Phyto-Pharmacological Studies on Genus *Oxalis* L. in India: A Comprehensive Review

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ABSTRACT

The family Oxalidaceae, comprising around five genera and 565 species, is predominantly found in tropical and subtropical regions, with species distributed globally, including temperate zones. The genus *Oxalis* includes about 500 species, most of which are native to South Africa and South America. These species are typically herbs, with some being woody, and exhibit a range of habitat adaptations, growing from sea level to altitudes over 3700 meters. In India, *Oxalis* comprises 10 species, including *O. acetosella* L., *O. corniculata* L., *O. pes-caprae* L., *O. debilis* Kunth. and others. Historically, *Oxalis* was placed in the family Geraniaceae in works such as the Flora of the Presidency of Madras and the Flora of British India. This review focuses on the phytochemical properties of seven common *Oxalis* species found in India (*O. corniculata* L., *O. acetosella* L., *O. pes-caprae* L., *O. latifolia* Kunth., *O. tetraphylla* Cav., *O. triangularis* A.St.-Hil. and *O. debilis* Kunth.), highlighting their bioactive compounds with potential medicinal applications. The species are known for their anti-inflammatory, antioxidant and antimicrobial properties, supporting their use in traditional medicine. The present analysis primarily focused on an overview of the phytochemistry and pharmacognosy of selected *Oxalis* spp. to understand their therapeutic potential.

Keywords: *Oxalis* spp., Oxalidaceae, India, Phytochemistry, Pharmacology.

INTRODUCTION

Oxalidaceae R.Br. is a small-sized family comprising about 5 genera and 565 species (Mabberley, 2008; 2017) distributed mainly in the tropics and subtropics of both hemispheres but extending into temperate regions (Lourteig, 2000) and most of which are found in South Africa and South America (Lourteig, 1994; Huang *et al.*, 1998). Members of *Oxalis* are herbs, rarely woody. Leaves radical or cauline, usually digitate, 3- to many-foliate. 1-many flowered axillary peduncles, usually umbellate, regular, and pentamerous. Disk without glands. Stamens 10, filaments free or united at the base. Ovary of 5, one or many ovulated cells. Capsule loculicidal. Seeds with an outer fleshy coat burst elastically.

Genus *Oxalis* was treated under family Geraniaceae in Flora of Presidency of Madras (Gamble, 1915) and Flora of British India (Hooker, 1883). In India, the genus is represented by 10 species, viz., *O. acetosella L. and O. cernua* Thunb. (now *O. pes-capare* L.), *O. corniculata* L., *O. corymbosa* DC. (now *O. debilis* var. *corymbosa* (DC.) Lourteig.), *O. dehradunensis* Raiz., *O. deppei* Lodd. (now *O. tetraphylla* Cav.), *O. griffithi* Edgew & Hook. f., *O. lasiandra* Zucc., *O. pubescens* H. B. K. (now *O. spiralis* Ruiz & Pav. ex G. Don.) and *O. variabilis* Jacq. (now *O. purpurea* L.) (Manna *et al.*, 1997).

The phytochemistry of *Oxalis* is important as it reveals bioactive compounds with potential medicinal properties, including anti-inflammatory, antioxidant and antimicrobial properties. The present review provides an in-depth analysis of the phytochemistry and pharmacognosy of seven common *Oxalis* species found in India: *O.*

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corniculata L., *O. acetosella* L., *O. pes-caprae* L. and *O. latifolia* Kunth. *O. tetraphylla* Cav. *O. triangularis* A. St.-Hil. and *O. debilis* Kunth. (Fig. 1 & Table-1).

Fig 1: *Oxalis* species common in India

This type of review may help to identify novel bioactive compounds having therapeutic potential. It also helps to compile and evaluate existing scientific evidence, guiding future research and drug development. It also helps to validate traditional uses of plants which helps to lead plant- based medicines.

METHODOLOGY

The data used in this study were systematically gathered from several reputable scientific databases, including Scopus, ScienceDirect, Springer, Web of Science, and Google Scholar. Relevant studies were identified and selected based on their titles, keywords, and abstracts. A total of over 84 references were consulted, comprising original research articles, review papers, books, and book chapters. To maintain the quality and relevance of the information, strict inclusion and exclusion criteria were implemented. Only peer-reviewed publications indexed in well-recognized databases were considered.

Phytochemical properties of *Oxalis corniculata* L.

Oxalis corniculata L., commonly called 'wood sorrel', is an herbaceous plant that typically thrives in moist and shaded areas. It is widely distributed in Asia, Europe, America and Africa. According to Kirtikar & Basu (1975), the plant is well known for its medicinal properties to serve as an effective appetite stimulant, and it also helps to alleviate the conditions related to kapha, vata and piles. The extracts of aerial parts, which are used for treating stomach aches, *Datura* poisoning, Scorpion sting and wound bleeding, are also reported (Muhammad & Mir, 2000). The roots are used to treat worms, diarrhoea, dysentery, and giddiness. Leaves are used for the treatment of fever, coughs, colds, mouth ulcers, eczema, headache, stomach ache, expulsion of gastrointestinal worms, jaundice, and hepatitis (Unni *et al*., 2009). Crushed fresh leaves are also used treat eczema (Saikia *et al*., 2006).

Phytochemical analysis of *O. corniculata* plant extracts in different solvents like methanol, ethanol, n-hexane and water indicated the presence of alkaloids, phenols, flavonoids, terpenoids, tannins, saponins, glycosides, ascorbic acid, sterols, inorganic acids, carbohydrates, reducing sugar and proteins. Studies have also identified the presence of essential elements, including carbon, nitrogen, phosphorus, potassium, sodium, calcium,

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magnesium, and sulfur, in this extract. (Kumar *et al*., 2012; Aruna *et al*., 2014; Panda *et al*., 2016; Kaur *et al*., 2017; Siddiqui *et al*., 2017; Sohail *et al*., 2019; Pawar *et al*., 2023; Wadankar & Wagh, 2023).

Pharmacological activities of *Oxalis corniculata* L. (Fig 2)

Antibacterial activity

The aqueous extract of the plant has antibacterial activity against the human pathogen E. coli and showed good inhibition zones (60mm) (Unni *et al*., 2009).

Antibacterial activity against three significant pathovars of phytopathogenic bacteria from the *Xanthomonas* genus and fourteen human pathogenic bacteria was assessed using the cup diffusion method on nutrient agar. The results indicated that methanol and ethanol extracts demonstrated notable effectiveness against both phytopathogenic and human pathogenic bacteria, with inhibition zones ranging from 14 to 27 mm. Extracts from other solvents, such as petroleum ether, benzene, and chloroform, did not produce any significant zone of inhibition compared to the control. The methanol extract exhibited highly significant activity against plant pathogenic bacteria when compared to K-cycline and Bact-805. For human pathogenic bacteria, the methanol extract showed moderately significant antibacterial activity compared with Streptomycin (Raghvendra *et al*., 2006).

Aqueous extracts of the leaves were tested for in vitro antibacterial activity against 14 significant human pathogenic bacteria using the cup diffusion method. The study showed that it is effective against 12 human pathogenic bacteria, including *Citrobacter* sp., *Escherichia coli*, *Klebsiella* sp., *Pseudomonas aeruginosa*, *Salmonella typhi*, *Salmonella typhimurium*, *Salmonella paratyphi* A, *Salmonella paratyphi* B, *Shigella boydii*, *Shigella flexneri*, *Staphylococcus aureus* and *Streptococcus faecalis*. However, no activity was observed against *Shigella sonnei* and *Proteus mirabilis* (Satish *et al*., 2008).

The aqueous extract of *O. corniculata* was effective against *S. aureus* and *E. coli*, with greater activity observed at higher concentrations. The maximum antibacterial activity of the plant at a 20% concentration was 21mm against *S. aureus* and 19.33mm against *E. coli* (Handali *et al*., 2011).

Rehman *et al.* (2015) examined the the antibacterial activity of the whole plant, which was evaluated using crude, methanolic extract and fractions of n-hexane, chloroform, ethyl acetate and n-butanol. The study found that the crude extract, n-butanol and ethyl acetate soluble fractions exhibited excellent activity against *Escherichia coli*, *Salmonella typhi* and *Bacillus subtilis*. Additionally, the crude extract, n-hexane, chloroform, and n-butanol fractions were effective against *Shigella dysenteriae*, while no activity was observed in the ethyl acetate-soluble fraction, and there was no activity against *Staphylococcus aureus*.

Antibacterial activity of different ecotypes of 2 *Oxalis* species was examined by Panda *et al. (*2016) using *Bacillus subtilis* (MTCC 441), *Pseudomonas aeruginosa* (MTCC 2453), and *Streptococcus epidermidis* (MTCC 3322). The study revealed that the maximum growth inhibition activity (20mm, 10 mg/ml) was observed against *S. epidermidis;* against *B. subtilis, the activity* was 12 mm, and there was no antimicrobial activity against *P. aeruginosa. The* extracts of *O. corniculata* are most effective against bacterial growth and show dose-dependent inhibition.

The antibacterial activity of petroleum ether extracts of the plant was evaluated using gram-positive and gram-negative organisms, viz., *Staphylococcus aureus* and *Streptococcus sp., as reported* by Mohan & Pandaey (2015). *Staphylococcus aureus* showed a larger zone of inhibition (17mm) than *Streptococcus* (15.75mm).

The zone of inhibition of methanolic extracts from different parts of *O. corniculata* against *Pseudomonas aeruginosa* and *Rhodococcus fascians* was studied by Kaur *et al*. (2017). Leaves of *O. corniculata* have a higher antibacterial activity than any other parts for both the bacterial strains.

Aqueous, methanol, chloroform and hexane extracts were evaluated against standard gram-positive bacterial strains, including *Staphylococcus epidermidis* and *Bacillus cereus*, as well as gram-negative strains such as *Enterobacter aerogenes, Pseudomonas aeruginosa, Salmonella typhimurium, Klebsiella pneumonia* and

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Escherichia coli, using the agar well diffusion method. The results indicated that the aqueous and methanol extracts exhibited broad-spectrum activity, effectively inhibiting the growth of both gram-positive and gram-negative bacterial strains. Bacterial growth exhibited dose-dependent inhibition. The diameters of the zones of inhibition for the aqueous and methanol extracts were comparable to those of the tetracycline disc against the pathogenic bacterial strains. The aqueous extract showed inhibition zones of 20 mm, 20 mm, and 21 mm against the gram-negative bacteria *Enterobacter aerogenes, Klebsiella pneumonia* and *Escherichia coli*, respectively, which were larger than the zones measured with tetracycline (14 mm, 19 mm, and 16 mm). The methanol extract produced inhibition zones of 21 mm, 17 mm, 15 mm, and 16 mm against *Enterobacter aerogenes, Klebsiella pneumonia, Escherichia coli* and *Bacillus cereus*, respectively, which were also similar to those of the tetracycline disc (14 mm, 19 mm, 16 mm, and 16 mm). In contrast, chloroform and hexane extracts showed minimal to negligible antibacterial activity. (Siddiqui *et al.,* 2017).

Aqueous and alcohol extracts of the *O. corniculata* showed very little antibacterial activity against three important bacteria, *E. coli, Salmonella typhi*and *S. aureus,* with a zone of inhibition ranging from 2-4 mm (Pawar *et al*., 2023).

Rather *et al.* (2023) investigated the antibacterial activities of 20 ethnomedicinal plants against various gram-positive bacteria (*Bacillus cereus, Bacillus subtilis, Listeria monocytogenes, Mycobacterium smegmatis* and *Staphylococcus aureus*) and gram-negative bacteria (*Escherichia coli, Klebsiella pneumonia, Pseudomonas aeruginosa, Pseudomonas diminuta, Salmonella typhimurium* and *Yersinia enterocolitica*). They found that the zone of inhibition for gram-positive bacteria ranged from 11 to 23 mm, with the largest zone (23 mm) observed for *Oxalis corniculata* against *S. aureus*. For gram-negative bacteria, the inhibition zones varied between 10 and 22 mm, with a maximum of 22 mm noted for *O. corniculata* against *P. aeruginosa* and *S. typhimurium*. The study concluded that all tested bacterial strains were susceptible to *Oxalis corniculata.*

Anti-tumour activity

The ethanolic extract of *O. corniculata* showed efficacy in suppressing tumor growth in both ascitic and solid tumor models. Its anticancer effects were assessed in Swiss albino mice with Ehrlich ascites carcinoma. Treatment resulted in a dose-dependent decrease in body weight, tumor volume, packed cell volume, and tumor cell counts, as well as an increase in median survival time (MST) and the percentage of animals with increased lifespan in the treated animals. It is also observed that there is a significant increase in RBC count, Hb content, and a reduction in total WBC count (Kathiriya *et al.,* 2010).

Anti-oxidant activity

The ethanolic extract of *O. corniculata* was studied for its antioxidant properties in Swiss albino mice with Ehrlich ascites carcinoma (EAC). The EAC control group showed a significant decrease in catalase (CAT) and glutathione (GSH) levels ($p < 0.01$), along with a significant increase in malondialdehyde (MDA) levels ($p < 0.01$) compared to normal animals. Administration of the ethanol extract at doses of 100 and 400 mg/kg significantly normalized CAT levels ($p < 0.05$ and $p < 0.01$, respectively), increased GSH levels ($p < 0.05$ and $p < 0.01$, respectively), and provided significant protection against lipid peroxidation ($p < 0.01$) compared to the EAC control group. Additionally, biochemical parameters, including SGOT, SGPT, and ALP, were significantly elevated ($p < 0.01$) in the EAC control group compared with the normal group. Treatment with ethanolic extract at doses of 100 and 400 mg/kg, and the standard drug cyclophosphamide at 25 mg/kg, significantly ($p < 0.01$) decreased SGOT, SGPT and ALP compared with EAC control groups (Kathiriya *et al*., 2010).

Rats with hyperlipidemia were treated with ethanolic extracts of *O. corniculata* leaves at a dose of 500 mg/kg body weight. By the end of the experimental period, hyperlipidemic rats exhibited a significant increase in plasma malondialdehyde (MDA) levels ($p < 0.05$) and a significant decrease in erythrocyte catalase (CAT) and superoxide dismutase (SOD) levels ($p < 0.05$) compared to the normal control group. After the treatment, MDA (40.55%) in serum decreased, and CAT and SOD activity increased significantly (Tassa *et al*., 2012).

The methanol extract of the whole plant was evaluated for its antioxidant activity using in vitro methods, including DPPH and nitric oxide radical scavenging assays. Lipid peroxidation inhibition was assessed using the thiobarbituric acid reactive substances (TBARS) method on isolated rat liver tissues. The results demonstrated significant DPPH and nitric oxide radical scavenging activities, with IC50 values of 302.93 ± 4.17 µg/ml and

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73.07 ± 8.28 µg/ml, respectively. Lipid peroxidation induced by the Fe2+ was inhibited by the extract with an IC50 value of 58.71±2.55µg/ml (Sakat *et al*., 2010).

The antioxidant capacity of extracts in various polar and non-polar solvents was evaluated in rats using in vitro assays that measured DPPH and ABTS radical scavenging potential. Results indicated that polar solvents, such as methanol and aqueous extracts, have higher IC50 values as compared to the non-polar solvents. Free radicals were scavenged by the extract/fraction in a dose-dependent manner across all models (Khan *et al*., 2012).

Diabetic rats showed decreased GSH, SOD, and Catalase activity and increased MDA and Plasma nitrite levels after 8 weeks of STZ injection. Treatment with the ethanolic extract at 400 mg/kg increased reduced glutathione (GSH) levels. After four weeks of treatment, there was a notable increase in superoxide dismutase (SOD) activity and a decrease in malondialdehyde (MDA) levels. Treatment with extracts at 200 mg kg' and 400 mg kg-' significantly inhibited the decrease in catalase activity and the significant reduction in plasma nitrite levels in a dose-dependent manner (Kumar *et al*., 2012).

Antifungal activity

The water extracts were tested for their antifungal activity against several plant pathogenic fungi, including *Aspergillus niger, Rhizoctoni asolani, Botryodiplodia theobromae* and *Pestalotiopsis theae*. Three days after incubation, the extract was very effective against *A. niger*. It was moderately active against *R. solani* and *P. theae* and showed less effectiveness against *B. Theobromae* (Iqbal *et al.*, 2001).

The antifungal activity of the petroleum ether extracts was assessed using the agar well diffusion method with two *Aspergillus* species *A. niger* and *A. flavus*. Crude extract produced a zone of inhibition of 15mm and 21 mm against *A. niger* and *A. flavus*, respectively (Mohan & Pandey, 2015)

The crude and n-hexane fractions showed significant activity against fungal strains, including *Fusarium solani* and *Aspergillus flexneri*. The crude extract, along with the chloroform- and ethyl acetate-soluble fractions, demonstrated activity against *Aspergillus flavus.* The n-butanol soluble fraction was only active against *Aspergillus flexneri*; ethyl acetate was only active against *Aspergillus flavus*; also, chloroform, ethyl acetate, and n-butanol soluble fractions were inactive against *Fusarium solani* and *Aspergillus niger* (Rehman *et al*., 2015).

Anti-protozoa activity

Bioactivity profiling of *O. corniculata* extracts revealed several compounds that exhibited anti-amoebic activity in axenic cultures of *E. histolytica.* The introduction of galactoglycerolipid (GGL), a compound isolated from *O. corniculata*, into xenic cultures of *E. histolytica* containing other microbial flora from the large intestine did not affect its anti-amoebic activity. Additionally, amoebicidal concentrations of GGL did not affect the intestinal microbial flora or the mammalian cell line HEK-293. GGL was also found to be equally effective against another protist pathogen, *Giardia lamblia,* which causes diarrhea in humans. Cells treated with GGL exhibited complete loss of viability within 48 hours, accompanied by aggregation and lysis. The standard anti-amoebic drug, metronidazole, showed the expected loss of viability after 48 h (Manna *et al*., 2010).

Anti-helminthic activity

An in vitro comparative study assessed the anthelmintic activity of petroleum ether, ethyl acetate, and methanol extracts of the whole plant against *Eisenia foetida* at three different concentrations (Dighe *et al.,* 2012). The methanolic extract of *O. corniculata* demonstrated the strongest anthelmintic activity, with paralysis and death times recorded at 11.33 and 41.33 minutes, respectively. In contrast, the petroleum ether and ethyl acetate extracts exhibited lower anthelmintic activity than the methanolic extract. Each extract, at various doses, caused dose-dependent paralysis that ranged from loss of motility to loss of response to external stimuli, ultimately leading to death.

Wound healing activity

The alcohol and petroleum ether extract of the entire plant were evaluated for their wound healing properties using excision, incision, and dead space wound models in animals. The extracts, administered at doses of 300 and 500 mg/kg body weight, demonstrated notable wound healing effects by enhancing the rate of wound

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contraction, increasing tensile strength, and significantly reducing the epithelization period. The percentage closure of the excision wound area, the time required in days for complete epithelization of the excision wound, and the scar area in mm at complete epithelization were significantly decreased in both alcohol- and petroleum ether extract-treated groups at both doses studied, compared with the control (Taranalli *et al*., 2004).

Anti-inflammatory Activity

The methanol extract of the whole plant was tested for its anti-inflammatory activity using in vitro methods. This evaluation included the albumin denaturation assay, membrane stabilization assay, and proteinase inhibitory activity at various concentrations, with aspirin serving as the standard drug. The experiments demonstrated in vitro anti-inflammatory effects by inhibiting heat-induced albumin denaturation and stabilizing red blood cell membranes, with IC50 values of 288.04 ± 2.78 µg/ml and 467.14 ± 9.56 µg/ml, respectively. Proteinase activity was also significantly inhibited by the extract (IC50=435.28±5.82µg/ml) (Sakat *et al.*, 2010).

Dighe *et al*. (2016) investigated the anti-inflammatory activity of the plant's leaves using the carrageenan-induced paw edema method. The petroleum ether, chloroform, and ethyl acetate extracts showed significant inhibition of paw edema compared to the control. The petroleum ether extract was selected for activity-guided fractionation to isolate β-sitosterol due to its superior efficacy compared to the other extracts. Analgesic activity was assessed using the hot plate test and acetic acid-induced writhing test. In the hot plate test, the petroleum ether extract exhibited the highest activity with a reaction time of 8.4 ± 0.4 seconds after 60 minutes, while the isolated β-sitosterol at a dose of 20 mg/kg showed a reaction time of 11.1 ± 0.3 seconds after 90 minutes. The petroleum ether extract and β-sitosterol (20 mg/kg) resulted in 43.14 ± 1.9 and 34.21 ± 1.4 writhings, respectively. Additionally, the isolated β-sitosterol (20 mg/kg) reduced rat paw edema to 0.32 ± 0.06 ml after 120 minutes. Dighe *et al.* (2016) concluded that isolated β-sitosterol is responsible for both analgesic and anti-inflammatory activities.

Anti-ulcer activity

Sakat, *et al.* (2012) investigated the antiulcer activity of a methanol extract using pylorus ligation and indomethacin-induced gastric ulceration in Wistar rats. In the pylorus ligation model, parameters such as gastric volume, pH, total acidity, and free acidity were measured, while the number of ulcers, ulcer scores, and ulcer index were assessed in both pylorus-ligated and indomethacin-treated rats. Pre-treatment with the test extract significantly reduced gastric volume, total acidity, and free acidity, while increasing the pH of gastric fluid in the pylorus-ligated rats. Additionally, it led to a notable decrease in the number of ulcers, ulcer scores, and ulcer index in the pylorus-ligated and indomethacin-treated rats.

Aqueous and ethanolic extracts of the plants, administered at doses of 200 and 400 mg/kg, were assessed for their anti-ulcer properties. This evaluation involved using ethanol-induced gastric mucosal ulcers and pylorus-ligated ulcers. Treatment with the extracts resulted in a significant decrease in gastric volume and reductions in free and total acidity. Additionally, levels of catalase and superoxide dismutase (SOD) increased, while lipid peroxidation decreased in both extracts (Mahadik *et al*., 2011).

Anti-Nematode activity

Ethanolic and aqueous extract of *O. corniculata* was tested to develop biological control methods effective against the root-knot nematode *Meloidogyne incognita*. The dried plant extracts have shown stronger activity, with 90% immobilization (Taba *et al.,* 2008).

Anti-diarrhoeal activity

Oral pre-treatment of rats with aqueous and methanolic extracts demonstrated significant anti-diarrheal potential, significantly increasing the latency of castor oil-induced diarrhea ($p < 0.05$) and reducing both the frequency of defecation and the total number of watery stools compared to untreated control rats. At all doses, the aqueous extract (160 mg/kg) was more effective than the methanolic extract. Both extracts also reduced the propulsion of charcoal meal through the small intestine, with the aqueous extract inhibiting it by 22.79% and the methanolic extract by 19%. The effect of the standard drug loperamide reduced the inhibitory propulsion by 48.8%. The methanol extract showed a dose-dependent action on all parameters (Watcho *et al.,* 2005).

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Cardio-protective activity

A dose-dependent study of the methanol extract (5 - 40 µg) demonstrated relaxant activity on isolated rabbit ileum and heart. In anesthetized rats, there was a temporary drop in blood pressure, with systolic blood pressure decreasing by 26% after the 5µg dose and reaching a maximum reduction of 29% after the 10µg dose. Subsequently, the percentage decrease in systolic pressure declined to 20% after the 40µg dose. Diastolic pressure also fell by 34% after the 5µg dose, reaching a peak reduction of 42% after the 10µg dose, before decreasing further with increasing doses, ultimately falling to 20% after the 40µg dose (Achola *et al*., 1995).

Anti-implantation and abortifacient activity

Petroleum ether and ethanol extracts were administered orally at doses of 100 and 200 mg/kg body weight from days 1 to 7 of pregnancy to assess their anti-implantation effects. The petroleum ether extract at 100 mg/kg resulted in an average of 6.83 ± 0.60 implants, indicating a 39.7% inhibition compared to 11.33 ± 0.33 implants in the control group ($p < 0.001$). At the 200 mg/kg dose, the same extract significantly inhibited pregnancy in all treated animals (6/6), with a mean number of implants of 2.0 ± 0.30, reflecting a 76.4% inhibition ($p < 0.001$). The ethanol extract at both 100 and 200 mg/kg also inhibited pregnancy in all treated animals (6/6), resulting in mean implant numbers of 8.16 ± 0.30 (27.9% inhibition) and 7.00 ± 0.36 (38.21% inhibition), respectively.

The results of the abortifacient study indicated that the petroleum ether extract was more effective than the ethanol extract in exhibiting abortifacient activity. At a dose of 10 mg/kg body weight, the petroleum ether extract demonstrated 43.3% abortifacient activity, resulting in pregnancy failure in 3 out of 6 rats, with a mean of 6.12 ± 0.12 pups born. At a higher dose of 20 mg/kg body weight, the extract showed abortifacient effects in 4 out of 6 rats, resulting in a 78.6% failure rate of pregnancy and a mean of 2.32 ± 0.56 pups born ($p < 0.001$) (Sharangouda & Patil, 2007).

Anti-epileptic activity

The methanolic leaf extracts underwent acute toxicity testing and were subsequently evaluated for antiepileptic activity using the Maximal Electroshock (MES) and Pentylenetetrazole (PTZ) seizure models in albino Wistar rats. In the MES model, doses of 200 and 400 mg/kg of the extracts significantly restored the reduced levels of brain monoamines, including noradrenaline, dopamine, serotonin, and gamma-aminobutyric acid (GABA). Similarly, in the PTZ model, the extracts significantly increased monoamine levels in the forebrain of the rats. Methanol extract increased the monoamines in the rat brain, which may decrease the susceptibility to MES and PTZ-induced seizure in rats (Kumar & Rajkapoor, 2010).

Hyperlipidaemia activity

Hyperlipidaemia induced rats were treated with ethanolic extracts of leaves of *O. corniculata* at a dose of 500mg/kg body weight. At the conclusion of the experimental period, hyperlipidemic rats exhibited a significant ($p < 0.05$) increase in total cholesterol, triglycerides, and LDL levels, along with a significant ($p < 0.05$) decrease in HDL compared to the normal control group. After the treatment, total cholesterol (6 7 .7 2 %), serum triglycerides (65.88%), LDL cholesterol level in serum (9 0 .4 2 %) decreased and the HDL- Cholesterol level was elevated significantly (74.43%) (Tassa *et al.,* 2012).

Hepatoprotective activity

Aqueous and ethanolic leaf extracts were evaluated for their effects against thioacetamide-induced hepatotoxicity in Wistar rats. Thioacetamide (TAA) administration caused significant increases in serum levels of SGOT, SGPT, GGT, alkaline phosphatase (ALP), and total bilirubin. However, oral administration of *O. corniculata* leaf extracts at 400 mg/kg led to significant reductions in these markers: SGOT decreased from 174.36 ± 1.26 to 146.42 ± 2.54 and 136.75 ± 1.37 IU/L for the aqueous and ethanolic extracts, respectively; SGPT dropped from 109.06 ± 0.80 to 81.96 ± 3.15 and 72.05 ± 2.33 IU/L; GGT decreased from 22.25 ± 0.52 to 16.6 ± 0.49 and 15.02 ± 0.68 IU/L; ALP fell from 304.68 ± 3.92 to 241.86 ± 3.94 and 202.42 ± 5.37 IU/L; and total bilirubin decreased from 0.579 ± 0.03 to 0.226 ± 0.00 mg/dL and 0.288 ± 0.01 mg/dL. The ethanolic extract was found to be more effective than the aqueous extract in all cases.

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Glutathione is a crucial endogenous antioxidant system, particularly abundant in the liver. The aqueous and ethanolic extracts led to a significant increase in liver glutathione levels compared to the TAA group. The treatment also resulted in a significant decrease in the lipid peroxidation in the liver by a decrease in the MDA levels in the liver (Das *et al.*, 2012).

The methanol extract of *O. corniculata* was assessed for its antioxidant capacity against carbon tetrachloride (CCl4)- induced hepatotoxicity. In the CCl4-treated group, there were significant increases in serum levels of aspartate transaminase (AST), alanine transaminase (ALT), alkaline phosphatase (ALP), lactate dehydrogenase (LDH), gamma-glutamyl transpeptidase (γ-GT), total bilirubin, cholesterol, and triglycerides, while total protein and albumin levels decreased compared to the control group. In the groups treated with both CCl4 and methanolic extract (at doses of 100 and 200 mg/kg), there were significant improvements in serum levels of total bilirubin, cholesterol, triglycerides, total protein, and albumin compared to the CCl4 group.

The activity levels of the antioxidant enzymes catalase (CAT), peroxidase (POD), and superoxide dismutase (SOD) in hepatic samples showed a significant ($P < 0.01$) decrease in the CCl4-treated group. In contrast, the groups that received both CCl4 and the methanolic extract (at doses of 100 and 200 mg/kg body weight) exhibited a significant ($P < 0.01$) increase in the activity levels of CAT, POD, and SOD compared to the CCl4 group.

In the CCl4-treated group, the activity levels of glutathione peroxidase (GSH-Px), glutathione S-transferase (GST), glutathione reductase (GSR), and quinone reductase (QR) were significantly ($P < 0.01$) reduced in hepatic samples. However, the groups treated with both CCl4 and various doses of methanolic extract (100 and 200 mg/kg body weight) showed a significant ($P < 0.01$) increase in the activity levels of GSH-Px, GST, GSR, and QR in the liver compared to the group that received only CCl4.

Treatment with CCl4 in rats significantly ($P < 0.01$) increased the level of TBARS, a marker of lipid peroxidation, while the levels of GSH, an endogenous antioxidant, were significantly ($P < 0.01$) reduced in hepatic samples compared to the control group. The groups administered both CCl4 and the methanolic extract (100 and 200 mg/kg b.w.) had significantly ($P < 0.01$) decreased TBARS levels, while liver samples showed increased GSH levels ($P < 0.01$) compared with the group given CCl4 only (Khan *et al.*, 2012).

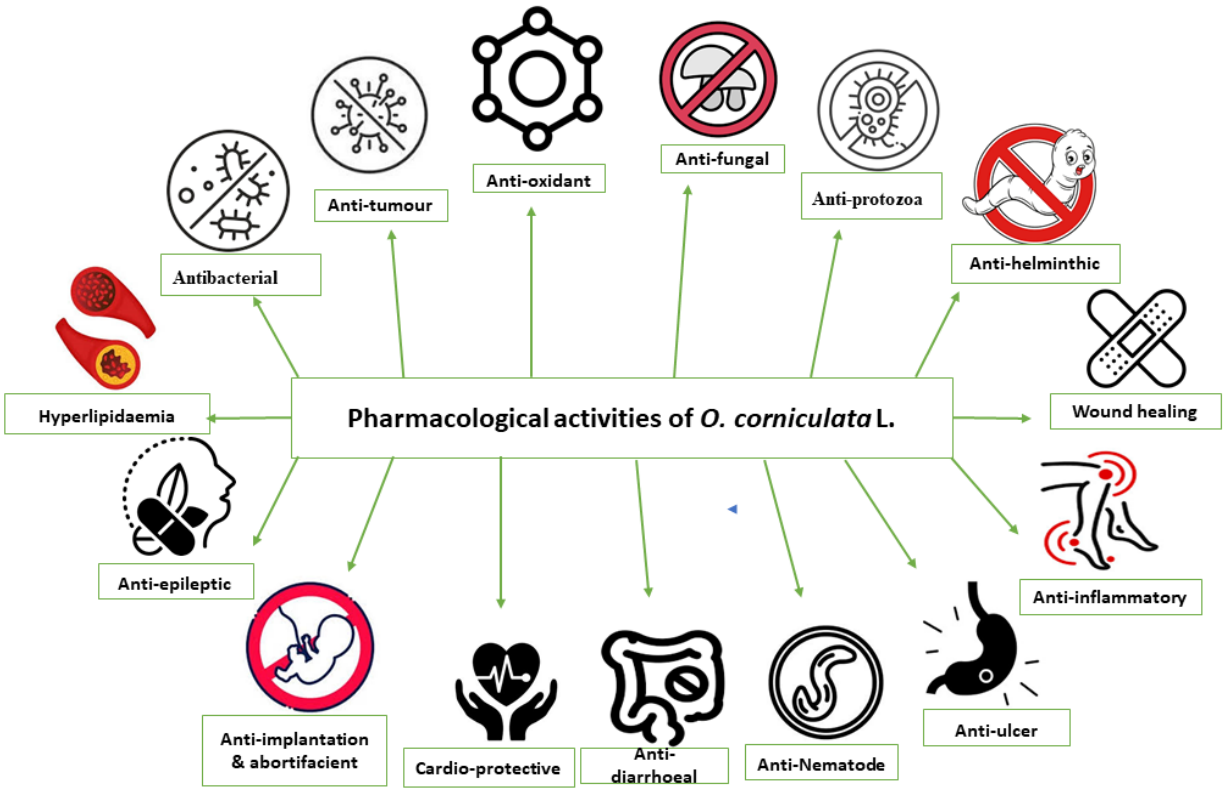

Fig 2: Major pharmacological activities of *Oxalis corniculata* L.

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Phytochemical properties of *Oxalis acetosella* L.

Oxalis acetosella L. is a common, edible wild plant native to the northern hemisphere. It typically thrives in moist woodlands, moorlands, and shaded rocky areas, often growing in dense populations. This plant is also a favored wild food choice. Its leaves have a pleasant, tangy flavor, making them a refreshing, thirst-quenching snack for those exploring the forest. They are usually used to make salads, soups, sauces, and desserts. The flowers are rarely used for different dishes as edible decorations (Šircelj *et al.*, 2010).

Since *O. acetosella* contains high oxalate, it must be consumed in moderation. The oxalate content reported for *O. acetosella* is 110–140 mg/g dry weight (Rodenkirchen, 1998). It is comparable to the two best-known high-oxalate garden-grown plants, rhubarb and spinach (Siener *et al.*, 2006).

O. acetosella is highly rich in carotenoids, ascorbic acid, tocopherols, xanthophylls, and flavonoids. The leaves contain two provitamin A carotenoids, β-carotene and α-carotene, with α-carotene making up less than 1% of the total carotenoids. The primary tocopherol found in the leaves is α-tocopherol, which accounts for approximately 82–92% of the total tocopherols, while the remaining tocopherols are γ-tocopherol and δ-tocopherol. Lutein and neoxanthin are present of which lutein was the predominant xanthophyll. Five phenolic acids reported from *O. acetosella* are chlorogenic acid, ferulic acid, p-coumaric acid, caffeic acid, and protocatechuic acid. Two flavan-3-ols (catechin, epicatechin) and four flavonol glycosides (Rutin, Hyperoside, Isoquercitrin, and Quercitrin) were determined in *O. acetosella* leaves, of which Rutin was the predominant flavonoid (Šircelj *et al.*, 2010).

Pharmacological activities of *Oxalis acetosella* L. (Fig 3)

Antioxidant activity

The antioxidant activity of *O. acetosella* leaves was assessed using the DPPH scavenging assay. The results indicated that the total antioxidant capacity ranged from 3.4 to 4.1 mM Trolox per 100 g dry weight in young leaves, while in older leaves, it was 2.9 mM Trolox per 100 g dry weight.

The antioxidant capacity of lettuce during the harvesting period of *O. acetosella* was found to be 2.5 to 4 times lower. These findings can be compared with the data for common vegetables reported by Miller *et al.* (2000). *O. acetosella* leaves had similar antioxidant capacity as spinach, higher antioxidant capacity than green cabbage and lettuce, but lower than red cabbage (Šircelj *et al.*, 2010).

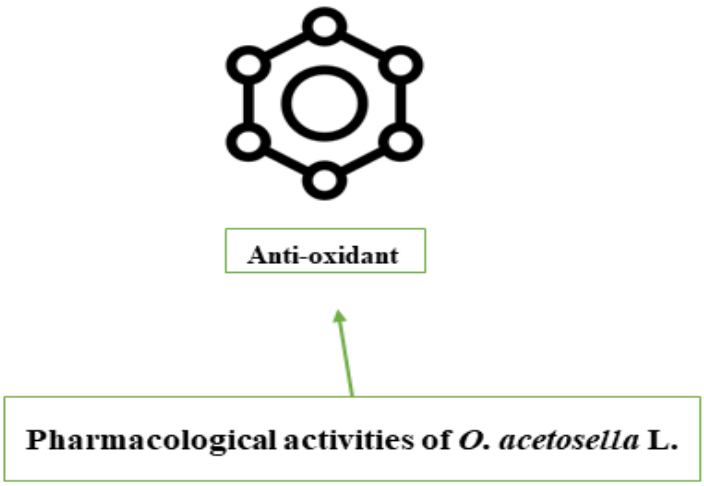

Fig 3: Major pharmacological activities of *Oxalis acetosella* L.

Phytochemical properties of *Oxalis pes-caprae* L.

Oxalis pes-caprae, commonly called 'Bermuda buttercup', is a perennial herbaceous plant with bulbiferous and subterranean stems that grows between 12 and 24 cm tall (Nasir, 1971).

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In small doses, the plant is non-toxic and edible. In several traditions, it is used in folk medicine, as food, and as a source of oxalic acid. Raw bulbs are used to treat tapeworm and many other worms. It also serves as a diuretic. Fleshy underground runners are also eaten with milk. A Yellow dye is obtained from the golden petals. The roots, stems, and leaves of *Oxalis pes-caprae* have strong medicinal properties and can be used to relieve pain, reduce inflammation, remove toxins, and dispel heat (Naila & Ibrar, 2018).

The aerial parts of *O. pes-caprae* contained phenols, esters, phenyl cinnamate derivatives, aromatic compounds, cinnamic acid esters, two dihydrocinnamic acid esters, cinnamic anddihydrocinnamic acids, phenols and coumarins. Two compounds, 2-methoxyphenyl 3- phenyl-propanoate, and 2-hydroxyethyl 3-phenylpropanoate, are reported for the first time as natural products from *O. pes-caprae*. It also contains luteolin and apigenin derivatives, 3-*O*-caffeoylquinic acid, 4-*O*-caffeoylquinic acid, and chlorogenic acid (Della Greca *et al.,* 2008; 2009; 2010). *O. pes-caprae* is characterized by the presence of 3, 4-Dihydroxybenzoic acid, esculetin, formononetin, cinnamic acid, 6-Hydroxynicotinic acid and 2-Isopropylmalic acid (Amal *et al.*, 2022).

Pharmacological activities of *Oxalis pes-caprae* L. (Fig 4)

Antioxidant capacity

Antioxidant activities of both aqueous and methanolic extracts of *O. pes-caprae* flowers and leaves were assessed by in vitro testing, such as free radical scavenging assays (DPPH and ABTS+), ferrous ions (Fe2+) chelating activity, and reducing power assay.

Both aqueous and methanolic extracts of flowers showed high DPPH trapping scavenging capacity, with IC50 values of 0.114 mg/mL and 0.134 mg/mL, respectively. Gallic acid showed an IC50 value of 0.009 mg/ml. Whereas, the methanolic extract of flowers showed a high capacity to quench ABTS+ with an IC50 of 0.297 mg/l compared to the aqueous extract of flowers (IC50 =0.366mg/l), but less potent than the quercetin (IC50 =0.039 mg/mL). The aqueous and methanolic extracts of leaves had a DPPH scavenging of 0.296 mg/mL and 0.214 mg/mL, respectively and ABTS scavenging of 0.88 mg/mL and 0.925 mg/mL, respectively. Hence, the scavenging capacity of *O.pes-caprae* flowers is higher than that of leaves.

The methanolic extract of *O. pes-caprae* flowers had a higher metal chelating activity compared to the aqueous extract of *O. pes-caprae* flowers, with an IC50 of 1.143 mg/mL versus 4.038 mg/mL for the aqueous extract, but less potent than the standard EDTA, which had an IC50 value of 0.296 mg/ml.

In the FRAP assay, the reducing power of both methanol and aqueous extracts is expressed as Ascorbic acid equivalent (AAE). The highest value of the reducing power was recorded in the methanol extract of flowers, with a value of 795.8 mg AAE/g dw, compared to the aqueous extract of flowers (690.8 mg AAE/gdw). In contrast, the methanolic and aqueous extracts of leaves presented a lower reducing power of 507.8 mg AAE/g dw and 387.4 mg AAE/g dw, respectively, compared to flower extracts. *O. pes-caprae* flowers showed potent antioxidant capacity exhibited by their scavenging ability, metal chelation, and reducing power. This activity may be related to the presence of different active phenolic compounds, such as polyphenols and flavonoids, that have the capacity to absorb and neutralize free radicals (Kabach *et al.,* 2023).

Methanolic and n-hexane extracts of stem, leaf, and flowers of *O. pes-caprae* were subjected to three antioxidant assays, such as DPPH free radical scavenging assay, phosphomolybdate assay to evaluate total antioxidant capacity (TAC), and reducing power assay. By DPPH free radical scavenging assay, the best calculated IC50 value (24.57 ± 0.76 lg/mL) was obtained by the hexane extract of flowers, while the lowest potential was exhibited by the n-hexane extract of the stem (66.8 ± 0.67 lg/mL). The highest value of TAC was (55.89 ± 1.758 mg/g) observed by the methanolic extract of leaves, and the lowest value (33.98 ± 1.874 mg/g) was observed by the hexane extraction of flowers. Reducing potential of plants is calculated by total reducing power assessment with a maximum value (34.98 ± 1.089mg/g) by the methanolic extract of the stem (Gul *et al.*, 2022).

Anti-oxidant activity of *O. pes-caprae* extracts in ethyl acetate, methanol, and n-hexane was tested by DPPH radical scavenging and H_2O_2 scavenging activity. In both assays, n-butanol extract displayed the highest anti-oxidant activity (Güçlütürk *et al.,* 2012).

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Antidiabetic Activity

Inhibition of two enzymes, α-amylase and α-glucosidase, is among the strategies used to control hyperglycemia and treat DM2. Acarbose is the common drug used to treat DM2 by inhibiting these two enzymes.

The antidiabetic activity of *O. pes-caprae* flower through the analysis of its inhibitory activity against α-amylase and α-glucosidase enzymes was examined by Kabach *et al.* (2023). Methanol extract of *O. pes-caprae* flowers had an important inhibitory effect on both α-amylase and α-glucosidase. The inhibitory activity of the methanol extract against α-glucosidase was 92.14% at a concentration of 890 µg/mL, while the inhibitory activity of acarbose was 50% at a concentration of 330 µg/ml. Similarly, the methanolic extract inhibited α-amylase activity by 67.857% at 187.50 µg/mL, while acarbose inhibited 50% of α-amylase at 13.64 µg/mL.From these results, it was clear that the methanolic extract of *O. pes-caprae* flowers contains molecules that could play the role of inhibitors of both α-glucosidase and α-amylase in a dose-dependent manner.

Antibacterial activity

Methanolic and n-hexane extracts of stem, leaf, and flowers were tested for antibacterial activity against gram-positive (*B. subtilis, S. aureus*) and gram-negative (*E. coli, K. pneumonia* and *P. aeruginosa*) bacteria by the disc diffusion method. After 24 h of incubation, the maximum zone of inhibition by extracts of *O. pes-caprae* leaves for both methanol and n-hexane was observed against *B.subtilis* as (24 ± 0.65 mm) and (20 ± 0.34 mm), respectively. For *S.aureus, P. aerugonisa, E. coli* and *K. pneumoniae,* maximum inhibition was 16 ± 0.45mm by the hexane extract of the leaf, 19 ± 0.34mm by the hexane extract of the leaf, and 13 ± 0.23 by the methanol extract of the stem, respectively (Gul,*et al.,* 2022).

Ethanolic, methanolic, acetone, n-hexane, and chloroform extracts of O. *pes-caprae* were tested against *Xanthomonas, Clavibacter michinganensis* and *Bacillus* at 100, 1000, 1500, and 2500 ppm. Significant inhibition zones were observed in all extracts at 2500 ppm against all bacterial strains. The ethanolic extract showed the highest inhibition against *Xanthomonas* (16.25±0.353), *Clavibacter* (17.75±0.35) and *Bacillus* (20.5±0.70) at 2500 ppm (Naila & Ibrar 2018).

Antibacterial activity of ethanol and methanol extracts of *O. pes-carpe* leaf and flower against two Methicillin-Resistant *Staphylococcus aureus* (MRSA) isolates, wound (W) and diabetic foot ulcers (DFU), was done by the disc diffusion method (Abdulrraziq *et al*., 2023). They also compared it with antibiotics (vancomycin and gentamicin). He observed that the leaf extract demonstrated a clear inhibition of MRSA-W in the diameters 3.9 mm and 2.5 mm corresponding to the methanol (26%) and acetone (16%) extracts, respectively. The flower extract of methanol showed a low sensitivity (3%) to this isolate, while the flower extract of acetone induced no inhibition against MRSA-W. Furthermore, MRSA-DFU demonstrated low sensitivity to the leaf extract of acetone (8%) and methanol (6%) with diameters of 1.2 mm and 1.0 mm, respectively. The flower extract had no effect on this MRSA isolate.

Vancomycin is commonly used in hospitals as a trial drug for patients with MRSA. All the strains were affected by the antibiotic vancomycin; the highest inhibition (40%) was for MRSA-W with a diameter of 6.0. MRSA-DFU showed medium sensitivity (20%) to this antibiotic with a diameter of 3.0mm. While gentamicin showed low-to-medium sensitivity (18%) against MRSA-W, with a diameter of 2.7 mm, it was ineffective against MRSA-DFU.

Cytotoxicity

Methanolic and n-hexane extracts of the stem, leaf, and flowers of *O. pes-caprae* were subjected to the Brine shrimp cytotoxicity assay (BSCA). A concentration-dependent response was observed: increasing extract concentration led to increased brine shrimp mortality. *O. pescaprae* the methanolic extract of the stem and the methanolic extract of the flower exhibited high percentage of mortality of *Artemia salina* of 96 and 82%, with LD50 19.66 and 26.46 (lg/ml), respectively. (Gul *et al.*, 2022).

Cytotoxic assays were conducted on the ethanolic, methanolic, acetone, n-hexane, and chloroform extracts of *O. pes-caprae*. At 1000 ppm, the ethanolic extract exhibited the highest significant cytotoxicity, causing 100%

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cytotoxicity (LD50 8.98). It was followed by the chloroform extract (93.33%), n-hexane (90%), methanol, and acetone (86.66%) (Naila & Ibrar, 2018).

Antifungal activity

The antifungal potential of *O. pes-caprae* extracts in ethanolic, methanolic, acetone, n-hexane, and chloroform were tested at 100 and 1000 ppm against fungal strains, including *Aspergillus flavus*, *Penicillium* and *Fusarium solani*. At 1000 ppm, ethanolic extract was found effective against *A. Flavus* (48.24±1.24%), followed by *Fusarium solani*(41.5±0.70 %) and *Penicillium* (35.34±0.98 %). (Naila & Ibrar, 2018).

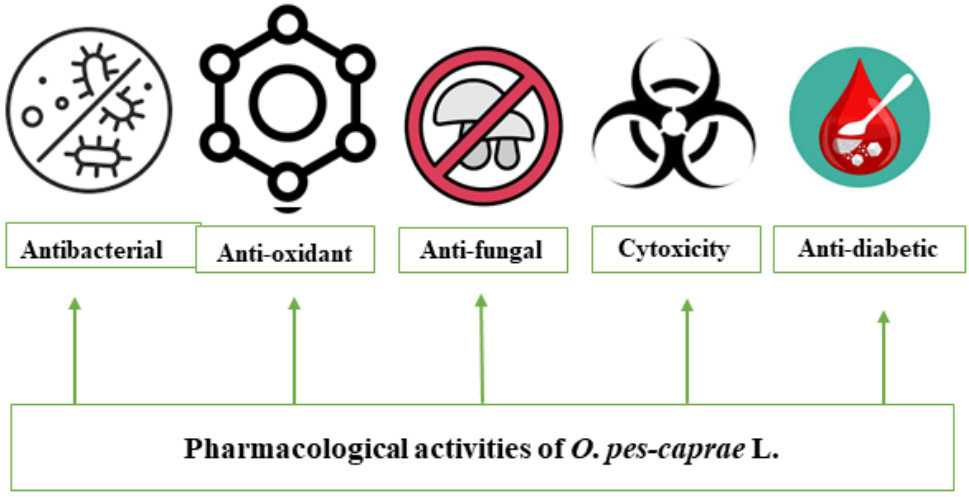

Fig 4: Major pharmacological activities of *Oxalis pes-caprae* L.

Phytochemical properties of *Oxalis latifolia* Kunth.

Oxalis latifolia Kunth., commonly known as "garden pink-sorrel" or "broadleaf wood-sorrel," is native to Mexico and is widely distributed in Central and South America as well as South Asia. This perennial herb, which grows from a network of small bulbs and spreads through stolons, is recognized as a highly versatile medicinal plant with a broad range of biological activities. Stem is absent. The leaves arise on long petioles from ground level, making it an excellent plant in nature, with a composition of all the essential constituents required for the normal and good health of humans (Kumar *et al.*, 2010). Leaves are used as a vegetable, Sour in taste (Devarkar & Bhogaonkar, 2014).

Phytochemical analysis revealed the presence of Alkaloids, Phenols, flavonoids, tannins, saponins, terpenoids, steroids, sterols, carbohydrates, reducing sugars, proteins, glycosides, fixed oils, and fats (Devarkar &Bhogaonkar, 2014; Subramanian, 2018; Krishnan *et al.*, 2019; Subramanian *et al.*, 2019). Qualitative ash analysis for the presence of inorganic compounds revealed the presence of Sulphur, Calcium, Iron, Chlorine, Phosphorus, and Sodium. Protein amino acid profile revealed the presence of Aspartic acid, DL-Alanine, Iso-Leucine, Lycine monohydrochloride, Methionine, Threonine, and Tryptophan (Devarkar & Bhogaonkar, 2013).

Pharmacological activities of *Oxalis latifolia* Kunth. **(Fig 5)**

Antioxidant activity

Subramanian, (2019) suggested that *O. latifolia* has very good in vitro antioxidant activity and can therefore be used as a therapeutic agent for Neuro degenerative disease (NDD).

The ethanol and aqueous extracts demonstrated 90.39% and 86.34% inhibition of the DPPH radical at 100 µg/ml, respectively, while the standard (ascorbic acid) exhibited 96.42% inhibition at the same concentration. The extracts displayed DPPH radical scavenging activity even at the lowest concentrations, with inhibition increasing in a concentration-dependent manner. Similarly, the ethanol and aqueous extracts showed 76.37% and 68.14%

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inhibition of nitric oxide radicals at 100 µg/ml, compared to 88.84% inhibition by the standard (ascorbic acid) at the same concentration. The extracts also demonstrated nitric oxide radical scavenging activity at lower concentrations, with inhibition increasing and being concentration-dependent.

The free radical scavenging activity of *O. latifolia* was evaluated based on its ability to reduce DPPH, a stable free radical. The highest scavenging activity was observed at a concentration of 512 µg/ml (66.8 ± 1.06%), while the lowest activity was noted at 2 µg/ml (4.3 ± 1.1%). The reduction in DPPH molecules can be linked to the number of available hydroxyl groups. Therefore, the significant scavenging activity may be attributed to the presence of these hydroxyl groups in the extracts.

In the ABTS assay, *O. latifolia* showed its highest scavenging activity at a concentration of 1000 µg/ml (67.7 ± 0.88%), whereas the lowest activity was observed at 2 µg/ml (9.0 ± 0.56%). This antioxidant activity is likely due to the diverse range of bioactive compounds, such as phenolics, flavonoids and tannins were found in the plant (Krishnan *et al.,* 2019).

Anticancer activity

Ethanolic and aqueous extracts of *O. latifolia* were evaluated for their in vitro anticancer activity using the Trypan blue method and MTT assay against MCF-7 and HT-29 cell lines. The extracts demonstrated a concentration-dependent cytotoxic effect, as evidenced by an increase in the number of dead cells with higher extract concentrations. At a lower concentration of 12.5 µg/ml, the ethanolic extract resulted in 19.23% dead cells, while at a higher concentration of 200 µg/ml, it caused 57.45% dead cells. These findings indicate that the extracts significantly inhibited the proliferation of MCF-7 and HT-29 tumor cells, with an ED50 of 200 µg/ml, indicating 50% tumor cell death.

The effect of ethanolic and aqueous extracts on MCF-7 & HT-29 cancer cell lines is significant and comparable to the standard drugs Tamoxifen & 5-Flurouracil. The extracts have shown activity even at the lowest concentration of 12.5µg/ml. The extracts exhibited significant activity that was dependent on the concentration (Subramanian, 2018).

Antihyperglycemic/ Antidiabetic Activity

The ethanolic extract of *O. latifolia* was evaluated for antihyperglycemic activity against streptozotocin-induced diabetic rats. The plant extract was given at three different doses—100, 200, and 400 mg/kg—to evaluate its dose-dependent activity. Even the lowest dose of 100 mg/kg resulted in significant effects after the administration of the crude extracts. However, the standard drug, tolbutamide, demonstrated more pronounced antihyperglycemic activity than the extract at all doses.

Three hours after administration, all diabetic animals treated with the extract showed a significant decrease in blood glucose levels, which dropped from 332.52 ± 6.14 to 197.49 ± 6.04 mg/dl for the 100 mg/kg dose, from 334.64 ± 5.14 to 137.94 ± 5.04 mg/dl for the 200 mg/kg dose, and from 333.65 ± 6.04 to 122.68 ± 6.44 mg/dl for the 400 mg/kg dose. It is comparable to the antihyperglycemic agent, Tolbutamide, which decreased blood glucose level from 327.48±6.91 to 112.26±3.09 at the dose of 100 mg/kg after 3 hours of administration (Subramanian *et al.,* 2019).

Anti-bacterial activity

Anti-bacterial studies of aqueous and methanolic extract of *O. latifolia* using *Bacillus Subtilis, Escherichia coli, Salmonella paratyphi* and *Klebsiella pneumonia* have shown a minimum inhibition zone (2-4mm) in 30 µl concentration of methanol extract and a maximum inhibition zone (9-10mm) in 90 µl concentration of aqueous extract (Krishnan *et al.,* 2019).

Antifungal activity

Anti-bacterial studies of aqueous and methanolic extract of *O. latifolia* using *Aspergillus niger* and *Aspergillus fumigates* have shown a minimum zone of inhibition (2-4 mm) in 30 µl of both methanol and aqueous extract,

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while a maximum zone of inhibition (10-11mm) was observed in 90 µl of aqueous extract (Krishnan *et al.*, 2019).

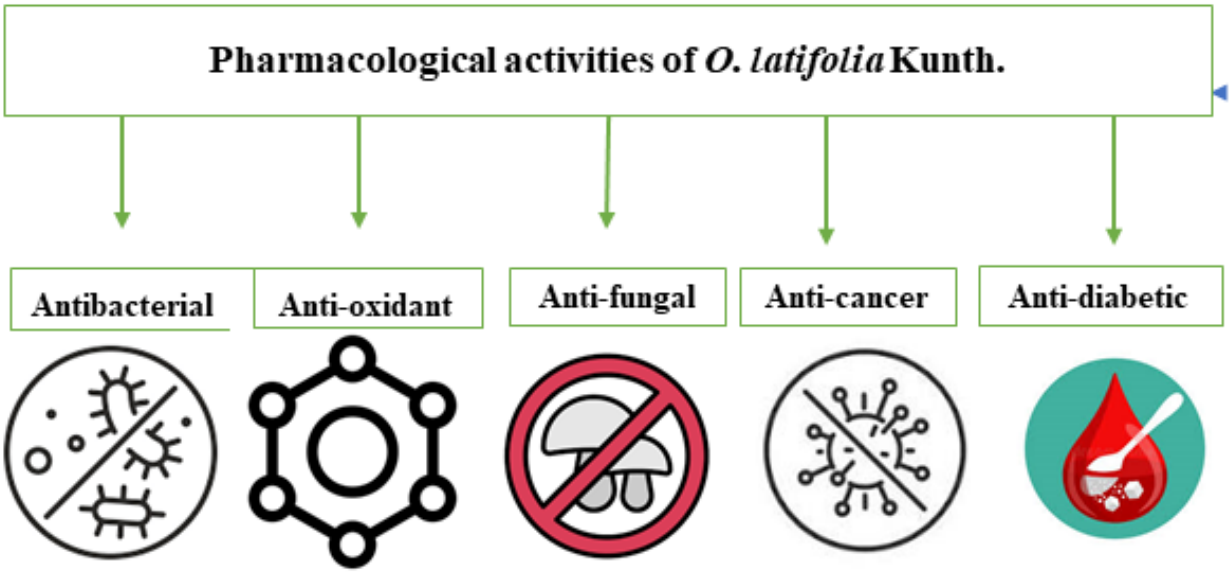

Fig 5: Major pharmacological activities of *Oxalis latifolia* Kunth.

Phytochemical properties of *Oxalis tetraphylla Cav.*

O. tetraphylla, traditionally called 'good luck clover', is a bulbous plant from Mexico and Guatemala. It is widely distributed in South America, Mexico and Africa (Loudon, 2009). It has four triangular green leaves with purple colour diffused at the centre of the leaves (Brickell & Zuk, 1997). This plant is primarily used for cattle grazing, though it has also been used for human consumption (Romero, 2000).

The phytochemical information on this plant is very limited in the literature, with only a single study. A HPLC analysis showed the presence of coumaric acid and flavonols (Ocampo-Gutiérrez *et al.*, 2022).

Pharmacological activities of *Oxalis tetraphylla* Cav.

The hydro-alcoholic extract of the stems and leaves of *O. tetraphylla* demonstrated a significant egg-hatching inhibitory effect and larvicidal activity against *Haemonchus contortus*. After 48 hours of exposure, the crude alcoholic extract at concentrations of 0.2 and 0.3 mg/mL achieved egg-hatching inhibition rates of approximately 60% and 70%, respectively. The LC50 results for this crude extract were notably promising, with the LC50 value determined to be just 0.213 mg/ml. It is also interesting that the ovicidal efficacies obtained with the different concentrations of extract were even higher than that obtained with 0.5 mg/mL ivermectin, one of the most potent commercially available anthelmintic all over the world (Ocampo-Gutiérrez *et al.*, 2022).

The in vitro larvicidal and *in-vivo* anthelmintic effects of the hydroalcoholic extract of *O. tetraphylla* were evaluated against *Haemonchus contortus* in experimentally infected lambs. After 24 hours of incubation, the mortality rate of sheathed larvae in the control group was low, with no mortality seen in exsheathed larvae. In the ivermectin-treated group, no live sheathed or exsheathed larvae were detected. In contrast, the hydroalcoholic extract of *O. tetraphylla* resulted in 80.9% mortality for sheathed larvae and 97% mortality for exsheathed larvae.

After 48 hours of incubation, the control group showed low mortality in sheathed larvae, with none observed in exsheathed larvae. In the ivermectin-treated group, 100% mortality was recorded for both sheathed and exsheathed larvae. In contrast, the series treated with *O. tetraphylla* extract demonstrated mortality rates of 86.87% for sheathed larvae and 98.85% for ex-sheathed larvae. (González-Cruz *et al.*, 2018).

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Phytochemical properties of *Oxalis triangularis* A. St.-Hil.

Oxalis triangularis, commonly known as "purple shamrock" or "purple clover," is an edible perennial plant native to tropical Mexico that is easy to cultivate. The leaves are particularly valued for their sour and exotic flavor, and the purple-colored leaves are often used to garnish salads and other dishes.

O. triangularis contains various phytochemical components. The leaves of *O. triangularis* have been found to contain anthocyanin-flavone C-glycosides, including (malvidin 3-O-(6(II)-O-alpha-rhamnopyranosyl (AIV)-beta-glucopyranoside (AII))-5-O-beta-glucopyranoside (AIII) (apigenin 6-C-(2(II)-O-beta-glucopyranosyl (FIII)-beta-glucopyranoside (FII) malonate (AV) (Miller, *et al.,* 2011). Flavone C-glycosides, such as luteolin 6-C-(2‘ ‘-O-β-xylopyranosyl-β-glucopyranoside), apigenin 6-C-(2‘ ‘-O-α-rhamnopyranosyl-β-glucopyranoside), apigenin 6-C-(2‘ ‘-O-β-xylopyranosyl-β-glucopyranoside), apigenin 6-C-(2‘ ‘-O-(6‘ ‘‘-(E)-caffeoylglucoside)-β-glucopyranoside), and apigenin 6-C-(2‘ ‘-O-(6‘ ‘‘-(E)-p-coumaroylglucoside)-β-glucopyranoside) have also been isolated from the purple leaves of *Oxalis triangularis* (Fossen *et al.,* 2007).

Pharmacological activities of *Oxalis triangularis* A. St.-Hil. (Fig 6)

The antibacterial activity of *O. triangularis* extracts was examined against five Gram-positive bacteria *(S. aureus, B. cereus, B. sphaericus, S. pyogenes, S. mutans*) and three Gram-negative bacteria (*E. coli, S. typhimurium, E. aerogenes*). The tests were conducted using both heat-treated extracts and extracts adjusted to various pH levels with NaOH. The heat-treated extracts from *O. triangularis* leaves exhibited similar antibacterial activity. However, a significant loss of antibacterial activity was observed with changes in the pH of the extracts. These findings suggest that the broad-spectrum antibacterial activity of *O. triangularis* is due to water-soluble, heat-stable substances that are effective only in acidic pH conditions. Thus, the antibacterial agents are likely oxalic acid or oxalate compounds, which are abundant in *Oxalis* species (Kim *et al.,* 2018).

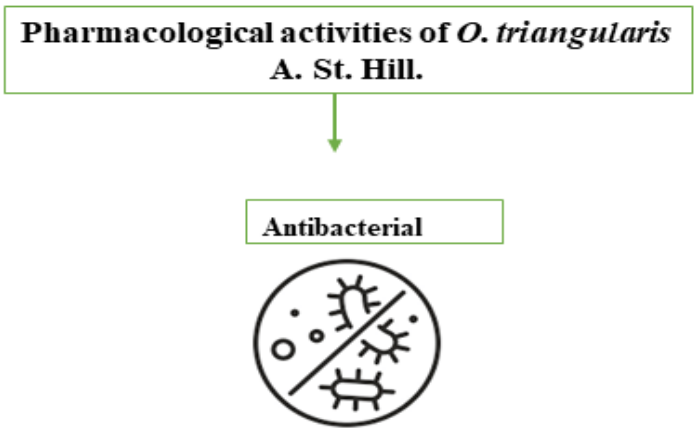

Fig 6: Major pharmacological activities of *Oxalis triangularis* A. St. Hill.

Phytochemical properties of *Oxalis debilis* Kunth.

O. debilis Kunth. commonly known as ‘pink woodsorrel’ is a medicinal, bulb-forming, edible perennial herb native to South America, distributed widely throughout the world (Junejo *et al.,* 2020). Herbs and their extracts have been used since ancient times to treat various human ailments. Traditionally, they have been used the treat dysentery and diarrhea. In traditional practice, the leaf extract of *O. debilis* is taken orally for curing fever (Luo *et al.,* 2006). An ethnobotanical study also reports the use of leaf decoction of *O. debilis* in the treatment of diabetes (Junejo, 2021). These are often incorporated into various traditional cuisines, such as sour fish and bottle gourd dishes (Patiri & Borah, 2007). In various parts of the Indian subcontinent, the plant is also extensively used as an antidote for toxicity (Singh & Dubey, 2012).

Phytochemical analysis revealed the presence of Steroids, alkaloids, terpenoids, tannins, saponins, coumarin, protein, and sugar (Singh *et al.,* 2017). Alkaloids, Glycosides, Phenolic compounds, and tannins, Flavonoids,

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Carbohydrates, Proteins, Fats and oils, Saponins, Steroids and Terpenes are also detected from plant extracts (Junejo *et al.*, 2016*;* Junejo *et al.*, 2021).

Pharmacological activities of *Oxalis debilis* Kunth. (Fig 7)

Antidiabetic activity

Junejo *et al.* (2021) assessed the α-glucosidase and α-amylase inhibitory activities of two bioactive compounds, AGD and STM, extracted from the methanolic extract of *O. debilis*. The study found that both compounds demonstrated effective inhibitory activities at the tested concentrations of 6.25–200 mg/ml, and these activities were dependent on the concentration.

The percentage inhibition of α-amylase was higher than that of α-glucosidase for both compounds. Compound AGD showed slightly greater inhibition of α-glucosidase, while STM demonstrated more inhibition of the α-amylase enzyme. Although the inhibitory activities of the test compounds were somewhat lower than those of the standard drug, acarbose, their effects were comparable to those of acarbose. No significant differences ($p > 0.05$) in inhibitory activities were found between the test compounds and acarbose, indicating that AGD and STM are considered equally effective as antidiabetic agents when compared to acarbose.

The IC50 values for AGD were 58.05 mg/mL for α-glucosidase and 51.45 mg/mL for α-amylase, while STM had IC50 values of 71.07 mg/mL for α-glucosidase and 39.14 mg/mL for α-amylase. In comparison, the standard drug acarbose had IC50 values of 30.01 mg/mL and 28.72 mg/mL against α-glucosidase and α-amylase, respectively. The assessment of IC50 values indicates that STM exhibits greater inhibitory activity than AGD, particularly against the α-amylase enzyme. The inhibitory activities of AGD and STM are comparable to those of acarbose, with no significant difference found between them. These results demonstrate that both AGD and STM exhibit α-glucosidase and α-amylase inhibitory activity, with STM exhibiting greater potency, particularly against α-amylase. Thus, both compounds are recognized for their antidiabetic activity as inhibitors of α-glucosidase and α-amylase.

The hydro-alcoholic extract of *O. debilis* leaves was investigated for its antidiabetic effects in streptozotocin (STZ)-induced diabetic rats, which showed a significant increase in blood glucose levels compared to normal rats. Following treatment with the extract, blood glucose levels were significantly reduced ($p < 0.05$) in diabetic rats at doses of 250 and 500 mg/kg. Additionally, rats treated with metformin (5 mg/kg) showed a significant ($p < 0.05$) decrease in plasma glucose levels compared with normal rats.

In STZ-induced diabetic rats, body weight, insulin levels, and glycogen content were significantly decreased. After 21 days of treatment with doses of 250 and 500 mg/kg, there was a significant increase ($p < 0.05$) in body weight, insulin levels, and glycogen content compared to the untreated diabetic rats.

In diabetic rats, triglycerides (TG), total cholesterol (TC), and low-density lipoprotein (LDL) were significantly increased, while high-density lipoprotein (HDL) levels were significantly decreased. In the 250 & 500 mg/kg extract-treated groups, TG, TC, and LDL levels were significantly ($p < 0.05$) reduced, and HDL levels were significantly ($p < 0.05$) increased compared with diabetic control rats (Junejo *et al.*, 2022).

In STZ-induced diabetic rats, there was a significant increase in the activities of SGOT, SGPT, and ALKP. However, after treatment with the extract at doses of 250 and 500 mg/kg, the activities of SGOT, SGPT, and ALKP were significantly reduced ($p<0.05$) compared with the diabetic control group.

In diabetic rats, there was a significant decrease in serum total protein (TPR) and a notable increase in creatinine (CRTN). However, after 21 days of treatment with the extract at 250 and 500 mg/kg, TPR levels significantly increased ($p < 0.05$), while CRTN levels significantly decreased ($p < 0.05$) compared with the diabetic control group.

In STZ-treated diabetic rats, the activities of SOD, CAT, GSH, and GPx were significantly elevated. Compared with normal rats, the diabetic group showed a notable ($p < 0.05$) decrease in the activities of these antioxidant enzymes. Metformin (5 mg/kg) also resulted in a significant ($p < 0.05$) reduction of these enzymes. Additionally, the increased levels of MDA, a marker of lipid peroxidation (LPO), in diabetic rats were significantly ($p < 0.05$)

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lowered following treatment with the extracts at doses of 250 and 500 mg/kg compared to normal rats (Junejo *et al.,* 2022).

Anti-inflammatory Activities

Anti-inflammatory activities of the Hydroalcoholic extract of O. *debilis* at different concentrations in a carrageenan-induced paw edema model in rats have not shown significant inhibition in the early study hours. The first phase of inflammation, which occurs within an hour of carrageenan injection, is partly due to the trauma of injection and partly to histamine and serotonin. Hence, it is concluded that there is no inhibition of histamine and serotonin.

The carrageenan-induced paw edema model in rats is known for its sensitivity to cyclooxygenase inhibitors and is often used to evaluate the effects of nonsteroidal anti-inflammatory drugs that primarily target cyclooxygenase, which is involved in prostaglandin synthesis. This model is crucial for assessing the second phase of the inflammatory response, measured after 5 hours, during which a significant inhibition ($p < 0.05$) is observed. Therefore, it can be concluded that the aqueous extract's inhibitory effect on carrageenan-induced inflammation may result from its ability to inhibit cyclooxygenase, thereby reducing prostaglandin synthesis (Junejo *et al.,* 2022).

Hepatoprotective Activities

Liver transaminases (SGOT and SGPT) and alkaline phosphatase (ALP) are key biomarkers for diagnosing hepatic injury and liver dysfunction. After oral administration of the hydro-alcoholic leaf extract of *O. debilis*, there were no significant changes in serum levels of SGOT, SGPT, ALP, triglycerides, or cholesterol ($P < 0.05$) compared to the normal untreated group, indicating that the plant does not contain hepatotoxic agents. Similarly, the unchanged count of the RBC and WBC indicated that the plant extract has little role in either the production or destruction of these cells (Junejo *et al.,* 2016).

The hepatoprotective effects of hydro-alcoholic extracts of *O. debilis* in CCl4-treated animals demonstrated a significant reduction in serum marker enzymes, including alanine aminotransferase (ALT), aspartate aminotransferase (AST), alkaline phosphatase (ALP) ($p \leq 0.001$), and total bilirubin (TB) levels compared to the CCl4 control group. The reduction in these serum marker enzymes was dose-dependent. Animals treated with CCl4 exhibited elevated levels of AST, ALT, and ALP, but the hydro-alcoholic extract of *O. debilis* effectively protected against hepatic injury. Notably, CCl4 treatment did not significantly affect the increase in ALP levels in the group pre-treated with 200 mg/kg, nor did it impact ALP and TB levels in the group pre-treated with 400 mg/kg. Further, the administration of 400 mg/kg of the extract reduces the serum marker enzyme activity to almost the level observed in the silymarin (100 mg/kg) group (Junejo *et al.,* 2022).

The hepatoprotective effects of the aqueous extract of *O. debilis* against CCl4-induced liver damage were evaluated by administering the plant extract both before and after CCl4 treatment. The group treated with CCl4 exhibited a significant increase in serum levels of glutamic oxaloacetic transaminase (SGOT), glutamate-pyruvate transaminase (SGPT), alkaline phosphatase (ALP), total bilirubin (TB) and direct bilirubin (DB) ($p < 0.001$) when compared to the normal group.

In both pre-treatment and post-treatment groups receiving the aqueous extract at doses of 250 mg/kg and 500 mg/kg, there was a significant reduction in the elevated serum levels of transaminases (SGOT and SGPT), alkaline phosphatase, and bilirubin, along with an increase in total protein levels compared to the CCl4-treated group. Additionally, animals treated with the standard drug silymarin showed a significant reduction in all the aforementioned serum parameters compared to the CCl4 group ($p < 0.001$). Notably, the post-treatment groups demonstrated greater hepatoprotective activity than the pre-treatment groups for both doses (Athokpam *et al*., 2017).

Antioxidant Activity

The antioxidant activity of *O. debilis* ($IC50=25.82 \pm 0.68$ μg/ml) was much higher than that of *O. corniculata* ($IC50=73.67 \pm 0.91$ μg/ml). This may be due to their higher phenolic content rather than the presence of vitamins C and E, carotenoids, flavonoids and thiol (SH) compounds, etc. (Sarma *et al*., 2015).

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Antimicrobial Activities

Panda *et al*. (2016) investigated the antibacterial activity of various ecotypes of *O. debilis* against *Bacillus subtilis* (MTCC 441), *Pseudomonas aeruginosa* (MTCC 2453), and *Streptococcus epidermidis* (MTCC 3322). The antimicrobial tests were conducted using ofloxacin as the standard antibiotic. The results indicated that the greatest growth inhibition was observed against *B. subtilis* (11 mm), whereas no antimicrobial activity was observed against *P. aeruginosa*. The plant extract showed a smaller zone of inhibition against *S. epidermidis* and bacterial growth inhibition was dose-dependent.

Antidiarrheal Activity

The activity of the hydro-alcoholic extract of *O. debilis* leaves was greater than that of the ethyl acetate extract. Administration of the extracts led to a significant reduction in wet faeces, effectively preventing defecation. The ethyl acetate extract at a dose of 250 mg/kg bw achieved a 24.83% inhibition of defecation, while increasing the dose to 500 mg/kg bw improved this effect to 44.15%. In contrast, the hydroalcoholic extract showed 40.01% inhibition at 250 mg/kg bw and a notable 73.37% inhibition at 500 mg/kg bw. The standard drug loperamide, administered at 50 mg/kg, resulted in an average of 3.12±1.32 diarrheal faeces over 4 hours, achieving a 74.67% reduction in defecation (Junejo *et al*., 2021).

Anthelmintic Activity

Adult Indian earthworms (*Pheretimaposthuma*) and tapeworms (*Raillietina spiralis*) were utilised to assess in vitro anthelmintic activity. The ethyl acetate extract demonstrated the highest anthelmintic effect in earthworms at a dose of 100 mg/ml, causing paralysis in 43.21 ± 1.57 minutes and death in 69.24 ± 0.68 minutes. The hydro-alcoholic extract also showed significant activity in earthworms at the same dose, leading to paralysis in 23.23 ± 0.33 minutes and death in 34.48 ± 0.39 minutes. In tapeworms, the ethyl acetate extract elicited a maximum paralytic response, causing paralysis in 41.51 ± 1.14 minutes and death in 63.71 ± 0.68 minutes at 100 mg/ml. The hydro-alcoholic extract exhibited similar activity against tapeworms, resulting in paralysis in 21.87 ± 0.88 minutes and death in 39.83 ± 0.69 minutes. The standard drug, albendazole, caused paralysis in 21.27 ± 0.74 minutes and death in 33.12 ± 1.47 minutes against earthworms, while it caused paralysis in 20.31 ± 1.57 minutes and death in 40.56 ± 1.57 minutes against tapeworms, both at a concentration of 100 mg/ml (Junejo *et al*., 2021).

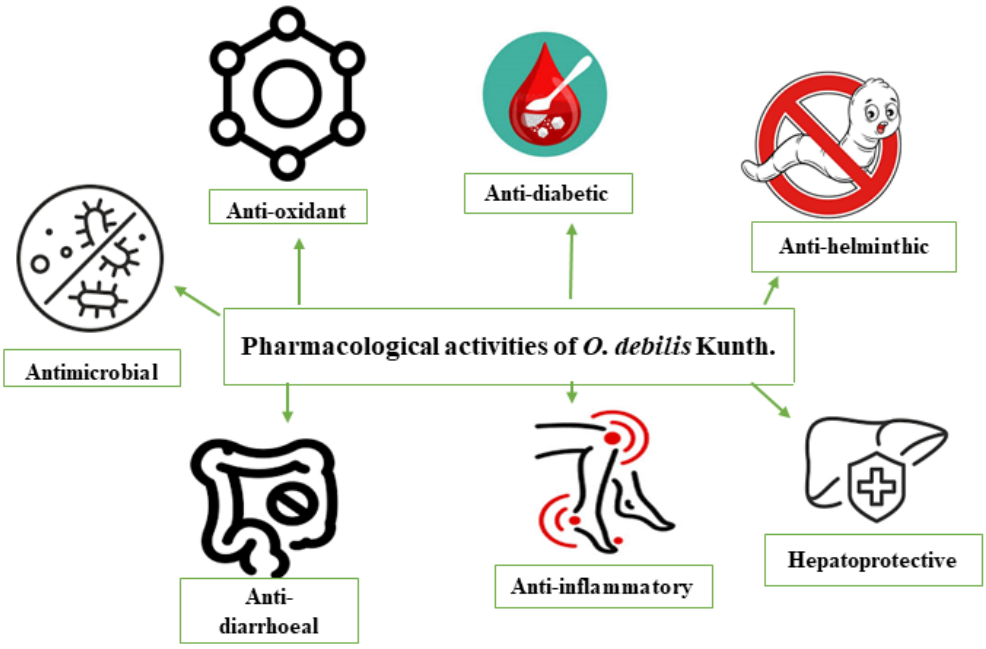

Fig 7: Major pharmacological activities of *Oxalis debilis Kunth.*

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Table 1: Major pyto-pharmacological activities in selected *Oxalis* species

SL. No.	Plant	Pharmacological activities	References
1.	***O. corniculata*** L.	Antibacterial activity	Raghvendra *et al.*, 2006; Satish *et al.*, 2008; Unni, *et al.*, 2009; Handali *et al.*, 2011; Rehman *et al.*, 2014; Mohan & Pandey 2015; Panda *et al.*, 2016; Kaur *et al.*, 2017; Siddiqui *et al.*, 2017; Pawar *et al.*, 2023; Rather *et al.*, 2023.
		Anti-tumour activity	Kathiriya *et al.*, 2010.
		Anti-oxidant activity	Kathiriya *et al.*, 2010; Sakat *et al.*, 2010; Kumar *et al.*, 2012; Khan *et al.*, 2012; Tassa *et al.*, 2012.
		Antifungal activity	Iqbal *et al.*, 2001; Rehman *et al.*, 2014; Mohan & Pandey, 2015.
		Anti-protozoa activity	Manna *et al.*, 2010.
		Anti-helminthic activity	Dighe *et al.*, 2012.
		Wound healing activity	Taranalli *et al.*, 2004.
		Anti-inflammatory Activity	Sakat *et al.*, 2010; Dighe *et al.*, 2016.
		Anti-ulcer activity	Mahadik *et al.*, 2011; Sakat *et al.*, 2012.
		Anti-Nematode activity	Taba *et al.*, 2008.
		Anti-diarrhoeal activity	Watcho *et al.*, 2005.
		Cardio-protective activity	Achola *et al.*, 1995.
		Anti-implantation& abortifacient activity	Sharangouda & Patil, 2007.
		Anti-epileptic activity	Kumar & Rajkapoor, 2010.
		Hyperlipidaemia activity	Tessa *et al.*,2012.
2.	***O. acetosella*** L.	Antioxidant activity	Miller *et al.*, 2000; Šircelj *et al.*, 2010
1.	***O. pes-caprae*** L.	Antioxidant capacity	Güçlütürk *et al.*, 2012; Gul *et al.*, 2022; Kabach *et al.*, 2023.
		Antidiabetic Activity	Kabach *et al.*, 2023
		Antibacterial Activity	Abdulrraziq *et al.*, 2013; Naila & Ibrar 2018; Gul *et al.*, 2022.
		Cytotoxicity	Gul *et al.*, 2022, Naila & Ibrar, 2018
		Antifungal activity	Naila & Ibrar, 2018.
2.	***O. latifolia*** Kunth.	Antioxidant activity	Subramanian, 2019.
		Anticancer activity	Subramanian, 2018.
		Antihyperglycemic Activity	Subramanian *et al.*, 2019.
		Anti-bacterial Activity	Krishnan *et al.*, 2019.
		Antifungal activity	Krishnan *et al.*, 2019.
		Anti-oxidant Activity	Krishnan *et al.*, 2019.
3.	***O. tetraphylla*** Cav.	Egg-hatching inhibitory effect &larvicidal activity	Ocampo-Gutiérrez *et al.*, 2022.
		In vitro larvicidal & in vivo anthelmintic effects	González-Cruz *et al.*, 2018.
4.	***O. triangularis*** A. St.-Hil.	Antibacterial activity	Kim *et al.*, 2018.
7.	***O. debilis*** Kunth.	Antidiabetic activity	Junejo *et al.*, 2021.
		Toxicological Activity	Junejo *et al.*, 2016.
		Hepatoprotective and Anti-inflammatory Activities	Junejo *et al.*, 2022.

		Antidiabetic and Antioxidant Activity	Junejo *et al.*, 2022.
		Antimicrobial Activities	Panda *et al.*, 2016.
		Hepatoprotective Activity	Athokpam *et al.*, 2017.
		Nutraceutical Activity	Sarma *et al.*, 2015.
		Antidiarrheal Activity	Junejo *et al.*, 2021.
		Anthelmintic Activity	Junejo *et al.*, 2021.

CONCLUSION

The review highlights the significant pharmacological potential of *Oxalis* species from South India, despite the fact that only 8 out of the 10 reported species have been studied for their phytochemical and pharmacological activities. Among these, *Oxalis corniculata* stands out as the most extensively researched species, demonstrating a wide range of bioactive compounds and therapeutic effects. Each species of *Oxalis* is characterized by distinct pharmacological properties, underpinned by a variety of phytochemicals that contribute to its medicinal value. This review emphasizes the need for further research on the remaining species with deeper exploration of the bioactive compounds within the *Oxalis* species to fully harness their therapeutic potential for the development of novel pharmacological agents.

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