DW collected the related references; J-J L worte the manuscript; NL and Y-J Z reviewed and edited the manuscript. All authors read and approved the final manuscript.

Declarations

Competing interests

The authors declare no conflict of interest.

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