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The Genus *Oxalis*: Ethnomedicinal Relevance, Phytochemical Diversity, Pharmacological Activities, and Toxicological Perspectives - A Comprehensive Review

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Abstract

Background: The genus *Oxalis* (*Oxalidaceae*) consists of around 800 species; many are recognised for distinctive taxonomic features and diverse ethnomedicinal uses. This review evaluates eleven *Oxalis* species in terms of their botany, taxonomy, phytochemistry, pharmacology, and toxicology, outlining their adaptive diversity and widespread distribution across temperate and tropical regions. **Aim:** To collate evidence on traditional medicinal applications, key bioactive compounds, and validated pharmacological effects of *Oxalis* species, and to highlight critical gaps impeding their development as standardised nutraceuticals and pharmaceuticals. **Methods:** An extensive literature search was performed to collate data from ethnobotanical records, phytochemical analyses, modern extraction techniques, and molecular assays. The review emphasises major bioactive groups, including flavonoids, tannins, alkaloids, anthocyanins, and fatty acids. Diverse pharmacological activities and toxicological aspects were also evaluated. **Results:** *Oxalis* species show a rich history of traditional uses, including wound healing, liver tonics, and remedies for metabolic, inflammatory, and infectious conditions. Phytochemical investigations have identified diverse classes of bioactive substances, underpinning *in vitro* and *in vivo* evidence for antioxidant, antimicrobial, anti-inflammatory, antidiabetic, hepatoprotective, anti-cancer, wound healing, and nephroprotective activities. Advanced extraction and molecular approaches confirm these pharmacological effects. However, toxicological concerns and a lack of standardised methodologies remain significant challenges. **Conclusion:** *Oxalis* comprises a promising botanical reservoir for innovative healthcare solutions. Bridging phytochemical characterisation with molecular validation is essential for safe and effective application of *Oxalis*-derived products. Integrated perspectives offer a foundation for future bioprospecting and ethnopharmacological innovation.

Major Findings: *Oxalis* species contains a rich spectrum of secondary metabolites, including flavonoids, phenols, glycosides, anthocyanins, and fatty acid esters. These phytoconstituents demonstrate diverse pharmacological effects, such as anticancer, antioxidant, hepatoprotective, antimicrobial, anti-inflammatory and anti diabetic potential.

Keywords: Bioactive Compounds, *Oxalis*, Phytochemistry, Pharmacology, Taxonomy, Toxicology

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1. Introduction

The genus *Oxalis* (family *Oxalidaceae*, which contains about five genera and 570 species), commonly referred to as 'Wood-sorrel' or 'Sourgrass' in English, '*Suring*' in Africa, '*Chari Amilo*' in Nepali, and '*Tinpatiya*' in Hindi[1]. The genus thrives in tropical, subtropical, and temperate climates, including Europe, Africa, North America, South America, and Asia[2,3]. Mostly herbaceous weeds or ornamentals (some shrubs/trees), it derives from the Greek word *oxus*, meaning sour[4,5].

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Some species within *Oxalis* have long been used in traditional practices across Europe, Africa, North America, South America, and Asia. For instance, *Oxalis acetosella* L. have long been admired and used by various tribes across the globe to cure sore throats, mouth sores, aphrodisiac, fever, nausea, cramping, as a thirst reliever, and a sugary delicacy[6,7]. In China, it has been used to treat wounds and skin infections. In Northern Pakistan, decoctions are used for pulmonary and dermatological issues[8,9]. In Kashmir, India, nomads chew its tubers to quench their thirst, while in Bosnia and Herzegovina, it is added to salads as a source of vitamin C[10,11]. Similarly, other species like *Oxalis latifolia* Kunth., have been utilised for their analgesic, antipyretic, antioxidant, anticancer, managing gastrointestinal issues, crippling weakness, and thirst[12]. In certain traditional systems, it is considered a digestive appetiser and is also used to cure piles, diarrhoea, and dysentery, as well as to remove warts and heal wounds[13]. *Oxalis debilis* Kunth is used for a range of folk remedies, including treatment of fever, diarrhoea, dyspepsia, jaundice, and headaches, and also as a vegetable; regional reports also cite uses as an antipyretic, antidiabetic, anthelmintic, and for snakebite and respiratory complaints[14-20].

Most studied species within the genus, *Oxalis corniculata* L. common across the Asian subcontinent and native to India, features prominently in *Siddha, Unani*, and *Ayurvedic* folk medicine and is also consumed as a leafy vegetable. Ethnobotanical reports list uses for gastric ulcers, diarrhoea, tonsillitis, toothache, dysentery, fever, rectal prolapse, and as an astringent and antiscorbutic[21-26]. On the other hand, *Oxalis cordata* A. St.-Hil, *Oxalis tetraphylla* Cav, *Oxalis erythrorhiza* Gillies ex Hook. and Arn., *Oxalis griffithii* Edgew. and Hook. f., *Oxalis pes-caprae*, *Oxalis stricta* L., and *Oxalis triangularis* A. St.- Hil. are among other species that have been used for various pharmacological investigations by researchers worldwide, but evidence of their traditional use is lacking in the available literature. Reported traditional claims for *Oxalis* species utilisation have been tabulated below in Table 1.

Notably, the current review focuses on taxonomy, phytochemistry, ethno-pharmacological relevance, and toxicological aspects of *Oxalis* species, emphasising mainly on *Oxalis corniculata*. This review is intended to direct and motivate further studies to investigate and expand this genus's therapeutic potential by incorporating new approaches and validating its traditional claims through experimental procedures.

2. Search Methodology

This review was conducted to explore traditional medicinal applications, key bioactive compounds, and validated pharmacological effects of *Oxalis* species, and to highlight critical gaps impeding their development as standardised nutraceuticals and pharmaceuticals. The systematic literature search was carried out using various primary databases: PubMed and Google Scholar. The literature search included all relevant studies published up to September 2025.

The following keywords and Boolean operators were used in various combinations: "*Oxalis*", "*Oxalis corniculat*", "*Oxalis debilis*", "*Oxalis pes-caprae*", "*O.*

Table 1. Reported traditional uses of the studied *Oxalis* species

Species	Reported Traditional Uses	References
Oxalis acetosella	Extracted salt ("sorrel salt") used as aphrodisiac by Algonquin; mouth sores and sore throat (*Cherokee*); thirst quencher (*Kiowa*); dessert with sugar (*Potawatomi*); cramps, fever, nausea (*Iroquois*); wound and skin infections (China, Pakistan); vitamin C source (Bosnia); tuber for thirst relief (Kashmir)	6-11
Oxalis latifolia	Juice: anticancer, antioxidant, antipyretic, analgesic; bulb for thirst, paralysis, stomach disorders; wound healing, wart removal, piles, diarrhoea, dysentery	12,13
Oxalis debilis	Fever, scurvy, diarrhoea, piles, antidote for snake bite (Uttar Pradesh); vegetable and stomach complaints (Assam); antipyretic, antidiabetic, antihelmintic, oedema, asthma (Pakistan); dysentery, diabetes, diarrhoea (West Bengal); jaundice, dyspepsia (Assam); headache (Western Himalaya); liver and inflammatory disorders (Northeast India)	14-20
Oxalis corniculata	Used by the folk medicinal system, *viz. Siddha, Unani*, and *Ayurveda* are used in conditions like ulcer, diarrhoea, tonsillitis, toothache, astringent, antiscorbutic, cooling, dysentery, fever, and biliousness; dietary supplements and vegetables (Odisha, India)	21-26

acetosella", "*O. cordata*", "*O. erythrorhiza*", "*O. griffithii*", "*O. latifolia*", "*O. tetraphylla*", "*O. triangularis*", "*O. stricta*", "phytochemistry", "ethnomedicine", "traditional uses", "pharmacological activity", and "biological activity" was employed in the search strategy.

2.1 Inclusion Criteria

- English-language articles published within September 2025.
- Reports from ethno botanical surveys, review articles, and research publications that have undergone peer assessment.
- Studies reporting pharmacological/biological properties, phytochemical makeup, or ethnomedical knowledge of *Oxalis* species.

2.2 Exclusion Criteria

- Abstracts from conferences, theses, and non-scientific sources without peer review.
- Studies with ambiguous methodological details.
- Reports that are solely about unrelated plant species.

Relevance screening was done on abstracts and titles, and full-text articles that met the requirements were critically assessed. With a focus on species-specific ethno-medicinal records, discovered phytoconstituents, and verified pharmacological activity, the data were extracted and arranged into thematic sections.

3. Taxonomic Description

The genus *Oxalis* has several morphological variations, establishing classification tedious[27]. The genus *Oxalis* was initially taxonomically addressed by Linnaeus in 1753[28]. He identified 14 species of the genus and divided them into two major, unranked groups according to the presence of the stem. Knuth updated the genus in 1930, bringing in 791 species that were divided into 37 divisions with several subsections and series based on the plant overall structure and flower features[29]. More recently, *Oxalis* was thoroughly revised by Lourteig[30], who focused especially on South American species. In her new subgeneric and subsectional categorisation, she identified four subgenera, mostly based on leaf morphology: *Oxalis*, *MonOxalis, Thamnoxys*, and *Trifidus*. These taxonomic data provide insights into diagnostic key characters that help in distinguishing the plant taxa.

Within the order *Oxalidales*, the wood sorrel family, or *Oxalidaceae*, is a tiny family of dicotyledonous plants with flowers that comprises around 570 species, and most of which are found in temperate, subtropical, or tropical zones. These genus plants are annual or perennial. The leaves could vary between simple at times, palmate, cordate or even pinnate. Flowers may appear solitary, umbellate, cymose, racemose, bisexual, or actinomorphic. Five petals and five sepals, or five-merous, make up the flower that is observed. Sepals are essentially independent or coupled, imbricate, and sometimes valvate. Petals are convoluted and have a little connate base. There are ten stamens, often two whorls, five per whorl, and outer whorls that face the petals. The bases of filaments have glandular attachments and are connected. Anthers possess 2 spaces (locules) and divide lengthwise. The ovary is implanted on the axile placenta and is superior, five-loculed, with one, two, or multiple ovules per locule. Fruit is a fleshy, loculicidal capsule that is occasionally a berry. Typically fleshy, seeds have elastic perisperm or, irregularly, hairs along with fleshy endosperm[31,32]. The detailed taxonomic and morphological traits of *Oxalis* species being reviewed are given in Table 2 and Figure 1, respectively.

4. Phytochemistry of *Oxalis* Species

The genus *Oxalis* is characterised by a great diversity of secondary metabolites that account for its vast range of pharmacological properties, including antioxidant, antibacterial, anti-inflammatory, and anticancer effects. The phytochemical composition varies significantly between species and is regulated by environmental factors such as soil type, climate, and geographical location.

Throughout the genus, flavonoids, phenolic acids, alkaloids, tannins, coumarins, terpenoids, and oxalates are the main types of bioactive substances. These substances' biological significance and potential for treatment have been thoroughly investigated. For example, flavonoids with established anti-inflammatory and antioxidant properties include luteolin, apigenin, vitexin, and isovitexin[40,41]. Phenolic acids, such as p-coumaric, caffeic, ferulic, and chlorogenic acids, have antibacterial, anti-inflammatory, and radical scavenging properties[42].

Table 2. Comparative taxonomic and morphological traits of the studied *Oxalis* species

Species	Common Name	Key Morphological Traits	References
Oxalis corniculata	Creeping wood sorrel	Trifoliate, heart-shaped leaflets; prostrate, branching stems that root at nodes; yellow, five-petaled blooms; explosive capsules; creeping, mat-forming perennial herb	31,33
Oxalis acetosella	Wood sorrel	A woody perennial with a moderate growth rate (less than 10 cm); trifoliate, heart-shaped, pubescent leaves; violet-veined white petals; Flowers and leaves wither in the rain or at night.	31,34
Oxalis latifolia	Garden pink-sorrel	Based on information from similar species, this perennial herb has broad trifoliate leaves, pink-purple blooms with five petals, and vegetative spread by bulbs and stolons.	35
Oxalis debilis	Large-flowered pink-sorrel	Heart-shaped trifoliate leaves; perennial, frequently bulbous or producing stolons; umbels with pink or lavender flowers (extensively documented in botanical literature)	36
Oxalis pes-caprae	Bermuda buttercup / Sourgrass	Bright yellow flowers and clover-like trifoliate leaves characterise this perennial bulbous plant, which reproduces via bulbils, a very invasive species feature.	37
Oxalis triangularis	Purple shamrock	Delicate pinkish blooms and rich purple/triangular trifoliate leaves characterise this ornamental perennial species.	38
Oxalis griffithii	Griffith's wood sorrel	Pubescent rhizomes, oblong, hairy leaves, and single, nodding pale lilac blooms characterise this perennial species	39
Oxalis cordata, Oxalis stricta, Oxalis erythrorhiza	Heart-leaved wood sorrel, Common yellow wood sorrel, Red-root wood sorrel	There is a scarcity of accessible peer-reviewed literature providing comprehensive morphological descriptions.	-

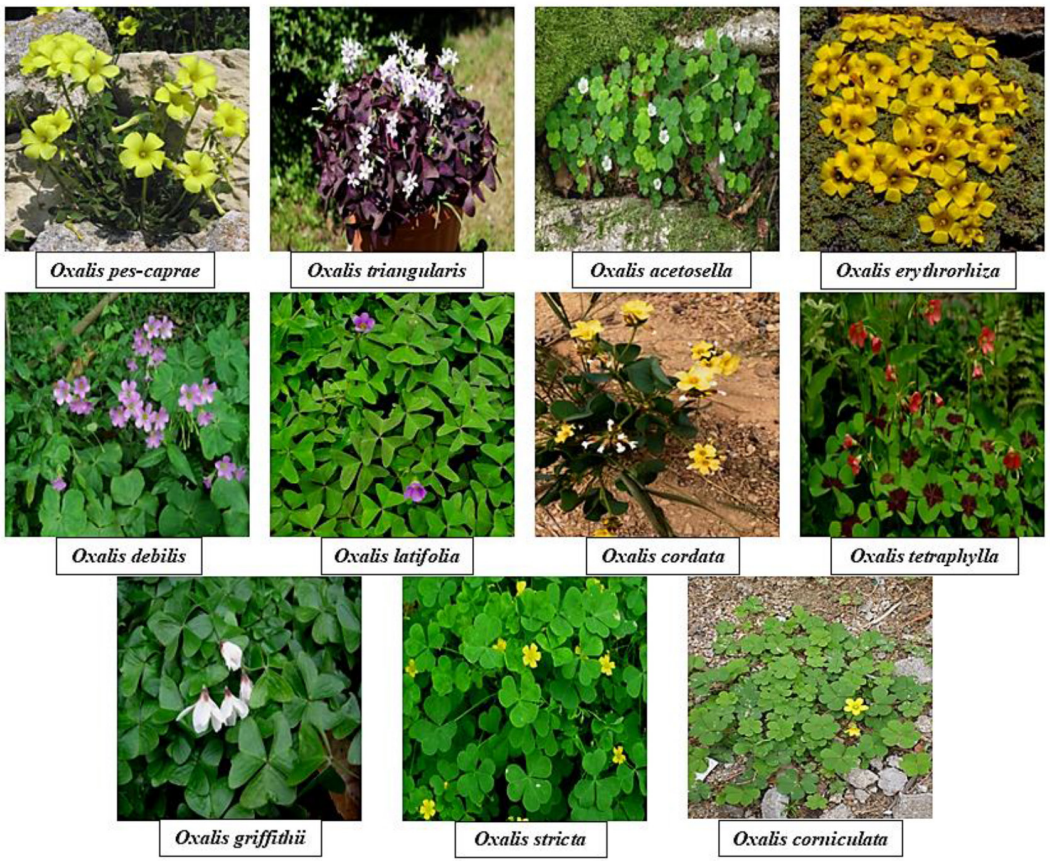


Figure 1. Representative images of selected *Oxalis* species showing morphological traits.

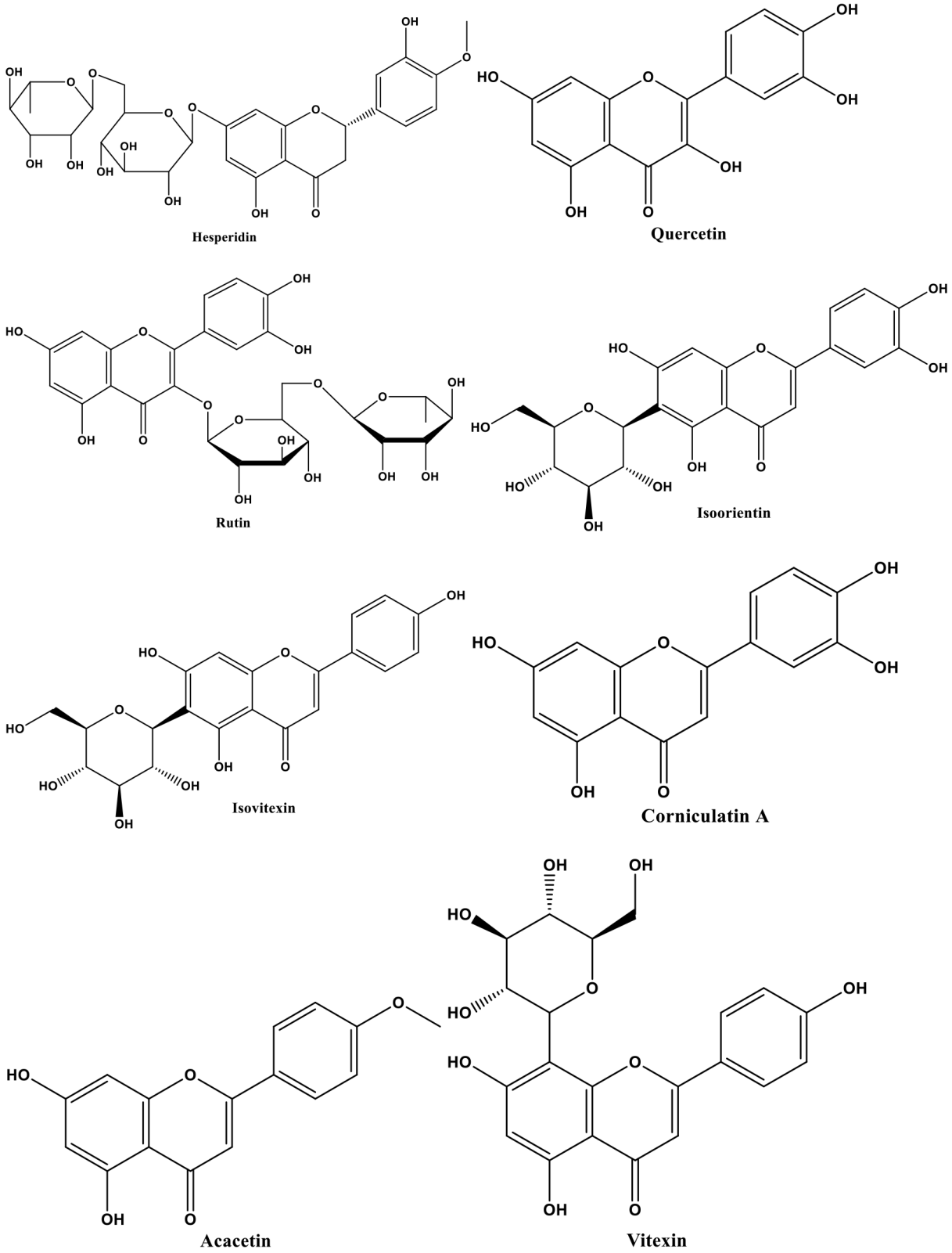
Table 3. Major phyto-constituents identified from *Oxalis* species

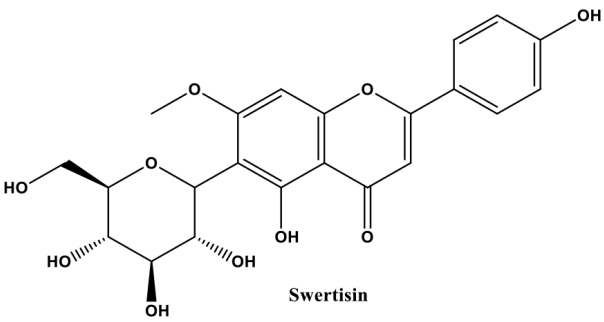
Species	Major Phytoconstituents	Phytochemical Class	References
Oxalis corniculata	Hesperidin; quercetin; rutin; isoorientin; isovitexin; corniculatinA; acacetin; vitexin; swertisin; diosmin; apigenin 7,4′-diglucoside; 5-Hydroxy-6,7,8,4′-tetramethoxyflavone; 5,7,4′-Trihydroxy-6,8-dimethoxyflavone;5,7-Dimethoxy-3,3′,4′-trihydroxyflavone; eburicoic*acid; 24-methylenecholest-4-ene-3β,6β-diol;3β-hydroxylanosta-8,24-dien-21-oic acid;* *p*-hydroxybenzoic acid; ferulic acid; vanillic acid**;** ethyl gallate**;** diosmetin-7-O-beta-D-glucopyranoside; β-sitosterol;	Flavonoids, terpenoids, phenolic acid, phenols, glycosides, phyto-sterols	43-50
Oxalis pes-caprae	7,3′-dimethoxyl-2″-O-glycosylorientin; luteolin; chlorogenic acid; p-coumaric acid; cinnamic acid derivatives; tangeretin; nobiletin; imperatorin; pterostilbene; matairesinol;	Flavonoids, phenolic acids, coumarins, stilbenoids, lignans	51,52
Oxalis acetosella	Apigenin, vitexin, isovitexin, catechin, epicatechin, rutin, quercitrin, ferulic acid, caffeic acid	Flavonoids, phenolic acids	53
Oxalis triangularis	Methyl linoleate, methyl linolenate, ethyl linoleate, ethyl linolenate, apigenin glycosides, malvidin derivatives	Fatty acid esters, flavonoids, anthocyanins	54,55
Oxalis erythrorhiza	Alkyl phenols, embelin, quinic acid, vicenin II, isovitexin, α-boswellic acid, daucosterol	Phenols, benzoquinones, flavonoids, terpenoids	56
Oxalis debilis	8-hydroxyapigenin 7-O-β-D-glucoside, stigmasterol	Flavonoid, steroid	57
Oxalis cordata	4-p-coumaroylquinic acid, orientin, vitexin rhamnoside	Phenols, flavonoids	58
Oxalis latifolia	Phytochemical profiling via GC/MS, LC/MS (no isolation yet)	-	59,60
Oxalis tetraphylla	Sterols, flavonoids, coumaric acid (characterised)	-	61,62
Oxalis griffithii	No studies on phytoconstituents reported	-	-
Oxalis stricta	Glycosides, tannins, phenols, flavonoids, oxalic acid (qualitative)	-	63

Certain species have distinctive or remarkable phytochemical characteristics. Particularly abundant in *O. corniculata* are flavonoids (hesperidin, quercetin, rutin, isoorientin, isovitexin, corniculatin A, acacetin, vitexin, swertisin, diosmin, etc), along with phenolic acid (p-hydroxybenzoic acid, ferulic acid, vanillic acid)[43-48], phenols (ethyl gallate), terpenoids (eburicoic acid, 24-methylenecholest-4-ene-3β)49, glycosides (diosmetin-7-O-beta-D-glucopyranoside), and phyto-sterol (β-sitosterol)[50]. Particularly abundant in *O. pes-caprae* are lignans (matairesinol), coumarins (imperatorin)[51], and polymethoxylated flavones (tangeretin, nobiletin, and demethylnobiletin)[52]. The high concentrations of catechins, rutin, and chlorogenic acid in *O. acetosella* make it a powerful antioxidant[53]. *O. triangularis* is distinguished by its anthocyanins, including variants of malvidin, which also help to give its leaves their unique colour, along with fatty acid esters, including methyl and ethyl linoleate/linolenate[54,55]. *O. erythrorhiza* includes chemicals with potent antibacterial and antiparasitic properties, such as embelin and alkyl phenols[56]. *O. debilis* showed the presence of flavonoid (8-hydroxyapigenin 7-O-β-D-glucoside) and steroid (stigmasterol) with potent antidiabetic activity[57]. *O. cordata* showed phenol and flavonoids (4-p-coumaroylquinic acid, orientin, vitexin rhamnoside), which supports anti diabetic activity[58].

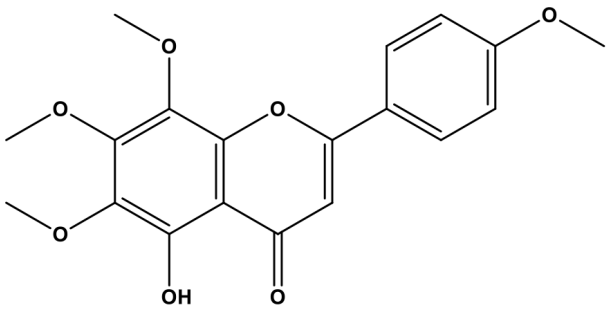
Although thorough isolation and structural examination of individual compounds are still limited, chemical profiling has been carried out utilising chromatographic and spectrometric techniques (e.g., GC–MS, LC–MS, HPLC, TLC) in a number of species, including *O. latifolia, O. cordata,* and *O. tetraphylla*[59-63]. This draws attention to a crucial area of study for pharmacognosists and phytochemists who want to investigate the complete medicinal properties of these plants. The main phytoconstituents identified from a studied *Oxalis* species, together with the appropriate chemical classes and pertinent literature references, are summarised in Table 3 along with its schematic

(I) Flavonoids

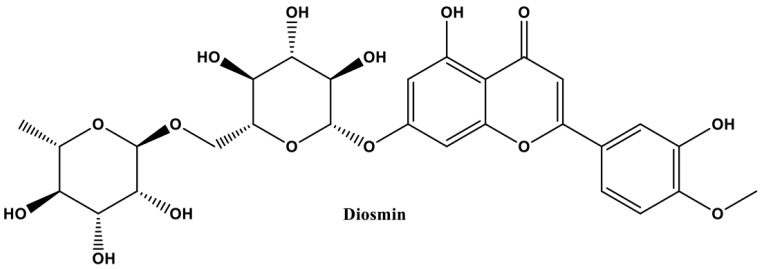




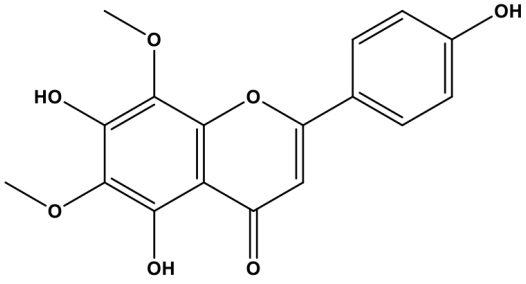
Swertisin



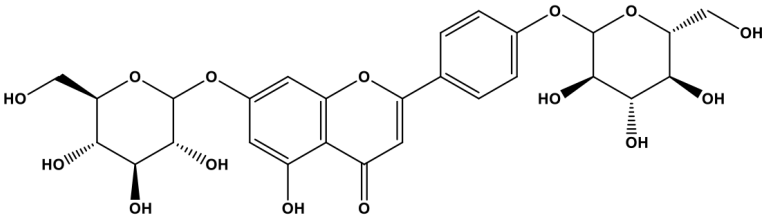
5-Hydroxy-6,7,8,4'-tetramethoxyflavone



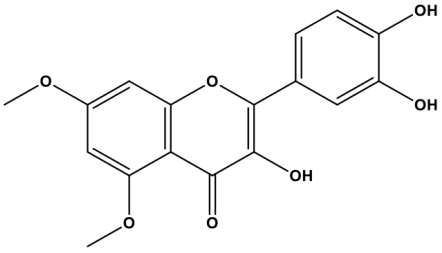
Diosmin



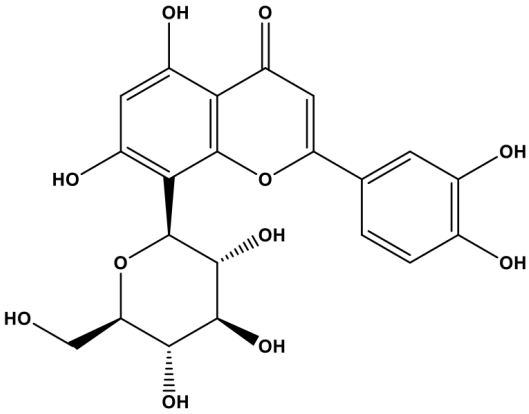
5,7,4'-Trihydroxy-6,8-dimethoxyflavone



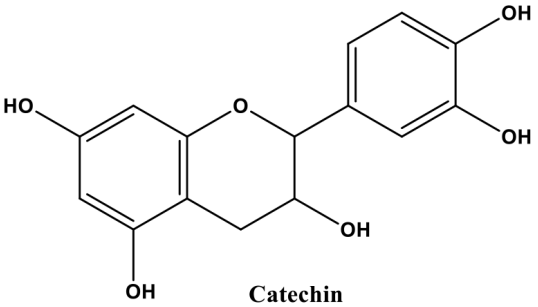
Apigenin 7,4'-diglucoside



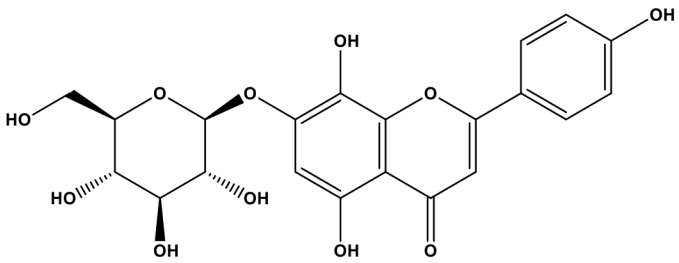
5,7-Dimethoxy-3,3',4'-trihydroxyflavone



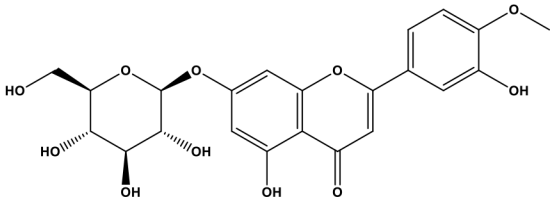
Orientin



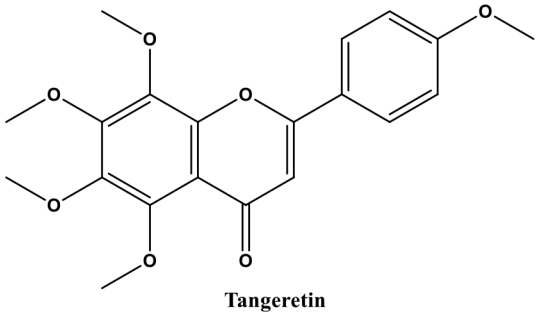
Catechin



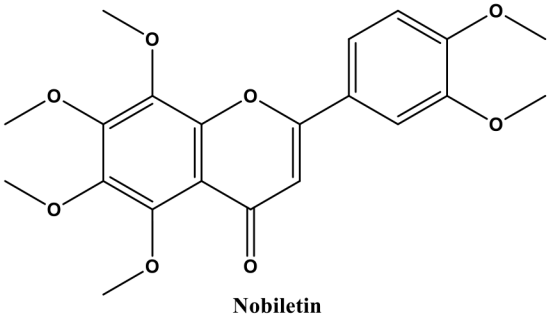
8-hydroxyapigenin 7-O-Beta-D-glucoside



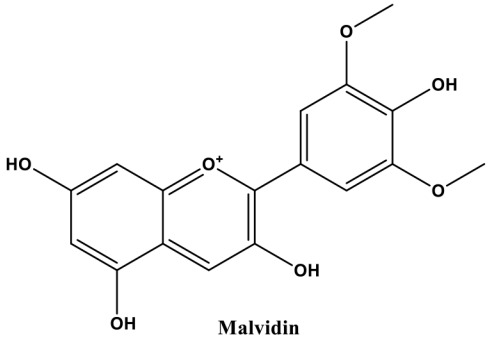
Diosmetin-7-O-beta-D-glucopyranoside



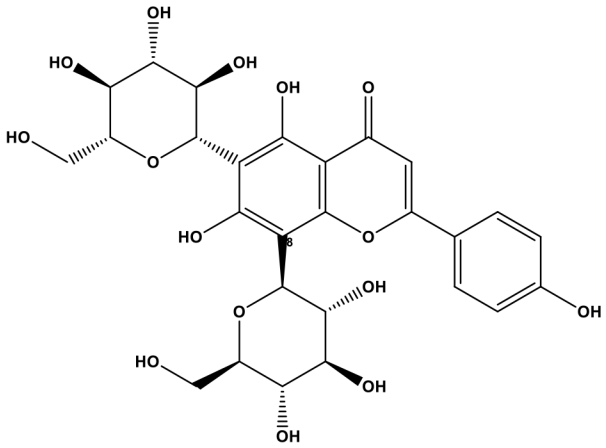
Tangeretin



Nobiletin

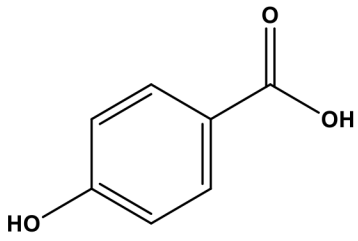


Malvidin

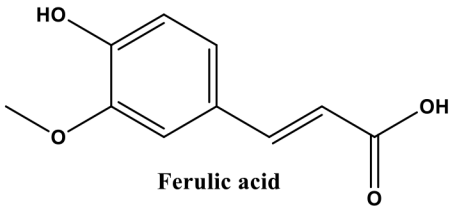


Vicenin II

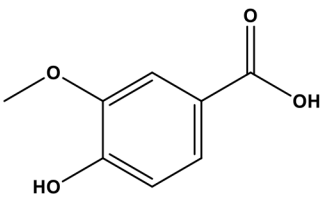
(II) Phenols



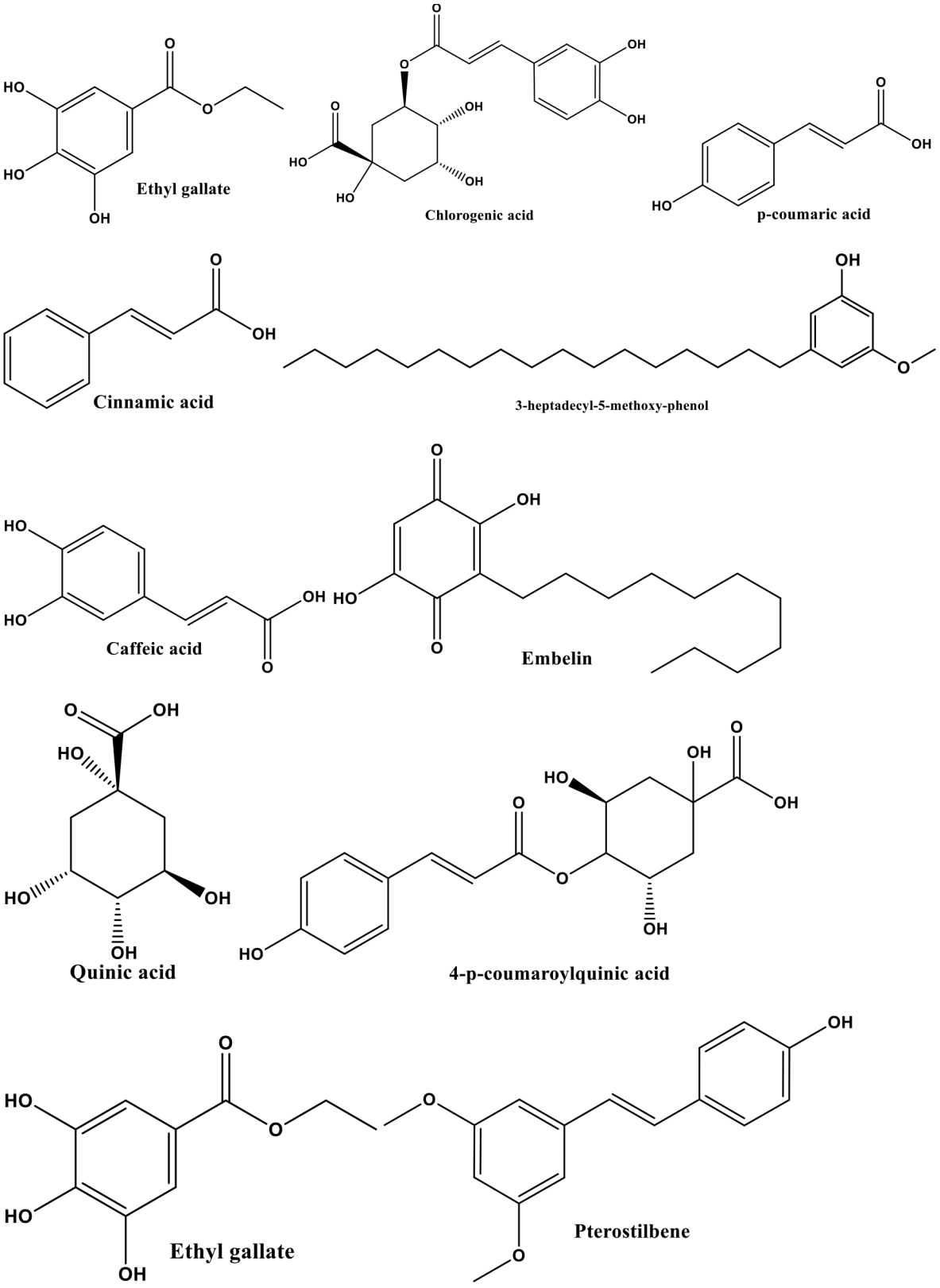
p-hydroxybenzoic acid



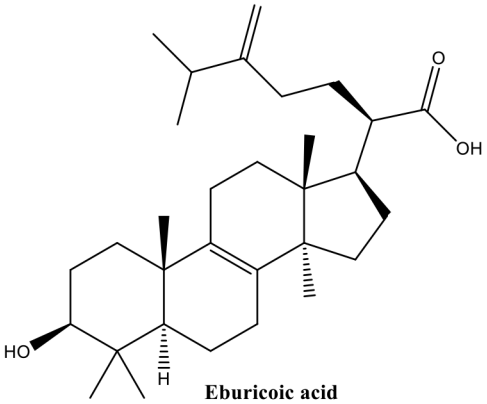
Ferulic acid



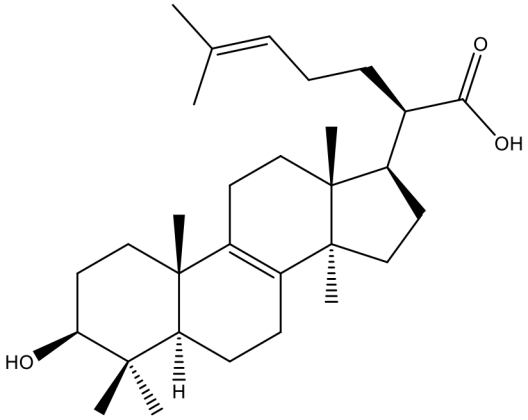
Vanillic acid


Ethyl gallate
Chlorogenic acid
p-coumaric acid
Cinnamic acid
3-heptadecyl-5-methoxy-phenol
Caffeic acid
Embelin
Quinic acid
4-p-coumaroylquinic acid
Ethyl gallate
Pterostilbene

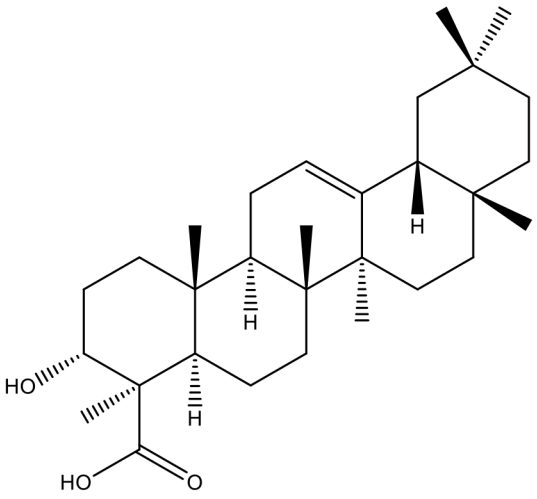
(III) Terpenoids



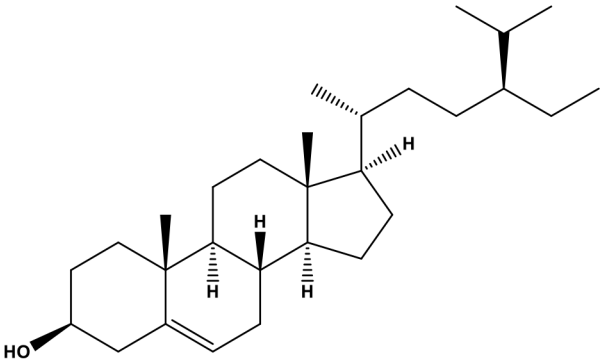
Eburicoic acid



3beta-hydroxylanosta-8,24-dien-21-oic acid

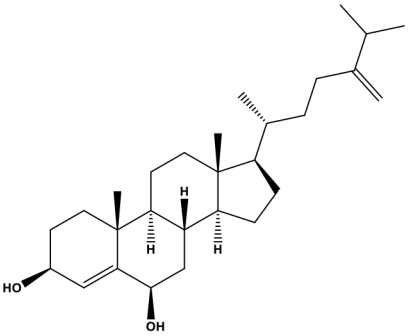


Alpha-boswellic acid

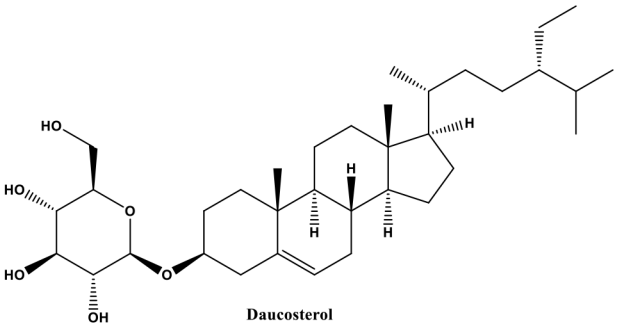


Beta-sitosterol

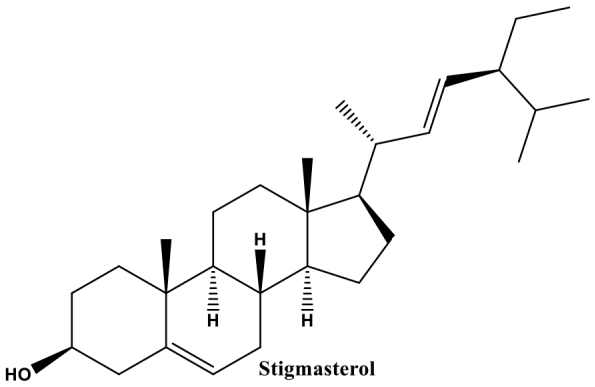
(IV) Steroids



24-methylenecholest-4-ene-3beta,6beta-diol

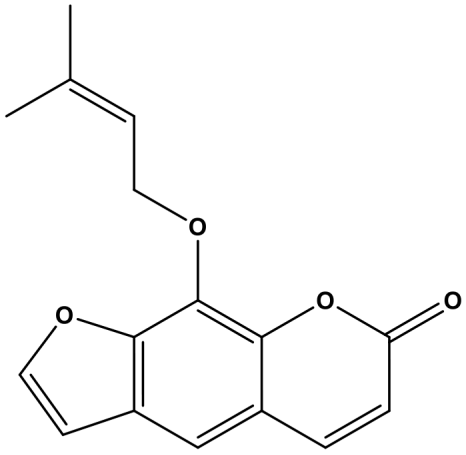


Daucosterol



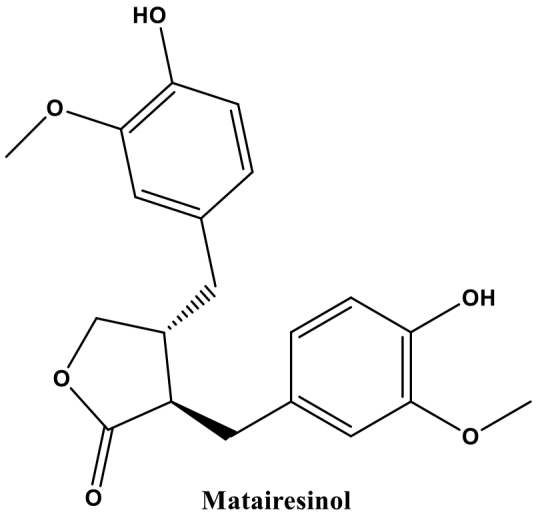
Stigmasterol

(V) Coumarin



Imperatorin

(VI) Lignan



Matairesinol

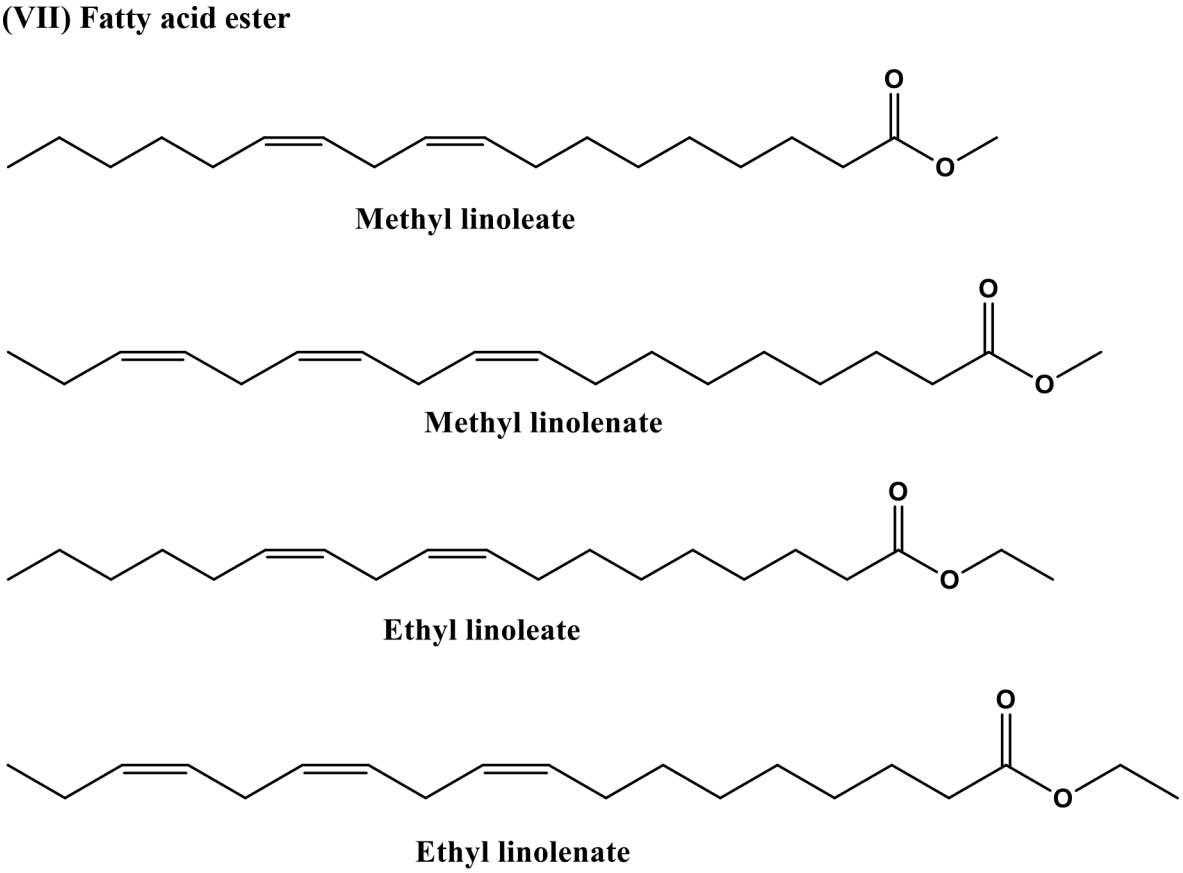


Figure 2. Schematic representation of the major phytochemical classes reported from the genus *Oxalis*: **(I)** Flavonoids; **(II)** Phenols; **(III)** Terpenoids; **(IV)** Steroids; **(V)** Coumarin; **(VI)** Lignan; **(VII)** Fatty acid ester.

infographic in Figure 2. All of these results point to the genus as a potentially rich source of structurally varied bioactive substances that need more investigation in order to discover new drugs.

5. Pharmacological Relevance of *Oxalis* Species

Various plant parts, extracts and isolated compounds from different species have been studied for their pharmacological properties. An overview of these activities has been depicted below in Table 4 and Figures 3a and 3b, respectively.

5.1 Anti-oxidant Activity

Oxalis species' high phenolic and flavonoid content results in notable antioxidant action. *O. pes-caprae* exhibited the highest antioxidant activity in the n-butanol extract, which correlated with the phenolic content seen in the ethyl acetate extract[64]. The DPPH and ABTS scavenging capabilities of flower extracts were robust, and methanolic extracts outperformed aqueous one[65]. *O. acetosella* exhibited antioxidant activity similar to spinach, showcasing its phenolic content potential[53]. Ethanolic extracts of *O. triangularis* (200 µg/mL) demonstrated significant phenolic content and antioxidant capacity[38]. *O. erythrorhiza* infusion and methanolic extracts have shown strong efficacy through reduction of lipid peroxidation and DPPH scavenging capacity[56]. *O. debilis* hydro-alcoholic extract decreased oxidative stress in rats with significant rises in glutathione peroxidase and superoxide dismutase levels[16]. *O. latifolia* bioactive components were responsible for high DPPH and ABTS activity[13,66]. Likewise, *O. stricta*, methanolic extract demonstrated antioxidant potential, validated by phosphomolybdate and DPPH tests, which correlates with its promising phenolic content[63].

Oxalis corniculata, the most explored species within the *Oxalis* genus, has been shown to have

phytoconstituents like glycosides, polyphenols, flavonoids, etc., that support its antioxidant potential. In one study, polysaccharide from aqueous extracts was tested for *in-vitro* antioxidant potential by DPPH, ABTS, hydroxyl radical scavenging, DNA nicking assay, and H_2O_2-induced oxidative damage in the HEK 293 cell line, where dose-dependent activity was observed, DNA damage was protected, and no cytotoxicity was found. In the same study, *in-vivo* model thermal stress in *Caenorhabditis elegans* demonstrated decreased levels of SOD, CAT, GSH-Px and an increase in MDA and protein carbonyl, which suggests thermal tolerance by the treated group, and results support *in-vitro* H_2O_2 induced oxidative damage in HEK 293 cell line[67]. In another study, various extracts were tested for antioxidant potential using protocols of scavenging free radicals, authentic peroxynitrite, nitric oxide, reducing power and CCl_4 induced hepatotoxic rat model. The ethyl acetate fraction showed strong activity against all models and was concentration-dependent. In the peroxynitrite nitric oxide assay ethyl acetate fraction showed 3-fold stronger results compared to standard penicillamine. Methanolic extract decreased oxidative stress in rats with significant rises in glutathione, superoxide dismutase and catalase and lowering lipid peroxidation in CCl_4 induced hepatotoxic rat model[68]. In a similar study, methanolic extract and its subfractions demonstrated strong antioxidant potential compared to ascorbic acid[69]. Apart from methanol, ethanol, ethyl acetate, chloroform, n-butanol fractions also showed promising results[70-72]. Moreover, this suggests the *Oxalis* genus to be a strong candidate for antioxidant research. Various plant parts, extracts obtained and isolated compound has been studied, but a gap remains among the species and their activity as well.

5.2 Anti-diabetic Activity

Oxalis pes-caprae methanolic extract outperformed conventional acarbose in terms of *in-vitro* α-glucosidase and α-amylase inhibition. Treatment (150–250 mg/kg, 3 weeks) decreased fasting blood sugar in diabetic mice, which is similar to glibenclamide (10 mg/kg)[65]. As effective as metformin, *O. debilis* hydroalcoholic extract (250–500 mg/kg), reduced glucose in streptozotocin-induced diabetic rats[16]. Ethanolic extract from *O. latifolia* showed quick antihyperglycemic action, which is analogous to tolbutamide[12]. *O. cordata* leaf extracts were tested for their ability to inhibit lipase enzymes and DPP-4. The crude extract showed an IC_{50} of 0.84 mg/ml for pancreatic lipase inhibition, while no action was seen against DPP-4. The ethyl acetate and aqueous fractions also displayed stronger inhibition[58].

Oxalis corniculata ethanolic extract against standard glibenclamide showed dose-dependent activity, proving its potential[73]. In another study, aqueous extract also showed final body weight rectification and blood glucose level in STZ induced diabetic model compared to the untreated group[74]. These studies all together brings up the potential of *Oxalis* species as an antidiabetic candidate.

5.3 Anti-inflammatory Activity

Several *Oxalis* species have been demonstrated to exhibit anti-inflammatory properties. Aqueous extract of *O. pes-caprae* did not decrease NO production in macrophages, indicating potential immunostimulatory rather than anti-inflammatory action[75]. An egg albumin denaturation test revealed that *O. triangularis* ethanolic extract was moderately effective (IC_{50}: 8.48), marginally less efficient than diclofenac sodium[76]. *O. erythrorhiza* decoction demonstrated significant COX-2 inhibition, but ethanolic extract demonstrated minimal action[56]. *O. debilis* hydroalcoholic extract showed strong anti-inflammatory effects in the carrageenan-induced paw oedema model, with inhibition comparable to indomethacin (68.68%)[77].

Oxalis corniculata methanolic fraction demonstrated significant reduction of paw inflammation and per cent of granuloma formation dose dependently against standard indomethacin in carrageenan-induced rat paw oedema and cotton pellet-induced granuloma formation model[71]. Ethanolic fraction demonstrated dose-dependent anti-inflammatory action in *in-vivo* acetic acid induced inflammatory bowel disease in rats, where sulfasalazine was employed as a standard[78]. Isolated β-sitosterol from the petroleum ether fraction demonstrated dose-dependent action reducing paw oedema in rats[50]. In another animal model, the ethanolic extract of acute peritonitis in mice showed anti-inflammatory action[79]. Overall, the anti-inflammatory properties of *Oxalis* species differ depending on the type of extract and model system, but it provides a potential option to explore and further research.

5.4 Antimicrobial Activity

Oxalis species have demonstrated promising antimicrobial properties. *O. pes-caprae* extracts in methanol and n-hexane showed promising inhibition zones against both Gram-positive and Gram-negative bacteria, demonstrating their antibacterial potential. On same study, compounds identified from plants were docked against the major protease (6LU7) of SARS-CoV-2.Strong binding affinities and hydrogen bonding interactions were demonstrated by compounds Vadimezan, Caeruleanone A, Matairesinol, and 20,40-Dihydroxy-200-(1-hydroxy-1-methylethyl) dihydrofuro[2,3-h]flavanone, indicating their potential as SARS-CoV-2 inhibitors, which support *O. pes-caprae* as an antiviral candidate as well[51]. *O. erythrorhiza* hexane and dichloromethane fractions demonstrated fungal growth inhibition, particularly the DCM fraction, which was more active against methicillin-resistant and methicillin-sensitive *S. aureus*. Isolated metabolite, embelin, for the species has also demonstrated efficacy against *T. rubrum* and *E. coli*[80,81]. Aqueous fractions of *O. acetosella* and *O. triangularis* have also demonstrated broad-spectrum antibacterial properties against *S. aureus*, *S. typhimurium*, *B. cereus*, *P. aeruginosa*, and *E. coli*, respectively[82,83]. *O. griffithii* methanolic extract silver nanoparticles demonstrated promising inhibitory zones against *E. coli* and *B. subtilis*, comparable to standard chloramphenicol[84]. *O. latifolia* methanolic extract demonstrated dose-dependent suppression of *S. paratyphi*, *A. fumigatus*, *A. niger*, *B. subtilis*, and *E. coli*, with 90 µL exhibiting the highest level of inhibition[13]. *O. debilis* acetone extract has also demonstrated strong suppression of *S. aureus*, *P. aeruginosa*, and *Penicillium* spp. respectively[85]. *O. tetraphylla* hydroalcoholic and aqueous extract demonstrated ovicidal and larvicidal activities[61], whereas aqueous fraction showed promising ovicidal action compared to ethyl acetate fraction[62]. Similarly, the methanolic extract of *O. latifolia* demonstrated larvicidal efficiency against *Cx. quinquefasciatus*[66].

Oxalis corniculata ethanolic and methanolic extract showed promising anti-bacterial potential against *Xanthomonas* and fourteen human pathogenic bacteria, which were compared to K-cycline and Bact-805 for plant pathogens and Gentamicin and Streptomycin for human pathogens[86]. Dose-dependent suppression of *E. coli* and *S. aureus* was observed by the methanolic extract using the hole diffusion method[87]. Ethanolic extract at 1% concentration showed prominent antibacterial activity and anti-biofilm activity against *S. aureus*[88]. Similarly, many other studies have been carried out using different extracts, which showed promising antibacterial potential against pathogenic bacteria[23,44,89-91]. Overall, the anti-microbial properties of *Oxalis* species differ depending on the type of extract and model system, but it provides a potential option to explore and further research.

5.5 Hepatoprotective Activity

Oxalis debilis aqueous extract significantly reduced liver enzyme levels in rats treated with CCl_4, and the effect observed was equivalent to that of silymarin[77]. Similarly, *O. stricta* ethanolic extract reduced bilirubin, ALP, SGPT, and SGOT and increased antioxidant enzymes (CAT, GSH, and SOD) to protect against hepatotoxicity caused by paracetamol. According to histopathology results, liver protection was similar to silymarin[92].

Oxalis corniculata methanolic extract showed promising results compared to pet ether, chloroform and aqueous extracts. Reduced levels of biomarkers SGPT, SGOT and ALP validate the effects in rats which were hepatotoxically exposed to CCl_4[93]. In another study, aqueous and ethanolic extracts showed promising protection of the liver and led to a reduction of liver enzymes SGOT, SGPT, GGTP, ALP and bilirubin content. The result was comparable to that of the standard drug silymarin[94]. Overall, the hepatoprotective properties of *Oxalis* species differ depending on the type of extract and model system, but it provides a potential option to explore and further research.

5.6 Anticancer Activity

Oxalis species cytotoxic and antitumor properties have been widely documented. *O. pes-caprae* methanolic extracts from stems and flowers demonstrated strong cytotoxicity in brine shrimp lethality tests[51]. *O. erythrorhiza* decoction prevented tumour growth; however, its ethanolic extract was more cytotoxic, specifically inhibiting HCT-116 cells without damaging healthy cells[56]. Aqueous and ethanolic extracts of *O. latifolia* inhibited the growth of HT29 and MCF7 cells

in a dose-dependent manner, which is similar to that of tamoxifen and 5-fluorouracil. Even at doses as low as 12.5 µg/mL, activity persisted[95]. Additionally, HT29 cell inhibition was demonstrated by employing the methanolic extract[66].

Oxalis corniculata ethanolic extract showed cytotoxic potential in MCF7 cell line, where RT-PCR revealed the regulatory influence on pro-apoptotic marker genes (p53, bax and CD95) and anti-apoptotic gene (bcl-2), which led to apoptosis[96]. In another study, ethanolic extract showed significant antitumor potential marked by dose-dependent reduction in body weight, tumour volume, packed cell volume, tumour cell counts and increase in median survival time (MST) and percentage increase in life span in treated animals[97]. Similarly, the hydroalcoholic extract of the plant also showed potential dose-dependent growth inhibition against Hep-G2 cell line, and the outcomes were similar to those of doxorubicin[98]. *In silico* study on phytoconstituents identified from plants has shown promising anti-cancer potential targeting Programmed death-ligand, B-Raf proto-oncogene, serine/threonine kinase, and poly (ADP-ribose) polymerase, with effective binding energy[99]. Overall, the anticancer properties of *Oxalis* species differ depending on the type of extract and cancer type, but it provides a potential option to explore and further research.

5.7 Wound Healing Activity

An antibacterial gel made from *O. triangularis* extract significantly accelerated healing in a rat punch biopsy wound model, lowering infection risk, scarring, and wound expansion rate (WER). Additionally, the gel showed stability and non-irritating qualities, suggesting that it might be a cost-effective wound care treatment[76].

The petroleum ether and ethanol extracts of *O. corniculata*, when administered to rats in excision, incision and dead space wound methods, showed potential wound healing activity. The activity was evidenced by the ability of the extract to promote granulation tissue formation, collagen synthesis, and wound closure[100]. Overall, the wound healing properties of *Oxalis* species differ depending on the type of extract, but it provides a potential option to explore and further research.

5.8 Anti-melanogenic Activity

Oxalis triangularis-derived fatty acid alkyl esters showed antimelanogenic action in B16 melanoma cells. Tyrosinase activity was suppressed, and forskolin-induced melanin formation was decreased by methyl and ethyl linoleate/linolenate through a decrease in intracellular cAMP generation. These results show that cosmetic skin-lightening formulations may find application in this species[54].

5.9 Nephroprotective Activity

An aqueous extract and its $AgNO_3$ nanoparticles prepared from *O. corniculata* effectively suppressed the growth of struvite stones and led to the dissolution of stones grown in a gel medium by the *in vitro* single diffusion gel growth technique[101].

5.10 Analgesic and Antipyretic Activity

The ethanolic extract obtained from *O. corniculata* showed remarkable reduction of writhing in acetic acid induced writhing model in rats and reduction of pyrexia in Brewer's yeast-induced pyrexia model, at dose dependent manner, which was comparable to the action of the standard drug aspirin[102].

5.11 Anxiolytic Activity

Oxalis corniculata ethanolic extract showed anxiolytic activity evidenced by improved locomotor activity in the open field test, open and free entry in the elevated plus maze test and reduced fighting in the anti-fighting test[103].

5.12 Cardioprotective Activity

Oxalis corniculata aqueous extract showed normal myocardial fibres with mild inflammatory changes in histopathological analysis of cardiac tissues after treatment with the extract. It also revealed a protective effect against isoproterenol-induced myocardial infarction model in rats with a decrease in CPK, LDH, serum total cholesterol, LDL cholesterol, triglycerides and lipogenic enzyme levels[104].

5.13 Antiimplantation and Abortifacient Activities

Though the entire treated group showed promising activity, petroleum ether extracts of *O. corniculata* at a

Table 4. Pharmacological activities of *Oxalis* species

Species	Extract Type	Model/Assay	Outcome (IC_{50}/EC_{50}/LD_{50}/ MIC, % Inhibition, etc.)	Positive Control	References
O. acetosella	Methanol	DPPH, ABTS	Antioxidant activity comparable to spinach; phenolics: 15,922–23,481 µg GAE/g dwt	-	53
	Aqueous	Antibacterial	Zones: 7–8 mm	-	82
O. cordata	Crude, ethyl acetate, aqueous	Lipase, DPP-4 inhibition	Lipase inhibition IC_{50}: 0.84–0.63 mg/mL; no DPP-4 activity	-	58
O. corniculata	Methanol, DCM, ethyl acetate, n-butanol, aqueous	DPPH, ABTS, nitric oxide, peroxynitrite, reducing power	Dose dependent	Penicillamine	68
	Methanol	DPPH	Dose dependent	Ascorbic acid	69
	Polysaccharide from aqueous	DPPH, ABTS, hydroxyl radical scavenging, DNA nicking assay, and H_2O_2-induced oxidative damage in HEK 293 cell line; *In-vivo* model thermal stress in *Caenorhabditis elegans*	Dose-dependent, DNA damage was protected, and no cytotoxicity was found. Decrease in levels of SOD, CAT, GSH-Px and increase in levels of MDA and protein carbonyl	-	67
	Methanol, DCM, ethyl acetate, n-butanol, aqueous	CCl_4 hepatotoxic model	Increase in activity of glutathione, superoxide dismutase, catalase and decrease in lipid peroxidation	-	93
	Ethanol, ethyl acetate, chloroform, n-butanol, n-hexane	DPPH, Isoproterenol-induced oxidative stress model, CCl_4-induced hepatotoxic model in male rats,	Dose dependent, Decrease in levels of GSH, CAT, SOD, GSH-Px, GST, GSR, QR and increase in levels of TBARS, hepatic lesions	-	70-72
	Ethanol, Aqueous	STZ-diabetic rats	Dose-dependent decrease in glucose level	Glibenclamide	73,74
	Methanol, β-sitosterol	Carrageenan paw oedema	Dose-dependent decrease of paw oedema	Naloxone	50,71
	Ethanol	Acetic acid induced inflammatory bowel disease in rats	Dose-dependent anti-inflammatory action	Salfasalazine	78
	Ethanol	Acute peritonitis in mice	Dose-dependent anti-inflammatory action	-	79
	Ethanol, methanol	*Xanthomonas* and fourteen human pathogenic bacteria	Dose dependent	K-cycline, Bact-805, Gentamicin, Streptomycin	86
	Methanol	*S. aureus* and *E. Coli*	Dose dependent	-	87
	Ethanol	Biofilm eradication assay	76.23±0.01% at 1% w/v	Chloramphenicol	88

Table 4. Continued...

Species	Extract Type	Model/Assay	Outcome (IC_{50}/EC_{50}/LD_{50}/ MIC, % Inhibition, etc.)	Positive Control	References
	Ethanol, methanol, chloroform	Agar disk diffusion assay	Dose dependent	Erythromycin, Nalidixic acid	89
	Methanol, n-Hexane, n-Butanol, chloroform, water	Agar well diffusion assay	Dose dependent	-	23,44,90,91
	Pet. ether, Chloroform, Methanol, aqueous	CCl_4 hepatotoxicity	Decrease in levels of SGPT, SGOT and ALP	Liv-52	93
	Aqueous, ethanol	Thioacetamide-induced hepatotoxicity	At 400 mg/kg; decrease in levels of SGPT, SGOT, GGTP, ALP and total bilirubin	Silymarin	94
	Ethanol	MTT assay (MCF7)	619.2 µg/µl; increase in p53, CD95 expression and decrease in bcl-2 expression	-	96
	Ethanol	Ehrlich ascites carcinoma	Dose-dependent reduction in body weight, tumour volume, packed cell volume, tumour cell counts and increase in median survival time (MST) and percentage increase in life span in the treated group.	Cyclophospha-mide	97
	Hydroalcololic	MTT assay (Hep-G2)	Dose-dependent growth inhibition	Doxorubicin	98
	Isolated compound	*In silico* approach	Acacetin and luteolin proved to be potential candidates among selected compounds	Doxorubicin, paclitaxel, and curcumin	99
	Petroleum ether, Ethanol	Excision, incision and dead space wound method in rats	Wound healing was observed in the doses of 300 and 500 mg/kg	2% Tween 80	100
	Aqueous extract and its bio-fabricated AgNPs	Struvite kidney stones, grown in a gel medium by the *in-vitro* single diffusion gel growth technique.	A decrease in the growth of struvite stones led to the dissolution of the stones.	-	101
	Ethanol	Acetic acid induced writhing method and Brewer's yeast induced pyrexia	Decrease in the number of writhing and pyrexia at 200 mg/kg and 400 mg/kg doses.	Aspirin	102
	Ethanol	Open field test, elevated plus maze test and anti-fighting test	Improved locomotor activity, open and free entry movement, and reduced fighting	Diazepam	103

Table 4. Continued...

Species	Extract Type	Model/Assay	Outcome (IC_{50}/EC_{50}/LD_{50}/ MIC, % Inhibition, etc.)	Positive Control	References
	Aqueous	Isoproterenol induced myocardial infarction in rats	Decrease in levels of CPK, LDH, serum total cholesterol, LDL cholesterol, triglycerides and lipogenic enzyme	-	104
	Petroleum ether, ethanol	Anti-implantation and abortifacient activities	Petroleum ether extract at a 100 mg/kg dose resulted in complete pregnancy inhibition	-	105
O. debilis	Hydroalcoholic	Rat oxidative stress model	Reduced oxidative stress; decrease in SOD and GPx levels	-	16
	Hydroalcoholic	STZ-diabetic rats	Decrease in glucose levels: 100.5 ± 14.9 (250 mg/kg), 78.8 ± 9.7 (500 mg/kg)	Metformin	16
	Hydroalcoholic	Carrageenan-induced paw oedema	Inhibition: 46.9–64.8% (200–800 mg/kg)	Indomethacin	77
	Acetone	Antimicrobial	Zone: 21 mm (*S. aureus*), 16 mm (*Penicillium*); MIC: 19 µg/mL	-	85
	Aqueous	CCl_4 hepatotoxicity	Dose-dependent hepatoprotection (200–400 mg/kg); comparable to silymarin	Silymarin	77
O. erythrorhiza	Infusion, methanol	Lipid peroxidation, DPPH	81–83% inhibition (250 µg/mL); EC_{50}: 62–70 µg/mL	-	56
	Decoction	COX-2 inhibition	86.97% inhibition (72 µg/mL)	-	56
	Hexane, DCM	Antifungal, antibacterial	MIC: 25–1000 µg/mL (*S. aureus*); emblemin active *vs. E. coli*, *T. rubrum*	-	80,81
	Decoction, ethanol	Cytotoxicity (HCT-116)	Dm = 0.0015; selective tumor inhibition	-	56
O. griffithii	AgNP (methanol-mediated)	Antibacterial	Inhibition zones: 10 mm (*E. coli*), 8 mm (*B. subtilis*)	Chloramphenicol	84
O. latifolia	Ethanol	DPPH, ABTS	EC_{50}: 66.8 ± 1.02 µg/mL	-	13,66
	Ethanol	STZ-diabetic rats	Decrease in glucose level: ~334 → ~122 mg/dL (200–400 mg/kg, 3h)	Tolbutamide	12
	Methanol	Antimicrobial	Broad inhibition (*B. subtilis, A. niger, E. coli*)	-	13
	Methanol	Larvicidal (*Cx. quinquefasciatus*)	LC_{50}: 28.7 mg/L	-	66
	Aqueous, ethanol, methanol	MTT, trypan blue (HT29, MCF7)	ED_{50} ≈ 200 µg/mL; effective ≥12.5 µg/mL	5-FU, tamoxifen	66,95
O. pes-caprae	Ethyl acetate, *n*-butanol, methanol	DPPH, ABTS, antioxidant assays	Phenolic content: 8.46 ± 1.20 mg GAE/mg; strong scavenging activity	-	64,65

Table 4. Continued...

Species	Extract Type	Model/Assay	Outcome (IC_{50}/EC_{50}/LD_{50}/ MIC, % Inhibition, etc.)	Positive Control	References
	Methanol	α-Glucosidase, α-Amylase inhibition; diabetic mice	α-Glucosidase: 92.14% (890 µg/mL); α-Amylase: 67.9% (187.5 µg/mL); decrease in glucose level to ~200 mg/dL (150–250 mg/kg)	Acarbose, glibenclamide	65
	Methanol, *n*-hexane	Antibacterial	Inhibition zones: 13–24 mm	-	51
	In silico docking	SARS-CoV-2 Mpro (6LU7)	Vadimezan, Caeruleanone A, Matairesinol active	-	51
	Methanol	Brine shrimp lethality	LD_{50}: 19.7–26.5 µg/mL	-	51
O. tetraphylla	Hydroalcoholic fractions,	Anthelmintic (*H. contortus*)	LC_{50} larvae: 28.01 mg/mL; eggs: 0.213 mg/mL	-	61
	Aqueous	*In vivo* anthelmintic (lambs)	Decrease in faecal egg count 45.6% (20 mg/kg, 8 days)	-	62
O. triangularis	Ethanol	DPPH, ABTS	IC_{50}: 1151.7 ± 59.22 µg/mL; high phenolic content	-	38
	Ethanol	Egg albumin denaturation	IC_{50}: 8.48 (*vs.* diclofenac 7.6)	Diclofenac sodium	76
	Aqueous (acidified)	Antibacterial	Inhibition of *S. aureus, S. typhimurium, and E. coli*	-	83
	Gel formulation	Wound healing (rat model)	Accelerated healing, decrease in WER, and less scarring	-	76
	Isolated fatty acid esters	B16 melanoma (antimelanogenic)	Inhibited tyrosinase, decrease of melanin *via* cAMP reduction	-	54
O. stricta	Methanol	Phosphomolybdate, DPPH	Total phenols: 25.26 ± 1.02 mg GAE; IC_{50}: 205.1 µg/mL	-	63
	Ethanol	Paracetamol hepatotoxicity	Protection at 250–500 mg/kg; increase in levels of SOD, GSH, and CAT	Silymarin	92

100 mg/kg dose showed complete pregnancy inhibition compared to ethanolic extract[105].

6. Toxicology of *Oxalis* species

A sub-acute oral toxicity was conducted for the ethanolic extract of *O. pes-caprae* in female mice according to OECD guidelines 425. No signs of behavioural changes, body weight loss and death or toxicity-associated symptoms were observed following administration of 100-400 mg/kg body weight[106]. In another study, a report was made for acute and chronic poisoning cases caused by *O. pes-caprae*. Acute episode led to the death of 40 animal and pathological findings revealed rumen tympanis, inflammation of abomasums, intestinal bleeding and inflammation, liver ascites, pale and hemorrhagic kidneys, and mesenteric lymph node changes. Chronic episode led to 7 deaths and pathological findings revealed chronic interstitial glomerulonephritis, thickened Bowman's capsule, tubular atrophy, interstitial fibrosis, and signs of cachexia. The presence of oxalates in plants may be a reason for the toxicity[107]. *O. debilis* hydro-alcoholic extract was studied for acute toxicity studies in rats

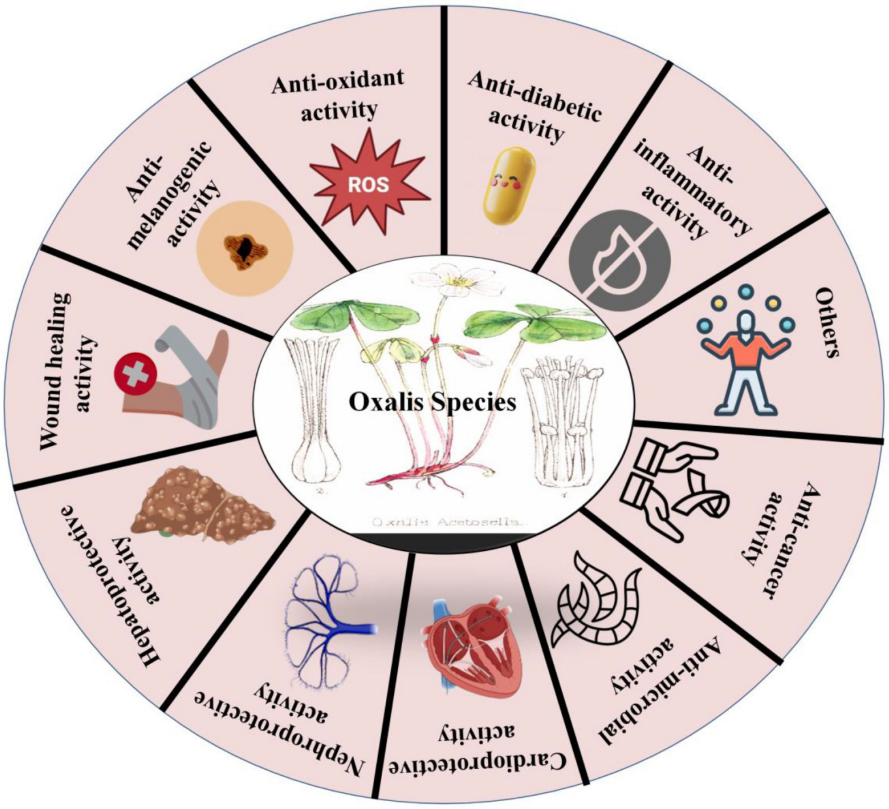


Figure 3a. *Oxalis* species wheel of pharmacological action. This overview image highlights the multi-targeted potential and therapeutic promise of *Oxalis* phytoconstituents by arranging the activities around a central hub.

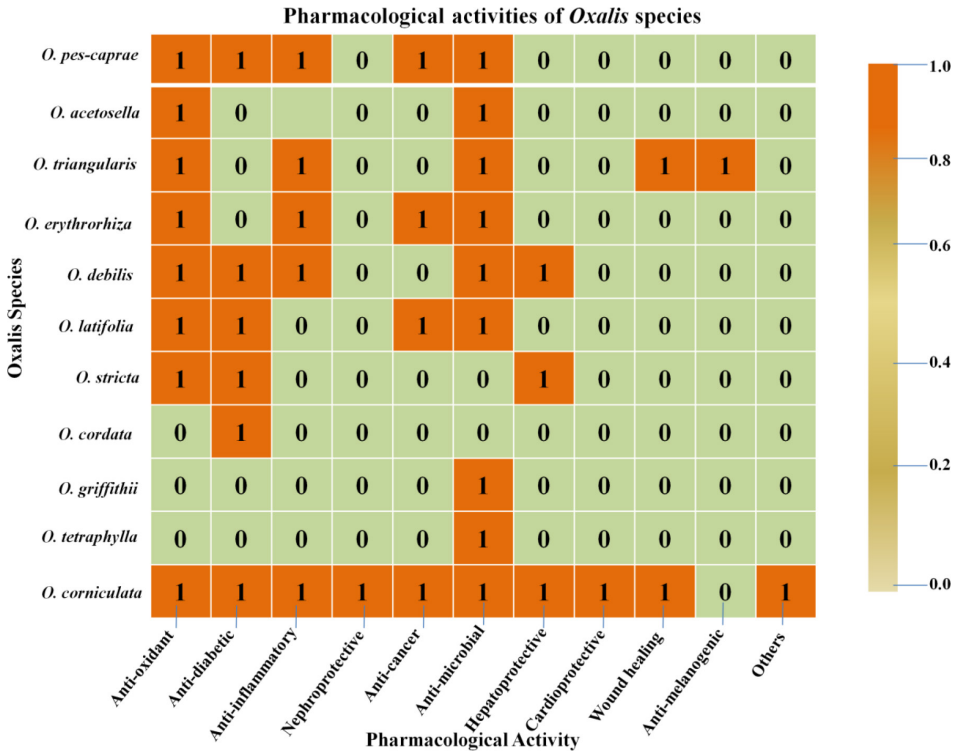


Figure 3b. A heat map that illustrates the *Oxalis* species pharmacological actions. Species are represented by rows and pharmacological activity by columns.

according to OECD guidelines 425, where no sign of toxicity and mortality was observed at the dose of 5000 mg/kg body weight[108].

Oxalis corniculata methanolic extract was similarly studied for acute oral toxicity according to OECD guidelines 425, where no signs of toxicity, mortality and behavioural change were observed in mice. Doses up to 2000 mg/kg body weight were found safe[25,109]. In other studies, the ethanolic extract was studied for acute toxicity according to OECD guidelines 423 and 425. At the dose of 2000 mg/kg body weight animal survived and no signs of toxicity was observed[110].

7. Conclusion

Since antiquity, medicinal plants have been utilised actively for managing, treating, and preventing illnesses. Many species of the genus *Oxalis* are used by traditional healers to treat a variety of illnesses, from infections and inflammatory problems to digestive issues, demonstrating the genus's considerable ethnopharmacological potential. Many of these traditional claims are supported by contemporary pharmacological research, which attributes the bioactivity to a variety of secondary metabolites, such as alkaloids, terpenoids, coumarins, flavonoids, and phenolic acids. The current understanding of the phytochemistry and pharmacological properties of *Oxalis* species is compiled in this article. Although the data points to the genus's significant medicinal promise, it also shows important research gaps. In terms of chemical profiling, mechanism-based pharmacology, and clinical validation, certain species—like *O. corniculata*, *O. pes-caprae*, and *O. latifolia*—have been well investigated, whereas others exhibit barely any.

Although the literature offers insightful information, a number of limitations weaken the quality of the available data. The heterogeneity of experimental approaches is one of the major issues. It is challenging to generate standardised pharmacological profiles and compare results across research because of variations in extraction solvents, assay procedures, and bioactivity models. Furthermore, the majority of phytochemical studies focus on qualitative screening, with little use made of quantitative profiling and sophisticated characterisation utilising modern techniques like LC-MS/MS, NMR, and metabolomics.

Oxalis species have anti-inflammatory, anti-microbial, anti-diabetic, anti-oxidant, and anti-cancer properties that are often highlighted in pharmacological research. These results, however, are mostly restricted to early *in-vivo* studies and *in-vitro* tests. Because there aren't many studies examining molecular pathways or signalling cascades, mechanistic insights are frequently lacking. The conversion of encouraging preclinical findings into clinically useful applications is hampered by this gap. The absence of a methodical toxicological assessment is another drawback. Comprehensive safety studies, which include dosage standardisation, chronic toxicity, and pharmacokinetic evaluations, are rarely carried out, despite the medicinal potential. This persists as a serious obstacle to the advancement of formulations based on *Oxalis*.

Additionally, contemporary methods like network pharmacology, molecular docking, and omics-based integration have been shown to reveal new processes and synergistic interactions; they have hardly ever been used on *Oxalis*. In a similar vein, sophisticated drug delivery methods, such as nanoformulations, have the potential to greatly increase the bioavailability of phytoconstituents but remain mostly unexplored. Overall, the existing research shows *Oxalis's* therapeutic potential, but it is still incomplete and fragmented. To fully unlock this genus's pharmacological potential, it will be imperative to address methodological deficiencies, improve mechanistic investigations, and integrate contemporary research methods. Future studies are supposed to focus on: i) Thorough phytochemical analysis to find new beneficial chemicals utilizing sophisticated analytical methods; ii) Research using mechanistic pharmacology to clarify molecular targets and action mechanisms; iii) Toxicological evaluation to establish acceptable dose limits; iv) Standardization of extracts is necessary to guarantee repeatability in clinical and laboratory research; v) Clinical studies that are carefully planned to convert preclinical results into medicinal uses.

Filling up these gaps will help integrate *Oxalis* species into evidence-based phytotherapy and contemporary drug discovery pipelines, as well as confirm their ethnomedicinal significance. Through well-coordinated, interdisciplinary research, the *Oxalis* genus may produce new, safe, and efficient treatments for a range of illnesses.

8. References

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Author Contribution

S.S.: Writing – Original Draft, Visualisation, Investigation, Data Curation, Conceptualisation; N. R.B.: Writing – Review And Editing, Supervision, Investigation, Formal Analysis, Data Curation, Conceptualisation; J.P.M.: Writing – Review and Editing, Formal Analysis. R.K.R.: Writing – Review and Editing, Supervision. All authors have read and agreed to the published version of the manuscript.