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Review Article

***Phyllanthus acidus* (L.) Skeels: A Comprehensive Review of Its Phytochemistry and Pharmacological Perspectives**

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ABSTRACT

Phyllanthus acidus (L.) Skeels, a deciduous fruit-bearing tree that belongs to the Phyllanthaceae family, is commonly known as the Otaheite gooseberry or stargooseberry. Flavonoids, tannins, saponins, alkaloids, and other bioactive substances are abundant in the plant and contribute to its wide range of pharmacological actions, which include anti-inflammatory, hepatoprotective, antioxidant, and antibacterial properties. [1] Preliminary in vitro and in vivo studies have provided significant scientific evidence supporting the therapeutic applications of *Phyllanthus acidus*. This review aims to offer a comprehensive overview of the plant's pharmacognostic properties, traditional uses, phytochemical composition, and pharmacological potential. Additionally, it identifies areas where further research may be warranted. The evidence presented is based on data gathered from peer-reviewed journal articles, ethnobotanical literature, and internationally recognized scientific databases, including Elsevier, Google Scholar, PubMed, Scopus, Springer, Web of Science, and Wiley Online Library, covering studies published between 1935 and 2025.

INTRODUCTION

Phyllanthus acidus L. Skeels, the little tropical tree which belongs to the Phyllanthaceae family, can reach a height of 12 meters and is abundantly bearing pale-yellow, waxy fruits on its branches. [1]. Leaves are densely arranged in the branch. The leaves size is 2 to 7.5 cm long with a light green color. The flowers are male, female, or

hermaphrodite. Flower size is 5 to 12.5 cm long with pink color. Fruits are 2 cm in diameter and densely clustered. Fruit is edible and the color is white to yellow. Fruits contain high moisture and taste sweet and juicy [2]. It is a native plant widely utilized in traditional medicine for managing various ailments, including cough, fever, bronchitis, asthma, respiratory problems, high blood pressure, diabetes, rheumatism, pain,

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psoriasis, and other skin conditions^[3]. *Phyllanthus acidus* L. are widely recognized in traditional systems of medicine, particularly Unani and Ayurveda, due to their abundance of bioactive phytochemicals that support human health. Recent scientific investigations have highlighted multiple pharmacological properties of *Phyllanthus* species, including antioxidant, α -amylase inhibitory, α -glucosidase inhibitory, cholinesterase inhibitory, and antidiabetic activities.^[4]

TAXONOMICAL CLASSIFICATION^[5]

Kingdom	Plantae
Division	Spermatophyta
Subdivision	Angiosperma
Class	Dicotyledonae
Order	Euphorbiales
Family	Euphorbiaceae
Genus	<i>Phyllanthus</i>
Species	<i>acidus</i>

SYNONYM

The accepted name of the plant is *Phyllanthus acidus* (L.) Skeels, and it has been known by several synonyms including *Averrhoa acida* L., *Cicca acida* (L.) Merr., *Cicca acidissima* Blanco, *Cicca disticha* L., *Cicca nodiflora* Lam., *Cicca racemosa* Lour., *Diasperus acidissimus* (Blanco) Kuntze, *Phyllanthus acidissimus* (Blanco) Müll.Arg., *Phyllanthus cicca* Müll.Arg., *Phyllanthus cicca* var. *bracteosa* Müll.Arg., *Phyllanthus cochinchinensis* (Lour.) Müll.Arg., *Phyllanthus distichus* (L.) Müll.Arg., *Phyllanthus distichus* f. *nodiflorus* (Lam.) Müll.Arg., *Phyllanthus longifolius* Jacq., and *Tricarum cochinchinense* Lour.

VERNACULAR NAMES

- Sanskrit Name: Lavali
- English Name: Star gooseberry, Country gooseberry, Otaheite gooseberry

- Hindi Name: Harpharevadi, Lavali, Harphauri
- Bengali Name: Noyal, Harphal, Orboroi, Noyal, Loboni, Hariful
- Marathi Name: Rayaval, Harpharori
- Gujarati Name: Ghati aavla
- Tamil Name: Arinelli, aranelli, arainellikai
- Telugu Name: Rachyusarika
- Kannada Name: Karinelli
- Konkani Name: Rajamvali
- Manipuri Name: Gihori
- Urdu Name: Harphauri
- Sri Lanka: Rata Nelli, Nelli Bilin
- Spanish Name: Grosellero
- French Name: Cerisier de Tahiti

PHYTOCONSTITUENTS

The roots of *Phyllanthus* species contain diverse secondary metabolites including lignans (spruceanol, phyllanthusols), phenolic derivatives (phyllanes A–B, phyllaciduloids A–D), flavonoids and related compounds (acidoflavanone, acidoaurone, acidoisoflavone, 5-O-methylacidoauronol), as well as triterpenoids (glochidone, glochidonol, lupeol, α -lupene). Recently, novel constituents such as phyllanthacidoid U.^[6-9] The stem bark of *Phyllanthus* species contains triterpenoids (lupeol, β -amyrin), lignans (phyllanthol, phyllaciduloids A–D), as well as novel metabolites including phyacidusin A–B and a wide range of phyllanthacidoids (A–T, N1, A1).^[10] The leaves are rich in diverse phytoconstituents, including nucleosides such as adenosine and a wide range of flavonoids like kaempferol and its glycosidic derivatives [kaempferol-3-O-(2- α -L-rhamnopyranosyl)- β -D-glucuronopyranosyl methyl ester, kaempferol-3-O-[α -L-rhamnopyranosyl (1 $\rightarrow$ 2)]- β -D-galactopyranoside, and kaempferol-3-O-(2- α -L-rhamnopyranosyl)- β -D-glucuronopyranoside], together with rutin,



quercitrin, and myricitrin. Other reported compounds include phenolics such as hypogallic acid, triterpenoids like 29-norlupane-1 β -hydroxy-3,20-dione, and structurally unique dichapetalins (pacidusins A–D). Additionally, phyllane C, ovoideal, spruceanol, and fluacinoid^[11-13]. The fruits contain sitosterol- β -D-glucoside along with a variety of volatile constituents, including terpenes, esters, acids, and phenolic compounds, which contribute to their medicinal properties.^[14-16]

ETHANOMEDICINE USES

The fruit of *Phyllanthus acidus* has long been valued in traditional medicine for its distinct taste and therapeutic properties. It is described as somewhat bitter, aromatic, pungent, and sour, and is believed to stimulate appetite. In Ayurveda, the fruit is considered to increase *Vata* and is therefore employed in the treatment of bronchitis. Additionally, it has been traditionally used for managing biliousness, urinary concretion (stone-like deposits in the urinary tract such as kidney or bladder stones), urinary disorders, and piles.^[17] It is also believed to enhance blood quality, serve as a liver tonic, and act as a natural blood purifier, further highlighting its ethnomedicinal significance across generations.^[18] In India, the bark has only minimal application as a tanning agent. The root extract of *Phyllanthus acidus* is traditionally used to manage asthma and to relieve cough and headache. In the Philippines, a leaf decoction is employed for the treatment of urticaria, while the bark is used to alleviate catarrh. The mucilaginous nature of the leaves makes them useful as a demulcent in the treatment of gonorrhea.^[19]

PHARMACOGNOSTICAL ASPECTS

Morphological description ^[20]

Flowers : Small, reddish-pink, cushion-shaped cymes that appear at the nodes of leafless branches on older wood

Leaves : Leaves are pinnate, measuring 20–40 cm long, with alternate ovate to ovate-lanceolate leaflets borne on short petioles of up to 7.5 cm. The leaf surface is smooth and green above, while the underside is bluish-green with a waxy bloom; each pinnate leaf bears numerous leaflets with two minute pointed stipules at the base

Fruit : Drupaceous, oblate berries measuring 1–2.5 cm in diameter, occurring in dense clusters along the leafless branches and upper trunk. They are greenish-yellow to creamy-white, crisp, and juicy. Fruiting occurs twice annually in South India (April–May and August–September), whereas in other regions the main season is January with scattered fruiting throughout the year.

Bark : Rough, grey, and marked with prominent lenticels. Leaves are pinnate, measuring 20–40 cm long, with alternate ovate to ovate-lanceolate leaflets borne on short petioles of up to 7.5 cm.



Flowers



Leaves



Fruit



Bark

PHYTOCHEMICAL EVALUATION

Parameters	<i>p.acidus</i>
Alkaloids	Present
Flavanoids	Present
Tannin	Present
Glycoside	Present
Terpenoids	Present
Saponins	Present
Phenolic Compounds	Present
Sterols	Present

PHARMACOLOGICAL STUDIES

1. Hepatoprotective activity

Phyllanthus acidus (L.) Skeels fruit has been traditionally used in India as a liver tonic. In an experimental study, the hepatoprotective potential of a 70% ethanolic extract of *P. acidus* fruits (PAE) was evaluated against acetaminophen (APAP)-induced acute hepatotoxicity in Wistar rats. Hepatotoxicity was induced with a single oral dose of APAP (2 g/kg), while PAE was administered orally at doses of 125, 250, and 500 mg/kg. Pretreatment with PAE significantly protected against APAP-induced liver damage, as reflected by normalization of serum biochemical markers and histopathological improvements in liver tissues. PAE also restored depleted enzymatic and non-enzymatic antioxidants, reduced lipid peroxidation, and exhibited free radical scavenging activity (DPPH assay). Additionally, prolongation of pentobarbital-induced sleeping time suggested modulation of the cytochrome P450 system. Although silymarin (100 mg/kg) showed greater efficacy, the findings collectively demonstrate that *P. acidus* fruit extract confers hepatoprotection, likely through inhibition of P450-mediated APAP bioactivation, along with antioxidant and free radical scavenging mechanisms.^[21]

Phyllanthus acidus extracts, similar to silymarin, demonstrated significant hepatoprotective activity, as indicated by reduced serum levels of AST, ALT, ALP, and lipid peroxidation, along with increased levels of total protein, GSH, SOD, CAT, and GPx ($P < 0.01$ or $P < 0.05$) compared to controls. These biochemical findings were further supported by histopathological examination of liver tissues. Additionally, *P. acidus* extracts markedly reduced hexobarbitone-induced sleeping time in mice ($P < 0.01$) and exhibited strong DPPH free radical scavenging activity.^[22]

Administration of APAP or TAA in rats caused marked hepatic injury, reflected by elevated serum AST, ALT, ALP, and total bilirubin levels, along with reduced total protein. Treatment with *Phyllanthus acidus* extracts and silymarin significantly reversed these alterations, confirming their hepatoprotective effects. Notably, the aqueous extract exhibited greater potency than the ethanolic extract, which was supported by its higher phenolic (175.02 ± 4.35) and flavonoid (74.68 ± 1.28) content, as well as stronger DPPH radical scavenging activity ($IC_{50} = 33.2 \pm 0.31 \mu\text{g/mL}$).^[23]

2. α -Glucosidase inhibitory activity

Extracts of *Phyllanthus acidus* leaves and fruits prepared with different ethanol ratios were evaluated for antioxidant, α -glucosidase, and nitric oxide inhibitory activities. The 50% ethanol leaf extract showed the strongest α -glucosidase inhibition ($IC_{50} = 1.5 \mu\text{g/mL}$), moderate nitric oxide scavenging, and the highest phenolic content (33 mg GAE/g). Similarly, the 50% ethanol fruit extract exhibited the highest phenolic content (9.4 mg GAE/g), strong DPPH and nitric oxide scavenging, and potent α -glucosidase inhibition ($IC_{50} = 2.4 \mu\text{g/mL}$). UHPLC-MS/MS identified 30 compounds, mainly quercetin, kaempferol, epicatechin, and phenolic acid derivatives. These results highlight the potential of *P. acidus* as a natural source for managing diabetes and inflammation-related disorders.^[24]

The juice of *Phyllanthus acidus* was found to possess moderate levels of total phenolics and vitamin C but exhibited the strongest antioxidant activities, including radical scavenging and reducing power, as well as the highest α -glucosidase inhibitory activity (95.37%). These effects are attributed mainly to phenolic compounds such as gallic acid, ellagic acid, myricetin, and quercetin, suggesting its potential

as a natural source for managing oxidative stress and diabetes.^[25]

3. Cytotoxic activity

The in vitro cytotoxic potential of different leaf extracts (hexane, chloroform, ethyl acetate, acetone, and methanol) using the MTT assay on HEP-2 cancer cells and Vero normal cells. The ethyl acetate, acetone, and methanol extracts exhibited IC_{50} values of 46, 49, and 43 $\mu\text{g/mL}$, respectively, against HEP-2 cell lines. In contrast, none of the extracts showed cytotoxic effects on Vero normal cells.^[26]

Investigations on the roots of *Phyllanthus acidus* led to the identification of two structurally novel diterpenes, phyllanes A and B, together with the known cleistanthane-type diterpene spruceanol. Among these, phyllane B exhibited moderate cytotoxic effects, showing activity against K562 ($IC_{50} = 28.90 \mu\text{g/mL}$) and HepG2 ($IC_{50} = 45.23 \mu\text{g/mL}$) cell lines, whereas phyllane A and spruceanol were inactive.^[27]

Four new cleistanthane-type diterpenoids, designated phyllaciduloids A–D (1–4), have been isolated from the roots and stems of *Phyllanthus acidus* (Phyllanthaceae). Structural elucidation was achieved through comprehensive spectroscopic analyses. Notably, phyllaciduloids B–D (2–4) feature an unusual C-7/C-16 ether linkage, a structural motif rarely encountered among diterpenoids. All isolates were further assessed for cytotoxic activity against a panel of five human cancer cell lines.^[28]

3. Antimicrobial activity

The ethanol extract of *Phyllanthus acidus* bark was reported to contain alkaloids, glycosides, and steroids. It exhibited moderate cytotoxicity in the brine shrimp lethality assay ($LC_{50} = 501.19$



µg/mL) and showed notable antibacterial activity specifically against Gram-negative bacteria, including *E. coli*, *S. typhi*, and *V. cholerae*. These findings indicate the bark as a potential source of bioactive antibacterial constituents.^[29]

Methanolic extracts of *Phyllanthus acidus* pulp and seed showed high phenolic/flavonoid content with strong antioxidant activity ($IC_{50} \approx 6$ µg/mL). Both extracts exhibited notable cytotoxicity in the brine shrimp assay ($LC_{50} \approx 6-7$ µg/mL) and mild to moderate antimicrobial activity, with the pulp extract most active against *Pseudomonas aeruginosa*.^[30]

Phyllanthus acidus, belonging to the *Phyllanthaceae* family, produces small edible yellow fruits that are crisp, juicy, and borne in clusters. The present study evaluated the phytochemical profile, antibacterial potential, and antioxidant activity of its acetone fruit extract. Screening confirmed the presence of flavonoids, tannins, phlobatannins, saponins, terpenoids, and glycosides. Antibacterial assays (well diffusion method) revealed moderate to good inhibition, particularly against *E. coli* and *P. aeruginosa*. The extract showed high phenolic (122.22 mg/g GAE) and flavonoid content (163.15 mg/g QE). In antioxidant studies, the DPPH radical scavenging activity increased with concentration, with an IC_{50} of 7.31 µg/mL, surpassing that of ascorbic acid (8.65 µg/mL). These findings suggest *P. acidus* fruit extract possesses significant antibacterial and antioxidant properties.^[31]

5. Antioxidant activity

Phyllanthus acidus leaves demonstrate notable anti-inflammatory, analgesic, and antioxidant activities, largely influenced by solvent type. Methanol extract at 500 mg/kg showed superior effects, comparable to standard drugs, while ethyl acetate and petroleum ether extracts were less

effective. The methanol extract contained high levels of phenolics (73.08 ± 0.682 mg GAE/g) and flavonoids (61.28 ± 0.062 mg QE/g), correlating with its strong antioxidant capacity. These phytochemicals are likely responsible for modulating oxidative stress, inflammation, and pain pathways. Similar bioactivities have been reported in related *Phyllanthus* species, supporting the role of polyphenolic compounds as key contributors. Collectively, *P. acidus* leaves represent a promising natural source of antioxidants and therapeutic agents for inflammation-related disorders.^[32]

The methanolic extract of *Phyllanthus acidus* (MEPA) was found to be rich in phenolics (116.98 mg GAE/g) and flavonoids (168.24 mg QE/g), contributing to its strong antioxidant potential. MEPA demonstrated high radical scavenging activity in DPPH (84.33%, $IC_{50} = 15.62$ µg/mL) and hydroxyl radical assays (77.21%, $IC_{50} = 59.74$ µg/mL), along with moderate lipid peroxidation inhibition ($IC_{50} = 471.63$ µg/mL) and metal chelation capacity ($IC_{50} = 308.67$ µg/mL). Additionally, MEPA inhibited acetylcholinesterase and butyrylcholinesterase in a dose-dependent manner, with IC_{50} values of 1009.87 µg/mL and 449.51 µg/mL, respectively, indicating potential neuroprotective properties.^[33]

Phyllanthus acidus, a member of the Euphorbiaceae family, has been evaluated for its antioxidant and cytotoxic potential using various solvent extracts. Extraction yields ranged from 1.13% to 20.25%, with ethanol providing the highest yield and water the lowest. Interestingly, the water extract showed the strongest antioxidant activity ($IC_{50} = 26.06$ µg/mL) and the highest cytotoxic potency in the brine shrimp lethality assay ($LC_{50} = 473.26$ µg/mL), whereas ethanol extract displayed the weakest activity. These results suggest that polar extracts of *P. acidus* may



be rich in bioactive compounds with therapeutic relevance.^[34]

Water was identified as the most suitable solvent for *Phyllanthus acidus* leaf extraction, yielding the highest levels of bioactive compounds with strong in vitro antioxidant activity. The crude water extract effectively inhibited lipid oxidation, demonstrated radical scavenging and cation decolorization, and showed notable reducing power in minced pork. These findings highlight the potential application of *P. acidus* leaf extract as a natural antioxidant in the meat industry.^[35]

Phyllanthus acidus seed extract (PSE) showed notable antioxidant activity (DPPH IC_{50} = 28.26 μ g/mL; ABTS IC_{50} = 23.44 μ g/mL) and inhibited α -amylase and α -glucosidase, supporting its antidiabetic potential. In vivo, PSE (200 mg/kg) significantly reduced blood glucose in normoglycemic and STZ-induced diabetic rats, with effects comparable to glibenclamide. These findings suggest PSE as a promising candidate for diabetes management.^[36]

Phyllanthus acidus stem bark contains phenols, flavonoids, tannins, and terpenoids, with total phenolic and flavonoid contents of 189.74 mg GAE/g and 38.92 mg QE/g, respectively. Methanolic and aqueous extracts exhibited strong antioxidant activity (IC_{50} $\approx$ 26.5 μ g/mL), comparable to ascorbic acid. HPTLC and FTIR analyses confirmed multiple phytoconstituents and phenolic functional groups, supporting its ethnopharmacological use as a natural antioxidant and providing reference data for quality control.^[37]

Phyllanthus acidus, a seasonal tropical plant with traditional medicinal use, has been evaluated for its in vitro bioactivities. Fruit extracts obtained using hexane, chloroform, ethyl acetate, and methanol were rich in flavonoids, terpenoids, and tannins. Methanol and ethyl acetate extracts

exhibited strong antioxidant activity, including DPPH, ABTS, hydrogen peroxide, and nitric oxide scavenging, with over 90% inhibition at 500 μ g/mL, while only the methanolic fraction showed significant nitric oxide scavenging (75.99%). These findings highlight the potential of *P. acidus* fruit as a natural antioxidant and therapeutic dietary supplement.^[38]

Phyllanthus acidus fruits are rich in secondary metabolites with significant antioxidant activity. Lignan 13 and phenylpropanoid 15 exhibited strong ABTS+ radical scavenging (IC_{50} = 203.7 and 232.9 μ M), comparable to Trolox, while terpenoids showed no cytotoxicity. These results highlight the fruits as a promising source of natural antioxidants.^[39]

6. Diuretic effect

Ethanol extracts of *P. acidus* (22.5–90 mg/kg bw) enhanced urine output in rats within 60 minutes of administration compared to control, though less effectively than furosemide (3.6 mg/kg bw, $P < 0.05$). Sodium excretion was significantly increased at 22.5 and 45 mg/kg, and potassium excretion at 45 and 90 mg/kg, relative to control, but remained lower than furosemide ($P < 0.05$).^[40]

7. Teratogenicity

Phyllanthus acidus (L.) Skeels, known for hepatoprotective, anti-inflammatory, antidiabetic, and antioxidant activities, has limited safety data during pregnancy. A study on pregnant Wistar rats evaluated ethanol leaf extract (EEPA) at 22.5, 90, and 1000 mg/kg from gestational days 6–15. EEPA caused mild maternal toxicity, evidenced by reduced fetal weight and litter size, but did not induce major skeletal or organ malformations. At the highest dose (1000 mg/kg), fetal kidneys, heart, and lungs were smaller and paler. These results suggest EEPA may affect fetal growth at



high doses, highlighting the need for further studies to assess its prenatal safety.^[41]

8. CNS Depressant, Antidiarrheal and Antipyretic activities

Ethanollic extracts of *Phyllanthus acidus* leaves exhibit significant CNS depressant, antidiarrheal, and antipyretic activities in animal models. The extract showed dose-dependent CNS depressant effects in hole cross, hole board, and open field tests, likely mediated via potentiation of GABAergic neurotransmission. Phytochemicals such as flavonoids, alkaloids, saponins, and steroids may contribute to this activity by acting on GABAA_A receptors. The extract also demonstrated antidiarrheal effects in castor oil- and barium sulfate-induced models, likely through inhibition of prostaglandin synthesis, antisecretory effects, and reduced intestinal motility. Additionally, intraperitoneal administration of the extract significantly reduced yeast-induced fever, suggesting antipyretic activity via inhibition of prostaglandin production.^[42]

9. Nephroprotective effect

Phyllanthus acidus fruit, widely used by native communities in Northeast India for its ethnomedicinal properties, was evaluated for nephroprotective effects in a gentamicin-induced mice model. Nanoparticles synthesized from fruit juice (PANH) and raw fruit juice (PAJH) were compared at low and high doses. High-dose PANH significantly reduced creatinine and urea levels, enhanced antioxidant enzymes (SOD, CAT, GSH), and improved glomerular structure compared to gentamicin-treated controls. In silico docking suggested inhibitory effects of both fruit juice and nanoparticles on the inflammatory protein NF κ B. PANH demonstrated superior nephroprotective activity over PAJH, highlighting

its potential as a therapeutic agent for kidney disorders.^[43]

10. Others

Pulmonary fibrosis (PF) is a progressive and often fatal condition characterized by alveolitis leading to interstitial fibrosis, with usual interstitial pneumonia as its pathological hallmark. A study evaluated the protective effects of ethanolic extract of *Phyllanthus acidus* (PAE) fruit against bleomycin-induced PF. Phytochemical analysis revealed the presence of alkaloids, saponins, phenols, flavonoids, tannins, and terpenoids. In bleomycin-treated mice, PAE administered at 100–400 mg/kg reduced oxidative stress markers, including malondialdehyde (MDA), while enhancing antioxidant enzymes (SOD, CAT, GPx). Additionally, elevated bronchoalveolar lavage fluid cell counts were normalized in treated groups. These findings suggest that *P. acidus* fruit exhibits protective effects against bleomycin-induced pulmonary fibrosis, likely through antioxidant and anti-inflammatory mechanisms.^[44]

11. Toxicity studies.

Several studies indicate that fruit and leaf extracts of *Phyllanthus acidus* are safe, showing no adverse effects in both in vitro and in vivo models. The study evaluated the toxicity and oral glucose tolerance of *Phyllanthus acidus* leaf extract (PAE) in Wistar rats. PAE was administered orally at doses of 0, 1,000, 1,500, and 2,000 mg/kg daily for 14 days. Toxicity assessment showed no mortality or overt signs of toxicity. Body weight, organ weight, blood chemistry, and most hematological parameters (WBC, MCV, PLT, PCT, MPV, PDW, BUN, creatinine, ALP) remained unaffected. However, RBC count, hematocrit, lymphocyte count, and hemoglobin were significantly reduced at 1,500 mg/kg. In oral glucose tolerance tests, a



single dose of PAE (250 mg/kg) did not significantly alter blood glucose levels compared to control or glibenclamide-treated groups, indicating no hypoglycemic effect in normal or glucose-loaded rats^[45].

CONCLUSION

Phyllanthus acidus is rich in diverse phytoconstituents, including alkaloids, flavonoids, saponins, tannins, phenols, and terpenoids, which contribute to its medicinal properties. These bioactive compounds underpin the plant's wide-ranging pharmacological activities. Pharmacologically, *P. acidus* has demonstrated anti-inflammatory, hepatoprotective, antioxidant, antibacterial, analgesic, neuroprotective, antidiarrheal, antipyretic, and nephroprotective effects in various in vitro and in vivo studies. Toxicity studies indicate that the plant is generally safe, though further research is needed to fully explore its therapeutic potential, optimize applications, and establish standardized clinical dosages.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest relevant to this article.

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