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 enclosed 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...
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. thrysiflorus, 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 Canadian medicine [16]. The leaves of more than 14 Rumex spp., such as R. acetosa, R. hastatus, R. thrysiflorus, R. aquaticus, R. crispus, R. gmelini, R. patientia, R. vesicarius, R. ecklonianus, R. abyssinicus, R. confluentus, 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 diams 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-hydroxyacetlated 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, xanthorinin-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, rumejapсидes 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, rumeoxe (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-glycosides 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].
| 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, khatmial | 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] |
| No | Species                   | Local names                              | Country                                                                 | Parts used                | Traditional uses                                                                                                                                                                                                 | Ref       |
|----|--------------------------|------------------------------------------|-------------------------------------------------------------------------|---------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| R11 | *R. nepalensis* Spreng   | Leaf, root and whole plant               | Asia, Europe and Africa, Ethiopia, Nepal, Pakistan and India            |                           | 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: antisyndentery                                                                                                                                  | [18, 72, 73, 203] |
| R16 | *R. luminostrum* 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] |
| 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, antidepressant, blood purification, constipation, tonic                                                                                                                                       | [78, 186] |
| R20 | *R. ecklonianus* Meissner |                           | South African dock                                                   | Young leaf                | Anemia, chlorosis                                                                                                                                                                                               | [79]      |
| R21 | *R. abyssinicus* Jacq    | Spinach rhubarb, mekmeko                | Europe, Africa and Spinach                                            | Young shoot, leaf, fresh or dried plant | Best 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] |
| 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 | Ithrib | North America, Europe | Leaf | For food | [95, 96, 200] |
| R26 | *R. nervosus* Vahl | Ithrib | Himalayas, Nilgiri, Nainital, East Africa and Arab | Leaf | Microbial infections, anticoagulid | [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-Il 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] |
| No | Compounds                                              | Formula            | Species | Plant parts | Ref                        |
|----|--------------------------------------------------------|--------------------|---------|-------------|----------------------------|
| 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_{20}H_{20}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_{22}H_{22}O_{10} | R13     | R           | [54, 130]                  |
| 12 | Emodin-8-O-β-D-glucoside (PMEG)                        | C_{22}H_{22}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_{18}H_{10}O_{6}  | R2, R8, R13 | R, WP, L    | [23, 27, 35, 112]          |
| 14 | 6-Hydroxy-emodin (citreoarsein)                        | C_{18}H_{10}O_{6}  | R9, R21 | WP          | [50, 123]                  |
| 15 | 6-Acetoxy-aloe-emodin                                  | C_{17}H_{9}O_{6}   | R1      | R           | [29]                       |
| 16 | Emodin dimethylether                                   | C_{17}H_{9}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_{18}H_{10}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_{22}H_{22}O_{10} | R7, R9  | R           | [26, 28]                   |
| 26 | Rumejaposide F                                         | C_{22}H_{22}O_{10} | R7, R13 | L, R        | [27, 28]                   |
| 27 | Rumejaposide G                                         | C_{22}H_{22}O_{9}  | R7      | R           | [28]                       |
| 28 | Rumejaposide H                                         | C_{22}H_{22}O_{9}  | R7      | R           | [28]                       |
| 29 | Rumejaposide I                                         | C_{22}H_{22}O_{10} | R7, R13 | L, R        | [27, 28]                   |
| 30 | Xanthorin-5-methylene                                 | C_{21}H_{14}O_{6}  | R13     | WP          | [23, 24]                   |
| 31 | Rumexone                                               | C_{15}H_{10}O_{4}  | R6      | R           | [30]                       |
| 32 | Rhein                                                  | C_{15}H_{8}O_{6}   | R2      | R           | [35]                       |
| 33 | Rhein-8-O-β-D-glucoside                                | C_{15}H_{12}O_{5}  | R9      | WP          | [50]                       |
| 34 | Cassialoin                                             | C_{10}H_{14}O_{4}  | R7, R13 | L, R        | [27, 28]                   |
| 35 | Phallacinol (telochistin)                              | C_{18}H_{12}O_{6}  | R11     | R           | [51]                       |
| 36 | 1,8-Dihydroxyanthraquinone                            | C_{14}H_{10}O_{4}  | R1      | R           | [29]                       |
| 37 | Martianine                                             | C_{22}H_{18}O_{17} | R11     | R           | [132]                      |
| 38 | Rumoside A                                             | C_{22}H_{20}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-Methoxy-10-hydroxyaloin A                            | C_{22}H_{20}O_{11} | R8      | R           | [32]                       |
| 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 | Rumexpatienside A                             | C_{22}H_{24}O_{10} | R11     | R           | [133] |
| 48 | Rumexpatienside B                             | C_{22}H_{24}O_{10} | R11     | R           | [133] |
| 49 | Nepalenside A                                 | C_{22}H_{24}O_{10} | R11     | R           | [33]  |
| 50 | Nepalenside B                                 | C_{22}H_{24}O_{10} | R11     | R           | [33]  |
| 51 | Helminthosporin                               | C_{15}H_{12}O_{5}  | R21     | Rh          | [80]  |
| 52 | 1,5-Dihydroxyanthraquinone                    | C_{14}H_{10}O_{5}  | R6      | R           | [30]  |
| 53 | 1,3,5-Trihydroxy-7-methylanthaquinone         | C_{15}H_{10}O_{5}  | R13     | R           | [130] |
| 54 | 1,3,7-Trihydroxy-6-methylanthaquinone         | C_{15}H_{10}O_{5}  | R2      | WP          | [134] |
| 55 | Przewalskinone B                              | C_{18}H_{19}O_{10} | R21     | WP          | [134] |
| 56 | Rumpictusoide A                               | C_{21}H_{19}O_{10} | R17     | WP          | [183] |

**Flavonoids**

| No | Compounds                   | Formula          | Species | Plant parts | Ref       |
|----|-----------------------------|------------------|---------|-------------|-----------|
| 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_{21}H_{20}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, R3 | 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_{11} | R1, R6 | L, WP       | [34, 39]  |
| 66 | Kaempferol-3-O-α-L-rhamnosyl-(1→6)-β-D-galactoside | C_{21}H_{20}O_{15} | R5, R7 | L, WP | [36, 40] |
| 67 | Kaempferol-3-O-α-L-arabinosyl-(1→6)-β-D-galactoside | C_{21}H_{20}O_{16} | 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_{10}O_{13} | R7, R13 | A           | [14, 46]  |
| 74 | Quercetin-3-O-β-D-glucosyl-(1→4)-β-D-galactoside | C_{21}H_{10}O_{17} | R5 | L | [40] |
| 75 | Quercetin-3-O-α-L-rhamnoside (quercitrin) | C_{21}H_{20}O_{11} | R4, R5, R9, R13, R3 | L, WP, R, A | [27, 38, 40, 49, 50] |
| 76 | Isorhamnetol                  | C_{18}H_{20}O_{7}  | R13     | WP          | [23, 37]  |
| 77 | Isorhamnetol-3-O-rutinoside    | C_{20}H_{20}O_{16} | R7      | WP          | [36]      |
| 78 | Isorhamnetol-3-O-β-D-galactoside | C_{22}H_{20}O_{12} | R7      | WP          | [36]      |
| 79 | Isorhamnetol-3-O-β-D-glucoside  | C_{22}H_{20}O_{12} | R7      | WP          | [36]      |
| 80 | Quercetin-3-O-α-L-arabinoside   | C_{20}H_{19}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_{20}H_{18}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-glucose                       | C_{21}H_{20}O_{11}           | R16     | WP          | [42]      |
| 90 | 7-Hydroxy-2,3-dimethyl-chromone                 | C_{21}H_{18}O_{3}            | R14     | R           | [52]      |
| 91 | 5-Methoxy-7-hydroxy-1(3H)-chromone             | C_{10}H_{9}O_{4}             | R13     | R           | [53]      |
| 92 | 5,7-Dihydroxy-1(3H)-chromone                   | C_{10}H_{9}O_{4}             | R13     | R           | [53]      |
| 93 | Mikanin (3,5-dihydroxy-4',6,7-trimethoxyflavone) | C_{18}H_{18}O_{7}           | R13     | L           | [27]      |
| 94 | 3,5-Dihydroxy-6,7,3',4'-tetramethoxyflavone     | C_{18}H_{18}O_{8}            | R13     | L           | [27]      |
| 95 | 2,5-Dimethyl-7-hydroxychromone-7-O-β-D-glucoside | C_{14}H_{20}O_{8}           | R8      | R           | [31]      |
| 96 | 2,5-Dimethyl-7-hydroxycromone                  | C_{11}H_{13}O_{3}            | R11     | R           | [51]      |
| 97 | 3-O-Methyl quercetin                            | C_{16}H_{14}O_{7}            | R8      | F           | [45]      |
| 98 | Tricin-7-O-β-D-glucoside                        | C_{15}H_{22}O_{12}           | R22     | R           | [137]     |
| 99 | 2-(2'-Hydroxypropyl)-5-methyl-7-hydroxycromone  | C_{13}H_{18}O_{4}            | R13     | R           | [138]     |
| 100| 2-(2'-Hydroxypropyl)-5-methyl-7-hydroxycromone  | C_{13}H_{18}O_{5}            | R13     | R           | [138]     |
| 101| Maackiain                                       | C_{16}H_{12}O_{5}            | R13     | A           | [46]      |
| 102| Maackiain-3-O-β-D-glucoside                     | C_{20}H_{22}O_{10}           | R13     | A           | [46]      |
| 103| Aloeosin                                        | C_{20}H_{22}O_{10}           | R11     | R           | [33]      |
| 104| 4'-p-Acetylcoumaroyl luteolin                   | C_{20}H_{22}O_{10}           | R19     | L           | [78]      |
| 105| Catechin                                       | C_{13}H_{14}O_{6}            | R1, R6, R13, R19, R31 | R, WP | [34, 49, 53, 54] |
| 106| 6-CI-catechin                                   | C_{13}H_{14}O_{6}            | R13, R19 | R           | [54]      |
| 107| Epicatechin                                     | C_{13}H_{14}O_{6}            | R13, R14, R31 | R, WP | [34, 49] |
| 108| (+)-Epigallocatechin                            | C_{13}H_{14}O_{7}            | R1      | R           | [135]     |
| 109| (−)-Epigallocatechin                            | C_{13}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_{19}H_{20}O_{4}            | R4      | A, R       | [148]     |
| 113| Quercetin-3,3'-dimethylether                    | C_{19}H_{20}O_{7}            | R4      | A, R       | [148]     |

Tannins

| No | Compounds                                      | Formula                      | Species | Plant parts | Ref       |
|----|------------------------------------------------|------------------------------|---------|-------------|-----------|
| 114| Epiafzelechin-(4β→8)-epicatechin-(4β→8)-epicatechin | C_{46}H_{28}O_{17}           | R1      | A           | [56]      |
| No | Compounds                                                                 | Formula      | Species | Plant parts | Ref   |
|----|----------------------------------------------------------------------------|--------------|---------|-------------|-------|
| 115| Epicatechin-(4β→8)-epicatechin-(4β→8)-catechin                           | C_{63}H_{38}O_{18} | R1      | A           | [56]  |
| 116| Epicatechin-(4β→8)-epicatechin-(4β→8)-epicatechin (Procyanidin C1)       | C_{61}H_{36}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                         | C_{60}H_{50}O_{24} | R1      | A           | [56]  |
| 119| Epicatechin-3-O-gallate-(4β→8)-epicatechin-3-O-gallate                   | C_{64}H_{56}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                                                  | C_{30}H_{26}O_{12} | R1      | A           | [56, 107]|
| 124| Catechin-(4α→8)-epicatechin                                               | 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_{40}O_{20} | R1      | A           | [56]  |
| 130| Epiafzelechin-3-O-gallate-(4β→8)-epicatechin-3-O-gallate                 | C_{44}H_{40}O_{19} | R1      | A           | [56]  |
| 131| Epicatechin-(2β→7, 4β→8)-epicatechin-3-O-gallate                          | C_{44}H_{40}O_{18} | R1      | A           | [56]  |
| 132| Epicatechin-(2β→7, 4β→8)-epicatechin-3-O-gallate                          | C_{41}H_{38}O_{17} | R1      | A           | [56]  |
| 133| Epicatechin-3-O-gallate-(2β→7, 4β→8)-epicatechin (cinnamantanin B1)      | C_{43}H_{46}O_{22} | R1      | A           | [56]  |
| 134| Epicatechin-(2β→7, 4β→8)-epicatechin-3-O-gallate                          | C_{43}H_{46}O_{14} | R1      | A           | [56]  |
| 135| Epiafzelechin-(4β→6)-epicatechin-3-O-gallate                              | C_{31}H_{26}O_{15} | R1      | A           | [56]  |
| 136| Parameritannin A1                                                         | C_{60}H_{60}O_{24} | R1      | A           | [56]  |
| 137| Epicatechin-3-O-gallate-(4β→8)-epicatechin-3-O-gallate-        phloroglucinol | C_{60}H_{60}O_{25} | R1      | A           | [56]  |
| No  | Compounds                                           | Formula               | Species | Plant parts | Ref               |
|-----|----------------------------------------------------|-----------------------|---------|-------------|-------------------|
| 138 | Epicatechin-(2β → 7, 4β → 8)-epicatechin            | C_{30}H_{26}O_{12}    | R1      | A           | [56]              |
| 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_{13}H_{14}O_{3}     | R18     | R           | [77]              |
| 143 | 3,5-Dihydroxy-4’-methoxystilbene                   | C_{13}H_{14}O_{3}     | R18     | R           | [77]              |
| 144 | 5,4’-Dihydroxystilbene-3-O-arabinoside             | C_{19}H_{22}O_{8}     | R18     | R           | [77]              |
| 145 | Nepodin (musizin)                                   | C_{13}H_{12}O_{3}     | R2, R8  | R, F        | [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_{8}     | R2      | R           |                   |
| 148 | Neposide                                            | C_{14}H_{14}O_{3}     | R2, R22, R24 | R, WP        | [140, 141]       |
| 149 | 2-Acetyl-3-methyl-6-methoxyl-8-hydroxy-1,4-naphthoquinone | C_{14}H_{14}O_{3} | R9     | WP          | [141]             |
| 150 | Torachrysone (TRA, 2-acetyl-1,8-dihydroxy-3-methyl-6-methoxynaphthalene) | C_{14}H_{14}O_{4} | R13     | WP          | [141]             |
| 151 | Torachrysone-8-O-β-D-glucoside                      | C_{19}H_{22}O_{8}     | 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_{14}O_{3} | R9, R10 | L, S, R     | [115, 116]       |
| 153 | 3-Acetyl-2-methyl-1,5-dihydroxyl-2,3-epoxynaphthoquinol | C_{14}H_{14}O_{3} | R9, R11 | R           | [51, 65]          |
| 154 | Rumexoside                                          | C_{16}H_{18}O_{10}    | R2      | R           | [110]             |
| 155 | 2-Acetyl-4-chloro-1,8-dihydroxy-3-methylnaphthalene-8-O-β-D-glucoside (patientoside A) | C_{16}H_{18}O_{10}Cl | R13     | R           | [117]             |
| 156 | Patientoside B                                     | C_{19}H_{18}O_{12}Cl  | R13     | R           | [117]             |
| 157 | 4,4’-Binaphthalene-8,8’-O,O-di-β-D-glucoside        | C_{39}H_{40}O_{16}    | R13     | R           | [120]             |
| 158 | 6-Hydroxymusizin-8-O-β-D-glucopyranoside            | C_{13}H_{16}O_{6}     | R2      | R           | [110]             |
| 159 | 3-Acetyl-2-methyl-1,4,5-trihydroxy-2,3-epoxynaphthoquinol | C_{13}H_{16}O_{6} | R13     | R           | [118]             |
| 160 | 3-Acetyl-2-methyl-1,5-dihydroxyl-7-methoxyl-2,3-epoxynaphthoquinol | C_{13}H_{16}O_{6} | R13     | WP          | [119]             |
| 161 | Rumexone A                                          | C_{14}H_{18}O_{4}     | R11     | R           | [142]             |
| 162 | Rumexneposide B                                    | C_{20}H_{22}O_{5}     | R11     | R           | [143]             |
| 163 | Rumexneposide B                                    | C_{20}H_{22}O_{10}    | R11     | R           | [143]             |
| 164 | Hastatuside B                                      | C_{20}H_{22}O_{5}     | R2, R13 | L, R        | [114]             |
| 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]         |
| 167 | Tormentic acid                                     | C_{30}H_{40}O_{5}     | R9      | ST          | [121]             |
| 168 | Myrianthic acid                                    | C_{12}H_{16}O_{6}     | R9      | ST          | [121]             |
| No  | Compounds                                      | Formula       | Species | Plant parts | Ref  |
|-----|-----------------------------------------------|---------------|---------|-------------|------|
| 169 | 2α,3α,19α-Trihydroxy-24-norurs-4(23),12-dien-28-oic acid | C_{20}H_{22}O_{12} | R9      | ST          | [121] |
| 170 | 4(R),23-Epoxo-2α,3α,19α-trihydroxy-24-norurs-12-ene-28-oic acid | C_{20}H_{22}O_{12} | R9      | ST          | [121] |
| 171 | Taraxasterol acetate                          | C_{32}H_{52}O_{2} | R2      | R           | [35]  |
| 172 | Lupeol                                         | C_{32}H_{52}O_{2} | R11     | A           | [189] |
|     | Diterpene alkaloids                           |               |         |             |      |
| 173 | 7,11,14-Trihydroxy-2,13-dioxoheptisane (orientinine) | C_{32}H_{52}O_{4} | R17     | A           | [75]  |
| 174 | 6,13,15-Trihydroxyhetisane (acorientine)      | C_{32}H_{52}O_{4} | R17     | A           | [75]  |
| 175 | 6-Hydroxy-11-deoxy-13-dehydrohetisane (panicudine) | C_{32}H_{52}O_{4} | R17     | A           | [75]  |
|     | Lignans                                        |               |         |             |      |
| 176 | Arctiin                                        | C_{20}H_{22}O_{11} | R13     | WP          | [23]  |
| 177 | 3-Hydroxyarctiin                               | C_{20}H_{22}O_{11} | R13     | WP          | [23]  |
| 178 | 3-Methoxyarctiin                               | C_{20}H_{22}O_{11} | R13     | WP          | [23]  |
| 179 | 4-Ketopiresinol                                | C_{20}H_{22}O_{7} | R13     | L           | [27]  |
| 180 | Syringaresinol                                 | C_{20}H_{22}O_{8} | R9, R13 | L, WP       | [27, 50] |
| 181 | Manassatin A                                   | C_{20}H_{22}O_{11} | R13     | L           | [27]  |
| 182 | Balanophonin                                   | C_{20}H_{22}O_{7} | R13     | L           | [27]  |
| 183 | Schizandrine                                   | C_{20}H_{22}O_{6} | R2      | WP          | [111] |
| 184 | (−)-Isolariciresinol-9-O-β-D-glucopyranoside   | C_{20}H_{22}O_{10} | R2      | WP          | [111] |
| 185 | (−)-S-Methoxylariciresinol-9-O-β-D-glucopyranoside | C_{20}H_{22}O_{11} | R2      | WP          | [111] |
| 186 | (+)-S-Methoxylariciresinol-9-O-β-D-glucopyranoside | C_{20}H_{22}O_{11} | R2      | WP          | [111] |
| 187 | (−)-Lyoniside                                  | C_{20}H_{22}O_{12} | R2      | WP          | [111] |
| 188 | Nudiposide                                     | C_{20}H_{22}O_{12} | R2      | WP          | [111] |
| 189 | (−)-Lyoniresinol-3α-O-β-D-glucoside            | C_{20}H_{22}O_{12} | R11     | R           | [33]  |
|     | Others                                         |               |         |             |      |
| 190 | Phenylethyl-α-α-L-arabinopyranosy-(1 → 6)-O-β-D-glucoside | C_{10}H_{22}O_{10} | R8      | R           | [31]  |
| 191 | Methylorsellinate                              | C_{10}H_{22}O_{4} | R11     | R           | [51]  |
| 192 | Ferulic acid                                   | C_{10}H_{22}O_{4} | R11     | R           | [51]  |
| 193 | Methyl 2-acetyl-3,5-dihydroxyphenylacetate     | C_{10}H_{22}O_{3} | R11     | R           | [51]  |
| 194 | 1-(2-Hydroxy-S-methyl-phenyl)-ethanon           | C_{10}H_{22}O_{2} | R11     | R           | [51]  |
| 195 | Methyl syringate                               | C_{10}H_{22}O_{3} | R11     | R           | [51]  |
| 196 | 1-(2,4-Dihydroxy-6-methylphenyl)-ethanon       | C_{10}H_{22}O_{3} | R11     | R           | [51]  |
| 197 | 4-Hydroxybenzene ethanol                       | C_{10}H_{22}O_{2} | R11     | R           | [51]  |
| 198 | Isovanillin                                    | C_{10}H_{22}O_{3} | R11     | R           | [51]  |
| 199 | p-Coumaricacid-n-ecosanoyl ester               | C_{10}H_{22}O_{3} | R13     | S           | [47]  |
| 200 | Z-Octadecyl caffeate                           | C_{10}H_{22}O_{4} | R13     | S           | [47]  |
| 201 | Dibutylphthalate                               | C_{10}H_{22}O_{4} | R11     | R           | [132] |
| 202 | 2-Methoxyhydroquinone                          | C_{10}H_{22}O_{3} | R11     | R           | [132] |
| 203 | Batiansuanmol                                  | C_{10}H_{22}O_{5} | R13     | R           | [138] |
| No | Compounds                              | Formula        | Species | Plant parts | Ref  |
|----|----------------------------------------|----------------|---------|-------------|------|
| 204| Orcinol                                | C₇H₈O₂         | R13     | R           | [54] |
| 205| p-Hydroxybenzoic acid                  | C₆H₄O₂         | R1, R9  | L           | [26, 39] |
| 206| p-Coumaric acid                        | C₉H₈O₆         | R1, R2, R7 | L, R, WP, A | [39, 48, 134, 144] |
| 207| Methyl 3,4-dihydroxyphenylpropionate   | C₁₀H₁₁O₄       | R1      | L           | [39] |
| 208| Vanillic acid                          | C₆H₈O₄         | R1      | L           | [39] |
| 209| Isovanillic acid                       | C₆H₈O₄         | R1, R7  | A           | [145] |
| 210| Gallic acid                            | C₇H₄O₄         | R2, R7, R13 | R,       | [35, 48, 53] |
| 211| Methyl gallate                         | C₆H₈O₃         | R2      | R           | [35] |
| 212| 2,6-Dimethoxy-4-hydroxybenzoic acid   | C₉H₁₀O₅        | R9      | A           | [26] |
| 213| Pyrocatechin                           | C₆H₈O₂         | R9      | A           | [145] |
| 214| Syringic acid                          | C₈H₁₀O₃         | R9     | A           | [145] |
| 215| 3,4-Dihydroxybenzaldehyde             | C₇H₈O₃         | R9      | A           | [145] |
| 216| Ethyl 3,4-dihydroxybenzoate            | C₈H₁₀O₄         | R9      | A           | [145] |
| 217| Ethyl gallate                          | C₈H₁₀O₄         | R9      | A           | [145] |
| 218| Rumexin                                | C₁₇H₂₂O₈        | R4      | A           | [38] |
| 219| Caffeic acid                           | C₈H₈O₄         | R4      | A           | [38] |
| 220| 1-O-caffeoylglucose                   | C₁₉H₁₄O₂        | R4      | A           | [38] |
| 221| 1-Methyl caffeic acid                 | C₁₉H₁₄O₂        | R4      | A           | [38] |
| 222| Neochlorogenic acid                   | C₁₉H₁₄O₂        | R27     | L           | [146] |
| 223| (S)-4′-Methylnonyl benzoate            | C₁₉H₂₂O₂        | R7      | A           | [14] |
| 224| 5-Methoxy-7-hydroxy-1(3H)-benzofuranone| C₉H₁₀O₄        | R11     | R           | [51] |
| 225| 5,7-Dihydroxy-1(3H)-benzofuranone      | C₉H₁₀O₄        | R13     | R           | [53] |
| 226| 5-Methoxyl-1(3H)-benzofuranone-7-glucoside| C₁₉H₁₄O₃       | R8      | R           | [31] |
| 227| Sinapic acid                           | C₁₉H₁₄O₃        | R1      | FL          | [147] |
| 228| Protocatechuic acid                   | C₁₉H₁₄O₃        | R1      | L           | [55] |
| 229| p-Hydroxycinnamic acid                | C₁₉H₁₄O₃        | R8      | R           | [190] |
| 230| Streptokordin                          | C₁₉H₂₀N₂        | R11     | R           | [132] |
| 231| Hastatuside A                          | C₁₉H₁₈O₃        | R2      | R           | [114] |
| 232| β-Sitosterol                           | C₂₀H₃₂O       | R1, R6, R7, R11, R13, R28 | A, R, S, L, WP | [34, 39, 47, 48, 53, 101, 189] |
| 233| Daucosterol                            | C₂₀H₃₂O₆        | 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         | C₂₀H₃₂O₃        | R21     | WP          | [123] |
| 235| Nonadecanoic acid-2,3-dihydroxypropyl ester | C₂₁H₄₄O₄        | R13     | R           | [53] |
| 236| Hexadecanoic acid-2,3-dihydroxypropyl ester | C₂₁H₄₄O₄        | R7      | R           | [48] |
| 237| 1-Stearylglycerol                      | C₂₁H₄₂O₄       | R4      | A, R        | [148] |
| 238| Triacanol                              | C₂₀H₃₂O₆        | R13     | S           | [47] |
| 239| Dotriacontanol                         | C₂₁H₄₂O₆        | R13     | S           | [47] |
| 240| Hexacosanoic acid                      | C₂₀H₃₂O₂        | R6, R13 | S, WP       | [34, 47] |
| 241| Dotriacontane                          | C₂₁H₆₆          | R13     | S           | [47] |
| 242| Glyceryl 1,3-dipalmitate              | C₂₁H₃₂O₅        | R13     | S           | [47] |
| 243| (2S)-8-Hydroxy-2,6-dimethyl-2-octenoic acid | C₁₀H₁₆O₃        | R11     | R,          | [132] |
| 244| Tetratriacontane                      | C₁₀H₁₈O₃        | R13     | S           | [149] |
| 245| Ceryl alcohol                          | C₂₀H₃₂O       | R20     | A           | [125] |
They are mostly derived from kaempferol (14, 23, 34–42), and quercetin (4, 3-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(3H)-chromone (91), 5,7-dihydroxy-1(3H)-chromone (92), 2,5-dimethyl-7-hydroxychromone-7-O-β-D-glucoside (95) and 2,5-dimethoxy-7-hydroxychromone (96) were reported from R. gmelini, R. nepalensis, R. patientia and R. crispatus [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)
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-(4β→8)-epicatechin-3-O-gallate (127), cinnamattannin B1-3-O-gallate (132) and epiafzelechin-(4β→6)-epicatechin-3-O-gallate (135), and trimers, epiafzelechin-(4β→8)-epicatechin-(4β→8)-epicatechin (114), and epicatechin-(2β→7, 4β→8)-epiafzelechin (4α)-epicatechin (132) were reported. In addition, some procyanidins and propelargonidins, epiafzelechin-(4β→8)-epicatechin-(4β→8)-epicatechin (114), epicatechin-(4β→8)-epicatechin-(4β→8)-catechin (114), procyanidin C1 (116), epicatechin-(4β→6)-catechin (121), procyanidin B1-B5 (120, 122–125), and epicatechin-(4β→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 in the Polygonaceae family [108]. It has been widely applied in cardiovascular protection and as an antioxidant 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, 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-Methoxyxypandrene (152) was isolated from R. japonicus and R. maritimus [115, 116]. Notably, some naphthalenes containing CI, 2-acetyl-1,4-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-epoxy-naphthoquinol (153), 3-acetyl-2-methyl-1,4,5-trihydroxyl-2,3-epoxy-naphthoquinol (159) and 3-acetyl-2-methyl-1,5-dihydroxy-7-methoxyl-2,3-epoxy-naphthoquinol (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-D-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 (4R)-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), acorintine (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-xylopyranose (178), and two known ones, arctinin (176) and 3-hydroxy-arctiin (177), were obtained from R. patientia [23]. Six lignan glycosides, schizandriside (183), (-)-isoriciresinol-9-O-β-D-xylopyranoside (184), (-)-5-methoxyisoriciresinol-9-O-β-D-xylopyranoside (185), (+)-5-methoxyisoriciresinol-9-O-β-D-xylopyranoside (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). Phenethyl-O-α-L-arabinopyranosy-(1→6)-O-β-D-glucoside (190) and 5-methoxy-1(3H)-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)
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. 6 Structures of diterpene alkaloids (173–175)

Fig. 7 Structures of lignans (176–189)
Fig. 8 Structures of other compounds (190–268) (Note: 268 not given)
parts of *R. aquatica* [38]. Recently, one new compound (5S)-4′′-methyleneonl 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, anhydroleutens I (256) and II (257) were separated from *R. rugosus* together with [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)-glucose (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)-glucose (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 compounds 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-hydroxyemodin (14), phycion (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-(4β→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. acetosa*, *R. acutata*, *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 (*R. conglomeratus* [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-stearoylglycerol (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 HaCaT cells [155]. Methanolic extracts of the roots and stems of *R. roseus* 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. aquatius* 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 log₁₀ reduction in HSV-2 at 6.25 μM, on a traditional virus yield reduction test and qPCR assay. It suggested that *R. aquatius* 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% effective against herpes simplex virus type-1 at concentrations > 1 μg/mL (IC₅₀ = 0.8 ± 0.04 μg/mL). At concentrations > 25 μg/mL (CC₅₀ = 78.6 ± 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 model 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), rumexpatientoseides A (47) and B (48) and napelside 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 (IC₅₀ = 118.8 μM) showed higher scavenging activity to DPPH free radicals than the other parts (leaves: IC₅₀ = 201.6 μM, flowers and fruits: IC₅₀ = 230.1 μM, stems: IC₅₀ = 411.2 μM) [163]. The roots of *R. thysiflorus* [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⁺, NO₂⁻ radical scavenging and phosphomolybdate antioxidant assays verified that *R. acetosella* has antioxidant properties [168]. Phenolic constituents from *R. maderensis* displayed 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 aequous 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 IC₅₀ 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. CCl₄-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. rotundifolius 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 IC₅₀ values of 33.45—62.56 μg/mL. At a concentration of 30 μg/mL, the chloroform extract of the stems inhibited the formation of ≥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-Methoxystympandrone (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 antiangiogenic 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 IC₅₀ values of 20.1 and 18.9 μM, respectively [180]. The alcohol extract of R. acetosella displayed stronger inhibitory activity on α-glucosidase (roots, IC₅₀ = 12.3 μM; aerial parts, IC₅₀ < 10 μM), compared to the positive control, acarbose (IC₅₀ = 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 (IC₅₀ = 19.1 ± 0.7 μM and 54.9 ± 0.3 μM, respectively) compared to acarbose (IC₅₀ = 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 PPARy 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 ± 4.55% and a MAP (70 mmHg) in hypertensive rats with a decrease of 48.40 ± 4.93%. In endothelium intact rat aortic rings precontracted with phenylephrine (1 μM), Ra.Cr induced endothelium-dependent vasorelaxation with EC₅₀ = 0.32 mg/mL (0.21—0.42), while in denuded endothelial rat aortic rings, EC₅₀ = 4.22 mg/mL (3.2—5.42), which was partially blocked with L-NAME (10 μM), indomethacin (1 μM) and atropine (1 μM).
isolated rabbit aortic rings precontracted with phenylephrine (1 μM) and K+ (80 mM), Ra.Cr induces vasorelaxation and the movement of Ca2+ [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 H2O2-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 CCl4-damaged rats investigated by an in vivo experiment, in which the ethanol extract protected effectively the CCl4-damaged rats [177]. The hepatoprotective effect of R. tingitanus was investigated by an in vivo experiment, in which the ethanol extract protected effectively the CCl4-damaged rats [177].

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 osteolast differentiation by suppressing the MAPK/NF-kB/ NFATc1 signaling axis and increases 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 antiangiogenic 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 IC50 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 (IC50 = 36.4, 45.0 μg/mL, respectively) [180].

Inhibition of human pancreatic lipase could reduce the hydrolysis of triacylglycerol into monoaclglycerol 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, anti-tumor 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-y)-2,5-diphenyl tetrazolium bromide; NF-κB: Nuclear factor-kappa B; QGC: Quercetin-3-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 wrote 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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