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Phytochemical And Pharmacological Activities Of Wood Apple: A Systemic Review

Dr. Akash Meghwal[1*], Dr. Manoj Adlakha[2], Dr. Nikita Panwar[3], Dr. Prem Kumar[4], Prof. Chandan Singh[5], Dr. Rajendra Prasad Purvia[6]

[1*]MD scholar, PG dept of Dravyaguna vigyan, PGIA DSRRAU Jodhpur
[2]Associate professor, PG dept of Dravyaguna vigyan PGIA DSRRAU Jodhpur
[3]Assistant professor, PG dept of Dravyaguna vigyan PGIA DSRRAU Jodhpur
[4]Assistant professor, PG dept of Shalya tantra, PGIA DSRRAU Jodhpur
[5]Head, PG dept of Dravyaguna vigyan PGIA DSRRAU Jodhpur
[6]Associate professor, PG dept of Dravyaguna vigyan PGIA DSRRAU Jodhpur

ABSTRACT

Background: Wood apple, botanically known as Feronia elephantum syn. Limonia acidissima, is a member of the Rutaceae family and has been valued in Ayurveda for its multifaceted medicinal properties. Traditionally used in managing various ailments, the plant is reported to be rich in significant pharmacological activities that include hypoglycaemic, hepatoprotective, antitumor, antimicrobial, and larvicidal effects, among others. The observed therapeutic benefits of this plant are attributed to bioactive phytochemicals, including alkaloids, flavonoids, polyphenols, lignans, and terpenoids. Despite its extensive use in traditional medicine, its phytochemical and pharmacological profile needs consolidation through a systematic review.

Objectives: The present review aims at compiling and analysing the existing scientific literature on the phytochemical composition and pharmacological activities of Wood apple, providing full insight into its medicinal potential.

Methods: This study presents a critical review of the literature about Wood apple, conducted in major databases like PubMed, ScienceDirect, Web of Science, Scopus, and Google Scholar for articles published between 2010 and 2024. The search was conducted by using keywords such as Wood apple, Feronia elephantum, Limonia acidissima, phytochemistry, and pharmacological activities associated with Boolean operators (AND/OR). Based on a structured selection process, only studies that described the phytochemical constituents and pharmacological activities of Wood apple were included.

Results: A review of literature revealed the presence of bioactive principles, which are responsible for its therapeutic use. Experimental studies indicated that Wood apple possesses antidiabetic, hepatoprotective, antimicrobial, Anti-hyperlipidaemic and anti-inflammatory activities. Besides, preclinical studies have pointed out its potential role in fighting against oxidative stress and metabolic disorders.

Conclusion: Wood apple (syn. F. elephantum, L. acidissima) is a rich source of bioactive phytochemicals like flavonoids, coumarins, alkaloids, essential oils, phenolic compounds, tannins, steroids, triterpenoids, carbohydrates, and amino acids. These are the constituents responsible for the wide pharmacological activities of this plant and, therefore, represent an important plant within traditional and modern medicine. Further research is needed to explore the full potential of F. limonia in drug development and nutritional applications.

Keywords: Wood apple, *Feronia elephantum*, *Limonia acidissima*, phytochemistry, pharmacological activities, traditional medicine, bioactive compounds.

1. INTRODUCTION

Human has been very close to the nature with its evolution and through thousands of years of observation process, it has come to know the medicinal properties of various plants and they are being used by human as traditional medicine to treat diseases. These medicinal plants having therapeutic activities as anthelminthic, antibacterial, antiviral, antifungal, antidiabetic, anticancer, anti-inflammatory, diuretic, antihyperlipidemic, antipyretic etc., due to presence of various phytochemicals such as alkaloids, flavonoids, polyphenols, lignin's, terpenoids etc. Numerous herbal plants and their formulations to treat the diseases are reported in Ayurveda.

Feronia elephantum, member of the family Rutaceae, is described in Ayurveda as *Kappitha,* has been used medicinally for thousands of years to treat the various diseases or clinical conditions by traditional healers. It is a religious plant which is native to Indian subcontinents.[1] Almost all part of the plant is used for various medical conditions. It has hypoglycaemic, hepato-protective, antitumor, antimicrobial and larvicidal activity.[2]

2. METHODOLOGY

Information regarding phytochemicals and pharmacological activities of F. elephantum was collected from different online databases such as PubMed, Science direct, Web of science, Scopus, Google scholar, Science direct, etc., and literatures published from 2010 to 2024 were searched thoroughly for relevant articles. The keywords *Feronia elephantum, F. limonia, Limonia acidissima, Anisifolium limonia, Crateva balangas, Crateva vallanga, Feronia balanghas,* phytochemistry, pharmacological activities, combined with "AND" and "OR" Boolean operators were used. Relevant appropriate research article containing phytochemical analysis and pharmacological potentials were retrieved. Article retrieval and screening process is presented in **Figure 1**.

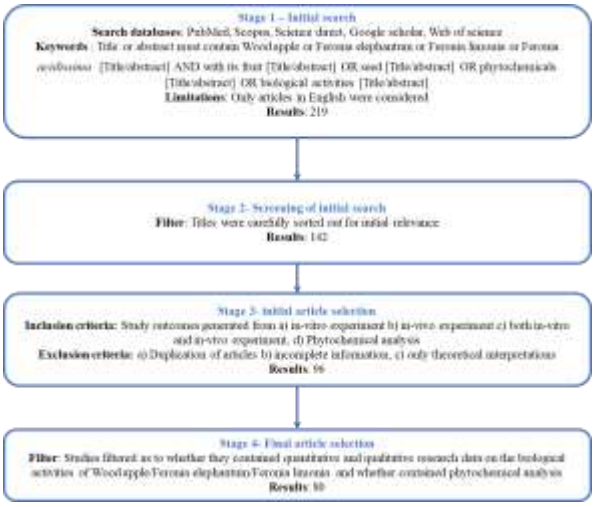

Figure 1 Showing steps for selection of articles

3. PLANT DESCRIPTION

3.1 Taxonomic classification and common name

Kingdom: Plantae
Phylum: Tracheophyta
Class: Magnoliopsida
Order: Sapindales
Family: Rutaceae
Genus: *Feronia*
Species: *elephantum* [3]

3.2 Synonyms

L. acidissima L., *F. limonia* (L.) *Anisifolium limonia* Kuntze, *Crateva balangas* K.D.Koenig, *Crateva vallanga* K.D.Koenig, *Feronia balanghas* K.D.Koenig.[4]

3.3 Vernacular name:

Sanskrit: *Kapittha, Kapipriya, Dadhiphala, Surabhicchada, Puspa phala, Dadhittha, Dantasatha.*[5]
Hindi: *Kaith*
Bengali: *Kathabel*
Tamil: *Velaga*
Malayalam: *Vilavu*
English: Elephant Apple, Wood Apple

4. MORPHOLOGICAL STUDIES

Size: A small deciduous glabrous tree, with slander branches having rough and spiny bark, approximately 9 meter in height. It is habituated for monsoon climate but can be survive in drought area light soils. Leaves having thick imparipinnate and are alternatively arranged. 5-7 leaflets about 25-30 millimetres in length and 10-20 millimetres in width are present in leaves (**Figure 2**). Citrus cent is evaporated on crushing the leaves. Its flowering season is between February to March month.

Its fruiting period is during cold season i.e. about October to November months. Fruits are globosely round, grey-white in colour, rough and woody hard and 2-3 inch in diameter. Inside the hard rind it contains a pulpy core which is brownish and aromatic resinous in nature. The pulp is sour or sweet in taste and a number of small whitish seeds are embedded in it.[1,6]

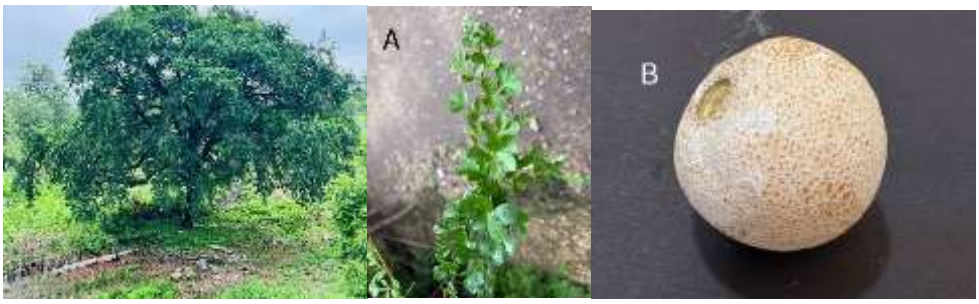

Figure 2 Wood apple tree in a natural habitat and A. Leaf, B. Fruit

Representation images of Wood apple tree, leaves and fruit are showing in Figure 2.

5. NATURAL DISTRIBUTION

Kapittha is indigenous to India, Pakistah, Mayanmar, Malaysia and Java, China and other part of Southeast Asia.[2] It is widely distributed in almost all part of India.[7] The *Feronia elephantum* Correa (F.E.), *F. limonia* swingle (F.L.), *L. acidissima* (l.a), and *Schinus limonia* (s.c) are the species of Feronia which is mainly found in India.[5,3] **Figure 3** is showing worldwide distribution of Wood apple.

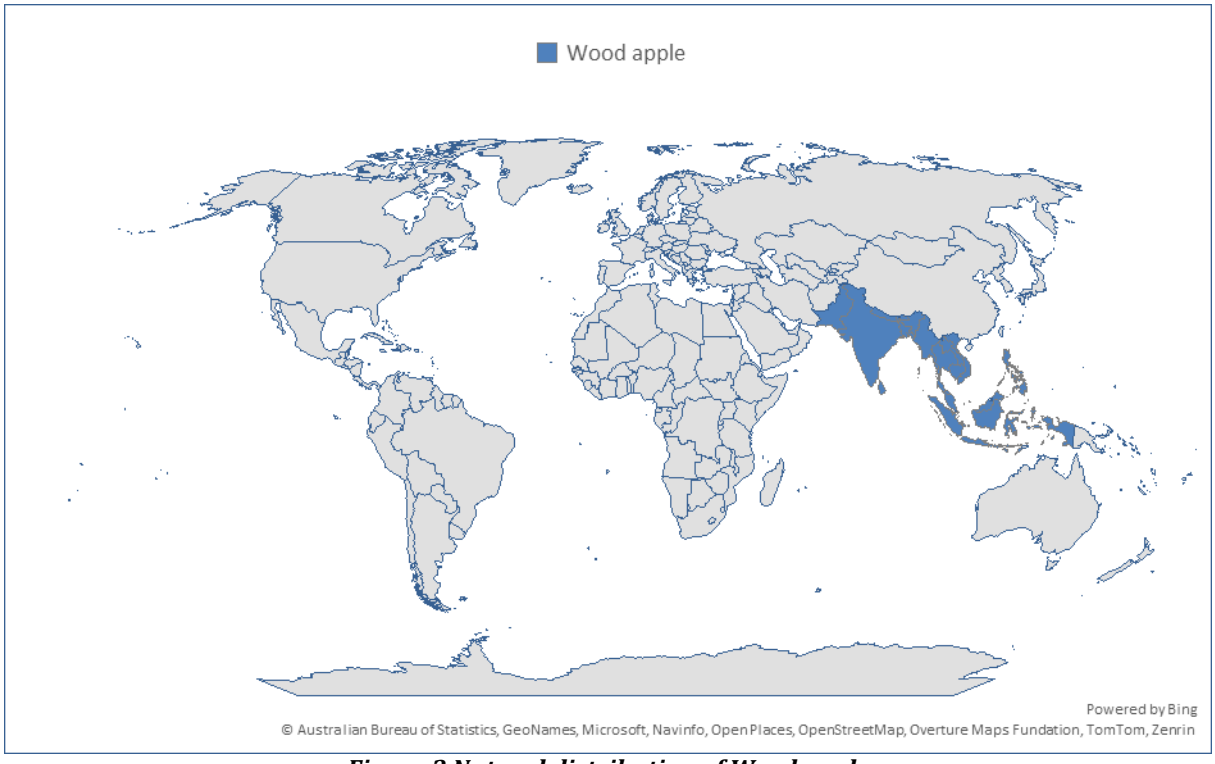

Figure 3 Natural distribution of Wood apple

6. ETHNOMEDICINAL USES

Ethnomedicinally its various parts have been utilized by folklore to treat various medical conditions.

6.1 Unripe fruits:

Its unripe fruit is *amla* (sour), *ushana*, *ruksha*, *laghu*, and astringent in nature. They are alexipharmic and balancing the vitiated *Kapha dosha*. It is used in chronic diarrhoea, dysentery, hiccup, itching, pharyngodynia, constipation and dyspepsia. It is also used to treat the whooping cough.[8]

6.2 Ripe fruits:

The ripe fruit of *F. elephantum* is sour-sweet in taste, *kashaya* (astringent), *grahi* (absorbent), *ruchijanaka* (taste-producing), *śītavīrya* (as of cooling virtues or properties), *veery vardhak* (semen enhancer), *Duṣpācya* (hard to digest) and pacifying the vitiated *tridosha* but specifically *vata* and *pitta dosha*. It is used to treat the *Śvāsa roga* (~asthma), *kṣayarōga* (~tuberculosis), diseases due to aggravation of *rakta dosha*, *vaman* (vomiting), hiccup, cough, and poisoning. They are carminative and used as appetizer.[8]

6.3 Seed and seed oil:

Its seeds are used to treat the heart disease, headache, erysipelas and poisoning. Oil of the seeds is *kashaya*, *grahi*, *ruchikara* (palatable), and balancing the vitiated *pitta* and *kapha dosha*. It is used to cure the hiccup, cough, and vomiting.

6.4 Pulp:
Its pulp is used to manage the diabetes mellitus, amoebiasis and locally for venous bug bites.[8,9]

6.5 Leaves and flowers:
Its leaves are used in anorexia, vomiting, hiccough, pneumonia, diarrhoea and cough. The juice of the leaves is useful in ear colic. Its flowers are useful to reduce the effects of toxin.[8,9]

6.6 Gum:
It is useful in diarrhoea, dysentery, gastritis, haemorrhoids, and diabetes.[8,9]

7. PHYSICO-CHEMICAL PARAMETERS

Physicochemical parameters such as ash values, moisture content, extractive values, and fluorescence analysis are essential for evaluating the purity and quality of medicinal plants. The key physicochemical findings for Wood apple leaves, bark, and stem are presented in **Table 1**.

Table 1. Physico-chemical parameters of various part of Wood apple.

Parameter	Volume % w/w (Leaves)	Volume % w/w (Bark)	Volume % w/w (Stem)	Volume % w/w (Fruit pulp)	Reference
Total Ash Value	10.16% ± 0.33	8.56%	10.00%	1.55%	10, 11, 12, 13,14
Acid Insoluble Ash	4.13% ± 0.08	0.90%	5.50%	17.6%	10, 11, 12, 13,14
Water Soluble Ash	0.46% ± 0.03	4.8%	2.16%	41.2%	10, 11, 12, 13, 14
Moisture Content	-	4.9%	7.55%	78.62%	11, 12, 13, 14, 15
Loss on Drying	-	11.46%	-	-	11, 13
Water Soluble Extractive	9.06% ± 0.34	3.32%	5.7%	-	10, 12, 13, 15
Alcohol Soluble Extractive	5.43% ± 0.23	3.12%	2.7%	-	10, 12, 13, 15
Petroleum Ether Extractive	1.90% ± 0.05	0.72%	-	-	10
Sulphated Ash	-	-	16.30%	-	12
Crude Protein	-	-	-	3.76%	14
Crude Fibre	-	-	-	2.95%	14
Crude Fat	-	-	-	2.50%	14
Carbohydrate Content	-	-	-	10.62%	14
Energy Value (Kcal/100g)	-	-	-	80.00	14

8. PHYTOCHEMISTRY

F. elephantum possesses a diverse phytochemical composition including flavonoids, coumarins, alkaloids, essential oils, phenolic compounds, tannins, steroids, triterpenoids, carbohydrates, and amino acids. Some flavonoids include 5,7-dihydroxy-6,8-dimethoxyflavone-7-O-β-D-glucopyranoside[16] and luteolin from the fruit pulp were identiied.[17, 18] Coumarins, such as marmesin, have been isolated from the fruit pericarp and stem bark.[19,20,21] In addition, a novel alkaloid named as feronine and several alkaloid precursors have been reported by Pitchai et. al..[22] Terpenes and phenolics compounds such as limonene, α-pinene, β-caryophyllene, linalool, and geraniol are the major constituents of the essential oils obtained from leaves and fruit pulp.[23, 24] Phenolic compounds and tannins were obtained by using solvent concentration methods.[25] Some steroids and triterpenoids, such as β-sitosterol and lupeol, have been identified in the stem bark.[12] Its fruit has a rich source of carbohydrates and amino acids, including leucine, isoleucine, and valine.[26, 27] These compounds are responsible for the plant's medicinal and nutritional properties. Major compounds of *F. elephantum* are presented in **Table 2.**

Table 2 Showing major phytochemicals in different parts of Wood apple

S.N.	USED PART	EXTRACT	METHOD	PHYTOCHEMISTRY SUMMARY	REFERENCES
1	**Flowers**	Acetone Extract	Column Chromatography	p-coumaric acid, Bergapten, N-phenylpropanamide, N-(2-methylphenyl) acetamide, N-(4-methoxyphenyl) acetamide, A novel compound 5-hydroxy-3-(1,2 dihydroxyprop-1-enyl)-1-methylquinolin-4-on. 1-[4-aminomethyl] (phenyl).	22

2	**Fruit**	Methanol Extract	FTIR, GC-MS Analysis,	Alkaloid and saponins, Flavonoids, Phenols, Alkanes, Amino acids, α, β-unsaturated esters, Nitro compounds, Aromatics, Aliphatic amines, Carboxylic acid, and Alkyl halides functional groups, Linoleic acid, Octadecanoic acid, Hexadecanoic acid, Maltol, Vinly guaiacol, Furanone, Ascorbic acid, Luteolins, fixed oil.	3 , , 2, 16,28, 29, 30
			FTIR, H-NMR, and LC-MS studies.	Luteolin - 2-(3,4-dihydroxyphenyl)-5,7-dihydroxy-4H-chromen-4-one, (C15H10O7).	31
			GC-MS Analysis	2,5- Furandione, dihydro-3-methylene (44.78%), n-Hexadecanoic acid (6.62%), 5-Eicosene, (E)- (4.04%), cis-13-Octadecenoic acid (6.08%) and γ-Sitosterol (2.99%), cis-Aconitic anhydride (5.19%), Ethanol, 2,2'-[(1-methylethyl) imino]bis- (6.27%) and Propanedioic acid, ethyl-, diethyl ester, and Dodecanoic acid (4.48%).	32
			Column Chromatography	5,4-dihydroxye3-(3-methyl-but-2-enyl) 3,5,6-trimethoxy-flavone-7-O-b-D glucopyranoside.	16
		Soxhlet Sequential Extraction	Reverse Phase-High Pressure Liquid Chromatography.	**Essential amino acids- Highest** -Isoleucine, Phenylalanine and Tryptophan, **Moderate**- Valine, Histidine and Leucine, Lowest- Methionine, Tyrosine, Lysine and Threonine. **Non-essential amino acids-** Proline, Glycine, Aspartic acid, and Alanine.	26
			Column Chromatography, TLC	Alkaloids, Carbohydrates, Glycosides, Saponins, Flavonoids, Tannins, Phenolic Compounds, Vitamin-C, Proteins, Phytosterol, Triterpenoids and Amino acids.	33, 34
			Gas Chromatography – Mass Spectroscopy (GCMS).	Oleic acid, n-hexadecanoic acid, Palmitoleic acid, and Octadecanoic acid. Sterols - Sitosterol, Stigmasterol, Ergost5-en-3-ol, (3beta.).	28
3	**Rind**	Methanolic	GC-MS chemical analysis	Alkaloids, Saponins, Gum and Mucilage.	2
		Aqueous Extract	GC-MS Analysis	Alkaloid, Tannin, Phenol, Flavonoid, Glycosides, Saponins, Triterpenoids, Gum and Mucilage.	35
		Methanolic	GC-MS chemical analysis	Alkaloids, Saponins, Gum, Mucilage, Flavonoids, Steroids, Glycosides, Carbohydrates, and Phenolic Compounds.	3, 35
		Methanol Extract	Vacuum Liquid Chromatography, Flash Chromatography, Radial Chromatography	3 Coumarins -Auraptene, Osthol, And Xhantotoxin.	20
		Ethanol Extract	GC-MS Analysis	2–Propenenitrile, 3–(3.4-dimethoxyphenyl)–(60.72%), Phenol, 4–(3-hydroxy-I-propenyl)-2-methoxy–(9.35%), 3-(2-NAcetyl–N-methylaminoethyl)indol (1.15%), cholesta–8,24–dine–3–ol, 4–methyl–(3a'-4a')– (0.86%).	36
5	**Seed**	Methanol Extract	GC-MS chemical analysis	Alkaloids, Flavonoids, Saponins, Gum and mucilage, and Fixed oil.	35
6	**Root**	Soxhlet Sequential Extraction	UV, IR, NMR and mass spectral studies.	Flavonoid - 5-hydroxy-2- (4-hydroxyphenyl)-7-methoxy-6-(3-methylbut-2-enyl) chroman-4-one (First isolation)* along with Imperatorin, Bergapten And Xanthotoxin.	37
7	**Leaves**	Methanolic extract	Column Chromatography, TLC	Alkaloids, Carbohydrates, Glycosides, Saponins, Proteins and amino acids, Phytosterols, Phenolic compounds, Flavonoids and Resins.	10, 38, 39, 40
		Soxhlet Sequential Extraction	UV, IR, NMR and mass spectral studies.	Flavonoid - 5-hydroxy-2- (4-hydroxyphenyl)-7-methoxy-6-(3-methylbut-2-enyl) chroman-4-one (First isolation) along with Imperatorin, Bergapten and Xanthotoxin.	37

		Hexane and Ethyl acetate Extract	Column Chromatography Followed by GC-MS Analysis,	Estragole (50.82%), Trans-anethole (p-propenylanisole, anise camphor) (14.98% and Caryophyllene (9.22%).	41
		Aqueous extract	Preliminary Phytochemical screening by standard method of Kokate and Harborne	Saponins, Tannins, Proteins, Carbohydrates and Flavonoids.	9
		Ethanol Extract	GC-MS ANALYSIS	7– Norbornadienyl t-butyl ether (17.26%) , 2–isopropyl–5-methyl–1– heptanol (11.40%), 1–Octanol,2–butyl (8.47%), Phenol, 4–[2–(dimethylamino)–ethyl]– (4.56%), 2,3–Dimethylquinolin-4(1H)–one (3.58%), Ethyl iso–allocholate (1.63%).	36
			Column Chromatography and Standard methods	Carbohydrates, Steroids/ Terpenoids, Flavonoids, Tannins, Phenols, Glycoside, Flavonoids, and Flavonol.	42, 43, 44, 45
8	**Essential Oil of Leaf**	Oil	GC-MS ANALYSIS	Estragole, Cis-dihydro-β-terpineol and P-cymene β-pinene (28.4%), Z-anethole (22.1%), methyl chavicol (12.0%) and E-anethole (8.1%). Eudesma-4 (14)11-dine (46.3%), Carvacrol (29.6%) and 1,5-cyclodecandine (13.4%).	23, 46, 47
9.	**Essential Oil from Fruit Pulp**	Oil	GC-MS ANALYSIS	Thymol (52.22%), Dodecanoic acid (19.34%), α-pinene (4.02%), Carvacrol (3.86%), Camphoric acid (3.25%) and Caryophyllene oxide (3.06%).	24

*(Fourier transformation – infra – red (FT – IR) spectrum)

9. PHARMACOLOGICAL ACTIVITIES OF F. LIMONIA

The phytochemical constituents of *F. limonia* contribute to its diverse pharmacological activities, including antioxidant, antimicrobial, hepatoprotective, cytotoxic, and anti-inflammatory properties.

9.1 Antioxidant Activity

The antioxidant activity of *F. limonia* has been extensively studied. Srivastava et al. (2021) demonstrated that the phenolic compounds and flavonoids present in the plant exhibit strong free radical scavenging activity.[25] The study found that the antioxidant activity of *F. limonia* is comparable to that of ascorbic acid, a well-known antioxidant. Similarly, Senthilkumar and Venkatesalu (2013) reported that the essential oil from the fruit pulp of *F. limonia* possesses significant antioxidant activity, as measured by the DPPH radical scavenging assay.[24]

In a study by Vikhe et al. (2021), the aqueous extract of *F. limonia* gum demonstrated significant antioxidant activity by scavenging free radicals and reducing lipid peroxidation. The extract also increased the levels of antioxidant enzymes such as SOD, CAT, and GPx, which protect cells from oxidative damage.[48]

Daphedar et al. reported that silver nanoparticles synthesized from *L. acidissima* fruit extract exhibit strong antioxidant activity due to their high phenolic and flavonoid content, neutralizing free radicals and reducing oxidative stress.[49] Similarly, Nyoe et al. found that extracts of L. acidissima fruit possess significant antioxidant properties and antimicrobial activity against Staphylococcus aureus and Escherichia coli.[14]

The antioxidant potential of *L. acidissima* stem bark was evaluated using the DPPH free radical scavenging assay. The chloroform soluble fraction exhibited strong antioxidant activity with an IC50 value of 18.8 ± 1.24 µg/ml, comparable to the standard antioxidant Butylated hydroxytoluene (BHT) with an IC50 of 17.69 ± 2.36 µg/ml. The petroleum ether fraction showed moderate activity with an IC50 value of 37.64 ± 3.87 µg/ml. These results suggest that the chloroform fraction is rich in phenolic compounds contributing to its potent free radical scavenging capacity.[50]

The methanolic extract of *F. limonia* fruit pulp (MEFL) demonstrated potent radical scavenging capacity against DPPH and ABTS radicals and showed high total antioxidant activity via the phosphomolybdate method. This antioxidant potential was positively correlated with its total phenolic content, suggesting that the phenolic compounds contribute to its free radical scavenging effects, highlighting its potential as a natural dietary antioxidant source.[51] Similarly, the crude methanol

extract (CME) of *F. limonia* bark and its chloroform fraction (CLF) displayed strong antioxidant activities in DPPH and hydroxyl radical scavenging assays, with the CLF showing the highest phenolic and flavonoid content (18.16 µg GAE/g and 160.20 µg GAE/g, respectively). The study identified Umbelliferone (7-hydroxycoumarin) as a key antioxidant compound isolated from the chloroform fraction, which also demonstrated notable lipid peroxidation inhibition capacity.[52] Furthermore, essential oil extracted from *F. elephantum* (syn. *F. limonia*) leaves exhibited substantial antioxidant activities, including DPPH and hydroxyl radical scavenging and metal chelating activities, which could be beneficial for food preservation and therapeutic applications.[53] Additionally, an aqueous extract of *L. acidissima* (syn. *F. limonia*) fruit pulp and rind showed a dose-dependent increase in antioxidant activity, validated by the phosphomolybdenum assay, underscoring the fruit's potential in mitigating oxidative stress.[54]

9.2 Antimicrobial Activity

The antimicrobial activity of *F. limonia* has been attributed to its essential oils and alkaloids. Senthilkumar et al. (2010) reported that the leaf essential oil of *F. limonia* exhibits strong antibacterial activity against Gram-positive and Gram-negative bacteria, including Staphylococcus aureus and Escherichia coli.[23] The study found that the antibacterial activity of the essential oil is due to the presence of terpenes and phenolic compounds. Similarly, Pitchai et al. (2012) demonstrated that the alkaloids present in *F. limonia* exhibit significant antimicrobial activity.[22] In a study by Islam et al. (2018), the ethanolic extract of *F. limonia* fruit pulp demonstrated significant antibacterial activity against both gram-positive and gram-negative bacteria, including Staphylococcus aureus, Escherichia coli, and Shigella shiga. The extract also exhibited antifungal activity against Candida albicans.[55] The antimicrobial activity of *F. limonia* is attributed to its ability to disrupt microbial cell membranes and inhibit the synthesis of essential microbial enzymes. Patil and Taranath also demonstrated that zinc oxide nanoparticles derived from *L. acidissima* leaves have potent antibacterial effects, particularly against Mycobacterium tuberculosis.[56]

A study by Buvanaratchagan and Dhandapani evaluated the antifungal properties of an ethanolic extract from *L. acidissima* leaves against common dermatophytic fungi. Utilizing the disc diffusion method, the extract was tested against Trichophyton mentagrophytes, Microsporum canis, and Epidermophyton floccosum, with Ketoconazole serving as the reference control. The results demonstrated that the ethanolic leaf extract exhibited significant antifungal activity against all three dermatophytes, with zones of inhibition measuring 32.42±1.43 mm for T. mentagrophytes, 27.56±0.95 mm for M. canis, and 28.62±1.37 mm for E. floccosum. These effects were comparable to those of Ketoconazole, which showed inhibition zones of 45.62±2.24 mm, 39.86±1.43 mm, and 32.61±1.88 mm, respectively. These findings suggest that *L. acidissima* leaves possess potent antifungal properties, supporting their traditional use in treating fungal infections.[57]

9.3 Hepatoprotective Activity

The hepatoprotective activity of *F. limonia* has been attributed to its flavonoids and triterpenoids. Dar et al. (2013) demonstrated that the flavone glycoside isolated from *F. limonia* exhibits significant hepatoprotective activity against paracetamol-induced hepatotoxicity in albino rats.[16] The study found that the flavone glycoside reduces the levels of liver enzymes, including ALT, AST, and ALP, in the serum of rats, indicating its hepatoprotective effect. Similarly, Kumar et al. (2012) reported that the triterpenoids present in the stem bark of *F. limonia* exhibit hepatoprotective activity.[12]

In a study by Dar et al. (2012), the ethanolic extract of *F. limonia* fruit pulp demonstrated significant hepatoprotective activity by reducing serum levels of liver enzymes (ALT, AST, ALP) and improving histopathological changes in the liver. The extract also exhibited antioxidant activity by increasing the levels of glutathione (GSH) and superoxide dismutase (SOD), which play a crucial role in mitigating oxidative stress-induced liver damage.[58] Similarly, Mishra et al. (2017) assessed the aqueous (ASFE) and ethanol (ESFE) extracts of *F. elephantum* (syn. *F. limonia*) stem bark and root. The extracts (50 and 100 mg/kg) significantly restored liver function biomarkers (SGOT, SGPT, ALP, TB, TC, TP) to near-normal levels. Histopathological analysis revealed reduced hepatic necrosis and improved architecture, suggesting membrane stabilization and parenchymal cell regeneration.[59]

Syed et al. (2008) investigated the methanolic extract (ME) of *F. limonia* leaves (200, 400, 600 mg/kg). The extract effectively normalized liver biomarkers and improved histological features by reducing fatty degeneration and maintaining liver architecture. The hepatoprotective effect was attributed to antioxidant phenolic and flavonoid compounds.[60, 61]

Sharma et al. and Jain et al. confirmed the hepatoprotective efficacy of *F. elephantum* leaf and fruit extracts, demonstrating their ability to prevent chemically induced liver damage in diabetic and non-diabetic rats.[62, 63, 64] Additionally, Meshack and Gupta reviewed its hepatoprotective potential, emphasizing its role in reducing liver enzyme levels and lipid peroxidation.[65] The hepatoprotective

mechanism of *F. limonia* is attributed to its ability to scavenge free radicals, inhibit lipid peroxidation, and enhance the activity of antioxidant enzymes.

In a study by Upadhyay et al. ferolactone, a novel compound isolated from the fruit of *F. limonia* was administered in albino Wister rats to assessing the compound's efficacy against carbon tetrachloride (CCl_4)-induced hepatotoxicity and its effects were compared to those of the standard hepatoprotective drug, silymarin. The results demonstrated that ferolactone significantly reduced elevated levels of serum enzymes associated with liver damage, including serum glutamate oxaloacetate transaminase (SGOT), serum glutamate pyruvate transaminase (SGPT), and alkaline phosphatase (ALP). Additionally, there was a notable increase in total protein (TP) levels, indicating improved liver function. Histopathological examinations further confirmed the hepatoprotective effect, revealing substantial recovery of liver tissue architecture in ferolactone-treated animals. These findings suggest that ferolactone from Wood apple exhibits potent antihepatotoxic activity, comparable to that of silymarin, supporting its potential therapeutic application in managing liver disorders.[66]

9.4 Gastroprotective and Antiulcer Activity

Mishra et al. found that *F. elephantum* fruit pulp extract alleviates gastric ulcers in albino rats by inhibiting oxidative stress and inflammatory mediators.[67] The ability of *F. limonia* to mitigate liver and gastric damage suggests that it may be useful in treating liver disorders and peptic ulcers.

A study evaluating *F. elephantum* leaf and bark extracts on indomethacin-induced ulceration in albino rats demonstrated significant ulcer-protective effects. The extract (500 mg/kg) administered thrice at 12-hour intervals before NSAID exposure effectively reduced ulceration. Parameters such as gastric juice volume and acidity were significantly lowered, comparable to the standard antiulcer drug ranitidine (20 mg/kg).[68] The leaf extract showed superior antiulcer potential compared to the bark extract, suggesting a stronger protective effect. Mechanistically, the protective effect is attributed to the inhibition of NSAID-induced cyclooxygenase (COX) inhibition, reduction in gastric acid secretion, and enhancement of mucosal defence mechanisms, particularly via flavonoids and tannins, which have astringent properties aiding in ulcer healing.

In another study, *L. acidissima* leaf extract was tested in an ethanol-induced ulcer model. Ethanol exposure leads to severe gastric mucosal injury through oxidative stress, microvascular damage, and increased gastric acid secretion. The ethanolic leaf extract (200 mg/kg and 400 mg/kg) significantly reduced ulcer index, increased gastric pH, and exhibited protective effects comparable to ranitidine.[69]

At 400 mg/kg, the extract provided optimal gastroprotection, likely due to its antioxidant and anti-inflammatory properties. Histopathological analysis revealed reduced epithelial disruption, leukocyte infiltration, and submucosal oedema in extract-treated groups, indicating a protective role against ethanol-induced oxidative damage.

9.5 Cytotoxic Activity

The cytotoxic activity of *F. limonia* has been attributed to its flavonoids, particularly luteolin. Hanchinalmath et al. (2021) demonstrated that luteolin isolated from the fruit pulp of *F. limonia* induces apoptosis in HepG2 cells.[17, 18] The study found that luteolin activates caspase-3 and caspase-9, which are key enzymes in the apoptotic pathway. Similarly, Nattudurai et al. (2014) reported that the fractions isolated from *F. limonia* exhibit cytotoxic activity against cancer cells.[41]

Thirugnanasampandan and David investigated the cytotoxic activity of essential oil from *F. elephantum* and found that it inhibits the proliferation of MCF-7 breast cancer cells, inducing apoptosis through mitochondrial pathways.[53] El Sayed et al. conducted a comparative metabolomics analysis and reported the antiviral potential of *L. acidissima* fruit and leaf extracts, suggesting possible anticancer applications due to their ability to modulate cellular signalling pathways.[70]

The cytotoxic effects of *L. acidissima* were assessed using the brine shrimp lethality bioassay. The petroleum ether fraction demonstrated significant cytotoxicity with an LC50 value of 0.2779 µg/ml, surpassing the standard cytotoxic agent Vincristine sulfate (LC50 = 0.445 µg/ml). The chloroform fraction showed lower cytotoxic potential with an LC50 value of 6.89 µg/ml. The pronounced cytotoxicity of the petroleum ether fraction indicates the presence of bioactive compounds with potential anticancer properties, warranting further investigation.[50]

9.6 Anti-inflammatory and Anti-nociceptive Activity

The anti-inflammatory activity of *F. limonia* has been attributed to its coumarins and steroids. Purwar (2023) reviewed the anti-inflammatory properties of marmesin, a coumarin isolated from the fruit pericarp of F. limonia.[19] The study found that marmesin reduces the levels of pro-inflammatory cytokines, including TNF-α and IL-6, in vitro. Similarly, Kumar et al. (2012) reported that the steroids present in the stem bark of *F. limonia* exhibit anti-inflammatory activity.[12] In a study by Saha et al. (2010), the methanolic extract of *F. limonia* leaves demonstrated significant analgesic activity in both

acetic acid-induced writhing and tail-flick tests in mice suggesting opioid receptor involvement. The extract also exhibited anti-inflammatory activity by inhibiting the production of prostaglandins and other inflammatory mediators.[71] Samal et al. found similar analgesic activity in experimental animal models, reinforcing its potential as a natural pain reliever.[72] Sujitha and Venkatalakshmi demonstrated that *L. acidissima* fruit extract exhibits anti-inflammatory effects through inhibition of cyclooxygenase enzymes, comparable to conventional NSAIDs.[54] In a another study by Momin et al. the analgesic potential of the ethanolic extract was assessed utilizing the acetic acid-induced writhing model in mice. The extract exhibited marked analgesic activity, demonstrating 23.74% and 45.32% inhibition of acetic acid-induced writhing at oral doses of 250 mg/kg and 500 mg/kg, respectively, in comparison to the 50.36% inhibition achieved by the reference standard Diclofenac sodium at a dose of 25 mg/kg. These results substantiate the traditional therapeutic application of *F. limonia* leaves in pain management and underscore the need for further investigations to isolate and characterize the bioactive constituents responsible for the observed analgesic effects.[42] A study by Khare et al. involved the intragastric administration of the ethanolic extract to mice at graded doses of 100, 200, and 400 mg/kg. The analgesic efficacy of the extract was evaluated through both thermal and chemical pain models. The results demonstrated a dose-dependent antinociceptive effect following a single dose of the extract, thereby corroborating the traditional use of *F. limonia* leaves in pain management.[73]

9.7 Anti-diabetic Activity

F. limonia has been traditionally used to manage diabetes, and recent studies have validated its antidiabetic potential. The plant's gum, in particular, has been shown to exhibit significant hypoglycaemic and antihyperlipidemic effects.

In a study by Vikhe et al. (2021), the aqueous extract of *F. limonia* gum was evaluated for its antidiabetic activity in streptozotocin (STZ)-induced diabetic rats. The extract significantly reduced blood glucose levels, improved insulin sensitivity, and restored the activity of hepatic glucose metabolic enzymes such as glucokinase and glucose-6-phosphate dehydrogenase. The extract also exhibited antioxidant activity by increasing the levels of catalase (CAT) and glutathione peroxidase (GPx), which protect pancreatic β-cells from oxidative damage.[48]

The antidiabetic activity of *F. limonia* is likely mediated through its ability to enhance insulin secretion, improve glucose uptake, and reduce oxidative stress. These findings suggest that *F. limonia* gum could be a promising candidate for the development of antidiabetic drugs.

Reddy et al. demonstrated that methanol fractions of *F. elephantum* fruit enhance glucose metabolism in type 2 diabetic rats via α-amylase inhibition and PPAR-γ activation, leading to improved insulin sensitivity.[74, 75]

9.8 Anti-hyperlipidaemic effect

Vikhe et al. reported that *F. elephantum* gum significantly reduces hyperlipidaemia in diabetic rats by lowering serum cholesterol and triglyceride levels.[48] Pandit et al. observed lipid-lowering activity of *F. limonia* leaf extract in hyperlipidaemic rats, supporting its potential as a cardiovascular protective agent.[76] These findings suggest that *F. limonia* could be developed into a natural therapeutic agent for managing metabolic disorders, particularly diabetes and dyslipidaemia.

9.9 Neuroprotective and Antidepressant Effects

Rakhunde et al. demonstrated that *F. limonia* fruit extract mitigates ischemia-reperfusion-induced brain injury in rats by reducing oxidative damage and inflammation, protecting neuronal integrity.[77] Jatav et al. investigated its antidepressant activity, showing that ethanolic extracts of *F. limonia* leaves improved behavioural markers of depression in Swiss albino mice, possibly through serotonin modulation.[78] The neuroprotective effects of *F. limonia* highlight its potential as a natural remedy for neurodegenerative diseases and mental health disorders.

9.10 Reproductive and Endocrine Effects

Dhanapal et al. reported that *F. limonia* fruit pulp exerts reversible antispermatogenic and antisteroidogenic effects in male rats, indicating its potential use in male contraception.[79] Verma documented the ethnobotanical use of *F. limonia* in livestock, highlighting its role in treating reproductive disorders.[80] The hormonal modulation effects of *F. limonia* suggest its potential for therapeutic applications in reproductive health.

9.11 Diuretic and Nephroprotective Activity

The diuretic potential of *F. limonia* was assessed in a study utilizing methanolic extracts obtained via Microwave-Assisted Extraction (MAE) and Bath Sonication Extraction (BSE). In an experimental model using male albino rats, extracts administered at 200 mg/kg exhibited significant diuretic activity, as evidenced by increased urine output and electrolyte excretion. The urine volume increased significantly ($p<0.001$) with the BSE extract, with notable enhancements in sodium, potassium, and chloride excretion.[81] The sodium-to-potassium ratio remained within physiological limits, suggesting a

natriuretic mechanism of action similar to low-ceiling diuretics.

Oxidative stress plays a critical role in nephrotoxicity, particularly in conditions such as fluorosis. An experimental study assessed the impact of *F. limonia* fruit powder on fluoride-induced renal damage in rats. Animals exposed to 100 ppm sodium fluoride (NaF) exhibited increased lipid peroxidation (TBARS) and decreased levels of antioxidant enzymes, including superoxide dismutase (SOD), catalase (CAT), and glutathione peroxidase (GPx). Administration of *F. limonia* fruit powder at doses of 2.5, 5.0, and 10.0 g% in the diet significantly restored antioxidant enzyme activity and reduced renal lipid peroxidation.[82] This nephroprotective effect is attributed to the plant's rich polyphenol, flavonoid, and ascorbic acid content, which counteract oxidative damage.

9.12 Antihyperuricemic Activity

A study by Yusnaini et al. investigated the antihyperuricemic potential of the ethanolic extract of *L. acidissima* fruit in potassium oxonate-induced hyperuricemic rats. The extract significantly reduced serum uric acid levels and downregulated urate transporter 1 (URAT1) expression, demonstrating a potential mechanism for its action. The extract also exhibited strong antioxidant properties. However, higher doses (400 mg/kg) were associated with increased blood urea nitrogen (BUN) levels, indicating potential renal toxicity. These findings suggest that *L. acidiss*ima fruit extract may be a promising candidate for hyperuricemia management.[83, 28, 84]

9.13 Antidiarrhoeal activity

The ethanolic leaf extract of *F. limonia* demonstrated significant antidiarrhoeal activity in some studies using the castor oil-induced diarrhoea model in mice. Bellah et al. (2014) reported a dose-dependent reduction in diarrhoeal frequency and severity at doses of 250 mg/kg and 500 mg/kg, showing statistically significant results ($p<0.02$ and $p<0.001$) compared to the standard drug loperamide.[85] Similarly, Momin et al. found that the extract exhibited moderate antidiarrhoeal effects, effectively reducing diarrhoeal episodes in a comparable model. Both studies suggest that the extract's antidiarrhoeal mechanism may involve antisecretory action, highlighting F. limonia's potential as a natural therapeutic agent for managing diarrhoeal disorders.[86]

Conclusion

Wood apple is a promising natural resource with significant pharmacological potential due to its bioactive phytochemicals, including flavonoids, coumarins, alkaloids, phenolic compounds, and terpenoids, which drive its extensive pharmacological activities. The plant's traditional use in Ayurveda for treating conditions such as diabetes, liver disorders, microbial infections, and inflammation is substantiated by contemporary scientific studies, which demonstrate its antioxidant, antimicrobial, hepatoprotective, cytotoxic, anti-inflammatory, antidiabetic, antihyperlipidemic, neuroprotective, and diuretic effects. These activities are mediated through mechanisms such as free radical scavenging, enzyme inhibition, and modulation of cellular pathways, as evidenced by robust in vitro and in vivo data and highlight its potential as a natural therapeutic agent for managing metabolic, infectious, and inflammatory disorders. However, further research is imperative to validate its efficacy and safety through well-designed clinical studies, explore underlying molecular mechanisms, and develop standardized formulations and nutritional applications.

Reference:

1. Sharma N, Radha, Kumar M, et al. Beneath the rind: A review on the remarkable health benefits and applications of the wood apple fruit. *Heliyon*. 2024 Apr 3;10(7):e29202. doi:10.1016/j.heliyon.2024.e29202
2. Pandey S, Satpathy G, Gupta RK. Evaluation of nutritional, phytochemical, antioxidant and antibacterial activity of exotic fruit "Limonia acidissima." *Journal of Pharmacognosy and Phytochemistry*. 2014;3(2):81-88. www.phytojournal.com
3. Sharma, P., Gothalwal, R., & Tenguria, R. PHYTOCHEMICAL SCREENING OF FRUIT AND STEM BARK EXTRACTS OFLIMONIA ACIDISSIMA (L.). *Journal of Advanced Scientific Research*, 2021;*12*(01 Suppl 1):326-329. https://doi.org/40
4. Mrinal Sharma, Sanjay Nagdev, Mayur Bhurat, Amitkumar Dhankani, Mayur Jain, Gaurav Mude. Feronia elephantum Correa: A Potential Traditional Drug. *International Journal of Ayurvedic Medicine,*. 2021;12(3):482-484. doi: https://doi.org/10.47552/ijam.v12i3.1965
5. Nandwate P, Dnyaneshwar Dhage M, Mehta N. A COMPREHENSIVE REVIEW ON KAPITHHA (L. ACIDISSIMA LINN.) ACCORDING TO AYURVEDIC AND MODERN ASPECT. *World Journal of Pharmaceutical Research*. 2024;13(14):578-590. doi: https://10.20959/wjpr202414-33255
6. Krishen P. *Jungle Trees of Central India: A Field Guide for Tree Spotters*. Penguin Books; 2013. https://books.google.co.in/books?id=Bvl5oAEACAAJ
7. Srivastava R, Mishra N, Agarwal S, Mishra N. *PHARMACOLOGICAL AND PHYTOCHEMICAL*

PROPERTIES OF KAITHA (F. LIMONIA L.) : A REVIEW. 2019;19(1):608-615. https://www.plantarchives.org/PDF%20SUPPLEMENT%202019/102_608-615_.pdf

8. Vanoshadhi Chandrodaya Vol. - Ii : Bhandari, Chandraraj : Free Download, Borrow, and Streaming : Internet Archive. Accessed November 22, 2024. https://archive.org/details/in.ernet.dli.2015.341570 /page/n183/mode/2up
9. Tamboli D, Saindane B, Sonwane P, Suryawanshi HP, Pawar SP. Phytopharmacological Screening of F. limonia Linn. *Saudi Journal of Medical and Pharmaceutical Sciences*. 2017;03(3A):133-137. https://saudijournals.com/media/articles/SJMPS_33A133-137.pdf
10. Mahendra Jain RKSASHMishra. Standardization of F. limonia L. leaves by HPLC, HPTLC, physico-chemical and histological parameters. *Bol Latinoam Caribe Plant Med Aromat*. 2011;10(6):525-535. doi: https://www.redalyc.org/pdf/856/85622434005.pdf
11. Vikhe S, Kunkulol R, Sunayana M, Vikhe R. Pharmacognostic evaluation of Feronia elephantum Correa bark. *Pensee*. 2020;50(12):187-205. https://www.researchgate.net/publication/346773484_Pharmacognostic_evaluation_of_Feronia_elephantum_Correa_bark
12. Kumar Kumawat B, Chand T, Singh Y. *Pharmacognostical and Physicochemical Evaluation on Stem Bark of Limonia*. Int J Pharm Bio Sci. 2012;03(3):198-209. https://ijpbs.net/abstract.php?article=MTQzOA==
13. Iqbal Dar A. Pharmacognostic Approach Of Wood Apple. *International Journal of Engineering, Applied and Management Sciences Paradigms (IJEAM)*. 2019;(Special Issue-3rd ICRMR-2019):01-05. doi: http://www.ijeam.com/PublishedPaper/SpecialIssue-ICRMR2019/1.pdf
14. Nyoe S, Ko N, Naing HH. Nutritional Compositions, Antioxidant and Antimicrobial Activities of Exotic Fruit L. acidissima L. *3 rd Myanmar-Korea Conference Research Journal*. 2020;3(3):798-805. doi: https://www.dagonuniversity.edu.mm/wp-content/uploads/2020/06/Sein-Nyoe-Nyoe-Ko-1.pdf
15. Pandavadra M, Chanda S. Development of quality control parameters for the standardization of L. acidissima L. leaf and stem. *Asian Pac J Trop Med*. 2014;7(S1):S244-S248. doi: https://pubmed.ncbi.nlm.nih.gov/25312130/10.1016/S1995-7645(14)60240-6
16. Dar AI, Masar G, Jadhaw V, Bansal SK, Saxena RC. Isolation and structural elucidation of the novel flavone glycoside from F. limonia L. *J Pharm Res*. 2013;7(8):697-704. https://doi.org/10.1016/j.jopr.2013.04.058
17. Hanchinalmath J, Londonkar R, Shivasharanappa K. Cytotoxic Effects of Luteolin Isolated from F. limonia Linn. *Asian J Biol Life Sci*. 2021;9(3):302-305. DOI:10.5530/ajbls.2020.9.45
18. Hanchinalmath J V, Londonkar R. CYTOTOXIC AND APOPTOSIS-INDUCING EFFECT OF LUTEOLIN ISOLATED FROM F. LIMONIA ON HEPG2 CELLS. *Biolife*. 2014;2(4):1287-1292. doi: https://dx.doi.org/10.5281/zenodo.7238666
19. Purwar C. A BIOACTIVE COMPONENT MARMESIN FROM F. LIMONIA FRUIT PERICARP: A REVIEW. *International Journal of Biological Innovations*. 2023;05(01):155-160. doi: https://doi.org/10.46505 /IJBI.2023.5113
20. Tjahjandarie TS. Coumarins from the stem bark of F. limonia. *J Chem Pharm Res*. 2014;6(12):499-504. doi: https://www.jocpr.com/articles/coumarins-from-the-stem-bark-of-feronia-limonia.pdf
21. Jain M, Trivedi A, Mishra SH. TLC Determination of Marmesin, a Biologically Active Marker from F. limonia L. *Am J Plant Sci*. 2010;01(01):12-16. doi:10.4236/ajps.2010.11002
22. Pitchai P, Ulagi R, Mohan S, Gengan RM. A novel alkaloid, four alkaloid precursors and a coumarin from F. limonia. *Indian J Chem*. 2012;51B:1771-1775. https://doi.org/10.1002/CHIN.201315192
23. Senthil Kumar A, Venkatesalu V, Kannathasan K, Chandrasekaran M. Chemical constituents and antibacterial activity of the leaf essential oil of F. limonia. *Indian J Microbiol*. 2010;50(Suppl 1):70-73. doi:10.1007/s12088-010-0052-7
24. Senthilkumar A, Venkatesalu V. Chemical constituents, in vitro antioxidant and antimicrobial activities of essential oil from the fruit pulp of wood apple. *Ind Crops Prod*. 2013;46:66-72. https://doi.org/10.1016/j.indcrop.2013.01.018
25. Srivastava R, Mishra N, Mishra N. *Evaluation of the Extraction Hours and Solvent Concentrations on Secondary Metabolites and Antioxidant Activity of F. limonia Fruit*.2021;12(03):463-471. DOI: http://op.niscair.res.in/index.php/IJNPR/article/view/26376
26. Priya Darsini DT, Maheshu V, Vishnupriya M, Nishaa S, Sasikumar JM. Antioxidant potential and amino acid analysis of underutilized

tropical fruit L. acidissima L. *Free Radicals and Antioxidants*. 2013;3(2013):562-569. https://doi.org/10.1016/j.fra.2013.08.001

27. Kerkar SP, Patil S, S. S A, Dabade A, Sonawane SK. Limonia acidissima: Versatile and Nutritional Fruit of India. *International Journal of Fruit Science*. 2020;20(S2):S405-S413. doi:10.1080/15538362.2020.1737302
28. Yusnaini R, Ikhsan, Iskandar, et al. The Identification of Phytocompounds from L. acidissima L. Fruit: A Short Report and Updated Review – Focusing on Antihyperuricemic and Antiarthritic Activities. *International Journal of Public Health Excellence (IJPHE)*. 2023;3(1):418-423. https://doi.org/10.55299/ijphe.v3i1.716
29. Hanchinalmath J V, Londonkar RL, Jayashree VH, Londonkar R. *Comparative Phytochemical Studies and Antimicrobial Potential of Fruit Extracts of F. limonia Linn*. Londonkar et al. Int J Pharm Pharm Sci. 2014;6(1):731-734. https://www.researchgate.net/publication/286642857
30. Ponnuraj S, Jaganathan D, Kanagarajan M, Priya T, Deivamarudachalam D. SPECTROSCOPIC ANALYSIS AND ANTIBACTERIAL EFFICACY OF BIOACTIVE COMPOUNDS FROM L. ACIDISSIMA L. FRUIT EXTRACT AGAINST CLINICAL PATHOGENS. *Int J Pharm Pharm Sci*. 2015;7(3):383-389. doi: https://journals.innovareacademics.in /index.php/ijpps/article/view/4711/8503
31. Hanchinalmath Jayashree V, Londonkar Ramesh. ISOLATION AND IDENTIFICATION OF A FLAVONE FROM FRUIT PULP OF F. LIMONIA. *Int J Curr Pharm Res*. 2014;6(4):28-31. doi: https://journals.innovareaca demics.in /index.php/ijcpr/article/view/3391/804
32. Reddy GJ, Reddy KB, Reddy GVS: GC-MS analysis and in-vitro anti-diabetic activity of bioactive fractions of Feronia elephantum fruit. Int J Pharm Sci & Res 2020; 11(5): 2415-24. doi: 10.13040/IJPSR.0975-8232.11(5).2415-24.
33. Dar AI. Phytochemistry and Hepatoprotective Potential of Wood Apple against Paracetamol Induced Hepatotoxicity in Albino Rats. *J Appl Microbiol Biochem*. 2022;6(7:034).01-14 doi: 10.36548/2576-1412.6.7.034
34. Mahour K, Mishra A, Kumar A, Vihan VS. Preliminary Pharmacognostical And Phytochemical Investigation On Feronia elephantum Corr. Fruit. *J Pharm Res*. 2008;1(1):44-47.
35. Thomas A, Ponnammal NR. PRELIMINARY STUDIES ON PHYTOCHEMICAL AND ANTIBACTERIAL ACTIVITY OF Limonia acidissima L. PLANT PARTS. Anc Sci Life. 2005 Oct;25(2):57-61. PMID: 22557192; PMCID: PMC3330905. https://pmc.ncbi.nlm.nih.gov/articles/PMC3330905/
36. Muthulakshmi A, Jothibai Margret R, Mohan V.R. GC-MS Analysis of Bioactive Components of Feronia elephantum Correa (Rutaceae). *J Appl Pharm Sci*. 2012;2(02):69-74. doi: https://japsonline.com/admin /php/uploads/382pdf.pdf
37. Intekhab J, Aslam M. Isolation of a flavonoid from F. limonia. *Journal of Saudi Chemical Society*. 2009;13(3):295-298. https://doi.org/10.1016/j.jscs.2009.10.012
38. S. S. Shirankar SGDRPL& APSomkuwar. THE PRELIMINARY PHYTOCHEMICAL SCREENING OF VARIOUS LEAf EXTRACTS OF PLANT L. acidissima Linn. *Indian Journal of Veterinary and Animal Sciences Research*. 2023;47(03):1321-1329. doi: https://epubs.icar.org.in/index.php/IJVASR/article/view/137841
39. Santhosharajan N, Kumaravel V. *Phytochemical Screening and Evaluation of Antioxidant Potential of F. limonia Leaves and Fruit Extracts*.; 2014;Special issue 2:October:36-40. https://www.jchps.com/specialissues /Special%20issue2/jchps%20si2%204%20saraswathi%2036-40.pdf
40. Warrier RR, Priyadharshini P, Kumar ANA. A COMPARATIVE ANALYSIS OF THE PHYTOCHEMICAL VARIABILITY OF ARBOREAL RUTACEAE MEMBERS. *IJPSR*. 2012;3(10):3801-3805. http://dx.doi.org/10.13 040 /IJPSR.0975-8232.3(10).3801-05
41. Article NATTUDURAI OG, Balachandran C, Gabriel Paulraj M, Duraipandiyan V, Ignacimuthu S, Al Dhabi NA. *Cytotoxic and Antioxidant Properties of Fractions Isolated from Feronia elephantum*.; Int J Pharm Pharm Sci. 2014;6(7):210-214. https://www.researchgate.net/publication/267035627
42. Momin M, Bellah SF, Rahman MM, et al. Phytopharmacological evaluation of ethanolic extract of F. limonia leaves. Am. J. Sci. Ind. Res., 2013;4(5):468-472. doi: 10.5251/ajsir.2013.4.5.468.472
43. Attarde D L CBJ and BRS. Phytochemical investigation and in vitro antioxidant activity of extracts from leaves of Limonia. *J Pharm Res*. 2016;4(3):766-768. https://api.semanticscholar.org/CorpusID:212547690
44. Panda N, Jagannath Patro V, Kumar Jena B, Panda P. Evaluation of Phytochemical and Anti-Microbial Activity of Ethanolic Extract of L. acidissima L. Leaves. *Int J Herb Med*. 2013;1(1). 22-27.

https://www.florajournal.com/vol1issue1/march2013/4.1.pdf

45. Jirekar D, Homepage J, Pramila G. Phytochemical Screening by FTIR Spectroscopic Analysis of Three Medicinal Plants. *Int J in Pharm Sci*. 2023;1(7):269-275. doi: 10.5281/zenodo.8162518
46. Kweka EJ, Mdoe FP, Lowassari NN, Venkatesalu V, Senthilkumar A. The Laboratory and Semi-Field Larvicidal Effects of Essential Oil Extracted from F. limonia against Anopheles arabiensis Patton. *J Parasitol Res*. 2023;2023:1-6. https://doi.org/10.1155/2023/5907603
47. Joshi RK, Badakar VM, Kholkute SD, Khatib N. Chemical Composition and Antimicrobial Activity of the Essential Oil of the Leaves of Feronia elephantum (Rutaceae) from North West Karnataka. *Nat Prod Commun*. 2011;6(1):141-143. doi: https://doi.org/10.1177/1934578X110060013
48. Vikhe S, Kunkulol R, Raut D. Antidiabetic and Antihyperlipidemic activities of Feronia elephantum gum in streptozotocin induced diabetic rats. Med. res. chronicles. 2021;8(3):233-251. https://medrech.com/index.php/medrech/article/view/508
49. Daphedar AB, Majani SS, Kaddipudi PJ, et al. Evaluation of antioxidant and antibacterial activities of silver nanoparticles derived from L. acidissima L. fruit extract. *Current Research in Green and Sustainable Chemistry*. 2024;8:100399:01-07. https://doi.org/10.1016/j.crgsc.2024.100399
50. Kasan Khosru K, Sultana S, Shermin S, Dey A. EVALUATION OF THE ANTIOXIDANT AND CYTO-TOXIC ACTIVITIES OF THE STEM-BARK OF L. ACIDISSIMA (FAMILY: RUTACEAE). International Journal of Research and Development in Pharmacy & Life Sciences. 2013;2(4):527-530. https://ijrdpl.com/index.php/ijrdpl/article/view/302
51. Hanchinalmath J V, Londonkar R. IN VITRO ANTIOXIDANT ACTIVITIES OF F. LIMONIA LINN. *Indo American Journal of Pharmaceutical Research*. 2014;4(6):2937-2942. www.iajpr.comhttp://www.iajpr.com
52. Akter A, Sadik MdG, Kader MdA, Islam KM. In Vitro Antioxidant Activity of F. limonia Bark Relevant to the Treatment of Oxidative Stress Mediated Neurodegenerative Disorders. *World Scientific Research*. 2016;3(1):62-69. doi: 10.20448/journal.510/2016.3.1/510.1.62.69
53. Thirugnanasampandan R, David D. In vitro antioxidant and cytotoxic activities of essential oil of Feronia elephantum Correa. *Asian Pac J Trop Biomed*. 2014;4(4):290-293. doi: 10.12980/APJTB.4.2014B878
54. S. Sujitha, P. Venkatalakshmi. Insights into the Invitro Antioxidant, Anti-Inflammatory and Anticancer Activities of L. acidissima Fruits. *Int J Life Sci Pharma Res*. 2021;11(3):1-11. https://doi.org/10.22376/ijpbs/lpr.2021.11.3.L1-11
55. Islam K, Islam N, Uddin MM, Al Mamun A. Antibacterial, Cytotoxic and Analgesic Activities of the Ethanol Extract of F. limonia Linn Fruit Pulp. *IOSR Journal of Pharmacy and Biological Sciences (IOSR-JPBS*. 2018;13(2):31-37. doi: https://10.9790/3008-1302053137
56. Patil BN, Taranath TC. L. acidissima L. leaf mediated synthesis of zinc oxide nanoparticles: A potent tool against Mycobacterium tuberculosis. *Int J Mycobacteriol*. 2016;5(2):197-204. https://10.1016/j.ijmyco.2016.03.004
57. Buvanaratchagan A. Antifungal Activity of Ethanolic Leaf Extract of L. acidissima against Dermatophytes. *Scholars Journal of Applied Medical Sciences (SJAMS*. 2016;4(11D):4161-4163. https://10.36347/sjams.2016.v04i11.059
58. Dar AI, Saxena RC, Bansal SK. *Assessment of Hepatoprotective Activity of Fruit Pulp of F. limonia (Linn.) against Paracetamol Induced Hepatotoxicity in Albino Rats*. J. Nat. Prod. Plant Resour. 2012;2(2):226-233. http://scholarsresearchlibrary.com/archive.html
59. Mishra M, Mishra R, Balakrishnan N, Verma SK. Hepatoprotective activity of aqueous and ethanol extracts of Feronia elephantum Correa. Stem bark and Root. *Asian Pacific Journal of Health Sciences*. 2017;4(4):119-122. doi: 10.21276/apjhs.2017.4.4.28
60. Ahamed SM, KN J, Rao V. Hepatoprotective and Antioxidant Activities of F. limonia (leaves). *Pharmacologyonline*. 2008;3(1):992-1005. https://pharmacologyonline.silae.it/files/archives/2008/vol3/103_Syed.pdf
61. Syed Mansoor Ahmed, Jayaveera KN, Venkateshwara Rao J, Nagarjun Tukuru. HEPATOPROTECTIVE AND ANTIOXIDANT ACTIVITY OF METHANOLIC EXTRACT OF F. LIMONIA LEAVES ON PARACETAMOL INDUCED HEPATIC INJURY IN RATS. *Adv Pharmacol Toxicol*. 2010;11(01):47-53.
62. Sharma P, Bodhankar SL, Thakurdesai PA. Protective effect of aqueous extract of Feronia elephantum correa leaves on thioacetamide induced liver necrosis in diabetic rats. *Asian Pac J Trop Biomed*. 2012;2(9):691-695. doi: https://10.1016/S2221-1691(12)60211-1

63. Jain M, Kapadia R, Navalsinh Jadeja R, et al. Protective role of standardized F. limonia stem bark methanolic extract against carbon tetrachloride induced hepatotoxicity. *Ann Hepatol*. 2012;11(6):935-343. https://doi.org/10.1016/S1665-2681(19)31421-8
64. Jain M, Kapadia R, Jadeja RN, Thounaojam MC, Devkar RV, Mishra SH. Amelioration of carbon tetrachloride induced hepatotoxicity in rats by standardized Feronia limonia. Linn leaf extracts. EXCLI J. 2012 May 23;11:250-9. PMID: 27418903; PMCID: PMC4941808. https://pmc.ncbi.nlm.nih.gov/articles/PMC4941808/
65. Meshack S, Gupta S. A Review of Plants with Remarkable Hepatoprotective Activity. *Journal of Drug Delivery and Therapeutics*. 2022;12(1):194-202. doi: https://10.22270/jddt.v12i1.5283
66. Upadhyay R, Verma A, Pandey ND, Narvi SS. Antihepatotoxic activity of ferolactone, a new furanocoumarin from F. limonia. *Medicinal Chemistry Research*. 2012;21(10):2955-2960. doi: https://10.1007/s00044-011-9825-8
67. Mishra A, Arora S, Gupta R, Kumar Punia R, Sharma AK. *Effect of Feronia elephantum (Corr) Fruit Pulp Extract on Indomethacin-Induced Gastric Ulcer in Albino Rats*. Trop J Pharm Res. 2009;8(6):509-514. DOI: 10.4314/tjpr.v8i6.49395
68. Muthulakshmi A, Margret RJ, Mohan VR. Antiulcer effect of Feronia elephantum Correa leaf and bark extract in indomethacin induced albino rats. *J Appl Pharm Sci*. 2013;3(4):71-74. doi: 10.7324/JAPS.2013.34.S13
69. Aneesha A, Rao NR, Siva N, et al. Phytochemical studies and anti-ulcer activity of L. acidissima linn. leaf in treating ethanol induced ulcer Albino rats. *Indian Journal of Research in Pharmacy and Biotechnology*. 2018;6(3):104-110. https://www.ijrpb.com/issues/ijrpb%206(3)%203%20Aneesha%20104-110.pdf
70. El Sayed AM, El-Abd EAW, Afifi AH, et al. Comparative metabolomics analysis of Citrus medica var. sarcodactylis Swingle and L. acidissima Linn. Fruits and leaves cultivated in Egypt in context to their antiviral effects. *Heliyon*. 2024;10(11):1-14. https://doi.org/10.1016/j.heliyon.2024.e32335
71. Saha MR, RSZ, & RAS. Antinociceptive activity of methanolic extract of the leaves of F. limonia Linn. *Bangladesh Journal of Physiology and Pharmacology*. 2014;26(1-2):21-24. doi: https://doi.org/10.3329/bjpp.v26i1-2.19962
72. Pradeep Kumar Samal, J.S. Dangi, Kedar Pd. Meena, N.R. Beck, Aswani Patel, Garima Maheshwari. Evaluation of Analgesic Activity of Leaves Extracts of Feronia limonia in Experimental Animal Models. Research J. Pharm. and Tech. 2011;4(5):710-714. https://www.rjptonline.org/AbstractView.aspx?PID=2011-4-5-34
73. Khare S, Khare P. ANALGESIC ACTIVITY OF ETHANOL EXTRACT OF F. LIMONIA (L.) SWINGLE LEAVES. *IJPSR*. 2011;2(2):351-356. http://dx.doi.org/10.13040/IJPSR.0975-8232.2(2).351-56
74. Reddy GJ, Reddy KB, Reddy GVS. In vivo anti-diabetic and anti-hyperlipidemic activities of ethyl acetate/methanol fractions of Feronia elephantum fruit in type 2 diabetic rats: Via α-amylase and ppar-γ by using in silico approach. *Indian Journal of Pharmaceutical Education and Research*. 2020;54(3):761-770. doi: https://10.5530/ijper.54.3.128
75. Reddy GJ, Reddy KB, Reddy GVS. In vitro α-Amylase and α-Glucosidase inhibitory activity of extracts of Feronia elephantum fruit and Paspalum scrobiculatum Grains. *Asian J Pharm Pharmacol*. 2019;5(S1):42-47. doi: 10.31024/ajpp.2019.5.s1.4
76. Pandit, Kanika, et al. "LIPID LOWERING ACTIVITY OF FERONIA LIMONIA LEAF IN TRITON WR-1339 (TYLOXAPOL) INDUCED HYPERLIPIDEMIC RATS". International Journal of Pharmacy and Pharmaceutical Sciences. 2014;6(8):156-158. https://journals.innovareacademics.in/index.php/ijpps/article/view/1525.
77. Rakhunde PB, Saher S, Ali SA. Neuroprotective effect of F. limonia on ischemia reperfusion induced brain injury in rats. *Indian J Pharmacol*. 2014;46(6):617-621. doi: 10.4103/0253-7613.144920
78. Jatav R, Gour R, K. Patel A. Pharmacological Evaluation of Anti - depressant Activity of Ethanolic Extract of F. limonia Leaves in Swiss Albino Mice. *International Journal of Science and Research (IJSR)*. 2023;12(12):1298-1301. doi: 10.21275/sr231215232314
79. Dhanapal R, Vijaya Ratna J, Sarathchandran I, Gupta M. Reversible antispermatogenic and antisteroidogenic activities of F. limonia fruit pulp in adult male rats. *Asian Pac J Trop Biomed*. 2012;2(9):684-690. doi: 10.1016/S2221-1691(12)60210-X
80. Verma RK. An ethnobotanical study of plants used for the treatment of livestock diseases in Tikamgarh District of Bundelkhand, Central India. *Asian Pac J Trop Biomed*. 2014;4(Suppl 1):S460-S467. doi: 10.12980/APJTB.4.2014C1067

81. Parial S, Jain DC, Joshi SB. DIURETIC ACTIVITY OF THE EXTRACTS OF L. ACIDISSIMA IN RATS. 2009;2(1):53-56. https://rasayanjournal.co.in/vol-2/issue-1/10.pdf
82. Vasant RA, Narasimhacharya A, Vidyanagar V. *ALLEVIATION OF FLUORIDE-INDUCED HEPATIC AND RENAL OXIDATIVE STRESS IN RATS BY THE FRUIT OF LIMONIA ACIDISSIMA*. Fluoride. 2011;44(1):14–20. https://www.fluorideresearch.org/441/files/FJ2011_v44_n1_p014-020sfs.pdf
83. Yusnaini R, Nasution R, Saidi N, et al. Ethanolic Extract from L. acidissima L. Fruit Attenuates Serum Uric Acid Level via URAT1 in Potassium Oxonate-Induced Hyperuricemic Rats. *Pharmaceuticals (Basel).* 2023;16(3):419. doi: 10.3390/ph16030419. PMID: 36986518; PMCID: PMC10054421.
84. Yusnaini R, Ikhsan, Nurman S, et al. Predicting anti-hyperuricemic and anti-gouty activities of fatty acids from L. acidissima L. fruit: In silico-in vivo study. *J Pharm Pharmacogn Res*. 2023;11(5):757-774. doi: 10.56499/jppres23.1652_11.5.757
85. Faysal Bellah S, Emdadur Rahman S, Murshid G, et al. *Evaluation of Antibacterial and Antidiarrhoeal Activity of Ethanolic Extract of F. limonia Leaves*. *The Pharma Innovation Journal.* 2015;3(11):50-54 https://www.thepharmajournal.com/archives/2015/vol3issue11/PartB/3-10-21.pdf
86. Motalib Momin MA, Khan MR, Rayhan J, Afrose A, Rana S, Begum AA. Evaluation of Antibacterial and Antidiarrhoeal Activities of F. limonia Leaf Extract. *Am J Plant Sci*. 2013;04(11):2181-2185. doi: 10.4236/ajps.2013.411270